Development of an Intersection Assessment Protocol in Boston, Massachusetts

Report Submitted to:

Robert Krueger

Donald R Brown

Boston Project Center

By

Andrew Abderrazzaq ________________________

Sean Kennedy ________________________

Evald Muraj ________________________

Kaileen Selen ________________________

Boston D'09 – letscross@wpi.edu

In Cooperation With

Jason Schrieber, AICP, Principal, Nelson/Nygaard Consulting Associates

Michael Alba, Associate, Nelson/Nygaard Consulting Associates

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Abstract

This report, prepared for the consulting firm Nelson-Nygaard, analyzes conventional protocols for assessing intersections. Through our analysis, we developed a new protocol which sought to provide a traffic engineer with more descriptive data on an intersection. Our protocol broke up an intersection timeline into phases and then quantified pedestrian behavior through those phases. The intersections of Boylston and Tremont in Boston, MA and Prospect and Mass Ave in Cambridge, MA were used to develop and test our protocol.

Executive Summary

In Boston, Massachusetts pedestrians make three out of every ten trips. This fact has rightfully earned it the title of *America's Walking City.* Unfortunately, most of Boston's street infrastructure was constructed before the existence of the automobile; thus resulting in some of present-day pedestrian/vehicle conflicts. These and other complications have proven to be detrimental to the safety of pedestrians, the well-being of drivers and oftentimes have the potential to be fatal. Pedestrians will interact with vehicles regardless of whether the situation is ideal or not. So, is it the pedestrian-vehicle relationships that is the problem or is it intersection design?

In order to assess the design, traffic engineers and consultants have used a series of conventional protocols for years. There protocols include tools in assistance for collecting data on delay, tracking surveys, and volume and/or conflict tabulating tables. What these protocols gave the engineers was a day's worth of data if they were lucky, but generally closer to just an hour's worth. This limited amount of data showed when or where a pedestrian did, but never combined the two and never went into just exactly what a pedestrian was faced with in terms of traffic at the time they were crossing.

Our protocol, which was designed in order to alleviate these problems, would develop and test a series of methods with this goal in mind. Our first step in developing a more elaborate protocol was to utilize collection during phases. These phases were broken down into major occurrences of a cycle where there was a unique set of traffic conditions between vehicles and pedestrians.

Most of the previous conventional protocols that we tested in our methods were attempted to be captured by phase in our protocol. We then tested a volume-conflict analysis on the Boylston-Tremont intersection, where we split up the data collected by phase and zone. Through each phase, we counted the total number of pedestrians or cars that passed through each zone and the number of conflicts either faced.

Conclusions we were able to make based off of splitting it up by phase and zone were determining which signal lengths that were too long, when the queue of vehicles cleared out

quickly and volume decreased, or the opposite for signal lengths that were too short. These also showed the safety concerns involved within each phase. The use of this can deem whether or not a concurrent crossing is appropriate and can also test the safety of one that is active already.

What the phased analysis showed us versus previous conventional analysis was when problems occurred at an intersection. Most conventional protocols showed where high volumes of pedestrians or vehicles were and where there conflicts were, but they never showed when. Typically, they would be collected over fifteen minute intervals at certain times of the day, but that was descriptive of behavior of that time, not behavior due to the intersection. What phased analysis integrated with other methods shows is how an intersection could be timed differently in order to make the intersection safer and more convenient for all modes of traffic or at least gauge the level of safety or convenience. This in-depth view of intersection timing can be used to help consider pedestrian interests and behaviors for traffic engineers when they are designing an intersection. This allowed one to consider signal time, but intersection structure still needed to be incorporated within the protocol.

We later tested tracking surveys on both intersections and found this process to be overall easy to collect and supplied a substantial amount of information on the intersection. If our group had more time, we would have attempted to incorporate this into one method through both volume-conflict collection and phase analysis.

Our group also tested timing pedestrian delay. We found this to be ineffective unless one had an appropriate vantage point for a camera. It was also decided that it would be a good method of testing changes to an intersection. We found intercept surveys to be inconsequential and too difficult to collect. A step by step outline of our protocol and the methods to conducting it is available in Appendix C.

Authorship Page

This report was written in part by all members of the pedestrian behavior group, which includes Andrew Abderrazzaq, Sean Kennedy, Evald Muraj, and Kaileen Selen. Each section of this project was completed individually and then compiled as a group. Every section of this project was then looked over collaboratively and reviewed in order to create balance between our vantage points. Written work done was split throughout the group, with consideration to the strengths and weaknesses of each member.

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Section 1: Introduction

Pedestrian fatalities account for more than ten percent of motor vehicle accidents annually. Close to half of those incidents occur at pedestrian crosswalks and intersections. In the United States alone, close to nine thousand pedestrian related accidents occur at intersections of urban areas, annually (Cote, 2002). Such data suggests that pedestrian/vehicular interaction is in need of improvement nationally and at the state level, especially in areas where pedestrian traffic is heavy.

In Boston, Massachusetts pedestrians make three out of every ten trips. This fact has rightfully earned it the title of *America's Walking City.* Unfortunately, most of Boston's street infrastructure was constructed before the existence of the automobile; thus resulting in some of present-day pedestrian/vehicle conflicts. These and other complications have proven to be detrimental to the safety of pedestrians, the well-being of drivers and oftentimes have the potential to be fatal. Pedestrians will interact with vehicles regardless of whether the situation is ideal or not.

So, is it the pedestrian-vehicle relationships that is the problem or is it intersection design? A perfect situation might consist of pedestrians crossing in a perfectly lawful manner and vehicle drivers would obey their laws, as well. In reality, though, pedestrians cross in an inconsistent and difficult to predict manner. Realistic crossing patterns generally contain unlawful paths and times when crossing the street, which causes many of these negative interactions between pedestrians and vehicles. These alternative routes are a product of inconveniently placed crosswalks for pedestrians and a lack of incentive or hindrance for one to walk and follow ordinances accordingly. These unpredictable factors have lead most traffic engineers to mostly neglect pedestrian behavior and to plan for drivers' best interests which generally come at the cost of pedestrians' best interests.

For this project we developed a protocol for the effective and easy assessment of intersections that are the home to a great amount of pedestrian/vehicle interactions and also are places are high incident rates. The project focuses on the intersection of Boylston and Tremont streets, an intersection that possesses both heavy pedestrian and vehicular traffic. Over a period of two weeks, we gathered data by recording intersection statistics at peak times of pedestrian/vehicular relocation. We observed the number of pedestrians crossing the intersection at specific phases and pedestrian crossing patterns to get them from point A to point B. Qualitative data such as pedestrian interviews were conducted through concise but thorough questionnaires, engineered to accommodate pedestrians' hurried dispositions. At the completion of the two weeks of statistical collection and research, our group applied our knowledge from previous studies to recommend adequate study models to assess intersections in an effective and efficient manner.

Section 2: Background

2-1: Introduction

The downtown area of Boston is the center of activity for the city, with major commuter arteries feeding from points outside the city and its neighborhoods. In addition, the transit lines end and begin here, thus there is a large amount of pedestrian foot traffic, as transit line commuters usually need to travel several blocks to reach their final destinations. Considering the amount of both vehicular and pedestrian traffic, as well as alternative forms of transportation, it is important that intersections are structured to cater to the needs of both drivers and walkers.

The purpose of this section is to convey the knowledge and information necessary to understand the challenges and obstacles facing pedestrians as they travel around the city. Many considerations in intersection structure, traffic calming, and pedestrian art, as well as other factors, need to be explored in depth to fully accomplish the goal of creating a protocol to assess intersection effectiveness.

A result of a large number of pedestrian incidents is negative interactions with vehicles. On average, across the country, a pedestrian is killed in a traffic incident every 113 minutes. Seventy-three percent of these occur in urban areas such as Boston (Weitz & Luxenberg, 2008). In the year 2003 alone, 98 pedestrians and bicyclists were killed in Massachusetts from traffic related incidents (Weitz & Luxenberg, 2004). Since 1997, the country has seen a 13% decrease in vehicle-pedestrian related deaths, which is attributed to the dispersion of advice to pedestrians (Weitz & Luxenberg, 2008), traffic planning, design, and regulations. Twenty-two percent of all vehicular deaths in the state of Massachusetts were a result of crashes that occurred at an intersection (Weitz & Lexenberg, 2004). Thus, it is important that this project results in a model that allows for effective and fast assessment of intersections so that dangerous problems can be ameliorated. The main point of this project is to create a protocol to improve the conditions for pedestrians. That does not mean vehicular interests were disregarded. The project sought an optimal balance between pedestrian convenience and vehicular comfort, however, mending pedestrian problems and obstacles is the key focus above all else.

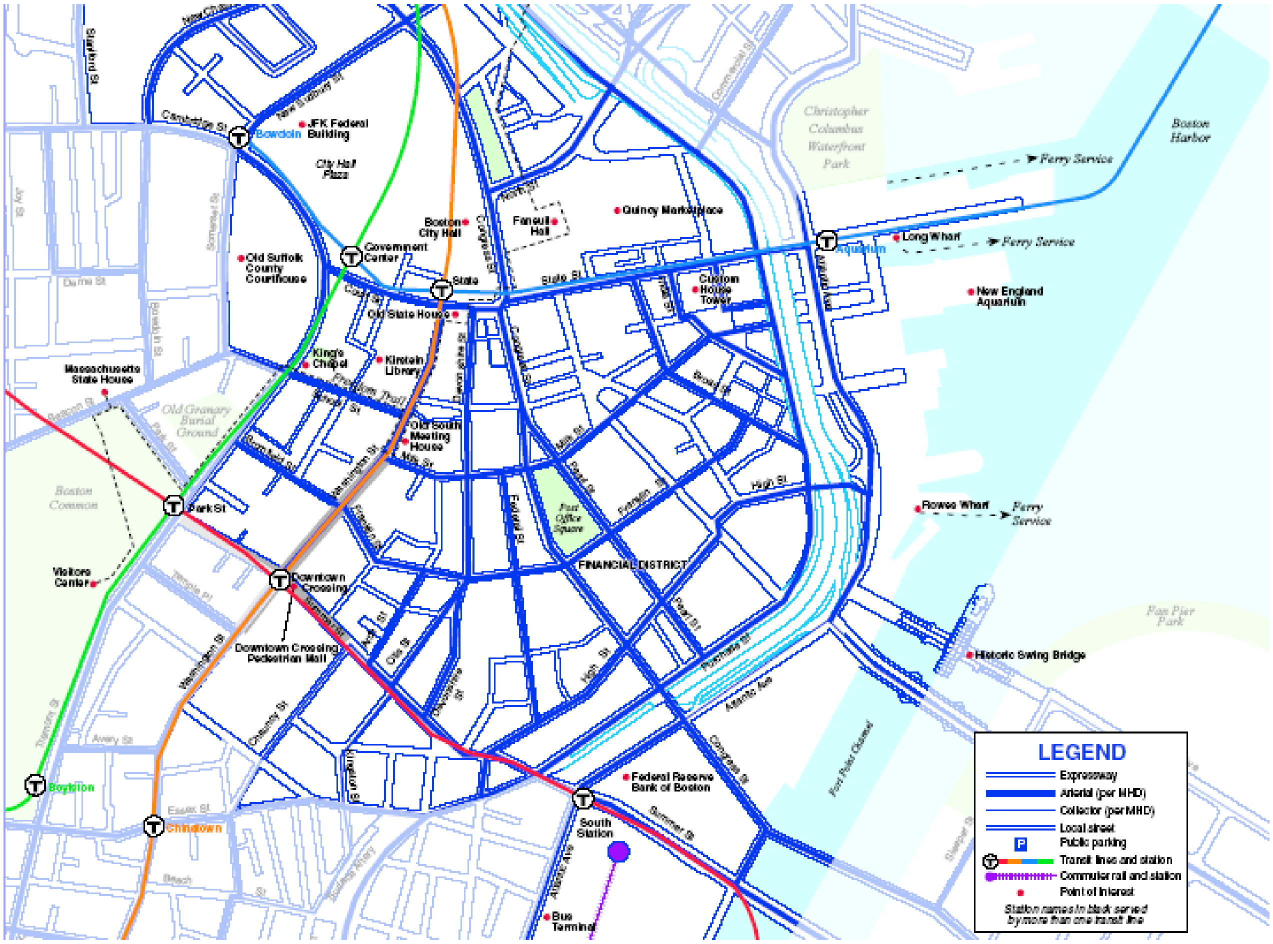
In this section, we review basic traffic fundamentals of Boston, such as the history and layout, pedestrian interactions, vehicle interactions, and alternative modes of transportation. We discuss modeling of intersection incidents between vehicles as well as outline a set of ordinances and regulations that must be followed by both drivers and pedestrians. Following this, we outlined a set of case studies. In the first one, the Passmore Study, we describe the study and then use it as a model for our own methodology and for devising the outline of objectives that we feel necessary to solve the problem. The concepts elaborated here have become the foundation to the steps we take in our methodology.

2-2: Traffic in Boston, Massachusetts

History and Layout of Study Area

Boston is one of America's oldest cities and it still uses many of the streets that were laid out in the 1600s. Some streets, highways, bridges, tunnels, interstates, parkways, and alleys that make up the city's roadway infrastructure are owned by different state, local, and regional entities, while others are privately owned. Boston is characterized by its many distinct neighborhoods, which are comprised of both commercial and residential areas (Access Boston, 2002, Intro). These neighborhoods are: East Boston, Charlestown, South Boston, Central, Back Bay/Beacon Hill, South End, Fenway/Kenmore, Allston/Brighton, Jamaica Plain, Roxbury, North Dorchester, South Dorchester, Mattapan, Roslindale, West Roxbury, and Hyde Park (Access Boston, 2002).

Boston has 785 miles of centerline roadways and 3,708 public streets. There are 784 signalized intersections and 300,000 public safety, informational, and regulatory signs. The map below gives a bird's eye view of the transportation infrastructure of downtown Boston.



Source: Access Boston

http://www.cityofboston.gov/transportation/accessboston/

Figure 1 – Downtown Roadway System

Virtually all journeys made within the downtown area are pedestrian trips. Because North and South Stations are located in the Downtown area, passengers from the transit lines usually walk several blocks to reach their final destination or switch to a local MBTA route, as is noted in the table below. This project's major focus is to prepare an observation protocol that can be used to easily and effectively assess intersections with heavy pedestrian traffic, and thereby giving the ability to address problems that make it difficult to be a pedestrian. To do this, we focused on one intersection in the downtown neighborhood of Boston, the intersection of Boylston and Tremont Streets. This intersection is at the heart of the Theatre District in Boston, in which 17,900 people are employed and which is also the home to Emerson College. In addition, the population growth in this neighborhood is increasing, with a 34.9% surge since 1980. Major commuter arteries feed into this area, as is displayed in the map above, which provides great access for commuters but makes it more dangerous to be a pedestrian. Data taken at one point indicates that the daily traffic volumes on these streets is approximately 15,000 on Tremont and 7,000 on Boylston, with 29% of travel styles being by auto (Access Boston/Chinatown 1).

Pedestrian Traffic

Boston is known as "America's Walking City." Of the 2,735,000 journeys that begin and end in Boston every day, three out of every ten of these trips are made by pedestrians (Access Boston, 2002). Although there are a large number of people that drive into Boston, some 600,000 each day, from surrounding areas for work, enjoyment, or tourism, there is a large population of people that walk. The close proximity of residential and commercial areas in Boston's neighborhoods allow for "walk mode" to be used for a large number of trips. As is displayed by the table below, most of the trips made by pedestrians are kept within the core neighborhoods of Boston.

