Affecting Driver Behavior Using Traffic Signal Control

An Interdisciplinary Qualifying Project
Submitted to the faculty of
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

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Abstract

This project, sponsored by the City of Cambridge, Department of Traffic, Parking and Transportation, examined utilizing existing traffic control technology to change driver behavior. The project goal was to use technology to lessen traffic volume on a critical residential street and thus address residents' concerns regarding the impact of traffic on the quality of residential life. Through traffic study and analysis, the project team made recommendations regarding use of traffic signal timing to improve the quality of urban residential life.

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Authorship

All members of the project group contributed equally to the development of this project.

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- Results and Analysis
- Conclusion
- Recommendation

Each group member contributed equally to the writing and reviewing of each of these sections.

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Executive Summary

There are currently more cars in the United States than ever before and as the population rises, traffic levels will continue to rise (EPA Impact of Commuters). New roads are not being built quick enough to cope with the ever-larger amounts of traffic. There is a strain on the roadways in many populated areas around the world. Drivers are seeing longer commute times as main roads fill up and many smaller roadways see an increase in traffic from spillover.

Cambridge, Massachusetts is a densely populated area, home to around 115,000, and employer to over 120,000 (City of Cambridge). With so many people traveling into, out of, and around the city there is an over abundance of traffic. Many of the larger roads can see around 30,000 cars per day and a few such as Memorial Drive have up to 50,000 cars (Boston Metropolitan Planning Organization). In order to curb or reduce this traffic, the city has strict parking restrictions in order to promote alternative transportation. Its public transportation system is impressive; and bike lanes and sidewalks are prevalent throughout the city in order to further decrease motor vehicle traffic. In addition to limiting parking, traffic controls are in place in order to ensure traffic flows optimally. With such a limited number of main roads to get to and from major areas in and around the city, traffic planning and control is highly necessary.

The Cambridge Traffic, Parking, and Transportation Department (CTPTD) were created to handle the task of managing traffic in the city. It's charged with studying traffic flow and managing the traffic on Cambridge's roads accordingly. It is solely responsible for conducting or outsourcing traffic studies and then using that data to make more effective decisions. In addition to efficiency, the CTPTD top goal is to ensure the safety for commuters, pedestrians, and residents throughout the city.

Once a study has been reviewed, the CTPTD may change something accordingly, such as a traffic signal's cycle or parking along the road. They will perform this change in the hopes that it will have a desired effect; however they are not basing the decision on any tested method. There are no rules for what to do given certain traffic conditions to improve the situation in an area, so the CTPTD is working somewhat blindly.

One of larger problems the CTPTD is trying to combat with traffic in the city is commuter cut-through. There are two main causes to cut-through travel, spillover from major arteries/roadways in a given area or drivers taking a road as a “short-cut”. Driver behavior plays a large role in how they will take a given route as opposed to another and cut-through an area on secondary roads when the typical way of travel is on an arterial or main road. The problem is more prevalent during peak travel times due to the large amount of travel on main roads. The smaller streets that are being used as cut-through are not meant to have the amount of traffic being imposed on them by commuters.

The goal of this project was to help the CTPTD evaluate the impact of a change in traffic signal timing that was hoped to have impact on driver behavior and reduce cut-through travel. Putnam Avenue was chosen as the street to study because of its location between several main arterial roadways and the fact it has several traffic lights along it.

First, the team identified all of the possible variables that would impact the results of the study. Weather, road construction, and school closings were a few of the more important ones. We designed our project such that when data was being collected, none of these variables would interfere. We worked around construction schedules; collected data in similar weather conditions, and around school breaks.

The team then moved onto initial data collection, in our “baseline” phase. The number of cars, or volume, traveling the street was recorded. Movements of cars at certain important intersections were another key issue. The team then measured how long it took to travel the street, as well as each segment of it. Next, speeds of cars at certain points along the road were measured. Finally an origin-destination study was performed, to see where the traffic was coming from and going to on Putnam Avenue. To buttress our data, we collected physical measurements of the street at many points to understand possible relationships between physical characteristics of Putnam and the behavior of drivers on it. A set process for each of these measurements was established so that our tests could be repeated again easily and exactly.

With this data in hand, the signal timing change was then implemented. Previously, the lights along Putnam Avenue had no particular timing sequence in relation to each other. The change adjusted the timing such that southbound travel along Putnam would flow very quickly, whereas northbound traffic would be inhibited by a string of red lights. After letting about two weeks pass since the change was enacted, we then began our "experimental" phase of data collection.

The exact same tests were performed again, at the same times and locations as before, under very similar if not exact conditions. We duplicated each process, and recorded them the same way as before.

The team then moved onto a database with the information we had collected. A Microsoft Access® database, as well as Excel® charts was created, in order to easily compare the data from our two phases. Using the Excel® spreadsheets, we were able to graph the data in many different, powerful ways to easily see the change, if any, that the traffic signal alteration had had upon traffic patterns. Using GIS software, we created new layers for each of our measurement methods and then linked the data in our Access® database to the layers. Comparing and evaluating the baseline and experimental data, we concluded that the light timing change had little, if no significant effect on traffic patterns. However, much of the data suggested the beginning of a trend, which could easily be proven or disproved with further study. With a little more study, the CTPTD will have a concrete answer to exactly what this type of change in signal timing has on traffic. This change, if effective, could then be used effectively in other areas. If it proves to be ineffective, it will suggest that the CTPTD find a different method for changing driver behavior, either of these conclusions being very valuable to the department and the city of Cambridge.

We designed the GIS and Access® database to be easy to duplicate and/or expand upon for future studies, should the CTPTD wish to use our templates to store and display future work. We created GIS layers that could easily be added onto with data from other streets, or updated data from Putnam Avenue. Having created a standard, the CTPTD now needs only repeat the studies our group performed using the methodology we created, and then enter that data into the templates we've created. This not only gives the department a simple and standardized method for evaluating traffic signal changes, but also any other change they may implement on a roadway. It also makes it easy for them to compile data about roads over the entire city in one place where it's easy to compare roads to each other, or compare two time periods concerning one road. The study can be used as a very powerful tool.

It is essential for the CTPTD to be able to comprehensively measure changes that they impose on given roadways in "before and after" study. Evaluation of traffic changes is important to make sure it is having the desired effect. If the city hopes to redistribute traffic in a beneficial way, they must be able to effectively judge the conditions in an area, and know what traffic control measures are best suited to accomplish their goals. The project is steps in making the city's goals become reality and having an effective method of carrying out traffic change studies. Employing methods used in this project can help the city make better decisions with its roads when trying to affect driver behavior using signals.

1. Introduction

With the development of easily affordable personalized transportation, the 20th century saw the emergence of the modern city, and people began to inhabit them in record numbers. Within a city is a complex web of roads that acts as a lifeline for its infrastructure. Currently in the United States, the number of vehicles is increasing twice as fast as the population (EPA Impact of Commuters). While cities continue to improve upon their road infrastructure in hopes of accommodating more vehicles, many major city traffic arteries remain congested, and increasing population can make matters even worse. The strained roadways result in economic damage to businesses, increased pollution, and in general a lowered quality of life for residents and commuters alike. In addition, city spending has increased for maintaining, upgrading, and controlling roadways, parking facilities, etc (City of Cambridge). Due to the continuing problem of overcrowded major roadways, the spillover of motorized traffic onto secondary arteries is becoming a significant problem for cities.

With the available space for roads and parking dwindling, cities are running out of ways to cope with their traffic. Cambridge, Massachusetts is employing innovative practices to reduce traffic, such as measures to restrict parking to promote public transportation and bicycling. Despite these measures, Cambridge still experiences a heavy traffic load. Motorists are exploiting secondary roads in order to bypass congested main roadways; which has an adverse effect on the residential and commercial areas through which these roads run. Putnam Avenue is a secondary roadway that is experiencing a congestion problem. The commuter traffic coming from the several main roadways in the area, such as Western Ave. and River St., is not compatible with the current traffic control measures in place.

Putnam Avenue is not equipped to handle its current traffic load. It has residential neighborhoods and a school along its length. The traffic has put a strain on the residents' quality of life along Putnam Avenue. It presents a danger to the young children who travel to school in the area. Residents cannot get out of their local streets easily, there is increased noise, and the large numbers of vehicles present a pollution problem.

Cambridge experiences a great deal of traffic, and the Cambridge Traffic, Parking and Transportation Department (CTPTD) utilizes traffic signals as a primary method of moving and controlling traffic as efficiently as possible. Putnam Avenue has seven traffic lights along it and the norm the CTPTD has established suggests that using signals is their method of choice for moving traffic along a street. Putnam Avenue's location and characteristics (multiple traffic signals, considerable length, high traffic levels) make it a perfect site for testing traffic control measures.