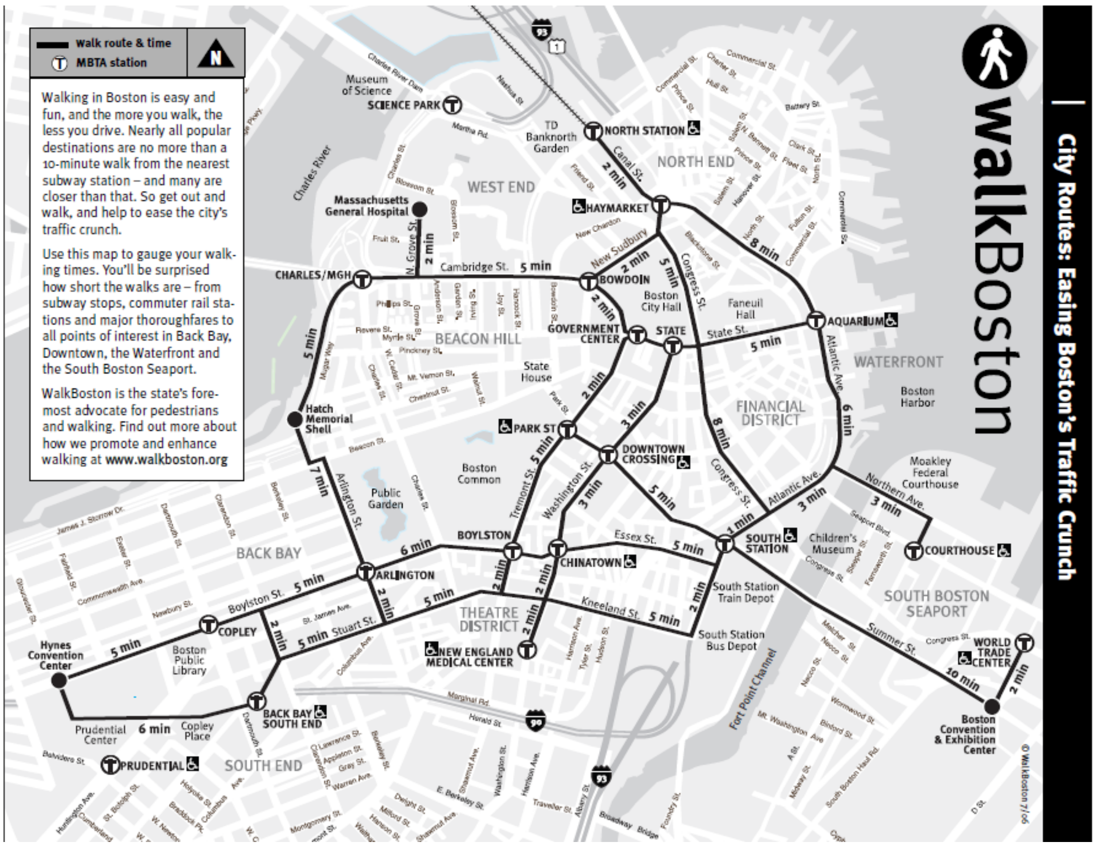
Mode Shares for Boston Trips	Auto	Transit	Walk
Trips entirely within a neighborhood	23%	3%	**74%**
Trips to or from the Core Neighborhoods	27%	40%	**33%**
Trips to or from the Rest of Boston	63%	29%	7%
Trips to or from the Inner Communities	72%	26%	2%
Trips to or from the Outer Communities	83%	17%	0%
All trips beginning or ending in Boston	51%	19%	**30%**

Source: Access Boston (from 2000-2010)

Table 1 – Proportions of Modes of Transit taken in Boston

The City of Boston labors to maintain the label of "the walking city" by marking crosswalks, performing regular maintenance of traffic signals and pedestrian pushbuttons, and pedestrian safety signs at busy locations such as in the downtown area, at schools, parks, playgrounds, elder complexes and libraries (Boston visitor's page, 2002). In an attempt to keep pedestrians safe as they travel, the city has also made physical modifications in some neighborhoods. These improvements include street closures, street direction changes, curb extensions, and textured pavement (Ped. Safety Boston, 2002).

The City must also devote efforts into finding ways to avoid pedestrian injuries and fatalities. Each year, vehicles are the cause of about 6,000 pedestrian fatalities and over 100,000 injuries nationwide. With Boston being a major destination for the work force in Massachusetts, there is dependence on automobiles to get to and from work. This does not aid the pedestrians though, as these roadways are usually unfriendly to pedestrians because there is a lack of sidewalk, cross-walks, and crossing-signals. In addition, Boston is known for its use of street parking, something that can pose a great threat to pedestrians. On-street parking helps enhance the pedestrian experience as a buffer from traffic, however, when parking occurs to close to a crosswalk without curb extension it is a problem due to sightline obstruction. This can be altered, though, with physical changes, or traffic calming measures (Frumkin, 2004, 113-117).



Source: City of Boston Visitor's Page, Walk Boston

Figure 2 – Diagram of Public Transit System within Walking Proximity in Downtown Boston

Problems that can be perceived at an intersection are anything from a lack of convenience of safety. In order assess these problems, data must be collected there by some protocol. A series of conventional data collection protocols have existed for years for traffic engineers to conduct and then consult in order to improve the structure of an intersection. These protocols were reviewed upon by our group and then adapted from in order to create a data collection protocol that would provide engineers with the necessary information for assessing the problems of an intersection and then provide potential solutions for those problems.

2-3: Conventional Data Collection Protocols

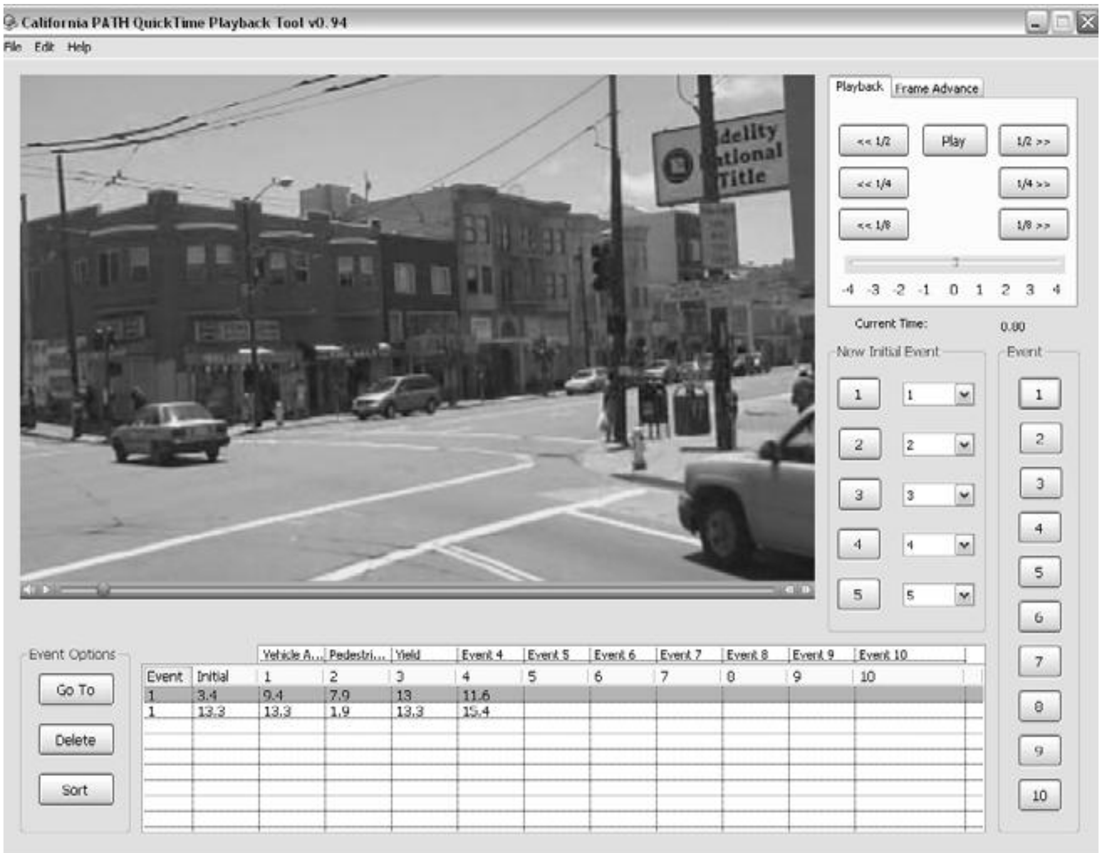
In order for our group to create and test a relevant protocol, it was necessary to consult the methodologies of common protocols already put to use and to consider their relevance. Our project is not to test the following protocols, but to draw from them and create an efficient method of collecting adequate data at an intersection.

San Francisco Intersection Improvement Implementation Study

A recent study in San Francisco stated that their goal was to implement safety devices to make high-injury areas (intersections) safer for pedestrians. In order to give decisions an appropriate background, they had to formulate an appropriate way to collect information. For their data collection protocol they looked at pedestrian arrival at the intersection, pedestrians beginning to cross, pedestrian reaching the end of the crosswalk, vehicle/pedestrian interactions, vehicle yielding, distance of yielding, vehicle conflict, pedestrian trapped, vehicle crosswalk blockage, pedestrian delay, and pedestrian crossing time (San Francisco, 2008, 4). Using the data they collected through the use of this protocol, they determined which parts of the intersection could be improved and where it was typically unsafe. They also implemented the use of intercept surveys in their study. Through the use of the protocol they were able to implement recommendations that would improve the overall quality of the intersection (San Francisco, 2008, 5). They went back to the intersection later to capture the before and after effect of the changes that were made, using the same parameters and methods as a guideline (San Francisco, 2008, 4).

One notable feature to the study was the use of recorded video (San Francisco, 2008, 4). This method was used for accurate and simplified data collection. The videos recorded allowed them to playback to assure that they didn't miss anything and they were able to collect and time data straight into the tool they used to play back and forth the videos (San Francisco, 2008, 6). The tool was developed by the California Partners for Advanced Traffic and Highways of UC

Berkeley Institute of Transportation Studies (San Francisco, 2008, 6). A preview of the program that they used to collect data is shown in the figure below.



Source: San Francisco, 2008, 6

Figure 3 – The California PATH playback tool used in the San Francisco study

From this study, we were able to get a set of parameters that we collected data from. Specifically, vehicle/pedestrian interactions, vehicle yielding, vehicle conflict, pedestrian trapped, vehicle crosswalk blockage, pedestrian delay, and pedestrian crossing time were all parameters that we evaluated or grouped together with another parameter in our Methodology in terms of developing our protocol.

The use of surveys, while originally planned out by our group, was not used, since our goal is to specifically test potential protocols, rather than provide an ultimate solution to the intersection. Also, categorizing by demographics were seen as inappropriate for our protocol, as it would serve limited and crossing habits wouldn't differentiate dramatically between classes.

Our protocol looks at an intersection from a broad perspective, figures in all demographics, and considers exclusively what the vast majority's habits are; It does not differentiate who does what.

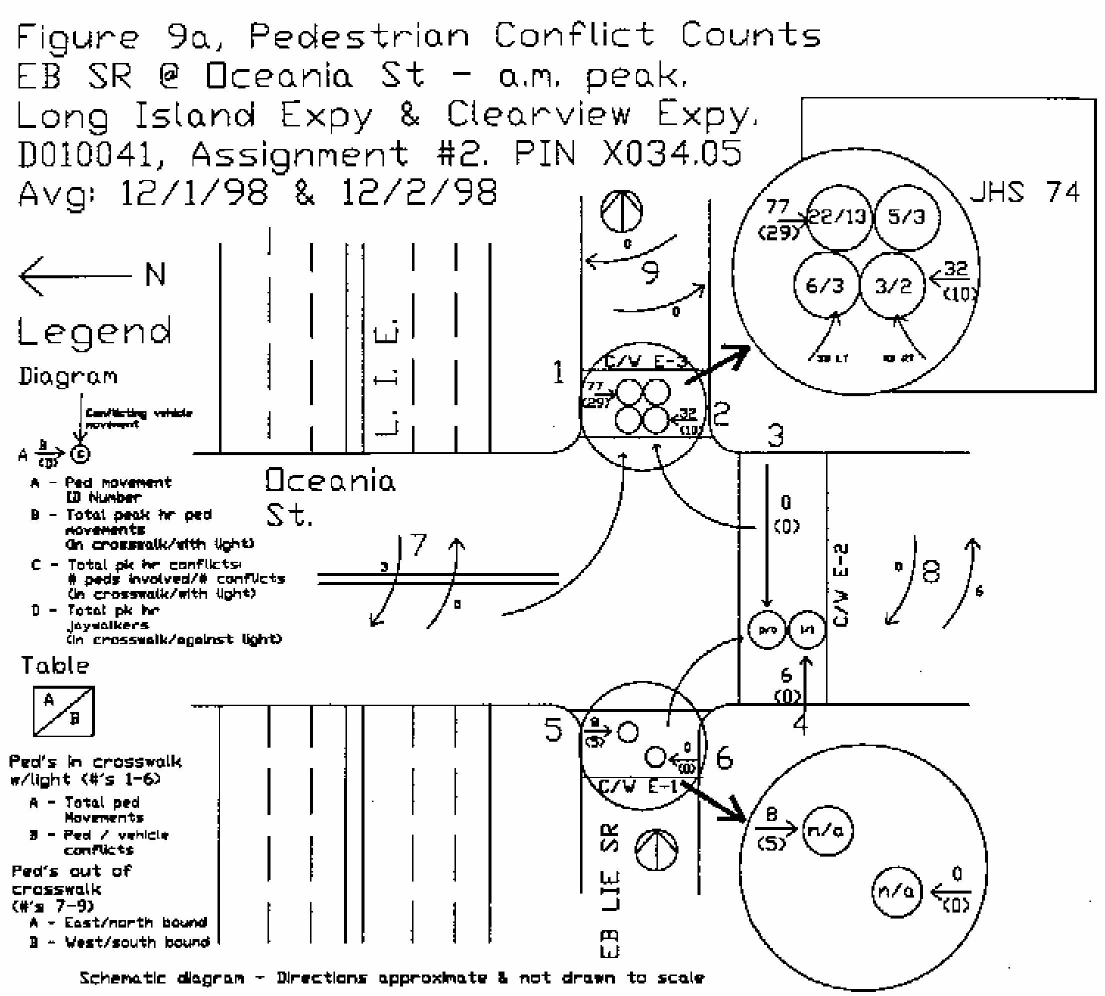
Another feature that was used in testing our protocols was the use of a camera. While we did not have access to the same playback tool, we were easily capable of watching the videos with another program and going back and forth through the footage to make sure we captured delay and desire lines accurately. For general counting information, use of a camera wasn't necessary.

The before and after portion of this study is not exactly relevant, but was used as a foundation for some of the logic behind our methods. It is not appropriate for us to recommend fixes at an intersection and even less so to make those changes and test them after. It is relevant to at least consider what some of the typical changes that can be made to an intersection are, how effective they can be, and how our protocol could potentially signal to those making the decisions on what to do.

Pedestrian Volume and Conflict Data Collection

In Konheim and Ketcham's model for analyzing pedestrian conflict, they conducted analysis on an intersection that crosses Oceania St. in Long Island, NY. They would look at type of crossing, which was defined by where the pedestrian was crossing a road, and whether that caused a conflict for a vehicle or pedestrian. In order to objectively define a conflict, they borrowed Dominique Lord's definition from *Analysis of Pedestrian Conflicts with Left-Turning Traffic*, where a conflict was described as "an event in which two road users (pedestrians, vehicles, bicycles) would have collided had their paths, speeds or both remained unchanged on an element of the transportation system (intersection, road section, ramp, and so forth)" (Lord, 61-67). They looked further into these potential conflicts by computing a time-to-collision (TTC) ratio. This ratio measured the speed of the vehicle and the distance between the two subjects, which would define the potential severity of an actual collision.

The intended result of this protocol was to give traffic engineers information on location and type of conflicts to be able to make geometric changes on the intersection, such as increasing walking space or changing the angles of the intersection structure. This would also provide suitable information to where crosswalks may need to be placed, as they included overall collection information on those pedestrians crossing outside of the crosswalk. The TTC ratio was a measure used to establish the importance of the possible changes.



Source: Konheim and Ketcham, Pedestrian Conflict Analysis Methodology

Figure 4 – Outline of the study intersection and identifications of data collection

In the figure above, you can see a two dimensional rendition of the group's study site. They outlined potential turning movements of vehicles and outlined the various types of crossing routes pedestrians usually take around the intersection. For data collection purposes, they also gave a numerical value for each type of crossing and differentiated between where the pedestrian was coming from at the three crosswalks. Also described is how exactly they would tally and tabulate data for actual collection purposes, as seen in their sample below.

The following figure shows an example of how they collected data at the site. The chart is broken down by type of crossing or ID number and by fifteen minute time intervals. In the top left corner of every box, it shows the total volume of pedestrians crossing and in the lower right corner it shows both the pedestrian and vehicle conflicts during that period.

Conflicts by Movements and Time

(in crosswalk / with light)

	Pedestrian Movement ID Number								
Time	1	2	3	4	5	6	7	8	9
8:00 - 8:15	6; 2/1	11; 1/1	0; 0/0	2; 0/0	2; n/a	0; n/a	0; 2	4; 0	0; 0
8:15 - 8:30	29; 17/11	10; 5/3	0; 0/0	0; 0/0	1; n/a	0; n/a	0; 0	1; 0	0; 0
8:30 - 8:45	34; 5/3	10; 3/1	0; 0/0	3; 1/1	4; n/a	0; n/a	0; 1	1; 0	0; 0
8:45 - 9:00	8; 3/1	1; 0/0	0; 0/0	1; 0/0	1; n/a	0; n/a	0; 0	0; 0	0; 0
Hourly Totals	77; 27/16	32; 9/5	0; 0/0	6; 1/1	8; n/a	0; n/a	0; 3	6; 0	0; 0

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Source: Konheim and Ketcham, Pedestrian Conflict Analysis Methodology

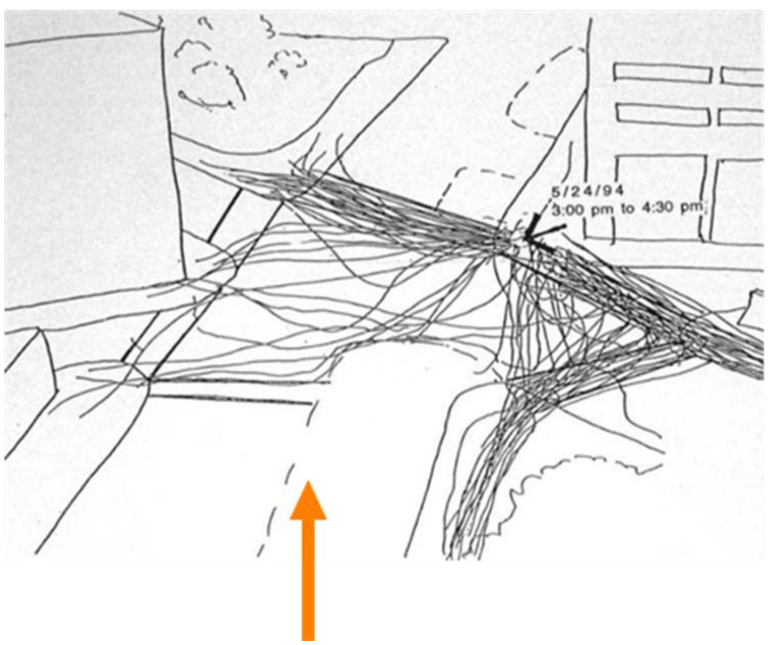
Figure 5 – Data collection table to collect volume versus conflicts over fifteen minute intervals

This study outlined what to look for at collecting pedestrian data at an intersection, how to define conflicts objectively, and how to collect that data. The TTC ratio information was not as valuable or necessary to our Methodology as the conflict information. The main concepts we drew from this study were the definition of conflict and a model for collecting data, by having both total volume and conflicts in the same table. The use of collecting data in fifteen minute intervals was used in our preliminary data collection of the intersection, but we deviated away from that later in our own protocol in favor of collecting by phases and cycles, which could also be split into timed intervals if you knew the length of a cycle and phase. Complex splitting of types of crossings also were determined to be inappropriate for our research. While is may serve a purpose, it proposed too many variables for our group to collect and by collecting just total volume of crosswalk usage was enough, as which side they were coming from would not impact them in terms of how they were being effected by traffic. Therefore, crosswalk patterns were dependent solely of traffic signals and not by destination.

Tracking Surveys

Tracking surveys are maps recording a pedestrians' path through and/or around an intersection or street. These surveys can be used for redesigning of an intersection, to see if it is necessary to add or subtract a crosswalk from and intersection, etc. This is similar to a college campus placing a sidewalk or pathway where grass is typically worn down from excessive use.

Our group looked over a series of these tracking surveys to determine what they were used and designed for. For instance in Manhattan when the city was planning on changing the infrastructure of an intersection they did a tracking survey to see where most of the pedestrians walked. With this information they know how to reconfigure the intersection to assist pedestrians and keep them safe. An example of a map for their tracking survey is in the figure below. In Bangkok a tracking survey was performed to see if a crosswalk was necessary and by doing this they found that people were going out of their way to walk in the crosswalk, which exposed them in the street for longer. So they found by removing the crosswalk pedestrians crossed in straighter lines and by this lowering their exposure time in the intersection.



Source: Tracking Surveys

Figure 6 – Map with hand drawn lines indicating pedestrian movement in Manhattan

This data collection knowledge is very valuable in a protocol because it can tell the client where pedestrian foot traffic is more frequent. With this information the client can then figure out ways to direct pedestrian traffic to the appropriate crossing and/or figure at what part of the intersection needs to have more time designated to pedestrians rather than cars.

2-4: Conventional Protocol Analysis in Sao Paolo, Brazil

Conventional models of traffic regulation and analysis have achieved many methods of accurately quantifying pedestrian behavior. Unfortunately, the City of Boston has yet to implement methods that yield data unique to a particular intersection. This distinct problem inhibits proper analysis of an intersection. Because pedestrian movement and interaction is not properly quantified, it is impossible for city engineers to structurally adapt the intersection to better accommodate the needs of the pedestrian.

Urban areas are important to pedestrian/driver interaction because of the confluence both parties provide to a specific region. Greater population density dictates greater pedestrian and vehicular interface and thus offers a higher probability for incidents. Through various scholarly studies on traffic regulation and the improvement of road conditions it was concluded that most pedestrian/driver accidents share stimuli. Analyzing individual motives (pedestrian/driver) and highlighting poor urban planning (city administration), outlines the common shortcomings at the scene of the average accident. Among others, *The Missing Leg* study by Dylan Passmore fittingly analyzed pedestrian behavior in urban areas. This and other studies contributed crucial information to pedestrian/driver interactions at urban intersections and suggested further, appropriate methodology for the current project-study.

Analysis of Motives

Pedestrians and drivers in urban areas often break traffic regulations in order to achieve a common goal, which is to arrive at their particular destinations as soon as possible. The more densely populated the area is, the more time consuming it is for drivers and pedestrians to be considerate of one another's time. Elementary reasons such as these ultimately cause pedestrian/driver incidents. These are common findings that helped locate the proper intersections for study. Our group intended to draw from this, by finding the approximate delay for pedestrians at a given point and cross-referencing it with other statistics we find from vehicular and pedestrian statistics at the same point.

Although outlining a goal in the Passmore study may seem simple, pedestrian perceptions of traffic regulations and the need to obey them involuntarily occurs as a part of their nature (Schattler, 2002, 8). An Illinois study on the countdown of traffic signals and pedestrian behavior showed a distinct variance based on sex. Not only was tolerance among male pedestrians lower than that of females, but it was also concluded that females use an informative approach to traffic regulation (Schattler, 2002, 6). This informative approach suggests that females examine an intersection for appropriate traffic markers and signals. In contrast, males use a normative approach, establishing their own standards for when it is and is not appropriate to cross an intersection or crosswalk regardless of traffic regulation. Similar statistics exist for the driver. The driver usually possesses a sense of authority over the road, being as how a vehicle grants him/her superiority in movement and to some extent even strength. This produces the theory that the street is meant for the driver and the pedestrian is but an irritating nuisance (Passmore, 2007, 37).

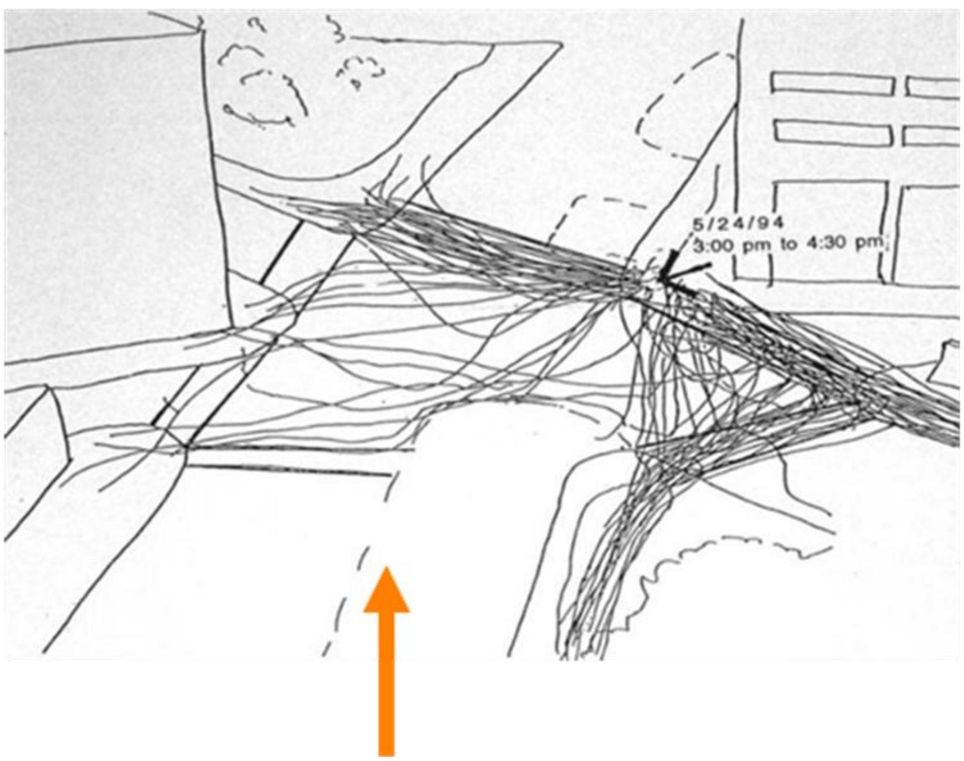
Substandard Intersection Maintenance

Although the relevance of the theory for a pedestrian/driver to want optimum time for his/her journey correlate with pedestrians and drivers around the world and the current project site, the disregard for pedestrian well being does not. The Passmore study's findings would be hard to duplicate in the United States, where penalties for such driver indifference towards the pedestrian are severe. Thus, contributing factors to driver negligence of traffic regulations were deduced. Studies concluded that in highly urban areas, constant use of the surrounding traffic art and road art regulating vehicular traffic wears down or is damaged to the point of illegibility (Lee, 2000, 781). This research suggests that continuous maintenance of urban intersections is necessary in order to keep drivers properly informed of the area's regulations.

Oftentimes, trouble spots of recurring accidents provoke a harsher response pedestrian/driver incidents can be reduced.

Figure 7 – Passmore Study

In Figure 7, the Passmore study illustrates an urban intersection where pedestrians choose to cross illegally via the shortest route to reach the opposite end of the street, rather than legally cross the traffic of vehicles and tracks (outlined in yellow) since the traffic signal that authorizes the crosswalk would amount to almost ten times the distance walked illegally (Passmore, 2007, 37).



Source: Tracking Surveys

Figure 8 – Map with hand drawn lines indicating pedestrian movement in Manhattan

This is a commonly utilized practice in other data collection protocols mentioned earlier. The most similar protocol is the tracking survey, as seen in Figure 8. These desire or trend lines on a Manhattan intersection illustrate the frequency of where pedestrians cross and can show what physical changes may need to be made to an intersection. For instance, after the survey in Figure 8 was completed on the Manhattan intersection, it saw greater crosswalk space, more paint in the crosswalks to make them more visible, and a more pronounced curb to allow more room for pedestrians to walk. Through use of a tracking survey, an engineer can determine if the pattern apparent in Figure 7 is a minimal problem or if it is a more frequent issue.

Ultimately, the Passmore Study helped define proper pedestrian crossing, which is a crucial study characteristic of any intersection. Because the intersection is divided in safe and unsafe zones of crossing (respectively on authorized crosswalks and unauthorized portions of the street) it was deduced that when pedestrians cross they do so in a manner that will allow them to reach their destination in the shortest time and distance. Therefore, they will break regulations in order to achieve optimum traveling time. As in the Passmore study, the research conducted at the intersection proved that pedestrians acted in such manners. Conclusions such as this one infer that signal timing does not provide adequate crossing time for the pedestrian and distances between crosswalks are too long.

2-5: Summary

Studies such as the Passmore paved the way for the current protocol by outlining the importance of pedestrian study. The principal objective of the project is to create an original protocol that can be implemented on multiple intersections. It includes methods of data collection that are original, conventional and have yet to be implemented in intersection analysis by Boston Traffic engineers. In light of aforementioned studies, proper analysis of pedestrian behavior is crucial to determining an intersection’s structural shortcomings. The protocol that was developed scrutinizes between pedestrian volume and movement. Also, it contains methodologies that present a statistical specificity in pedestrian study that has yet to be achieved by current intersection analysis in the City of Boston.

Section 3: Methodology

3-1: Introduction

Our project goal is to develop a data collection protocol that will give traffic engineers or consultants more substantive information on an intersection given the duration of data collection in order to make walking at intersections safer and more convenient for pedestrians. The protocol looks at pedestrian and vehicular behavior, as well as the infrastructure of the intersection. This section details the data collection and analysis procedures for our study. All the following objectives were repeated at different intersections to establish the validity of our protocol.

3-2: Objective #1 – Selecting an Appropriate Study Site

It was crucial to decide on our study site so that we could have a foundation for data collection as early as possible. In determining our study site, we made sure that what we selected would be both appropriate and feasible to the goal of our project.