While the traffic signal method of controlling traffic in Cambridge has been well developed by the CTPTD, the department had no set method for comprehensively testing the effectiveness of the control measures taken. Many factors affect traffic in a given area, which makes it difficult to accurately judge traffic before and after changes have been implemented. Several variables such as time of day, week or year, weather, section of street, direction of traffic, etc. can all impact data collection processes and lead to uncertain or erroneous findings. The CTPTD had encountered difficulty in determining the best course of action to resolve issues like those on Putnam Avenue. Views within the department differed as to whether a certain traffic control practice would improve a situation, have no effect, or make it worse. Without a method for assessing efficacy, the CTPTD was handicapped in its functions, and asked WPI for help with devising a method for evaluating traffic control measures. This team's efforts were then applied to Putnam Avenue, which served as a test case.

The goal of this project was to design and conduct an experiment to accurately quantify the effect that a change in traffic light timing will have upon traffic flow, and use this methodology to evaluate a traffic control measure put into place. How fast cars are going at sections of the street, how long a wait is at each light, how long it takes to travel from one section to another on the street, etc. were important pieces of data that traffic engineers needed to streamline traffic flow through the street. These data were collected before and after the traffic light change, and then compared so that the impact of that measure was evident in several important ways.

In addition, we sought to control traffic-altering factors in order to isolate the effects the change in light timing had on traffic. In order to conduct this experiment, our group looked at *how* each of these external factors affects traffic flow. For example, how traffic varies by day or week. We assessed how much of the traffic on Putnam Avenue was using the street inappropriately as a "shortcut," versus how much traffic was coming from the adjacent neighborhoods. We collected these important pieces of data and identified all of the intervening factors, and our research yielded three products. First, we were able to accurately evaluate the impact a traffic altering action had. Second, we were able to assess, and thus eliminate, external factors as possible causes for changes in traffic flow after the traffic signal timing change was implemented. The third product was a method created for the CTPTD to accurately assess traffic control measures on any street. With our data the CTPTD is now more effective in implementing these types of changes that will have an impact on other problem areas like Putnam Avenue all over the city. Using this study as a tool, the CTPTD can accurately judge the best way to manage traffic on many secondary roadways, and thus come closer to eliminating traffic congestion on neighborhood streets.

2. Background

Understanding the background information of a problem is a key element before proposing solutions. There are various areas of background information that must be discussed before addressing the problem at hand. The first topic that will be discussed is the conditions around Putnam Avenue, the area that surrounds it, and reasons fueling the problems seen. Traffic engineering is an important field of study since it discusses how traffic studies are performed, methods used to collect traffic data, and methods of reducing traffic. These are the most important topics that will be addressed in the upcoming background information.

2.1 Conditions around Putnam Avenue

Putnam Avenue is a 1.5 mile long, two-way street that runs perpendicular to several main arterial streets in Cambridge (see Figure 1, and also Appendix B: Detailed Maps of Putnam Avenue) (Geography Network Explorer). The street connects many local streets to the arterials that take residents to and from these streets, as well as points of interest in and around Cambridge. There are businesses, one school (Martin Luther King), and many residences along the street. The current method of controlling traffic flow depends on 6 traffic lights, designed to move traffic as efficiently as possible.

The conditions of Putnam Avenue are explored in this section by explaining the current traffic situations in the area. The following section will describe the area of Putnam Avenue emphasizing factors that are along the street and located in the vicinity. Current conditions faced by the city of Cambridge in regard to transportation will be addressed to demonstrate that traffic conditions continue to worsen. Furthermore, some of the reasons that have prompted the City of Cambridge to look at Putnam Avenue for remediation will be explained.

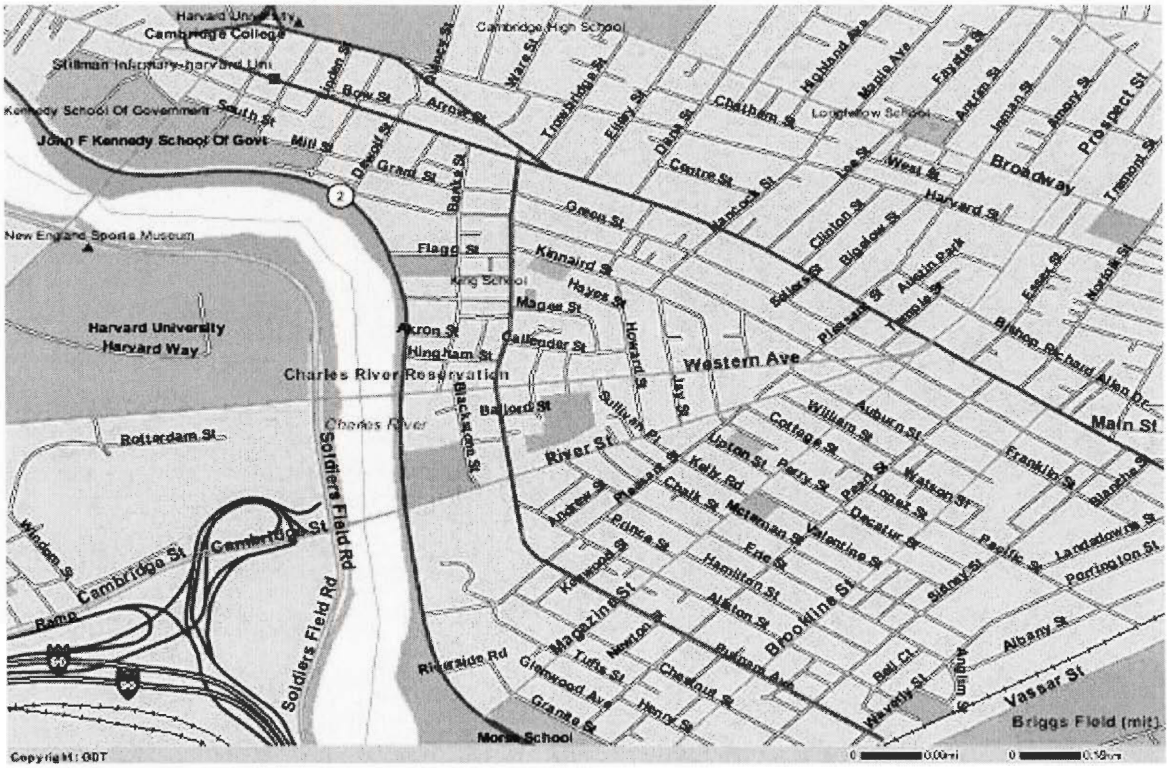


Figure 1: Map of Putnam Avenue (in magenta). (Geography Network Explorer)

2.1.1 Explanation of the Area's Situation

The area in which Putnam Avenue is located has two main one-way arterials crossing it, Western Avenue and River Street. There is a great deal of travel on these arterials since they are links to surrounding cities including Boston. A great deal of travel is done in and out of both the city of Boston and the city of Cambridge each day. Each of the main arterials, Western and River, sees roughly 30,000 cars per day going across their bridges in and out of Cambridge (Boston Metropolitan Planning Organization).

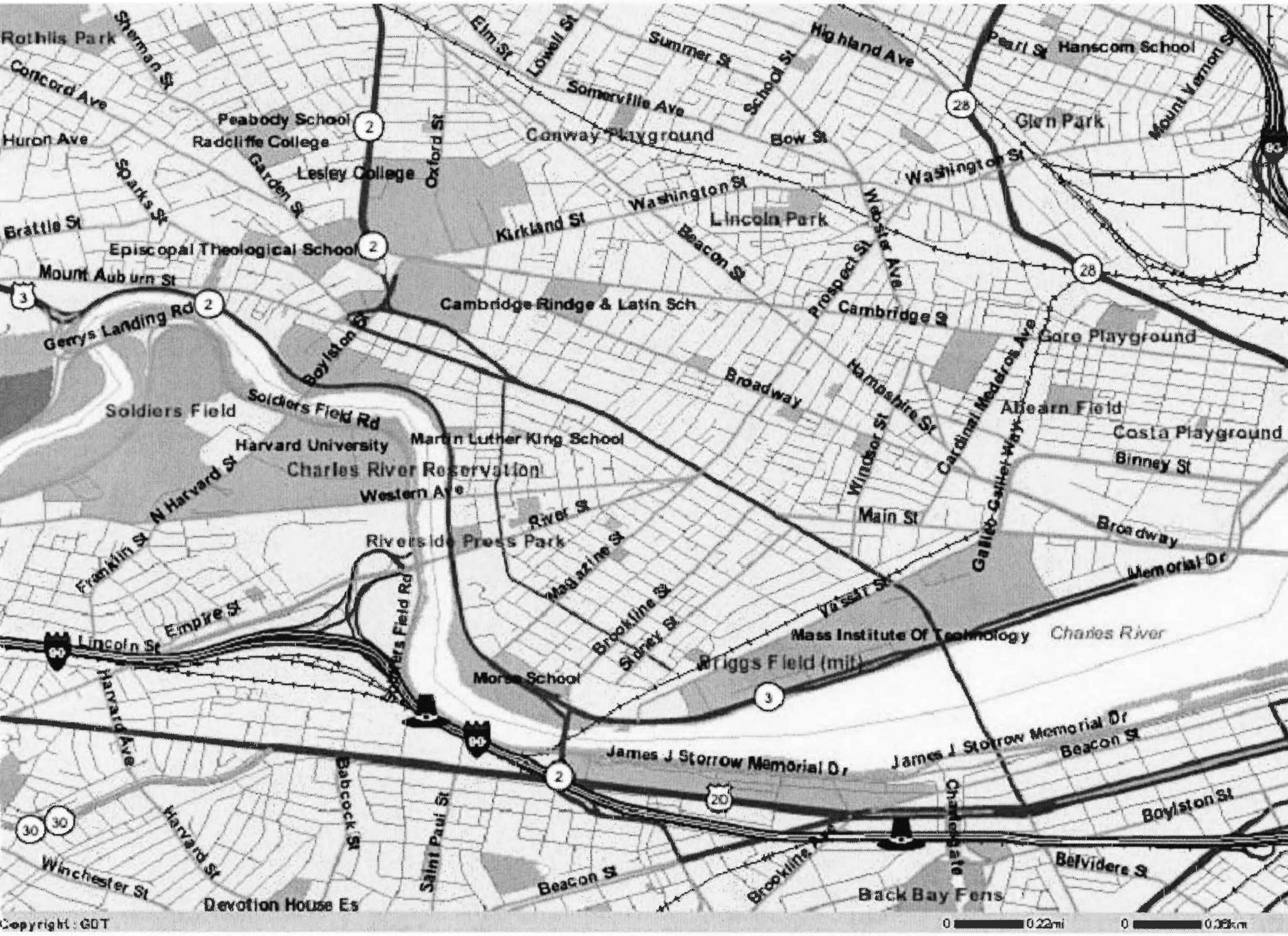


Figure 2: Putnam Avenue (in magenta) and surrounding areas of Boston and Cambridge

Not only is commuter travel increasing congestion in an already congested region, but Putnam Avenue has a school (Martin Luther King School, seen in Figure 2: Putnam Avenue (in magenta) and surrounding areas of Boston and Cambridge) located in the northern section of the street which has bus drop-offs and pick-ups during the day. Combining the local resident travel, the narrowness of the street, and the traffic looking to by-pass major arterials within Cambridge, the problems can clearly be seen. Cambridge is home to several major corporations and has many businesses that have offices in the city. There are approximately 5,300 businesses, which have nearly 120,000 employees (Cambridge Chamber of Commerce). In addition to having large high tech and biotechnology companies, Cambridge is home for some of the leading institutions in the world. Harvard University and the Massachusetts Institute of Technology (MIT) claim Cambridge as their home. These two large universities both have large student populations. Harvard has over 16,000 students at all levels of study and MIT has over 10,000 enrolled. Both of the Universities have 96% of their undergraduates residing in Cambridge on campus. The majority of the schools' total enrollment is within the graduate schools (College Board Website). Graduate students usually do not live on campus, making it necessary for them to travel to and from class from the surrounding area. A large source of commuter traffic is driven by a combination of Harvard's and MIT's University Park. The park combines academic research labs and also high-tech and biotech research firms to have buildings in a concentrated area. The large corporations, thousands of employees, many students, and visitors' traveling on the major arterial of Massachusetts Avenue increases the use of Putnam Avenue as a detour.

The many attractions that are present in the city and the location of Putnam Avenue may also help explain the reason congestion is experienced. The hypothesis that commuters are using Putnam Avenue as a "shortcut" between arterials seems to be well founded. Looking at Figure 1 and Appendix B: Detailed Maps of Putnam Avenue, Putnam Avenue intersects 5 major arterials, suggesting it may be used inappropriately, that is by commuters not residing in the area.

2.1.2 Reasons for Action on Putnam Avenue

The residents of Putnam Avenue do not feel that the road is safe given the amount of use it is currently seeing. Many children live on or around Putnam Avenue since it is zoned primarily residential (See Appendix E: Zoning Map of Putnam Avenue Area for detailed map). Residents feel that it is unfair that commuters are using their street as a "cut-through" or "shortcut." These residents want the CTPTD to take action and make their street safer and more appropriately used.

Complaints from residents are received by the CTPTD regularly via mail or phone call. Investigation reveals that residents believe Putnam Avenue is their street and that non-residents should not use it as a shortcut. The other complaint that is predominant from residents is the high speed at which cars travel along Putnam. The speed factor is one of great concern on a narrow street with many residences like Putnam Avenue.

Addressing the issues/complaints of the residents is one of the CTPTD's biggest concerns.

Furthermore, the greatest factor driving action on Putnam Avenue is that the signals currently in place are proving to be ineffective at relieving the congestion and cut-through traffic situation. Investigation into the use of traffic signals shows that they can do more harm than good at relieving traffic problems such as cut-through (City of Phoenix). As previously stated, Putnam Avenue utilizes 6 different signal devices along it, a number very high for a street dubbed as a "collector" type. Problems like cut-through and congested traffic on the street are expected when signals are placed on a collector street environment like Putnam Avenue (City of Phoenix). The driving forces behind the project are the conditions seen and the City of Cambridge's goal to try to utilize the current traffic control methods. Traffic signals are not typically used to perform traffic calming (slowing down traffic to increase safety); however, the goal is to use what is presently there in a more effective way to achieve this goal. A possible source of the problem (too many traffic lights) currently is going to be used as the possible solution on Putnam Avenue.

2.2 Traffic Engineering

In order to understand traffic engineering, one must first understand the different types of streets. There are three types of streets in a city: locals, collectors and arterials. Each has its own specific job in how traffic flows throughout a city. A local road is supposed to be used solely for the purpose of residential traffic. Arterials are used for traffic to get in and out of the city, and are major roadways. Collectors, like Putnam Avenue, gather traffic from both local and arterial roads, and bring them to other major streets. Land Access (the amount of land that is available for housing, businesses, etc. near a road) is the priority in residential areas, vs. Arterials where traffic mobility is the goal. This relationship can be seen in Figure 3: Functional Highway classification and type of service provided (Traffic Engineering 38). In the following section, established practices and methods of traffic control, as well as complaints from residents on Putnam Avenue, will be discussed.

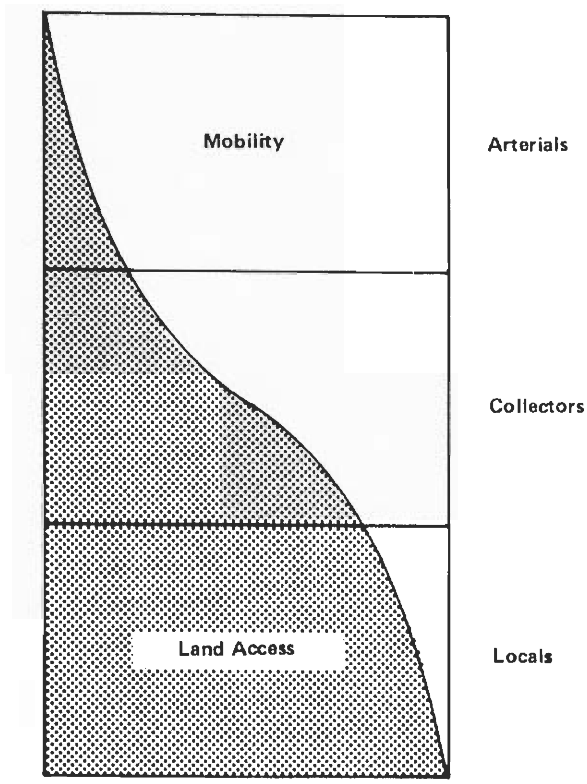


Figure 3: Functional Highway classification and type of service provided (Traffic Engineering 38).

2.2.1 Established Practices and Methods

The introduction of streetlights to the area definitely changed the amount of traffic and its flow. The traffic signal was invented in 1923, and has been used in Cambridge since nearly that time. The purpose for this invention was to increase safety on the streets. There are currently 144 full traffic lights in Cambridge, with many flashing lights as well (Annual Report 2003). By coordinating the timing, traffic signals decrease vehicle idle time and commute time, but increase overall speed. The signals on Putnam Avenue are not currently synchronized, but this study will help prove/disprove the efficiency of the lights on the street. In order to please both the residents and the drivers, a compromise must be reached.

Currently, there are several methods to slow traffic in neighborhoods, as well as to discourage cut through traffic. Some of these include horizontal shifts (where the road shifts to one side by a lane's width), roadway narrowings, and parking on one or both sides of a street (Traffic Calming Measures 2004). These methods of slowing traffic and obstructing movement help discourage motorists from "cutting through" residential neighborhoods rather than using the appropriate main roads to lessen their commute time. These methods are useful in many traffic situations, but on Putnam Avenue, there will be no traffic calming, slowing the speed of vehicles, taking place.