Process of Analysis

For the first week we were in Boston, we completed on site overviews of the potential intersections we were considering and determined which ones are most appropriate. Our sponsor provided several intersections that handle a large volume of pedestrians and are overall problematic or inconvenient for various modes of transportation. The intersection that we decided on was the Boylston-Tremont intersection by the Boston Common based on the following criteria:

1. Volume of cars and pedestrians: This was first assessed by general observation, to determine the relative usage of the intersections. It was later established by statistics acquired from sources referred to us be the Boston Transportation Department and then crosschecked by our own gathering of statistics. For the data collected, we considered the following questions on each intersection:

   a. Does the intersection provide a large enough sample size that will provide us with enough information to draw conclusions and obtain consistent results?
      i. For the Boylston-Tremont intersection, we determined that there is a consistent flow of pedestrian traffic during peak hours and still suitable amounts of traffic during non-peak hours. The intersection also sees consistent flow of vehicles, which gave ample opportunity for pedestrian-vehicle interactions.
   b. Is collecting accurate data going to be feasible or is it too complex for our limits?
      i. This was the more difficult task to re-assure ourselves of for the Boylston-Tremont intersection. The most beneficial condition was that even though it has a large flux of pedestrian and vehicle usage, it's a simple four-way intersection where we were able to place one group member at each corner and have them collect data for a specific field of vision where we would make sure all vantage points of the intersection would be covered. We understood that we may lose some data in making sure we record values for every given interval, but the loss would be negligible and we would already have a suitable sample size and accurate enough volume counts.
2. Provision of data to conduct critical analysis upon: This would be assessed by taking the data and considering if there were legitimate problems, such as a common lack of compliance by pedestrians or overall flaws of the intersection. To justify this concern, we responded to the following questions for intersections that we considered:
   a. Does the data we collect show enough non-compliant crossings and/or unsafe crossings that indicate dissatisfaction with the intersection?
      i. From initial observation at the Boylston-Tremont intersection, there definitely appeared to be a relatively consistent set of pedestrians failing to comply with crossing standards or just crossing in an unsafe manner. In later objectives, we researched whether these were due to a lack of desire to cross appropriately due to delay or to reach a specific point of interest more conveniently.

b. Are there any obvious structural or design flaws apparent that may lead to the increase in dissatisfaction with the intersection?
    i. The first day we got to the Boylston-Tremont intersection, we noticed that there was an obvious point where it could have had a concurrent crossing on the incoming point of the intersection on Tremont, where the street is a one-way street and all traffic was yielded. There also appeared to be a problem with overall delay amongst the pedestrians waiting to cross.

After our initial field research and analysis of the necessary criteria, we then had our study site selected. With the site established, we were able to continue with the following objectives to go into depth.

This method of critically analyzing recommended intersections was considered more appropriate for our project than another method of just randomly selecting intersections. While random selection would have reduced the chance of potential bias in selecting a study site, it overall would not have been wise and would have greatly reduced the chance of getting appropriate data. For example, choosing ten intersections randomly, on average, would potentially produce only one or two that would be ideal in providing the necessary information to providing solutions and would be feasible for collecting data. The other eight or nine may be intersections that don't have a specific problem with pedestrians crossing, have a lack of pedestrians, or are too complex for four people to collect accurate data. It was important to use critical thinking in our decisions, as opposed to utilizing pure chance.

Following the completion of our Boylston-Tremont intersection analysis we would design a quick test of our methods for another intersection. This intersection was one that was perceived to be safer and had concurrent crossings in order to see what our protocol said about their use. Given that the city of Cambridge, MA had a pedestrian plan put in place, we eventually chose the intersection of Mass Ave. and Prospect, which exclusively had concurrent crossings and was considered safer than the Boylston-Tremont intersection.

3-3: Objective #2 – Defining Intersection Design Variables

After our group collected information on pedestrian and vehicle behaviors, it was important for us to see if the design parameters at the intersection would cause the tendencies for pedestrians and drivers facing the intersection to not comply with its structure. The data necessary for this objective was collected in a time period of one week and utilized on the intersection of Boylston Street and Tremont Street.

Process of Analysis

In order to establish fundamental knowledge of the intersection, we had to determine a series of design parameters, such as the time it takes for a traffic light to go from green to red, a crosswalk signal rotation from DON'T WALK to WALK, and where the crosswalk are located are all part of an intersections structure. All of this data, both qualitative and quantitative, was found both on the street and through interviews with professionals and surveys with pedestrians. We timed how long a crossing signal took to go from WALK to DON'T WALK. We also figured out how long the traffic lights indicate stop (red) when the crossing signals are on WALK. Lastly we observed the intersection layout of intersections.

Elaborations on the methods that we took to establish structure follow:

1. Defining phases of the intersection.
    a. When we measured the timing of crosswalk signals the stop watch was started when the WALK signal appears and stopped when the DON'T WALK signal was at a glow. These measurements told us how much time the pedestrians were given to cross from one side of the street to another. That data was then compared to the average walking speed of a pedestrian (three feet per second) and it was to see if the pedestrians were given enough time to cross safely.
    b. When the light indicated the stop signal (RED) the stop watch was started and as soon as the light shined GREEN the watch was stopped. This information told us the actual time pedestrians have to cross the street (even though the pedestrian may not be complying to the crosswalk signal). This data was compared to the above information of the pedestrian crossing time as well with pedestrian and vehicular behavior.

c. These variables were considered, grouped, and then analyzed to defining a series of phases where we would be collecting data. Any phase would be where there would be a noticeable change, such as a crosswalk light changing from walk to a flashing countdown.

d. A rough sketch of an example at Boylston-Tremont for the noon peak hour is shown in Figure 9.

<table>
<tr><th>PHASES</th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th></tr>
<tr><td>A</td><td colspan="2">DON'T WALK</td><td colspan="2">WALK</td><td>COUNTDOWN (11 SEC.)</td><td colspan="2">DON'T WALK</td></tr>
<tr><td>B, C, D</td><td colspan="2">DON'T WALK</td><td>WALK</td><td>COUNTDOWN (15 SEC.)</td><td colspan="3">DON'T WALK</td></tr>
<tr><td>TRAFFIC</td><td>TREMONT GREEN</td><td>T.A.</td><td colspan="2">ALL RED</td><td colspan="2">BOYLSTON GREEN</td><td>B.A./B.R.</td></tr>
</table>

Figure 9 – An example of a table outlining the phases of the Boylston-Tremont intersection.

2. Establishing the physical structure of the intersection.

a. This was accomplished by simply observing the intersection and measuring out crosswalk widths, lengths, and distance between crosswalks. This gave our sponsor a visual aid of the intersection without them needing to go on site at the intersection. When these intersections were drawn out as a visual aid all of our observations and data for pedestrian and vehicular behavior were placed on them.

b. The representations that we made of the intersection also included points of interest that would influence pedestrian and vehicular patterns.

c. This specific method was completed earlier to be able to track the patterns of pedestrians at the Boylston-Tremont intersection.

Obstacles

Even though the data collection processes seemed straightforward there were a few obstacles that had to be accounted for in our procedure. One of these obstacles was that even though one crosswalk was safe to cross the WALK signal never came up. Even though that was an easy fault found in the intersection structure we couldn't change it so we still needed to consider it "noncompliant" for the pedestrians to cross.

3-4: Objective #3 – Measuring Pedestrian Behavior

Pedestrian behavior can be defined by looking at the movements, actions, and motivations of a pedestrian. The information we needed to know included:

1. Number of pedestrians crossing at an intersection on and off peak hours.
2. Where people cross the street.
3. Why pedestrians cross where they do.
4. Adherence of street laws by pedestrians.
5. Delays that people face before crossing.
6. Pedestrian input and opinions on intersections.

Gathering this information allowed us to gain a full understanding of where and why pedestrians are attracted to crossing the street. This data was found on the streets, at a specific intersection, and through pedestrians themselves. This information enabled us to develop a protocol to make subsequent intersection analysis more efficient and pedestrian friendly.

Process of Analysis

The time-line we gave ourselves to obtain the data was roughly two weeks, and over these two weeks. Through observations and pedestrian counts, we acquired data that gave our team the insight needed to get a grasp on the movements of pedestrians and gave us the ability to create a protocol to improve intersections in Boston.

In order for us to gather all the information and data needed to complete this project effectively our team employed very efficient and quality methods. We utilized a triangulation method, by looking at the same information in a variety of different ways. Thus, we took a given intersection, observed the pedestrians movement there, collected data from that intersection, and researched the intersection.

In order to collect the necessary information, we devised the following methods for gathering data:

1. Determining pedestrian volume and conflicts during phases at an intersection.
    a. To complete this method, we had each person at the intersection counting pedestrians moving across a specific crosswalk and to also determine and count the number of conflicts those pedestrians faced.
    b. In order to test this protocol, we collected data once during the 4:30 PM to 5:30 PM peak hour. Over this duration, we made certain to distinguish between collecting data from different phases and cycles that we determined the intersection was going through.
    c. An example of the data collection sheet we used is in the figure below. Cycles were numbered 1-50 to allow sufficient data collection space. In each box, the number in the top left indicated the total number of pedestrians using that intersection and the number in the bottom right indicated the number of pedestrians that faced a conflict.
    d. This was subject for analysis with collecting similar data on vehicles at the same intersection later in this section. A sample for the data collection sheet used is shown in Figure 10.

Figure 10 – An example of the data collection sheet for counting pedestrian volume and conflicts

2. Drawing desire lines of pedestrians at the intersection.

    a. Our group first drafted a 2-D representation of the main points of the intersection and drew the paths of pedestrians as they entered and left the proximity. To do this, we randomly selected an incoming pedestrian and tracked where they walked by drawing their pattern on a printout of the representation. This showed us typical interests and general motives at pedestrians when facing the intersection. A sample of this is shown in Figure 11.

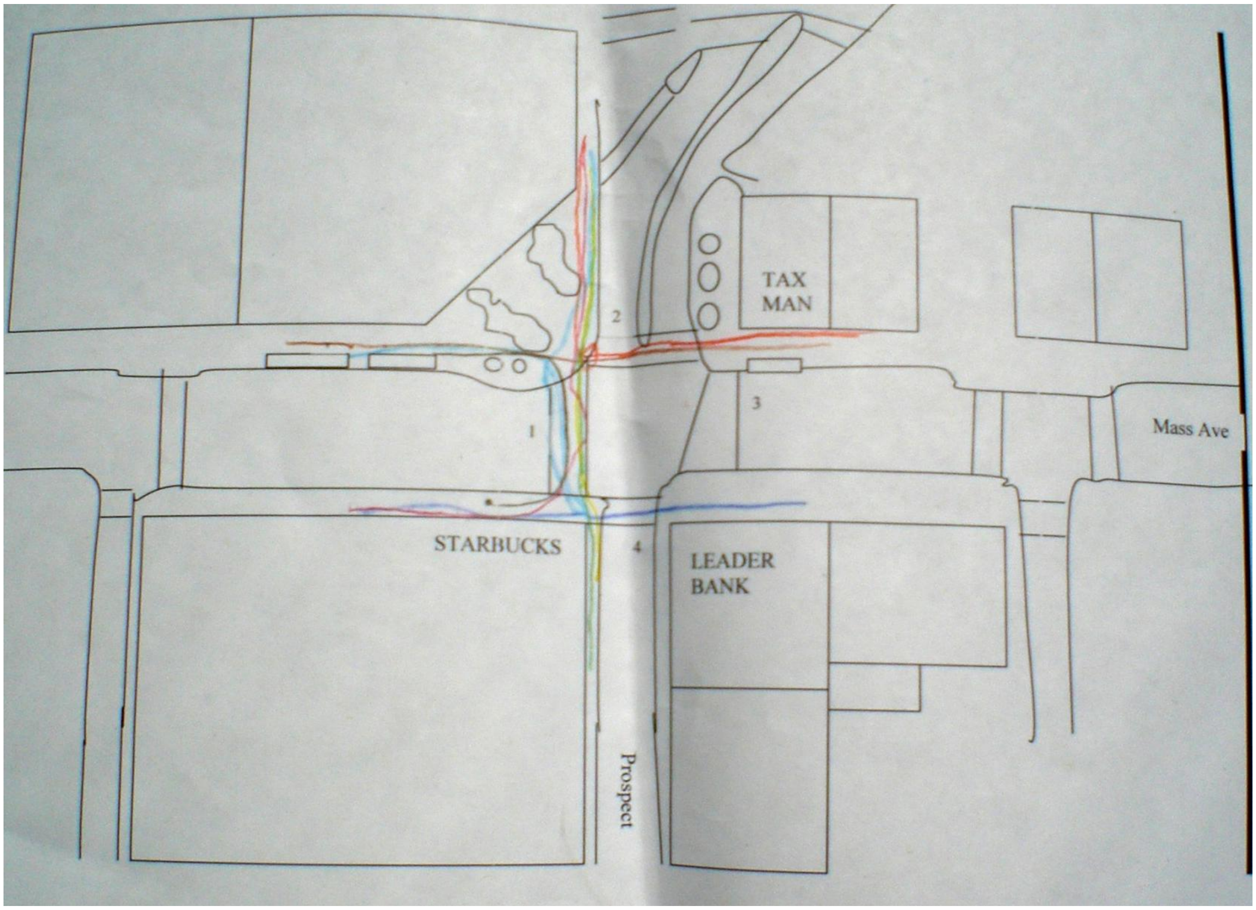


Figure 11 – An example of a tracking survey at Prospect/Mass Ave

3. Timing pedestrian delay.

   a. There were two subjects of pedestrian delay that we determined. Theoretical delay from the given timing of the intersection and the actual delay from deviances that develop from human factors of when pedestrians get to the intersection.

   b. The theoretical delay shows us the average amount of time a pedestrian would be expected to wait by engineers at the intersection by how long it takes to cycle to when they are allowed to walk again and typical considerations for pedestrian volume entering the intersection. We used a spreadsheet based off of an equation in the Highway Capacity Manual.

c. The actual delay used a camera to record video, so we could get a playback and not use our own indiscretion in choosing pedestrians. We timed each individual pedestrian waiting at an intersection, how long they waited at that intersection, and against what phase of the intersection that they decided to cross at. This shows how long a pedestrian generally actually waits at the intersection.

4. Surveying pedestrians.

    a. In order to get feedback from pedestrians, we drafted a brief, optional five-question survey where we could either hand them to pedestrians or ask them to answer ourselves.

    b. The information gathered from this was most appropriate from pedestrians crossing non-compliantly and/or unsafely, since it would show dissatisfaction and one of the questions was optionally exclusive to those who weren't crossing in an appropriate manner.

Obstacles

We inevitably faced some obstacles when attempting to gather our data. The unwillingness of pedestrians to answer or fill out our surveys hindered the input of pedestrians who regularly travel the area, thus making it harder for us to establish pedestrian motivation for their crossing behavior. Another obstacle we faced was the excessive volume of the intersections. This resulted in a loss of accuracy due to needing to stop briefly and record data on paper as pedestrian traffic continued. At any given intersection that had heavy foot traffic, it was hard to time pedestrian delay and how long it took for people to cross.

The methods that we employed in this objective allowed us to gain a better understanding of pedestrian behavior, which would be indirectly related to vehicle behavior and directly related to interactions between vehicles and pedestrians. These methods allowed us to gather the data necessary to reach conclusions, thus gave us the ability to make an effective data collection protocol in assessing pedestrian behavior at an intersection.

3-5: Objective #4 – Analyzing Vehicular Behavior

It was important to analyze driver behavior at intersections in order to completely understand vehicular/pedestrian interactions. After completing our pedestrian behavior objective, analyzing vehicle behavior gave us interpretation to the variable pedestrians face when trying to navigate through traffic. Data for this objective was quantitative and was measured at the Boylston-Tremont intersection. While our group theoretically could have performed surveys or interviews with drivers, there would have only been opportunities when drivers parked and left their vehicle. Considering that most parking along the Boylston-Tremont intersection was for commercial vehicles, it was determined to not be wise to interrupt civilians while they were working. Potentially compliant subjects would appear too rarely to go searching for them.

Process of Analysis

The process of analysis for this portion of the data collection was quantitative. Over a period of one week, traffic delay time and other statistical observations such as turn counts were collected at Boylston Street and Tremont Street.

In order to collect the necessary information, we devised the following method for gathering data:

1. Determining vehicle volume and conflicts during phases at an intersection.
    a. To complete this method, we had each person at the intersection counting vehicles driving across a specific crosswalk and to also determine and count the number of conflicts those drivers faced.
    b. In order to test this protocol, we collected data once during the 4:30 PM to 5:30 PM peak hour. Over this duration, we made certain to distinguish between collecting data from different phases and cycles that we determined the intersection was going through.
    c. An example of the data collection sheet we used is in the figure below. Cycles were numbered 1-50 to allow sufficient data collection space. In each box, the number in the top left indicated the total number of vehicles

driving across that intersection and the number in the bottom right indicated the number of pedestrians that faced a conflict.

d. This was subject for analysis with collection from similar data on pedestrians at the same intersection that was outlined earlier in this section. A similar sample of the data sheet used for pedestrians is shown in Figure 10.

Obstacles

Aside from the infeasibility of being able to get driver input, the main hindrance to our work was the overall volume and complexity of the intersection. The streets at this intersection see up to four lanes at a time, with different directional patterns at each. Making sure to tally accurately was difficult and group work was needed to make sure every vehicle was accounted for. Missing vehicles was not as much of a problem as missing pedestrians, but differentiating and accounting for their direction was more difficult.

3-6: Summary

In conclusion, the methods that we employed in our project include written and verbal surveys, general observations, and timing vehicles, pedestrians, signals, and traffic lights. These methods allowed us to gather the data necessary to reach conclusions, thus allowing others the ability to help solve the situation at the Boylston-Tremont intersection and prove the validity of the data collection protocol we have displayed here for future analysis of other streets and intersections. To make these recommendations, we analyzed the discovered flaws as well as consider traffic calming strategies, regulations, and ordinances that were discussed earlier which may be appropriate.

Section 4: Findings/Discussion

4-1: Introduction

Through our methods we have tested six significantly different approaches to a data collection protocol. They are compliance-safety data collection, phase analysis, volume-conflict data collection, surveys, tracking surveys, and pedestrian delay. Our results on each for the Boylston-Tremont intersection, their interpretations, and an analysis of the approach are available in this section. The results from testing the ones we considered most appropriate at another intersection are also shown here. We concluded with what is our recommended protocol to be used in order to collect appropriate data at an intersection for traffic engineers.

4-2: Phased Analysis

In an attempt to make our protocol for intersection analysis more descriptive than what was already put in place, we decided to look at collecting data from a phase by phase and cycle standpoint. We initially considered that the main benefits from this would be that depending on the data collected during these phases, what timing flaws may possibly exist, what concurrent crossings may be able to be put in place, and overall how these effect overall pedestrian or vehicle behavior and their interactions.

Given our definition of phase that we described in our Background, we were able split a cycle at the intersection of Boylston and Tremont into phases. The result and the non-descript timeline of a cycle at this intersection is shown in Figure 12.

<table>
<tr><th>PHASE</th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th></tr>
<tr><td>Zone 1</td><td colspan="2">DON'T WALK</td><td colspan="2">WALK</td><td>COUNTDOWN (11 SEC.)</td><td colspan="2">DON'T WALK</td></tr>
<tr><td>Zones 2, 3, 4</td><td colspan="2">DON'T WALK</td><td>WALK</td><td>COUNTDOWN (15 SEC.)</td><td colspan="3">DON'T WALK</td></tr>
<tr><td>TRAFFIC</td><td>TREMONT GREEN</td><td>T.A.</td><td colspan="2">ALL RED</td><td colspan="2">BOYLSTON GREEN</td><td>B.A./B.R.</td></tr>
</table>

Figure 12 – Phase by phase timeline for a cycle at the Boylston-Tremont intersection

From just going to and not collecting data on the intersection for the first week we were in Boston, we were able to find some basic qualitative observational trends with behavior amongst pedestrians and cars in each phase. An overall description of action happening in each phase and the trends that we discovered are listed in Table 2.

Phase	Description	Observed Trend
A	Tremont has a green light and traffic can pass through each crosswalk zone.	Heavy traffic from zone 1 to zone 3, with relatively less turning into 2 and 4. Pedestrians attempted to cross in those two zones concurrently.
B	Tremont has an amber light and traffic can pass through each crosswalk zone.	Traffic sped up from zone 1 into each other zone in an attempt to beat the upcoming red light, traffic flow overall increased depending on the number of cars remaining. Pedestrian flow actually increases from A, as this is reaching the longest point from the last time they were allowed to walk.
C	All streets have red lights and pedestrians have the walk signal.	Minimal amounts of cars would attempt to make turns, heaviest amount of pedestrian traffic.
D	All streets have red lights, zone 1 has the walk signal, the other three have a fifteen second countdown.	Minimal amounts of cars would attempt to make turns, second heaviest amount of pedestrian traffic.
E	Boylston has a green light, zone 1 has an eleven second countdown, the rest have don't walk signals. Traffic can't pass through zone 1.	Pedestrians crossed in zone 1 with the flashing fifteen second countdown. Heavy vehicle movement from zone 4 to zone 2 with a relatively smaller number turning into zone 3.
F	Boylston has a green light, all pedestrians have a don't walk. Traffic can't pass through zone 1.	Pedestrians still continued to cross zone 1 knowing vehicles couldn't move through it. Heavy vehicle movement from zone 4 to zone 2 with a relatively smaller number turning into zone 3.
G	Boylston has an amber light, all pedestrians have a don't walk. Traffic can't pass through zone 1.	Traffic began to slow, not as many vehicles left in the queue as there was in B. Pedestrian traffic seemed to increase everywhere except zone 1.

Table 2 – Observational descriptions of trends by each phase at Boylston-Tremont

After early observations were made through our protocol on each phase, it was then required to consider timing issues at the intersection. The time of each phase were set by a traffic engineer or department for the company and were consistent throughout peak hours. Table 3 shows a summary of each interval.

Phase	Noon Peak Hour (11:30-12:30)	Afternoon Peak Hour (4:30-5:30)
A	24 seconds	29 seconds
B	3 seconds	3 seconds
C	7 seconds	7 seconds
D	15 seconds	15 seconds
E	11 seconds	11 seconds
F	16 seconds	21 seconds
G	4 seconds	4 seconds
Total	80 seconds (1:20)	90 seconds (1:30)

Table 3 – Length of each phase at noon and afternoon peak hours

The process of splitting an intersection into phases was easy as long as it follows a set definition of a phase. The remaining problem is to decide which phases blend in with each other. For this intersection, it was Phase G for data collection. The one second of red was too minimal to collect data and vehicles and pedestrians had observed to have the same patterns throughout the entire phase.

Observational improvements could possibly be made on an intersection, but they rely on theoretical backing and do not have the statistical evidence to support potential claims. It's with that that we looked at other more comprehensive methods in order to allow our protocol to supply a sufficient amount of information to traffic engineers.

4-3: Volume-Conflict Data Collection

To provide a statistical background to each phase, our group collected data on overall volume of pedestrians and overall volume of cars that went through each zone of the intersection at any given cycle and phase of data collection. Pure volume rates for each zone and section by phase in the 4:30-5:30PM peak hour are available in Table 4.

Pedestrians/min					Vehicles/min				
Phase	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Phase**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
A	0.40	11.15	0.87	14.22	**A**	61.40	10.40	36.47	11.33
B	0.00	6.45	3.87	17.42	**B**	61.50	3.00	41.50	20.00
C	60.55	27.37	64.42	50.60	**C**	2.57	0.86	2.36	2.36
D	9.29	8.26	15.23	10.97	**D**	0.20	0.10	0.10	0.00
E	14.96	1.23	5.10	0.53	**E**	0.82	28.64	6.27	33.00
F	5.53	0.92	7.83	1.38	**F**	0.43	20.50	6.64	30.50
G	2.42	6.77	12.10	4.84	**G**	0.00	12.00	7.50	16.88

Table 4 – Volume rate of pedestrians and vehicles per minute through each zone and phase

What this data tells us is when pedestrians and vehicles are moving and what may arise from their combined movements. For instance, our observations on Zone 4 were backed up during the A and B phases. What the data shows is an obvious increase in both vehicle and pedestrian traffic, which is likely due to the reasons stated earlier. For vehicles, they're trying to beat the oncoming red light that starts at Phase C and for pedestrians, they haven't been able to walk compliantly since Phase D, so they are at both their max delay and the greatest backlog or queue of pedestrians waiting to cross.

This protocol also alerts us of a number of other possible interactions. For instance, Zone 3 through Phases E through G sees some consistent concurrent traffic and Zone 2 sees some minimal amounts in Phases A, B, and G. Zone 3 has a turn signal for those three phases, but these are at a low enough rates that pedestrians find it comfortable and safe to pass. This is also the case for Zone 2 in the A and B phase, but it sees through traffic during the G phase. The G phase also sees a decrease from Zone 4 for vehicles which are driving through to Zone 2. What this could indicate is that the queue of cars typically wanes out during the longer E and F phases. This indication could lead a traffic engineer to the possible solution that the time of some of these phases should be shortened to reduce delay for those trying to move in other phases. This coincides with the idea that an engineer would also potentially recommend Phase E to take more time from Phase F, as the small queue has already diminished from Zone 1 for vehicles and pedestrians still obviously want to cross and have no potential of having a concurrent crossing during the A and B phases. This is the inverse for Phase A and Phase B for at least Zone 3 and Zone 4, as both see an increase in traffic when the light switches to amber, possibly indicating that the queue has yet to be cleared or that it's being filled as it's emptying at too fast of a rate.

From here we need to look at the rates of conflicts during each of these, to see if the interactions between pedestrians and vehicles are safe enough to allow a concurrent crossing. Our data collected on conflicts in the 4:30-5:30PM peak hour is available in Table 5.

Pedestrian conflicts/min					Vehicle Conflicts/min				
Phase	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Phase**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
A	0.27	0.33	0.47	3.20	**A**	0.16	0.21	0.36	1.50
B	0.00	0.00	0.65	4.52	**B**	0.00	0.00	1.50	1.00
C	0.00	0.00	2.21	0.28	**C**	0.00	0.00	0.00	0.43
D	0.13	0.00	0.52	0.13	**D**	0.00	0.00	0.00	0.00
E	0.00	0.35	0.88	0.53	**E**	0.00	0.14	1.23	1.50
F	0.09	0.00	1.01	0.00	**F**	0.00	0.07	0.79	0.43
G	0.00	0.97	1.94	0.48	**G**	0.00	0.00	2.63	0.00

Table 5 – Conflict rate of pedestrians and vehicles per minute through each zone and phase

Pure volume numbers alone don’t illustrate the entire story. Just because you have concurrent crossings occurring, doesn’t mean the potential for conflict is small or large for any given phase.

Considering the indications mentioned earlier, it goes unsurprisingly that Zone 3 and Zone 4 see the most conflicts. Zone 3, as we saw in the volume rates, sees some traffic, but overall inconsistent amounts, at least for phases E through G, which makes it desirable for pedestrians to cross. However, what it didn’t originally show was that it was causing for negative interactions between the two modes of traffic, as both sees at least 0.79 conflicts per minute and up to 2.63 conflicts per minute during those phases. For Zone 4, the increase in speed by vehicles to get across in Phase B and the overall backlog of pedestrians at that point signifies that pedestrians see an obvious increased risk for a conflict due to drivers mostly caring about getting across the intersection in time, rather than the pedestrian’s health. A potential solution an engineer could make from this is to shift Phase A and Phase B past C and D in order to clear the backlog of pedestrians waiting to cross, as it is obviously a desirable, but unsafe time to cross.

This data does not say all concurrent crossings by pedestrians lead to conflicts. Zone 2, during Phase A, sees a rate of ten per minute of both vehicles and pedestrians, but less than a combined value of one conflict per minute. In fact, the combined value is right around half a conflict per minute. What this could indicate is that it may be appropriate for a traffic engineer to deem this zone and phase to have a concurrent or flashing crossing, especially if it gets pushed passed Phase D, like suggested earlier, where pedestrians can continue crossing past the all walk signals.

Comparative Analysis to Conventional Protocols

Conventional protocols for quantifying intersection usage and conflicts are generally ineffective when it comes to determining problems with phase timing at an intersection. Figure 13 is an example of this.

Conflicts by Movements and Time

(In crosswalk / with light)

Time	Pedestrian Movement ID Number								
	1	2	3	4	5	6	7	8	9
8:00 - 8:15	6 / 2/1	11 / 1/1	0 / 0/0	2 / 0/0	2 / n/a	0 / n/a	0 / 2	4 / 0	0 / 0
8:15 - 8:30	29 / 17/11	10 / 5/3	0 / 0/0	0 / 0/0	1 / n/a	0 / n/a	0 / 0	1 / 0	0 / 0
8:30 - 8:45	34 / 5/3	10 / 3/1	0 / 0/0	3 / 1/1	4 / n/a	0 / n/a	0 / 1	1 / 0	0 / 0
8:45 - 9:00	8 / 3/1	1 / 0/0	0 / 0/0	1 / 0/0	1 / n/a	0 / n/a	0 / 0	0 / 0	0 / 0
Hourly Totals	77 / 27/16	32 / 9/5	0 / 0/0	6 / 1/1	8 / n/a	0 / n/a	0 / 3	6 / 0	0 / 0

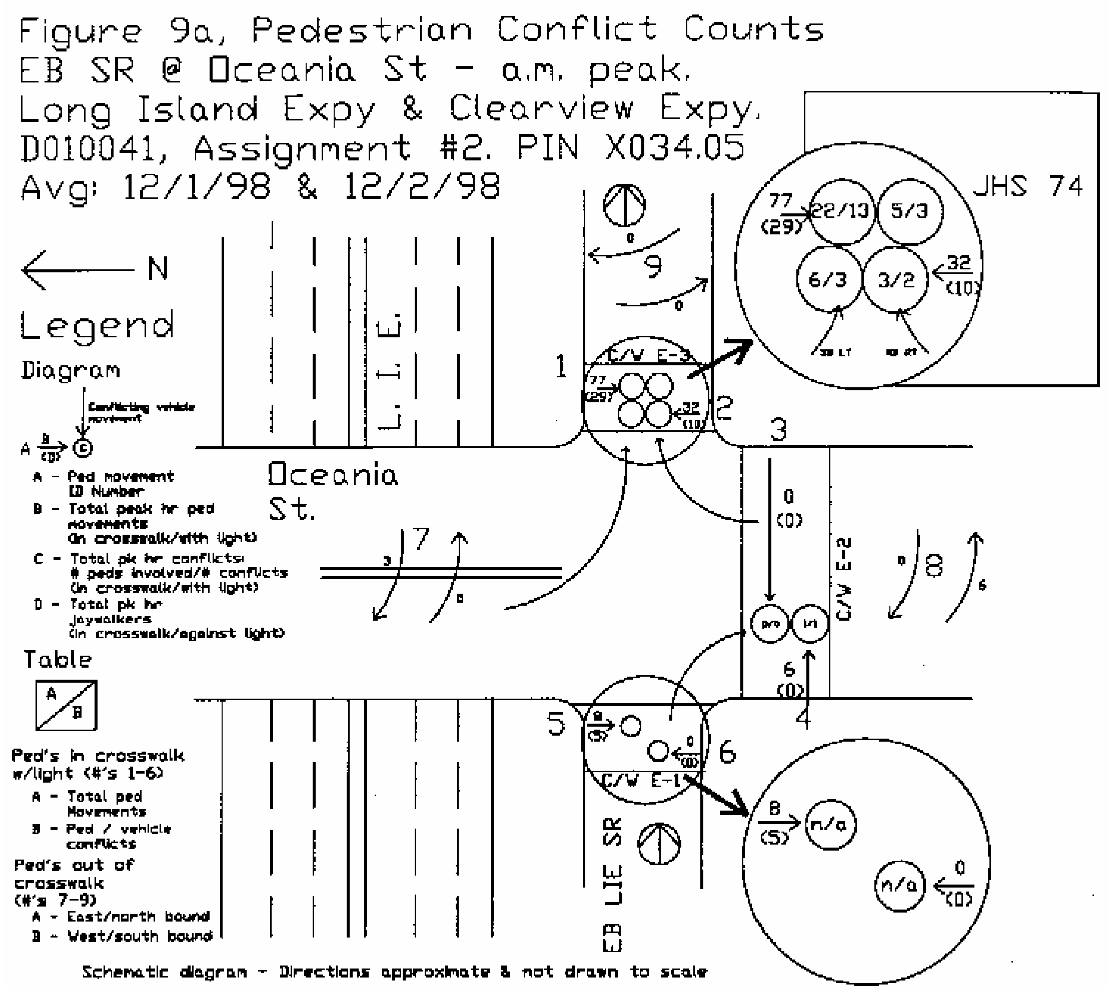
J:\cv-lle.akw\traffic\ocean\eb-oc-ped2

Source: Konheim and Ketcham, Pedestrian Conflict Analysis Methodology

Figure 13 – Data collection table to collect volume versus conflicts over fifteen minute intervals

What this protocol does do well is that it shows all the various types of crossings a pedestrian can make when facing an intersection. For the protocol we conducted, perhaps we could have been more elaborate with which direction a pedestrian was headed in a zone, but overall that information seemed unnecessary due to the structural simplicity of Boylston-Tremont for pedestrians. They have only one concurrent crossing at the moment and the only available crosswalks are those along the sides of the intersection. There isn't enough valid information a traffic engineer could gather from assessing the direction of a pedestrian in a crosswalk. What they need to know is how many are entering or facing conflicts in order to adjust potential flaws with the timing design.