When a traffic problem on a collector street is established, the Bureau of Transportation System Management (BTSM) recommends several steps to solve the problem. The first step is called 'survey to proceed,' in which surveys are handed out to the residents of the street. At least thirty percent are usually returned and the majority of those usually feel a change should be made. Next is 'plan development,' which consists of four meetings at which the BTSM works with the residents to come up with an approach that makes the most sense. The third step, 'project ballot,' is a vote where most of the people responding must be in favor of this change for it to pass. Fourth is 'city council action' where a proposal is presented to the City Council so that a change can be implemented. The next step is 'design and construction/implementation' where the traffic calming devices are constructed on the street. Finally, the last step takes place about six months after implementing the device(s) and it is called 'project evaluation' (City of Portland Traffic Calming). This shows whether or not the chosen method was useful. These steps are suggested when there is a long period of time to investigate the problem at hand. Given the tight schedule, the Cambridge Traffic Group did not carry out all of these steps, but rather followed a concise experimental setup without any public input.

2.2.2 Traffic Studies

There are various types of traffic studies that can be performed on streets in order to understand the problem at hand. Included in these are volume, speed, travel-time, delay, density, and headway and spacing studies. On Putnam Avenue, only the first four of these were carried out. A typical volume study records regularly how many vehicles travel past a certain point on a street or highway. During speed studies, the focus is placed upon vehicle speeds usually during uncongested times of day. Travel time is the next typical study used, when a vehicle is clocked over a certain section of road to see how long the trip takes. The last study that is relevant for Putnam Avenue is delay, which is a study of where, when, and for how long a vehicle is stopped along a specific route (McShane 1990). These studies are necessary first for finding baseline data, and then again after the experiment is performed to collect data and compare it with the original information.

Putnam Avenue has been previously studied using Automatic Traffic Recorders (ATRs) and Turning Movement Counts (TMC's) at several different locations. ATR's are machines laid on a street that collect speed, volume and length of vehicles that pass over them. TMC's, on the other hand, are done manually, and they show how many vehicles turn left, right, or go straight through a given intersection. Out of the raw data that were collected, there were several conclusions drawn. On average, the southbound travel on Putnam Avenue tended to be heavier than the northbound traffic in the morning, but only by small amounts. During rush hour in the evening, the traffic pattern switched as the northbound route doubles the southbound (City of Cambridge 2000). These findings suggested that commuters using the Massachusetts Turnpike travel on Putnam Avenue when going to and from work each day.

2.2.3 Traffic Signals and Timing

A large portion of this project will focus on optimizing the traffic signals on Putnam Avenue in order to produce the goal of discouraging commuter traffic cut-through. Traffic signals' main goal is to allow safe travel and passage of cars and pedestrians in an intersection. There are several purposes and advantages to traffic signals outlined below from *The Manual on Uniform Traffic Control Devices* (MUTCD):

- They provide for the orderly movement of traffic;
- They increase the traffic-handling capacity of the intersection;
- They reduce the frequency and severity of certain types of crashes, especially right-angle collisions;
- They are coordinated to provide for continuous or nearly continuous movement of traffic at a definite speed along a given route under favorable conditions;
- They are used to interrupt heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to cross.

Traffic signals also have negative impacts when used; they are listed below:

- Excessive delay;
- Excessive disobedience of the signal indications;
- Increased use of less adequate routes as road users attempt to avoid the traffic control signals;
- Significant increases in the frequency of collisions (especially rear-end collisions) (FHWA MUTCD 2003).

Signalized traffic intersections are the most complicated portions to a traffic system. There is very precise planning and timing that goes into the workings of an effective and safe intersection. There are several variables that are computed when looking into an intersection. The central factors of an analysis of an intersection are capacity and level of service (Highway Capacity Manual 9-2). Timing and delay of signals are determined by many factors that are analyzed about the intersection and the street on which the intersection is located. Projected rate of flow of the approach divided by capacity of the approach ratios (*v/c*) are calculated to contribute in determining the delay of a signal. Furthermore, the level of service is based on averages of the stopped delay of various movements in an intersection. Combining these factors along with others like length of green phases, progression, cycle lengths and others give a range of delay values that are appropriate for the intersection (Highway Capacity Manual 9-3). The equation below in Figure 4 shows delay assuming random arrivals, the type of equation that is used to calculate delay in the level of service on Putnam Avenue.

1. *Delay assuming random arrivals*—The delay for each lane group is found using the following relationship.

$$d = 0.38\,C \frac{[1 - g/C]^2}{[1 - (g/C)\,(X)]} + 173\,X^2 \left[(X - 1) + \sqrt{(X - 1)^2 + (16X/c)}\right] \quad (9\text{-}18)$$

where:

d = average stopped delay per vehicle for the lane group, in sec/veh;
C = cycle length, in sec;
g/C = green ratio for the lane group; the ratio of effective green time to cycle length;
X = v/c ratio for the lane group; and
c = capacity of the lane group.

Figure 4: Delay Equation assuming random arrivals (Highway Capacity Manual 9-18)

Equations like the one shown in Figure 4 are used to calculate the lights of an intersection. The CTPTD uses a software program called Syncro® to determine signal timing. The program used information about the road and the conditions of the intersection in calculating timing factors using equations similar to the one above. The controlled experiment with light timing was calculated using the same software program only adjusting the calculation to have un-favored progression. Normally an intersection will operate to allow the optimum amount of cars across an intersection safely. Traffic signals have timing for peak and off peak periods. The peak and non-peak timing depends on the locations and direction that the signal controls. Timing can also be synchronized with other signals along the street. The project utilized these features to signal timing and programming to perform an experiment exploiting factors that make unfavorable progression in certain directions at specific times along Putnam Avenue.

2.2.4 Traffic Calming

There are many practices used to alleviate traffic congestion. There is a science that many traffic engineers use to perform "traffic calming," the slowing of traffic for safety purposes. The basic, widely used theory deals with the "3 E's," education, engineering, and enforcement (ITE and FHWA). There are different methods utilized by traffic engineers to achieve traffic calming. Different devices are used for different goals in achieving traffic calming on a particular roadway. Some of the goals that are associated with using traffic calming devices are: speed reduction, reduce traffic volume, pedestrian safety, bike safety, and crash reduction. Examples of devices used to achieve these goals include speed bumps, signs, and street designs (City of Portland Traffic Calming). In Appendix C: Traffic Calming Selection Criteria, there is a selection chart which the City of Portland uses to determine severity of traffic and the need for traffic calming. The most common methods used in traffic calming for a neighborhood collector street are speed bumps, curb extensions, and slow points (areas in a street that narrow) (City of Portland Traffic Calming). Looking at how traffic calming has evolved over time can be helpful as well. Comparing publications of the ITE shows that there are few significant differences in the methods applied as solutions for traffic congestion issues although the decision process to use them has changed. In the 1980 publication of *State of the Art: Residential Traffic Management*, the process of alleviating traffic congestion begins with the identification of the problem and then analysis of possible solutions to the problem (FHWA Residential Traffic Management). The difference in thinking today comes after the problem is identified: there are studies done on the conditions of the area (ITE and FHWA). Instead of the previous thinking of coming up with solutions and implementing them and seeing how effective they are, there are measurements and studies performed before solutions are presented. Studying the problem before the actual implementation of a traffic calming method will allow a more scientific and thorough analysis. It seems that the older practice of traffic calming has been used on Putnam Avenue due to the high number of signals present on the street. The method that was explored in our project uses the signals to our advantage in coming up with an effective timing that will discourage travel and also reduce the volume seen on the residential collector.

Investigation into many literature sources and background information help make the project successful and meaningful. Looking into the methods that are applied in signalized intersection timing and how they are calculated allowed the project team to focus on the complexity of the issues, and educated us on the theoretical underpinnings of traffic engineering. Information concerning streets like Putnam Avenue, along with the current information regarding it, provided necessary data on which to base goals. Our research into established methods of traffic studies and the different types of studies performed allowed us to select those that were the most relevant to Putnam Avenue. All of the research helped us to gain a broad background for the project and helped us make it a success.

3. Methodology

The project set out to help the City of Cambridge discourage commuter traffic on Putnam Avenue by devising a method of traffic signal change that will bring travel back onto main arterials. Analysis of current traffic data and conditions created a baseline to which the controlled experiment was compared to measure its effectiveness. The experimental results were measured in an identical manner as the initial (baseline) conditions were and then they then were compared against each other. Ultimately the project team's hopes were that the methods used in the study and analysis are carried over on not just further study on Putnam Avenue but streets like it in Cambridge.

The project was broken into three major phases: initial conditions measurement (baseline), experiment implementation and measurement, and then evaluation and comparison of the phases. Figure 5 shows an example of how the project has come together and some areas of importance associated with each of the three phases.