The intersection this conventional protocol was conducted on was a more rural intersection with more potential crossings, as visible in Figure 14.



Source: Konheim and Ketcham, Pedestrian Conflict Analysis Methodology
Figure 14 – Outline of the study intersection and identifications of data collection

The protocol did allow an engineer or consultant to determine what may be physical flaws with the intersection, but this may be a location where a tracking survey may be more appropriate and it still fails to analyze potential flaws in phase times or order. While one could make assumptions off of when one is crossing, it is too ambiguous to determining whether the pedestrian was even crossing compliantly, not even when, which is where our rendition of this protocol excels. The result of if we found our data by use of the conventional protocol is found in Table 6 and in Table 7.

	Pedestrians/min					Vehicles/min			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**		**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
	9.61	7.98	10.95	11.53		22.27	12.35	15.98	16.40

Table 6 – Volume rate of pedestrians and vehicles per minute through each zone

	Pedestrian conflicts/min					Vehicle Conflicts/min			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**		**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
	0.13	0.19	0.86	1.31		0.05	0.10	0.62	0.83

Table 7 – Conflict rate of pedestrians and vehicles per minute through each zone

What these show you specifically is which zones may be problematic. They confirm that Zone 4 and Zone 3 to an extent may need to be researched further or improved due to their high conflict levels, but it does not outline a specific problem or pose a possible solution to the problem. This is where phased analysis is beneficial for collecting data for pedestrians. It can show what phases may need adjustments or possible where concurrent crossings are more appropriately used.

4-4: Survey Data Collection

A survey was administered to fifty pedestrians crossing the intersection during the peak afternoon hours. The pedestrians were asked to comment as to whether they felt safe walking at the intersection and as to whether they saw the intersection as a relatively inconvenient place to cross. A summary of the data collected is in Table 8.

	Male			Female			Male Jaywalker			Female Jaywalker		
Regulars Yes/No	10	6		10	0		8	0		16	0	
Feel Safe Yes/No/Sometimes	6	0	10	2	2	6	22	2	2	4	0	12
Relatively inconvenient I.S. Yes/No/Sometimes	4	4	8	0	8	2	0	0	2	6	2	12

Table 8 – Summary of results from intercept survey at the Boylston-Tremont intersection

The results revealed that the majority of those pedestrians who were regular crossers at the intersection found the intersection inconvenient and unsafe. A common complaint that pedestrians revealed was that signals were not in the favor of the pedestrian. Pedestrians also felt that they did not know how much time they had to wait at a sidewalk before they were authorized to cross. Because of such drawbacks pedestrians were sometimes forced to apply their own concurrent crossings when they were not authorized. Many pedestrians in a hurry would survey the intersection for cars and neglect pedestrian signals if they were not advantageous. When they deemed it safe to cross during times of extremely high traffic congestion or extremely low vehicle count they would do so.

The surveys also revealed that pedestrians were vexed by the fact that during some phases of the traffic signals neither cars nor pedestrians would appear to be authorized to move. This was determined to be the phases we labeled as A and B at the intersection and into Zone 4. When we conducted the volume-conflict study, we found that there were in fact a large number of concurrent crossings, as visible in Table 4.

Through both phases, Zone 4 saw approximately fifteen pedestrians per minute at any given point, even though they did not have the walk signal. However, they were also faced with a similar ten to twenty vehicles per minute crossing through that zone. This poses an obvious safety risk, as visible in Table 5.

Through phases A and B across Zone 4, pedestrians saw a 24.4% chance of a conflict. What cross-referencing these two protocols show is that the perceived risk is much less than the actual risk of crossing during these times.

Analysis of Approach

While it may be appropriate and helpful to get subjective interpretations from those that actually use intersections, it doesn't always mean that the information they provide is appropriate, accurate, or easily attainable. The most apparent point we realized from testing the use of surveys was how time consuming they were. It took a few hours for two members in our group to get the limited amount of information they found with this. In reality, those few hours were spent tracking down what pedestrians perceive that happens at the intersection, not what actually happens. It may be helpful to get their input to figure out what may need to be changed, but overall pedestrian input did not provide enough potential information to traffic engineers to warrant the amount of time and effort it took to get.

4-5: Timing Pedestrian Delay

Our group utilized an equation to determine theoretical delay at the Boylston-Tremont intersection and recorded video in an attempt to tabulate actual delay most pedestrians faced over a period of time at each corner of the intersection.

Theoretical Average Delay

In order to find what the theoretical delay of the intersection way, we used the following equation: [0.5*(Cycle Length-Walk Time)^2]/Cycle Length. Essentially, what this equation does is plot a data point for each second of a cycle, how long that data point's delay would be, then average the points out. The theoretical average delay for each zone at the Boylston-Tremont intersection for the 4:30-5:30PM peak hour is available in Table 9.

Zone	Cycle Length	Walk Time	Theoretical Delay	PLOS
1	90 seconds	33 seconds	18 seconds	B
2	90 seconds	22 seconds	26 seconds	C
3	90 seconds	22 seconds	26 seconds	C
4	90 seconds	22 seconds	26 seconds	C

Table 9 – Theoretical average delay for each zone at Boylston-Tremont

What this confirms is that Zone 1 sees a shorter average delay since it receives a concurrent crossing following the flashing don't walk phase. Each zone also received a subjective, arbitrary PLOS grade given to specific delays by traffic engineers. Zone 1 was the only to receive a B, while the rest received C's. While not atrociously bad, no zone had an ideal or substantially positive theoretical delay.

Actual Pedestrian Delay

Through the use of video, our group backtracked through our recording of the intersection and timed how long each individual pedestrian waited at any given corner. The results for two of the corners at the intersection are visible in Figure 15 and Figure 16.

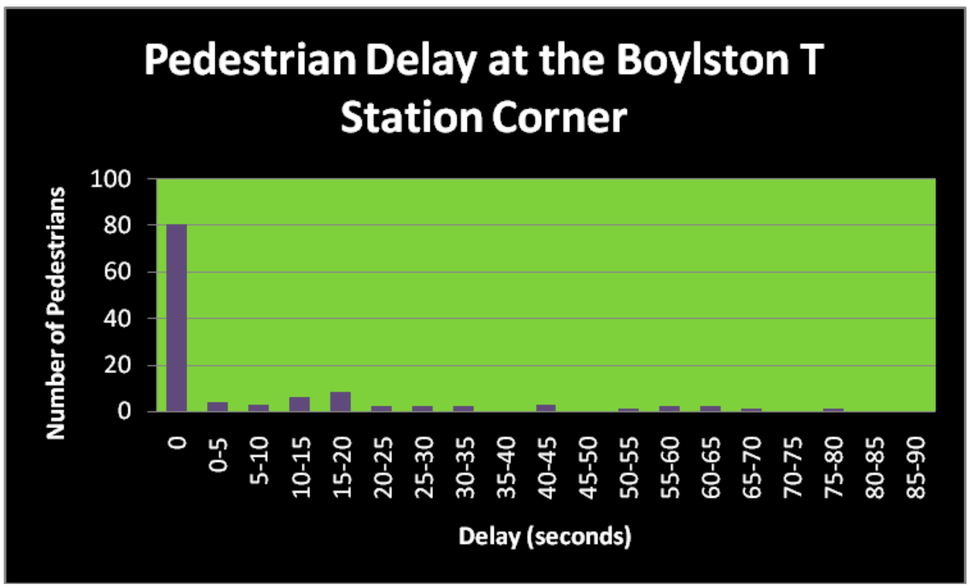


Figure 15 – Histogram of actual delay for the T corner of Boylston-Tremont

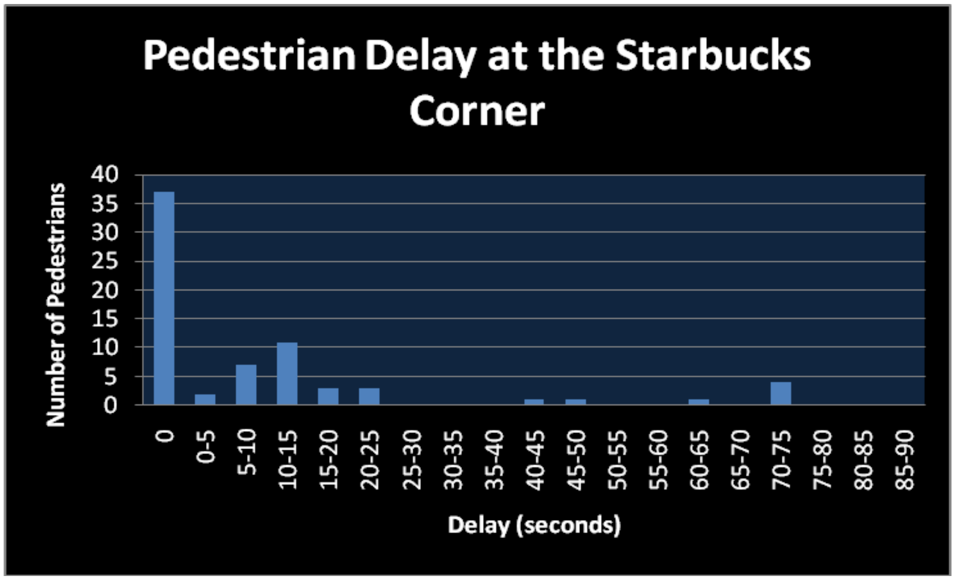


Figure 16 – Histogram of actual delay for the Starbucks corner of Boylston-Tremont

What Figure 15 and Figure 16 show is a large number of pedestrians that didn't wait to cross, where they got to the intersection and immediately walked because they either had the walk signal or because they deemed it was safe to cross. What it doesn't show is when an individual crossed and thus why they would have. There is also no determination of whether or not a conflict existed. This is more a problem with capturing this information. The video angle we were able to acquire did not allow us to make thorough judgments on crossing and it was too difficult to interpret exactly what phase was active at any given point.

Analysis of Approach

The biggest problem we found with this protocol was the technological limitations that we were faced with. From the inability to tell exactly when or where a pedestrian was crossing, it meant the overall value of the collected information wasn't worth the work to collect such data. In that regard, even if one could get appropriate information out of it, this is a very time consuming process. It took approximately an hour to analyze and record data on 15 minutes of any given corner. Considering the limitations of recommendations a traffic engineer could make and the overall difficulty to collect data, this protocol was deemed to be ineffective at analyzing an intersection from our perspective, but we perceived it to have some merit at potentially gauging how convenient an intersection is for pedestrians if a convenient method were available.

4-6: Tracking Surveys

Our group was unable to utilize videos for use in collecting tracking surveys. Instead we chose a random pedestrian at a time entering the intersection and tracked their progress until they left the area. The result of placing our results onto one map is visible in Figure 17.

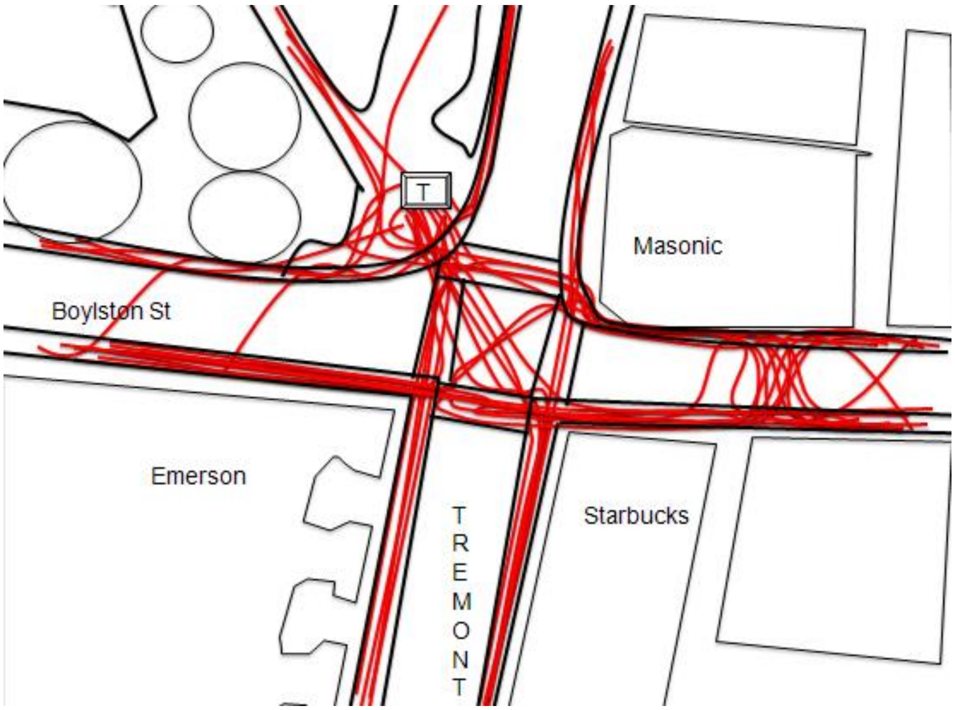


Figure 17 – Tracking survey for the Boylston-Tremont intersection

Most of our general observations were captured by this survey. Most pedestrians use the crosswalks at the intersection or cross through during a walk phase. One deviation from the standard progress of pedestrians is that many cross along the street between the Masonic building and Starbucks. What a traffic engineer could conclude is that another crosswalk may be appropriate here as well as a traffic signal which coincides with Zone 3's light to signal more pedestrians that it's acceptable to cross. What the reason for crossing there is not as important as the fact that they do. If an engineer wishes to prevent pedestrians from crossing there, they could recommend public art, a fence, or advertisement to be placed there to impede pedestrian movement.

Analysis of Approach

We found this to be a very easy process. Maps, if not available, could be developed in Microsoft Word in less than an hour and then we found that about one person in an hour or a group of four in about fifteen minutes could plot a sufficient amount of data to be used. Overall, we believe this method is very appropriate at determining potential structural flaws at and around an intersection.

4-7: Testing the Protocol on a Second Intersection

In order to check the validity of some methods of our potential protocol, we decided to test it on another intersection. This intersection, we decided, would have to be a generally safer, more convenient intersection that has a concurrent crossing in order to determine what our protocol says is acceptable for one to occur. After checking a series of intersections, we decided to use the Prospect-Mass Ave. intersection in Cambridge, Massachusetts. This intersection had consistent phased cycles which weren't effected by pedestrian push buttons and didn't have a single exclusive walk phase. All walk phases were done concurrently with turning traffic. A map of the intersection with the zones labeled is visible in Figure 18.

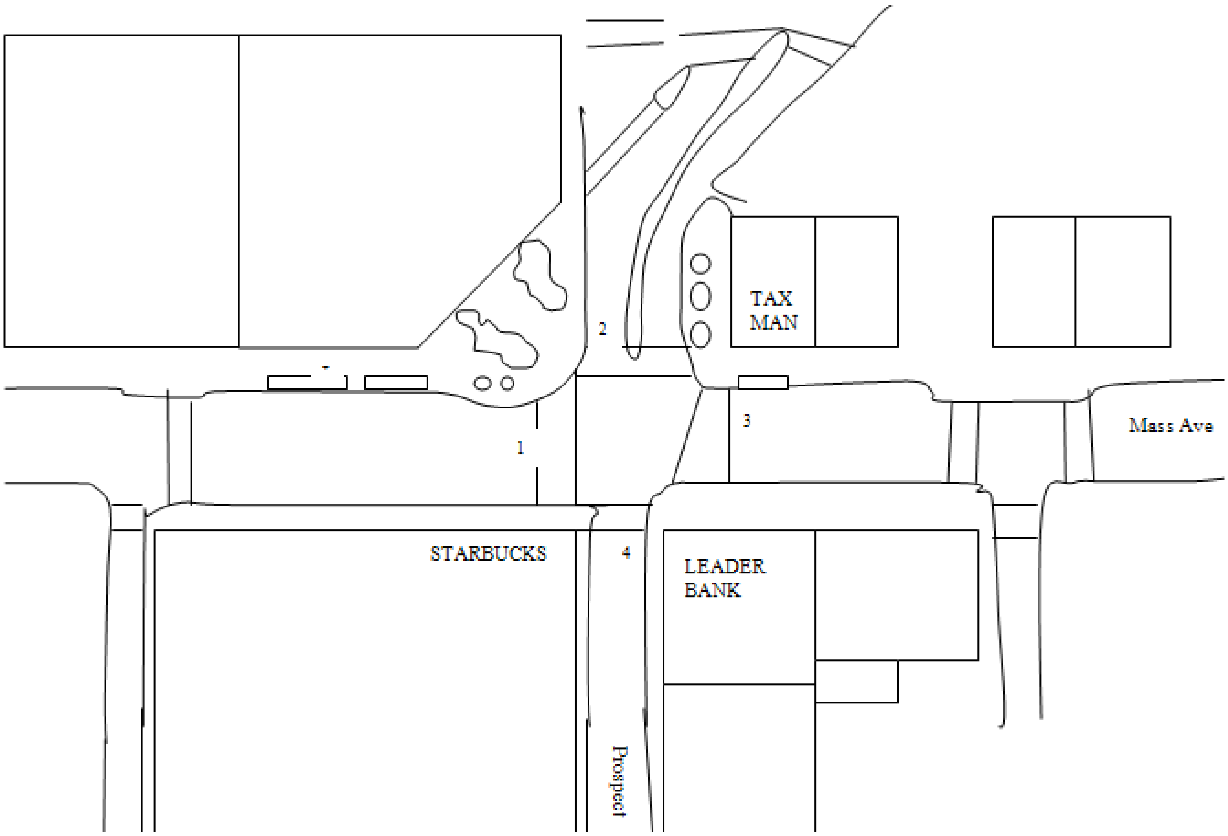


Figure 18 – Map of the Prospect-Mass Ave. intersection in Cambridge, Massachusetts

Phased Analysis

For testing on the second intersection, we decided to skip the compliant-safety tables, as we determined earlier that they could be resolved by the volume-conflict tables and tracking surveys, so we decided to skip straight to the phased approach. What we determined to be the data collection phases are visible in the cycle timeline in Figure 19 and a description of each phase is available in Table 10.

Phase:	A	B	C	D	E	F	G	H
Zones 1,3	DON'T WALK					WALK	18 SEC C.D.	
Zones 2,4		WALK	18 SEC C.D.		DON'T WALK			
Mass Ave	RED	GREEN		AMBER	RED			
Prospect	RED					GREEN		AMBER

Figure 19 – Phase by phase timeline for a cycle at the Prospect-Mass Ave. intersection

Phase	Time	Description	Observed Trend
A	4 sec	All red, Zones 2 and 4 get the walk signal.	Queue of pedestrians waiting for Zone 2 and Zone 4 clear out.
B	20 sec	Mass Ave. gets a green signal, Zones 2 and 4 continue to have the walk signal.	Zones 2 and 4 continue to see pedestrian movement. Zones 1 and 3 see heavy vehicular movement, Zones 2 and 4 see minimal turning vehicles.
C	15 sec	Mass Ave. has a green signal, Zones 2 and 4 have a flashing countdown.	Zones 2 and 4 continue to see pedestrian movement. Zones 1 and 3 see heavy vehicular movement, Zones 2 and 4 see minimal turning vehicles.
D	3 sec	Mass Ave. has an amber signal, Zones 2 and 4 have a flashing countdown.	Traffic volume slows, but the speed of cars increases to beat the red light. Minimal pedestrian movement.
E	4 sec	All red, Zones 1 and 3 get the walk signal.	Queue of pedestrians waiting for Zone 1 and Zone 3 clear out. Pedestrians attempt to move across Zone 2 relatively frequently.
F	25 sec	Prospect has a green signal, Zones 1 and 3 have a flashing countdown.	Zones 1 and 3 continue to see pedestrian movement. Zones 2 and 4 see heavy vehicular movement, Zones 1 and 3 see minimal turning vehicles. Pedestrians attempt to move across Zone 2 relatively frequently.
G	15 sec	Prospect has a green signal, Zones 1 and 3 have a flashing countdown.	Zones 1 and 3 continue to see pedestrian movement. Zones 2 and 4 see heavy vehicular movement, Zones 1 and 3 see minimal turning vehicles. Pedestrians attempt to move across Zone 2 relatively frequently.
H	4 sec	Prospect has an amber signal, Zones 1 and 3 have a flashing countdown.	Traffic volume slows, but the speed of cars increases to beat the red light. Minimal pedestrian movement.

Table 10 – Observational descriptions of trends by each phase at Boylston-Tremont

The main characteristic we noticed that was worth keeping a note on was the movement of pedestrians in Zone 2 when it didn't have the walk signal. Our observations noted that there was a barrier in the middle of the zone that pedestrians felt it safe to cross onto when one side wasn't seeing heavy traffic, then continue across to the other side when vehicular traffic began to clear on the following side. We considered each occurrence of this to be a conflict, since a pedestrian was in the process of crossing and then altered their movement to avoid an incident.

Tracking Surveys

Tracking surveys were collected the same manual way at Prospect-Mass Ave as they were at Boylston-Tremont. We chose to do this before volume-conflict data so we didn't have a preconceived idea of where pedestrians cross before we tracked their patterns in order to accurately where typical movements are. Our result from our tracking survey is shown in Figure 20.

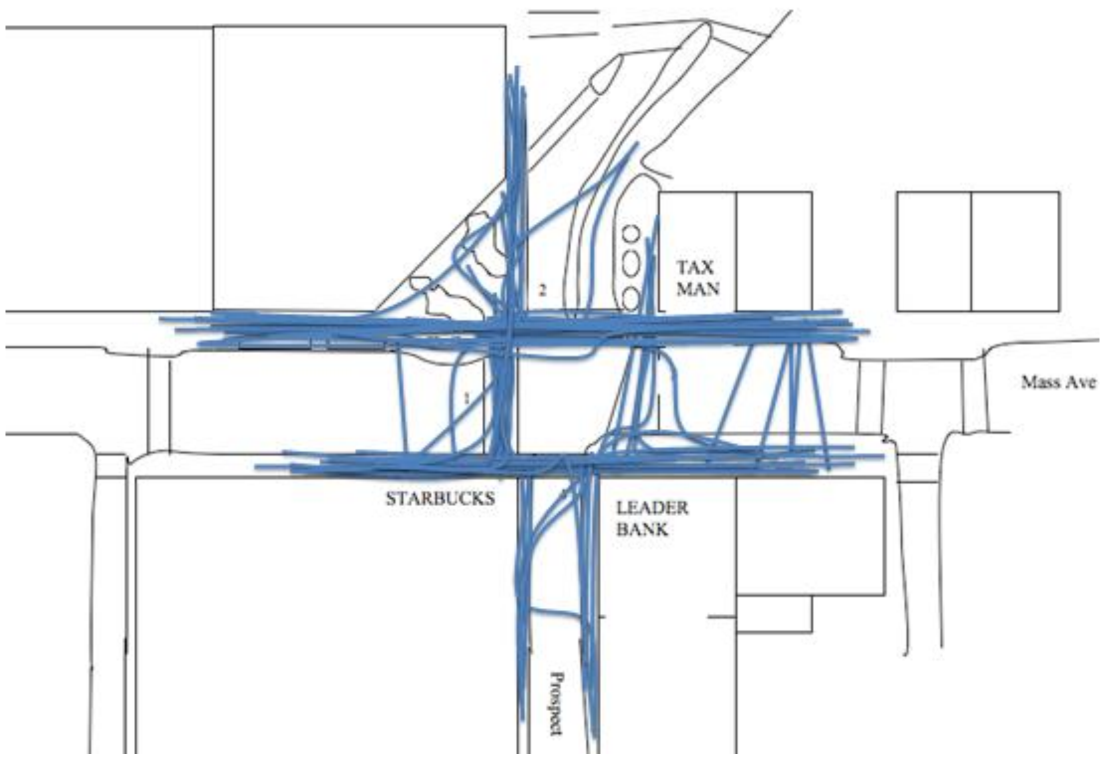


Figure 20 – Tracking survey for the Prospect-Mass Ave. intersection

What the tracking survey showed was that most crossings were at or around the crosswalks either right on the Prospect-Mass Ave. intersection of at a crosswalk at a neighboring intersection. There is a high frequency of crossings on the street in between crossings along Mass Ave., but those are infrequent compared to those in the intersection and they are relatively close to another intersection down the road. Essentially, there are no recommendations a traffic engineer would need to make off of this method, proving that the intersection is fundamentally sound as far as structure is concerned.

Volume-Conflict Data Collection

Our group made similar sheets for volume-conflict collection as we did for the Boylston-Tremont intersection. We then collected data for pedestrians and vehicles for an hour each. Our results for volume per phase are shown in Table 11.

Pedestrians/min					Vehicles/min				
Phase	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Phase**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
A	3.75	39.00	0.00	40.50	**A**	4.50	21.00	0.00	0.00
B	1.20	10.35	0.75	20.85	**B**	35.40	0.15	32.40	3.60
C	3.20	3.40	1.00	8.60	**C**	28.80	0.00	13.20	4.00
D	8.00	4.00	0.00	13.00	**D**	26.00	1.00	0.00	0.00
E	4.50	5.25	12.75	9.75	**E**	4.50	0.00	0.00	0.00
F	21.84	0.84	12.60	0.12	**F**	4.08	42.00	0.24	35.16
G	8.80	1.80	4.40	1.80	**G**	8.60	44.40	2.60	61.60
H	7.00	1.00	5.00	3.00	**H**	9.00	53.00	14.00	23.00

Table 11 – Volume rate of pedestrians and vehicles per minute through each zone and phase

Most of the values re-affirmed what we already derived in our observations earlier. Most traffic through any zone was for their appropriate movement phase. Some oddities such as the high pedestrian movement in Zone 2, Phase E and vehicle movement in Zone 3, Phase H were likely subject to small sample sizes, since both of those were three or four second long phases and any movement could greatly skew or impact the data given its duration of collection. This was also a case for conflicts within these zones, as apparent in Table 12.

Pedestrian conflicts/min					Vehicle Conflicts/min				
Phase	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Phase**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
A	0.00	0.00	0.00	0.75	**A**	0.00	0.00	0.00	0.00
B	0.00	0.00	0.75	0.75	**B**	0.00	0.15	0.00	1.20
C	0.00	0.00	0.60	0.80	**C**	0.20	0.00	0.00	0.80
D	0.00	1.00	0.00	2.00	**D**	0.00	0.00	0.00	0.00
E	0.00	4.50	2.25	0.00	**E**	0.00	0.00	0.00	0.00
F	0.00	0.72	0.00	0.00	**F**	0.12	0.84	0.00	0.00
G	0.00	1.20	0.00	0.20	**G**	0.00	0.80	0.00	0.00
H	0.00	1.00	0.00	1.00	**H**	0.00	0.00	0.00	0.00

Table 12 – Conflict rate of pedestrians and vehicles per minute through each zone and phase

Overall, an engineer would see a greater number of zero conflict areas that signal a safer, more efficient intersection like one could make from qualitative observations. The main problem area is Zone 2, where we rationalized earlier what the main problems were. First, pedestrians find more opportunities to cross due to the barrier in the center of the road where they can pause and wait for traffic to thin. Any instance of these was considered a conflict due to the nature of a pedestrian having to adjust their movement, but overall were not necessarily unsafe. The only major area of concern was Zone 2, Phase E, where it was determined that it was a small sample size, being 4 seconds collected over 40 cycles, which meant any pedestrian that crossed would have a greater impact at that point than one that crossed during a longer phase.

Section 5: Conclusion/Recommendations

5-1: Introduction

In this section, now that we have analyzed and discussed the data from our methods in our findings, we will outline a series of conclusions for each possible method of a protocol that we tested. The conclusions and recommendations stated here will outline the pros and cons of each method, what they can provide a traffic engineer or consultant in terms of information, and whether they would be an efficient part of a protocol.

5-2: Phased Analysis

Our results showed that collecting data over phases provided a more in depth analysis on what is occurring during certain durations of timing parameters. This method of data collection can provide more insight than just on physical structure of an intersection and can be easily conducted. The entire process of outlining the cycle of an intersection should only take a few hours to go out and time each specific event of the intersection and then outline their order and split them into phases. Through the results of our findings, we recommend this method for future protocols, due to its ability to characterize or describe an intersection and for the level of detail it potentially has dependant of what other methods are collected through this analysis.

5-3: Volume-Conflict Data Collection

We found our method of volume-conflict data collection to be a substantive method of describe usage and safety of an intersection. Volume is an invaluable, prerequisite value to collect in order to capture the overall description of the intersection. Conflicts were found to be a valuable parameter of measuring safety at the intersection. Considering how infrequently an actual incident may take place, it's necessary to have a method of quantifying the potential for one and our results found conflicts to be the most appropriate measurement.