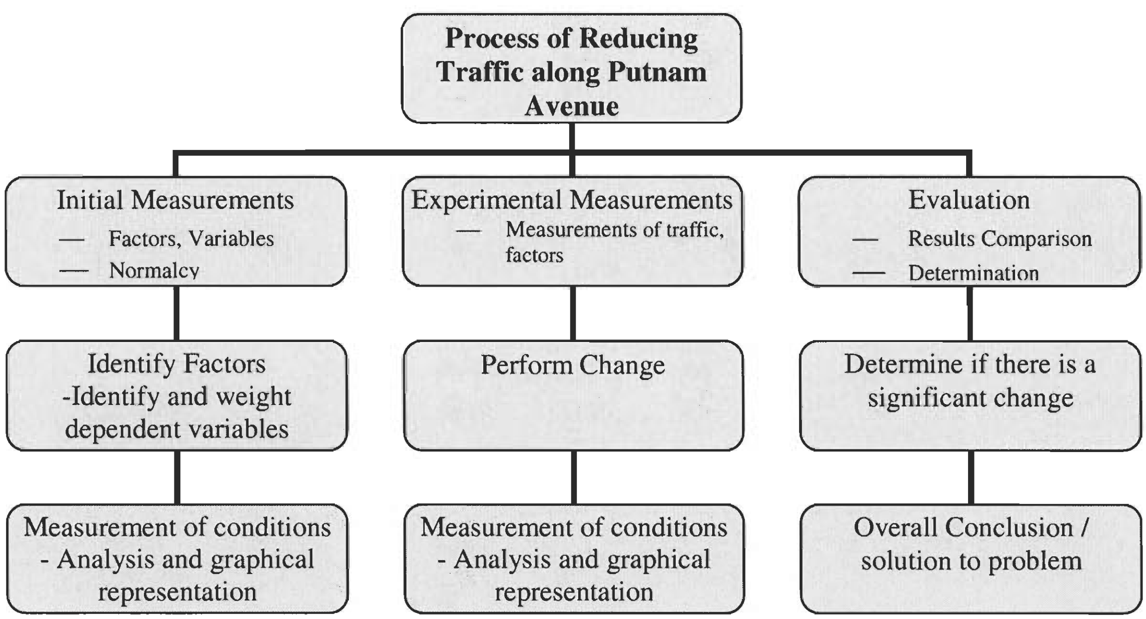


Figure 5: Organization of the Methods involved with reducing Commuter Traffic on Putnam Avenue

The project began with the collection of baseline data on Putnam Avenue. Our team arranged with the CTPTD to start collection of data on Putnam Avenue before we arrived on site. We collected baseline conditions starting on day one with the help of our liaisons. In the first week a good deal of information relating to the existing traffic conditions was collected and ready for analysis. During the experimental phase we used the baseline information to measure any changes observed by the traffic signal change. The data collected in both the baseline and experimental phases were compared and statistically analyzed.

The project took place in Cambridge, Massachusetts between March 14^{th} and May 4^{th}, 2004. The data collection and experiment was performed on Putnam Avenue, which is located in the southeast corner of the city near the Charles River. The baseline data was collected from March 9^{th} until March 19^{th}. The experimental data was collected from April 5^{th} until April 16^{th}. The analysis of the data and the center of the project were based out of the Cambridge Traffic, Parking, and Transportation Department's office.

The methodology of the project began by identifying the factors or variables that would affect the data we were collecting. The variables we identified fell into three different categories: dependent, independent, and intervening. Specific factors that were related to not only the baseline but also the experimental data were identified and discussed among the group and with our liaisons. We used established methods and practices that are used in traffic studies to collect our information. Conclusions were drawn from our detailed data analysis that created meaningful comparisons and representations of the effectiveness of the traffic signal change. The analysis was used as a tool not only to support our recommendations on Putnam Avenue but also as a tool that can be applied to similar streets.

3.1 Identification of Data Collection Variables

In order for the project to achieve success, we first needed to identify factors that would affect our collection of traffic data. The identification of these variables was the first priority in the project and was completed before arriving on site. There were some variables that were uncontrollable, or intervening in the study, identification and minimizing factors like these helped the study to be more significant. These intervening variables can be divided into two groups: predictable and unpredictable variables; discussion into these variables comes in a later section. We also looked at the independent and dependent variables involved in the study. Having a good understanding of all variables in the study helped the project to be successful.

3.1.1 Independent Variables

The only independent variable was the timing of the traffic signals. The signal timing has been developed and calculated by Jeff Parenti, Cambridge's Traffic Engineer. Jeff used the computer program Syncro® to calculate exact timing and delay information. The timing existing before the experimental signal change was that the lights along Putnam ran independent of each other with no synchronization. The experimental signal change will synchronize the lights to run on a specific timing delay and progression. The signals that were affected by the change are shown on the map in Figure 6.

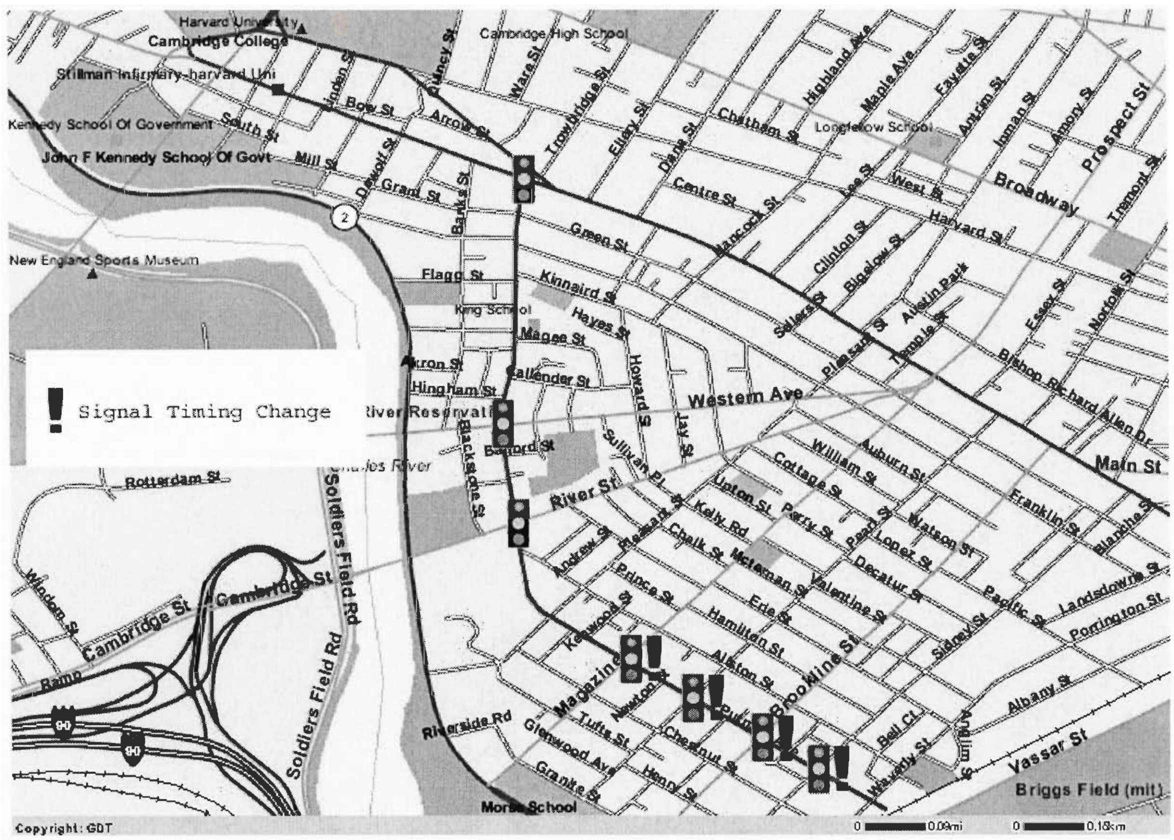


Figure 6: Map of Intersections affected by the Signal Timing Change

The timing that was used at Sidney Street, Brookline Street, Pearl Street, and Magazine Street is shown in Appendix D: Syncro Time – Space Diagrams of Signal Changes on Putnam Avenue. The signal timing change had the proposed goal of discouraging commuters from using Putnam Avenue. The study looked at the impact it had on driver's behavior when they had to wait longer at a signal than previous timing. The results of the study were to show if the experiment was an effective way to discourage Putnam Avenue as a road for commuter cut-through.

3.1.2 Dependent Variables

The dependent variables in the study are those that were to be measured throughout the study. The variables are Volume, Travel Time, Speed, and Use. The volume relates to the number of cars measured in a particular section over a certain interval. The "Volume" measurements we took related to the number of cars recorded at a certain point on Putnam Avenue in one hour increments. The "Travel Time" is the amount of time that it takes a car to go from one end of the street to the other. Measurements were broken up into the direction (northbound or southbound) that the car was traveling and the time of day the measurement was taken. The time of day periods were: AM Peak (8:00am – 9:00am), Midday (12:00 noon – 1:00pm), and PM Peak (5:00pm – 6:00pm). "Speed" is the average velocity in miles per hour a car is going at a point on Putnam Avenue. The averages were compiled in one-hour increments. The "Use" variable is the number of cars that were determined to be using Putnam Avenue as a cut through. The "Use" was calculated from results of Turning Movement Counts and Origin-Destination Studies carried out by the project team.

3.1.3 Intervening Variables

Intervening variables are those factors affecting traffic rates that we had no way of controlling. Weather was our largest intervening variable. While weather reports did lend some insight, we couldn't be sure of what the weather was any given day. We had to adjust days to when different studies were performed due to rain. Throughout the studies we made sure that the weather was similar in both baseline and experimental readings. Car accidents were another threat to the validity of data collection. If an accident occurred on the street, it fouled the data for some time. Fortunately, we did not encounter any major accidents that had significant impact on traffic flow. There are some more predictable variables in our study that were carefully planned around. Our study looked into the construction schedule around and on Putnam Avenue to make sure delays or changes in traffic patterns did not occur during our samplings. The group attended a Cambridgeport neighborhood construction meeting to make sure the times when data was being collected was not impacted by road detours or construction. Another factor was school closings and holidays that occurred during our study. The table below shows some of the major predictable intervening variables that were taken into account when collecting data.

Intervening Variable	Pertinent Data
Harvard School Schedule	Spring Break Mar. 27-Apr. 4
MIT School Schedule	Spring Break Mar. 20-28
Martin Luther King School Schedule	Feb. Vacation 16-20, no school on Mar. 17
Holidays	Easy to identify on a calendar
Construction	Cambridgeport roadways construction project on East side of Putnam
Direction of Traffic	Relates to time of day (direction of commute)
Large Business Openings/Closings	
Bus Routes	Available from City

Table 1: Significant Predictable Intervening Variables.

3.2 Traffic Study Methods

Although there are many different methods of traffic data collection, our group felt that only five would be necessary. These entail the dependent variables of Travel Time, Delay, Volume, Speed and level of cut-through traffic. Travel Time studies measured not only the total time it took for a vehicle to drive the length of Putnam Avenue, but also the delay it faced at each traffic signal. Automatic Traffic Recorder counts (ATR) provided the number of cars passing by an exact location on the street, as well as their average speed. Speed studies were executed using a radar gun to pinpoint exact speeds of vehicles traveling on Putnam Avenue. Finally, both the Turning Movement Counts (TMC's) and origin-destination studies provided information on the level of cut-through traffic on Putnam Avenue. By keeping these counts as consistent as possible before and after the change, it helped us to draw valid conclusions. The upcoming section will discuss how we performed these studies along Putnam Avenue.

3.2.1 Travel Time

Otherwise known as a floating car time, travel timings were carried out by using a stopwatch to record how long it took our vehicle to get from one end of the street to the other. The timing would begin at one end of Putnam, when we passed through the first traffic signal. Each time we hit an intersection, the time would be recorded onto a chart. If there was a queue at a signal, this time would be recorded, along with what time we actually crossed the intersection at, in order to determine the delay. The time would be stopped when we exited Putnam at either Mt. Auburn Street or Sidney Street. In order to achieve valid data, we took several timings at peak traffic times (8:00 – 9:00 a.m. and 5:00 - 6:00 p.m.) so that an average could be formed. The last piece of information recorded was the weather so that our data was kept as constant as possible.

3.2.2 Automatic Traffic Recorder Counts

The ATR machines were extremely useful for finding volume and average speed on Putnam Avenue. The machines worked by being mounted in middle of a traffic lane and recorded information about cars that passed. The machine recorded volume, speed, temperature, road condition, and vehicle type. Each hour they recorded the average speed and the total number of cars that passed over them in a certain direction on the street. Our group decided upon three strategic locations on Putnam Avenue as shown with red dots in Figure 6. These were placed at the King School, to the west of River Street, and to the west of Magazine Street, from west to east respectively. Every time a vehicle passed over the unit, it would record the speed, volume and vehicle type (car, large truck or bus). However, because of its limited memory, it could only store values for each hour, so that it could run for an entire week.

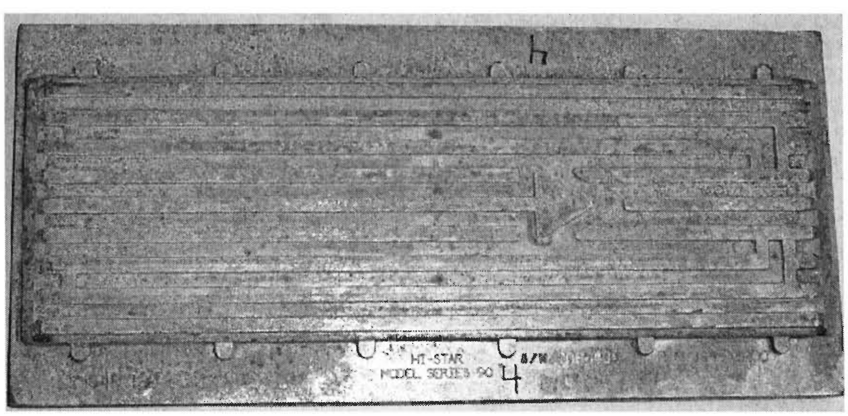
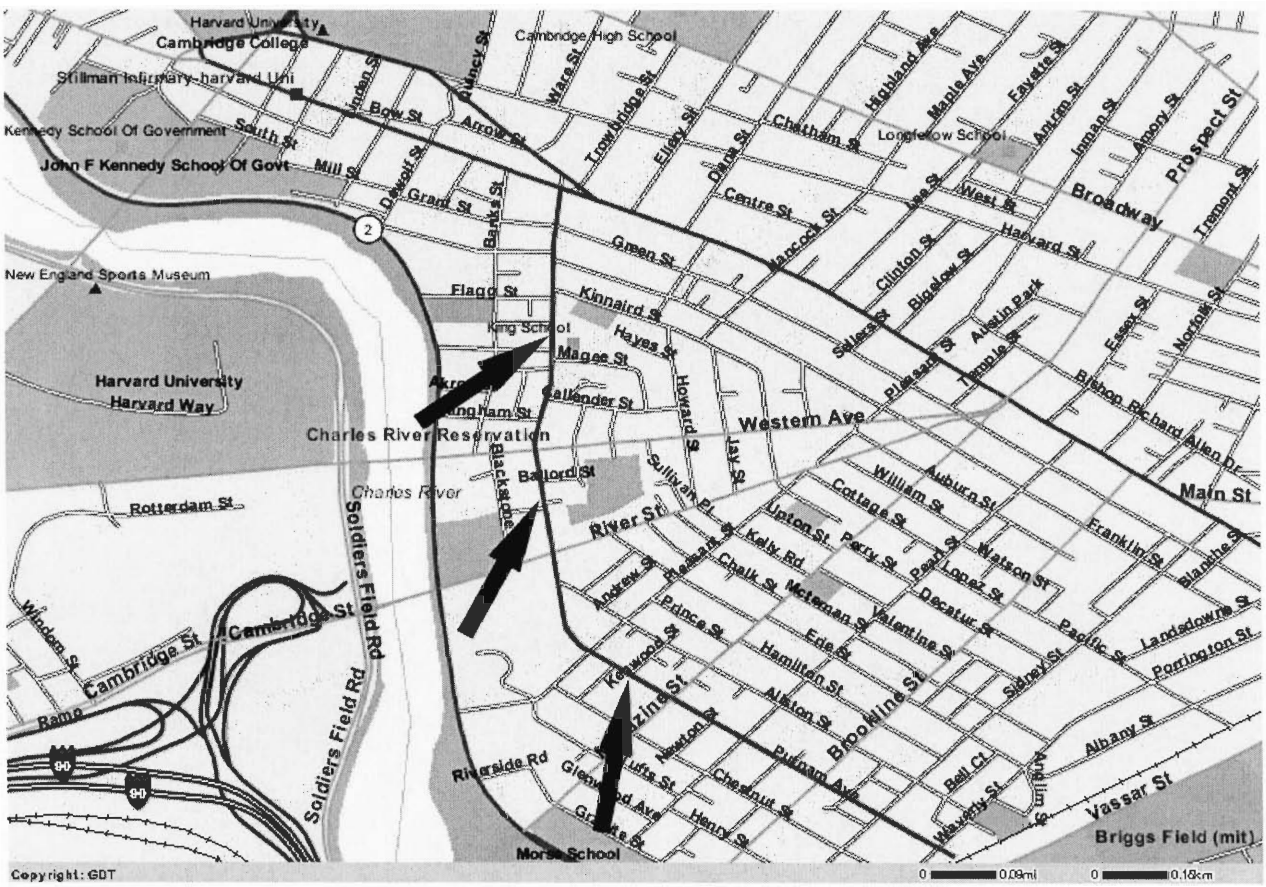


Figure 7: Automatic Traffic Recorder



Putnam Avenue is seen here in Magenta.
Our ATR placement locations are denoted with arrows.
Figure 8: Map of ATR locations on Putnam Avenue (Geography Explorer)

3.2.3 Speed Study

Our group felt that the average speed for an hour did not represent each vehicle's speed fairly. Therefore, in order to get an accurate idea of speeds we used a radar gun to clock the speeds of 100 cars at the same locations as our ATR's. The speeds were measured during off-peak hours. We were interested to see if changing the traffic signal timing would affect how fast vehicles traveled between the lights.