We also found this method to be relatively easy to collect. Counting volume and conflicts simultaneously became natural and accurate with minimal practice. Collecting data on this is easily quantifiable and enough data can be taken on an intersection over the course of an hour. The one stagnating point of producing results is that pedestrians and vehicles have to be collected separately without the use of video. On a whole, this method is easy to collect in collaboration with phase analysis.

The use of this method is highly recommended by our group, due to the amount of information it can produce, the ease of learning and replicating the process, how objective it is at determining safety, and through how easily it can be collected by phase. Collecting only volume or conflicts can provide some information, but it is advised to do both, due to simplicity of collecting them simultaneously. The main deliverable from this method is determining the safety of a concurrent crossing or when they may be more appropriate. This in collaboration with phased analysis will allow engineers to adjust phases at an intersection to make it more convenient for pedestrians and potentially drivers as well.

5-4: Survey Data Collection

Our results showed a limited amount of information that we were actually able to obtain through the use of surveys, especially given the amount of time it took to collect them. It took our group approximately three hours to collect fifty individual surveys, which ultimately didn't yield much usable data. Our results displayed the perception of how pedestrians view the intersection and how safe it is, as well as some comments pedestrians had to improve the intersection. If one insists on collecting surveys, then we recommend outlining each phase for how and when one will ask questions and then try to get information from them on what they are considering doing, such as are they thinking about crossing or have any other possible actions planned out. However, these can be inferred from other methods of data collection outlined already or just be general observations.

5-5: Timing Pedestrian Delay

While we were able to produce results for actual delay, we found them to be incredibly difficult to distinguish in collection and time consuming. The biggest problem was not having a suitable camera angle to collect this information. Ideally, we would have liked to collect this data be zone and phase, but it wasn't feasible given our bureaucratic restrictions.

Our group decided that this would be valuable to have to assess the intersection and its convenience for pedestrians. The results it could possibly show would be descriptive data points on the quality of the intersection, by use of maximum, mode, average, and minimum pedestrian delay and their standard deviations. These could be used especially for a before and after study on an intersection, where one would quantify the intersection by its delay, apply changes, then re-collect delay values and see if the changes were appropriate. We'd recommend finding a way to make finding this data more convenient or feasible.

5-6: Tracking Surveys

Our results through this method proved to be useful in terms of what one could infer from behavior around an intersection. It allowed our group to find potential structural flaws at an intersection that impact how a pedestrian traverses an intersection. We determined that pedestrians had a strong desire to cross down Boylston St. away from the crosswalks and this was easily qualified and quantified in an hour's worth of time. This method is easy to replicate and can produce a fundamental, descriptive interpretation of the intersection.

We highly recommend the use of tracking surveys, but also recommend further development of this method. For instance, it should be somehow incorporated with phased analysis and maybe volume-conflict data collection in order to potentially determine how pedestrian patterns affect vehicle movement and the overall flow of traffic.

5-7: Recommended Protocol

Through our methods, we found phased analysis, tracking surveys, and volume-conflict data collection to provide the most informative information for traffic engineers to help alleviate problems at an intersection. We found intercept surveys to provide insufficient information and be too difficult to collect. Data from pedestrian delay would be an informative parameter in determining pedestrian tolerance at an intersection and useful for a before and after study on making changes at an intersection, but is rather difficult to collect unless one has an appropriate camera and angle to record the intersection from. A detailed, step by step guide to conducting our protocol is available in Section 6-3 of the Appendix.

Phased Analysis

It is crucial to define what is to be collected and when it is to be collected at the intersection initially. After a day of general and analytical observations, one should have an outline of the cycle that the intersection goes through split into phases, the times of those phases, and general observations on what's going on for future analysis. The phases should be significant and split into when major changes happen at an intersection, such as when a light turns from green to amber or when pedestrians get a walk signal. It was deemed that if you have an instance of something like one street changing from amber to red for one second before anything else happens and nothing else significant occurs, then that can probably be simplified into the same phase. The key to phases is simply to get a general determination of who is doing what and when. Over analysis of phases, to the point where you have individual one second phases, depletes the effectiveness of manual data collection and may be disrupted due to a small sample size. Phases, in general, last three seconds to however long the longest event in a cycle is, which can last up to a minute generally.

Tracking Surveys

It is wise to get objective tracking surveys done and out of the way before volume-conflict data collection to make sure one collecting it doesn't have a preconceived notion of how many people should be crossing where and therefore filling out their map accordingly. These could be done before phase analysis, but it would be wiser to get a general feel for the problem first.

For tracking surveys, if not already completed, one should draft a two-dimensional map of the intersection, with key buildings, sidewalks, and crosswalks outlined in order to plot movement accurately. The one collecting data should then select a pedestrian at random as they enter the intersection and track their movement until they leave. This should be reiterated until a sufficient amount of data is collected. This can be assisted through the use of video from a higher vantage point as well.

The traffic engineer will then be able to tell where a crosswalk may be more appropriate or what crosswalk may need to be changed in terms of design. Collection of this data is relatively simple and could be done in an hour by one person.

Volume-Conflict Data Collection

This is essential to be completed at least after the phase analysis, to ensure data is relevant to when it's being collected at the intersection. By each phase and cycle, one should tally how many total cars and vehicles pass through a section and also the number of conflicts. A traffic engineer should be able to make educated adjustments on the cycle, such as phase time or order, after they receive the information from this method.

5-8: Future Recommendations

Our results showed that phased analysis, tracking surveys, and volume-conflict data collection were the most appropriate methods for a protocol. What we would have liked to have done and what we would recommend for future analysis is a way to integrate the three together in one more analytical method of quantifying pedestrian behavior and a way to better convey the information that they collect.

Done separately, the volume-conflict data collection only showed when a pedestrian was crossing and if they experienced a conflict at four different locations. It would be beneficial to integrate this more with tracking surveys to develop an approach that analyzes more areas of the intersection. It would also be wise to find a way to integrate phased analysis with tracking surveys. Theoretically, most desire lines start on one phase, go through possibly several cycles, and finish on another, but it would provide more insight if one could look at a tracking survey and know when a pedestrian is crossing erratically or not making use of the crosswalks provided.

This protocol has the potential to collect a very great deal of data, so finding a way to convey that information more appropriately would be helpful to its impact. Currently, how data was presented within this paper needed a lot of explanation to even other traffic engineers. We'd recommend researching a way to present either all or the most important data collected in a way that can be interpreted with minimal explanation. This would likely consist of a more graphical approach than the use of numbers and tables we outlined here, along with a key that characterizes the use of phases. This graphical approach may be best suited to be displayed on or with an outline of the intersection, with zones, streets, and locations labeled, where one could hopefully integrate an image that details the integration of tracking surveys and volume-conflict data collection. The main goal of this would be so that an engineer could quickly get a feel for the intersection from just quickly glancing at the visuals.

Our group has set the foundation for the use of this protocol and it is capable of being used in its current state. However, the recommendations we've outlined here for future would provide the protocol with more potential for providing more information to an engineer and being easier to comprehend.

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Appendix A: Terminology

In order to simplify descriptions our group had to learn some of the vocabulary used by traffic engineers and define what our interpretations of these may be for our own research. In order to eliminate some of the subjectivity involved in counting different types of crossings, we had to establish a set definition for conflicts, compliant, and what is the safe extent to cross around a crosswalk. Below are a series of terms that we felt necessary to elaborate upon for the rest of our work. They are used extensively within our Methodology, so it is necessary to have background knowledge on these terms.

Cycle and Phase

A cycle is the full rotation from when an intersection is at a certain traffic point to the point where it reaches it again. For example, a cycle may begin when a certain street just turns green and that cycle will not end until the intersection phases through until that light has another session where it immediately turns green.

Throughout a cycle are several different phases. A phase is any change within the cycle that defines different traffic patterns. For instance, there would be three different phases when a street has a green, amber, and then red light. There also exists different phases between when one street may have a walk signal and changes to flashing don't walk or just don't walk during a traffic light.

Volume

Volume was defined as the overall number of pedestrians or cars that are counted over a specific set of parameters. The value is solely quantitative and can be expressed as a rate found over a time frame. The volume is not just for overall usage of an intersection, but can be broken down into parts, such as at the four different crosswalks at a standard city intersection, diagonal, and established between different types of crossing.

Conflict

Our group defined a conflict as any time a person has to change their pace due to the actions of someone in another mode of transportation. So for a pedestrian, a conflict would be any time they have to pause, stop, or speed up to allow a vehicle to pass ahead or behind them. A conflict for pedestrians also exists when they have the walk signal and vehicles should be stopped, but they can't even start their travel due to cars driving when they shouldn't have been to beat the red light that preceded the cross signal. Similarly for a driver, a conflict for them is any time they need to slow down in order to let pedestrians cross ahead of them.

Compliant versus Non-compliant

Our group defined compliant as any pedestrian crossing that starts when they have a walk signal or a flashing countdown. This was used for preliminary data collection to determine the potential problems faced at an intersection. Data collection was later split into phases and cycles over time intervals and crossing types.

Safe Zone

This was another type of crossing used for preliminary data collection. Due to personal indiscretion, there are times when a pedestrian makes it appear that even though they aren't in a crosswalk, there is direct intent to be within its confines, or where they consider themselves safe or apparent to traffic. We defined this area as anywhere around a vehicle length from the edge of the crosswalk and anywhere in the middle of four crosswalks for instances of four way intersections.

Appendix B: Road Safety Planning

Intersections are seen as a planned conflict in a roadway system. They are complex traffic situations that motorists and pedestrians encounter. Road safety is something that city planners, highway departments, and private organizations try to improve periodically. Despite improvements there has not been much difference in vehicle crashes (Intersections, 2007, 1).

Pedestrian knowledge of street laws, sign usage, and traffic all has a contribution in road safety. All must be taken into account when planning on how to improve street safety through a data collection protocol. A survey of public opinions was needed to create an understanding of how much people know about the laws of the road, which is handled in both our pedestrian and vehicle behavior objectives. In addition the use of signage around a crosswalk was observed and evaluated. The actual construction of the intersections was heavily considered and evaluated in our intersection structure objective. Other topics regarding ordinances, regulations, and traffic strategies are considered when choosing recommendations which would improve the structure of roads by using data from our protocol.

Overview of Ordinances

There are many rules for walking and driving on streets and sidewalks in urban areas. A focal point for this project will be how drivers approach and react at a crosswalk, and when and where pedestrians have the right-of-way. How these ordinances affect pedestrians and vehicles was more or less considered in our recommendations and deliverables, as opposed to being conducted in our study.

It is Massachusetts Law for all vehicles to yield for pedestrians crossing the street within a crosswalk. If this law is violated the person will be fined no more than 200 dollars. But, if a pedestrian is injured in a crosswalk there will be an investigation prompted to figure out how this injury came about (The General Laws of Massachusetts, 2008, Chapter 8 Section 11, p.1).

The same applies to pedestrians as well. People must cross the street in a crosswalk if there is one within 300 feet. Otherwise this is considered “jaywalking” and the person can be fined up to 50 dollars. However, if there is not a crosswalk within 300 feet of the crosser, then the pedestrian must yield to traffic and may only cross when it is safe to do so (Pedestrian Crosswalk Regulations, 2001, p.1).

The knowledge of these ordinances gave us the ability to define how pedestrians and vehicles can be non/compliant at an intersection. Also this knowledge allowed us to determine vehicle/pedestrian conflicts. Establishing number of conflicts and how many people are walking/driving compliant with the law within our protocol helped determine where potential issues could be fixed.

Pedestrian Signage and Road Regulations

Boston has very specific road and signage regulations when it comes to constructing crosswalks and signage that is affiliated with these crosswalks. These regulations are to keep the streets as safe as possible for pedestrians, but also to keep traffic flowing at a steady pace. Our recommendations seek to keep this balance between active and passive transportation.

The WALK and DON'T WALK signals are not designed to get an average aged pedestrian completely across the street. According to the City's Streetscape Guidelines, they are designed for a pedestrian to walk from the curb to halfway through the last lane of traffic. Also, on streets that have a high turning volume the crossing signals will not tell a pedestrian to walk parallel to traffic. The signals will wait for all directions of traffic to come to a stop for the pedestrian to cross. At streets with low turning volumes, the crossing signals will allow a pedestrian to cross parallel with traffic (concurrent crossing). Pedestrians are advised while crossing the street, with or without a signal, that they should look both ways before crossing (Streetscape Guidelines for Boston's Major Roads, 2008, 24-26).

Crosswalks at intersections require signs to alert both pedestrians and drivers that there is a crosswalk. That can either be a traffic light, a sign showing a pedestrian crossing, or (but required at mid-block crosswalks) a sign stating "State Law-Yield for Pedestrians in Crosswalk" (Streetscape Guidelines for Boston's Major Roads, 2008, 19).

Knowing how signals at an intersection work and why they are used were useful for our protocol because it gave us the ability to break up the intersection into several different phases. This gave our data collection more specifics and information about the intersection, which when looked at by a traffic engineer can indicate problems during a certain phase or with the signals themselves.

Appendix C: Deliverables

This section breaks down how our protocol can be utilized in a step-by-step format. This outlines how to conduct the protocol that we conducted and recommended. This does not outline potential recommendations we made, such as incorporating tracking surveys with phased analysis or volume-conflict data collection.

1) The intersection is to be broken up into study zones. A study zone is a street that is flowing in and/or out of the intersection. A zone is made up of the section or crosswalk one wishes to collect data in. A standard four way intersection with four crosswalks will have four zones: Each crosswalk and about fifteen feet from the crosswalk which is considered within a safe range.

2) The intersection signals (traffic lights and crosswalk signals) are to be split up into phases. A phase is whenever a signal changes (i.e. if during a green light the crosswalk signal changes from WALK to flashing DON'T WALK that is a start of another phase). This is explained further in Section 3-3 of our Methodology and an example is available in Figure 9.

3) Tracking surveys are to be recorded next. A tracking survey shows the desirable walking patterns of pedestrians to and through an intersection. These surveys require a scale model of the intersection so that the pedestrian desire lines can be drawn. If you are able to get a hold of camera footage from above the intersection you can follow pedestrian at a time and rewind to get a higher quality analysis. But, if that video footage cannot be accessed you can stand at a corner of the intersection and draw the desire lines as pedestrians walk them (the downfall of this is you cannot rewind and get other pedestrians walking at the same time). This is explained further in Section 3-4 of our Methodology and an example is available in Figure 11.

4) Create a data sheet that shows every phase and have boxes next to each phase so that information can be recorded during each cycle and phase of the intersection. The boxes are to be split in half and the top will have the volume and the bottom with

indicate conflicts (for both vehicles and pedestrians). This data sheet is to be used at every study zone. A conflict is when either a pedestrian or vehicle needs to alternate their path to accommodate for one another. This is explained further in Section 3-4 and Section 3-5 of our Methodology and an example is available in Figure 10.

5) The phased data collection (above) can be then placed into Excel sheet that shows volume and conflicts per minute at each zone and each phase in that zone. Then this data can be placed into a graph that can easily show where the most conflicts are happening in that particular intersection.

6) Actual pedestrian delay can be recorded next. Even though this can be difficult to do while standing at the intersection an overhead camera holds the best data. When recording actual pedestrian delay (which is when a pedestrian comes to the intersection and stops and then starts up again when crossing that time they are stopped is their delay) a stopwatch is started every time a pedestrian stop at the intersection and it is stopped when they step off the curb to cross. This data can be then placed into a histogram that will then show how many people are stopping for how long (in seconds).

7) All the following data can then be observed/analyzed and show where there can be possible problems with the intersection and at what certain phase that the problem is occurring.