Figure 9: Radar Gun used to clock speeds for the speed study.

3.2.4 Turning Movement Counts

Cut-through traffic was one of the main reasons for changing the traffic signal timing, in the hopes of deterring those vehicles from using Putnam Avenue. The turn movement counts were collected at the corner of an intersection. These counts included the number of vehicles turning left, right and going straight for each direction of travel. This would show us where people get on and off Putnam Avenue. The three locations that we picked were at the intersections of Western Avenue, River Street, and Magazine Street (See Map in Figure 11). We did these studies at 3 different times of day, 8-9 a.m., 12-1 p.m., and 5-6 p.m., in order to collect both peak and off-peak times.

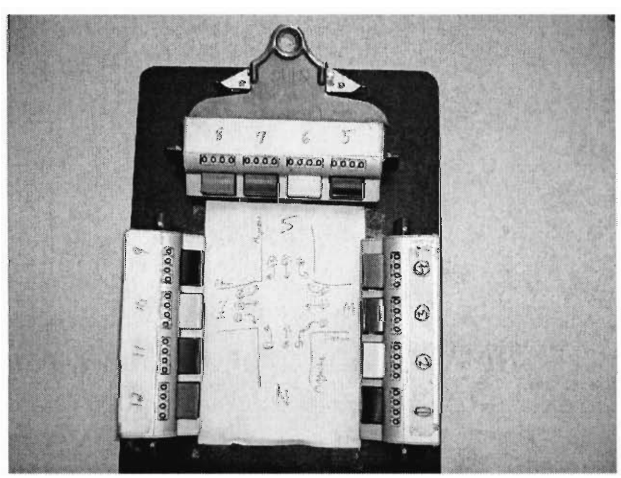


Figure 10: Turning Movement Count (TMC) Counter.

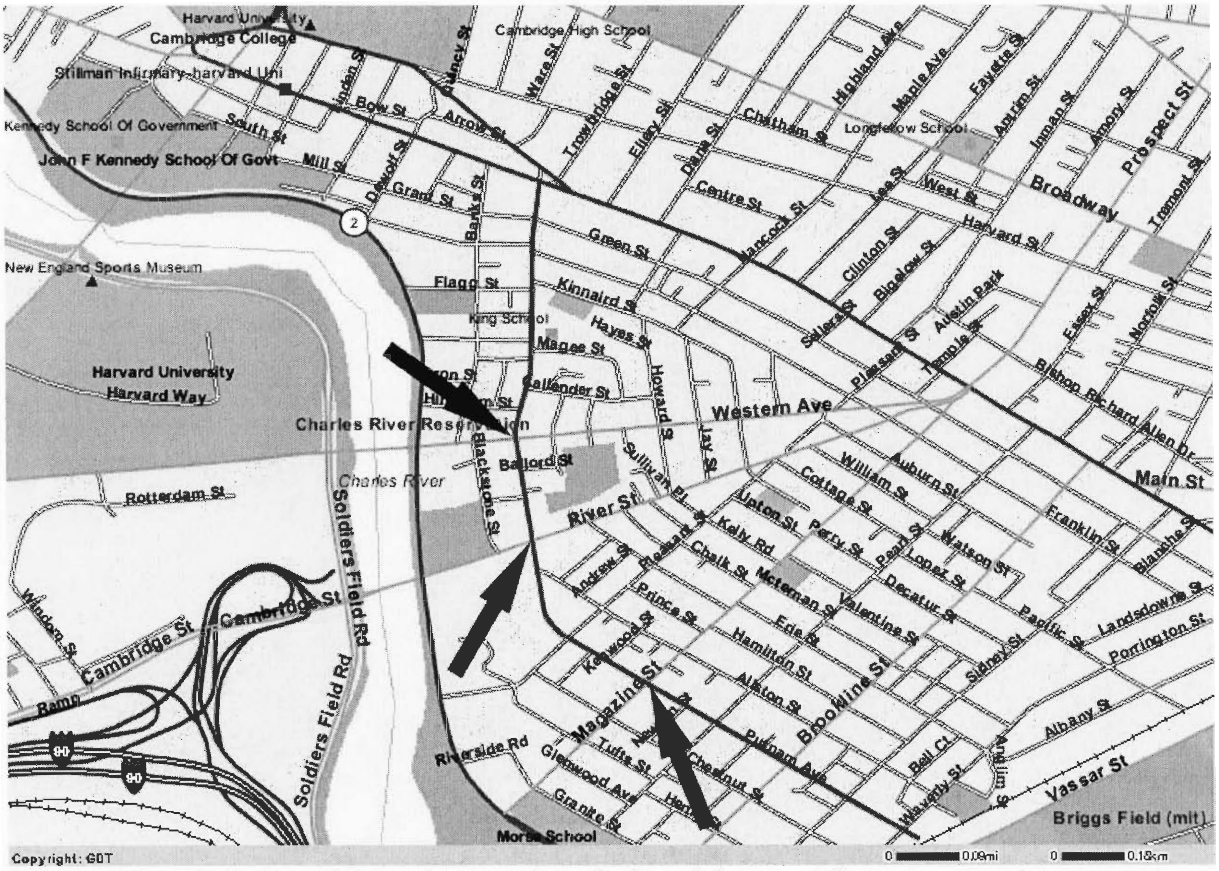


Figure 11: Locations along Putnam Avenue where the Turn Movement Counts were performed.

3.2.5 Origin-Destination Study

The last type of study that was performed was an origin-destination study. Our group picked 3 locations to record the last 3 digits of license plates that performed a certain movement at their intersection. In other words, one person noted every vehicle that turned right on Putnam from Mt. Auburn, and right on Mt. Auburn from Putnam. Another was set up to record the plates of vehicles turning both left and right from Putnam to Western Avenue. Finally, the last person had all vehicles turning right or left onto Putnam from Magazine Street, as well as those continuing westbound on Putnam through that intersection. We carried this study out during rush hour (5-6 p.m.) before and after the change was made. With both this study and the TMC's we felt that cut-through traffic on Putnam Avenue could be evaluated.

3.2.6 Making a Street Inventory

When any street is analyzed, it's important to have data about the dimensions of, and rules on, that street. Parking regulations, lane widths, and sidewalk data are all important factors to understand when studying traffic. Parking can affect driver perceptions and alter their speeds, as can lane widths. Small sidewalks may force pedestrians to cut onto the road, which can alter traffic as well. Additionally, small lane widths can alter traffic flow when bikers are using the road if there is no bike lane present.

We measured the many zones under different parking regulations (residential only, loading zones, unregulated, etc.) in order to understand the street better. Loading zones can mean heavier truck traffic; bus stops affect traffic flow; and fire hydrants are possible points of traffic holdup from emergency vehicles. Sidewalk widths were taken, as were "effective widths," the minimum width a sidewalk on a certain block sees if there is a tree, telephone pole or sign blocking part of it. Lane widths were measured, and a standard 8 feet allotted to on-street parking to determine "effective lane width" for eastbound traffic.

Using this data, we can look at how certain street attributes affect traffic volume, vehicle speed averages and distributions (to be mentioned later), and safety aspects.

3.3 Data Analysis

The final step to determine the effectiveness of the signal change was analyzing the data in a meaningful way. Data collected in the initial and experimental phases were analyzed and then compared against each other. Statistical tests were performed to determine if there was a significant difference in traffic studies. Using appropriate tests and interpretations of the data collected gave support to conclusions that were drawn. In addition to comparison of individual tests, a Congestion Index was created. The index helped to give a broad idea of the impact of the traffic signal change by combining different variables and displaying them graphically. It was important to have an effective and significantly meaningful method of analyzing the data collected in our project. Having set methods gives more power to our conclusions and recommendations for Putnam Avenue.

3.3.1 Statistical Comparison

The method of comparing the initial and experimental phases of the project made use of a statistical test. The statistical test that was performed is one that gave meaning to the differences seen from the different phases. The tests performed by the group were an Analysis of Variance Test (ANOVA) and Post-Hoc test where applicable. The Post-Hoc tests performed to determine difference between different times of data was a Tukey HSD test. A 95% confidence interval was used throughout each test. The project team made use of the statistical analysis program SPSS by SPSS, Inc. to determine the values seen in the results.

3.3.2 K- Factor and D- Factor

The K - factor is an established method of determining what percentage of traffic seen at a particular peak hour is a part of the average daily travel (volume) (ADT). This value is used by the CTPTD a lot in understanding what times the most traffic is seen and where to focus efforts in adjusting flow by various methods. The project team has computed K-values for both the AM and PM Peak times. The equation used is:

$$\frac{\text{AM or PM Peak Average}}{\text{Average Daily Travel (ADT)}} = \text{K - Value}$$

The K – Value is then computed into a percentage. These percentages are used to compare the use of a particular roadway at a given time and location. Ranges for K – Factors on street like Putnam in an urban setting are between 7% and 12% (Traffic Engineering, 50). The higher values closer to 12% are very good indicators of "cut-through" use on the roadway. Values that are closer to 7% indicate more of an acceptable use for the roadway, less cut-through travel (Parenti, 2004). Comparison of the K – Factor provides the group with two key pieces of information: a value that can be historically compared and a value that can help support other studies in trying to determine cut-through travel.

The D – factor is very similar to the K – factor. The difference between the two is that the D – factor is calculated by taking into account the direction that traffic is moving during a peak time period. In the case of Putnam Avenue, the two peak times AM and PM correspond to a specific direction to which the majority of traffic is going. During the AM peak most cars are traveling in the southbound direction. The PM peak is the inverse of what the AM is, the moajority of cars traveling in the northbound direction. The D – factor is caculated into a percentage from the D- value. The D – Value is calculated from the following equation:

$$\frac{\text{AM or PM Peak Direction Average}}{\text{Average Peak Travel (APT)}} = \text{D - Value}$$

The peak direction average is the average of cars traveling in the most used direction for either the AM or PM peak times. The average peak travel (APT) is the total amount of travel seen during the peak time period being measured. Example, if the AM peak D-value is being calculated for Putnam Avenue then the numerator would equal the average number of cars traveling in the southbound direction for 8:00am – 9:00am. The denominator would equal the both the northbound and southbound travel for that peak period (8:00am – 9:00am in this example). D – factors that are typically seen for streets like Putnam Avenue should be in the 55%-60% range. Values significantly over this give meaning that there is misuse of the road during these times (Parenti, 2004). Combining calculations of D and K factors to our analysis will give a good comparison tool to determining when cut-through travel is most severe and the impact the signal change had on it.

4. Results and Data Analysis

There were 5 main traffic studies performed before and after the traffic signal timings were changed. Each study provided crucial information that our group needed to assess the conditions on Putnam Avenue. This section will present and analyze each studies data and also compare the baseline to experimental phases of the project. Each section will present information related to the locations and the results of each of the studies performed. We will start with the Automatic Traffic Recorders and Turning Movement Counts, and then finish up with the Origin-Destinations, Travel Times and Speed Study. The analysis is conducted by comparing baseline and experimental data using graphs and statistics.

4.1 Automatic Traffic Recorders (ATR's)

The ATR data that the machines collected unfortunately was not all valid. There was no data from the southbound west of Magazine ATR before the traffic signal change, and also the King School and River/Western southbound machines after the implementation. Therefore the only legitimate data that was collected both before and after the experiment were all three northbound locations. This was the direction that the shifted the focus from the beginning due to the large number of vehicles utilizing it during the PM rush hour.

4.1.1 Volume

Since the signal synchronization favored southbound travel, our team expected the volume of the northbound experimental data to decrease compared to that of our baseline. However, after analyzing the data collected from all three northbound ATR's, it is clearly evident that this did not occur. The volumes after the signal change were lower during the AM peak, yet higher during the PM peak(Figures 12-14). These slight differences in volume can not be attributed to the traffic light change because they were so insignificant. This could be the beginning of a major traffic pattern change if observed over the next six months. Due to the limited amount of data both before and after the implementation, there can not be any valid conclusions drawn pointing to a change.

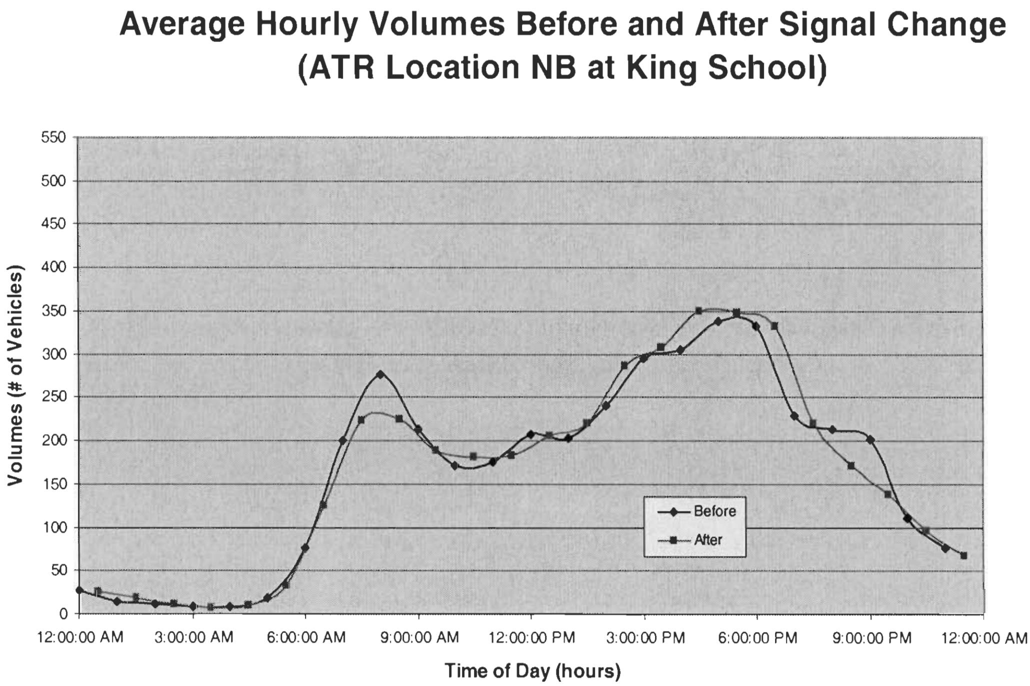


Figure 12: Average Hourly Volumes before and after signal timing change northbound at the King School on Putnam Avenue.

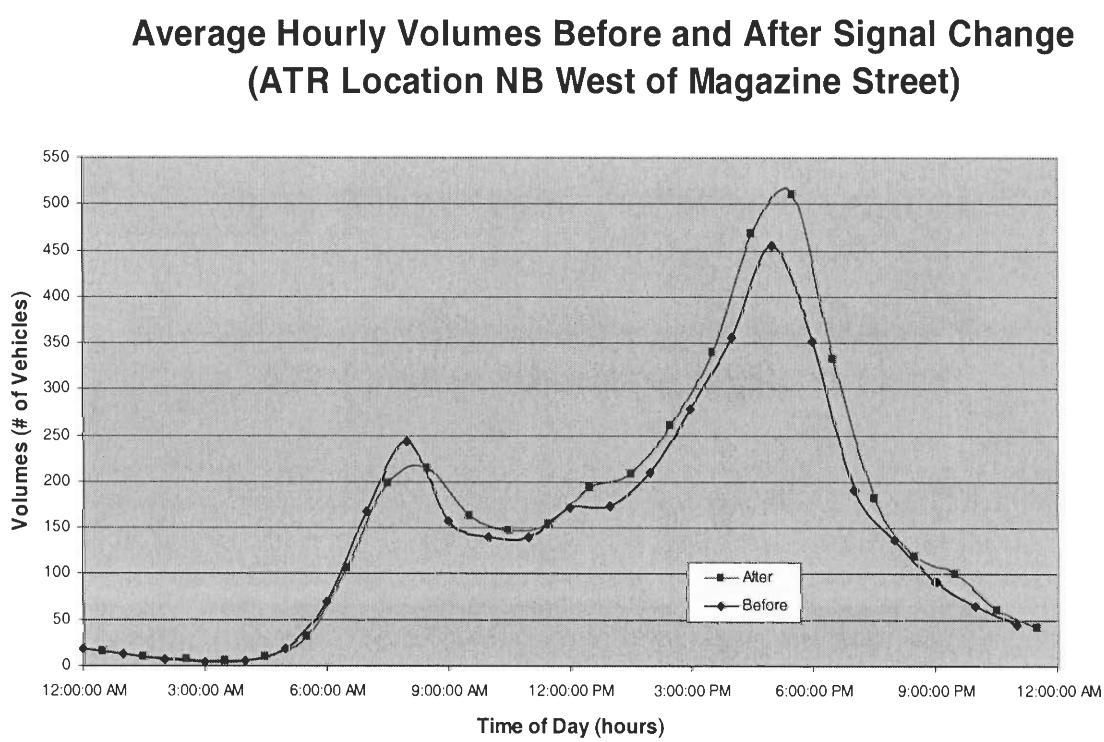


Figure 13: Average Hourly Volumes before and after signal timing change northbound west of Magazine Street along Putnam Avenue.

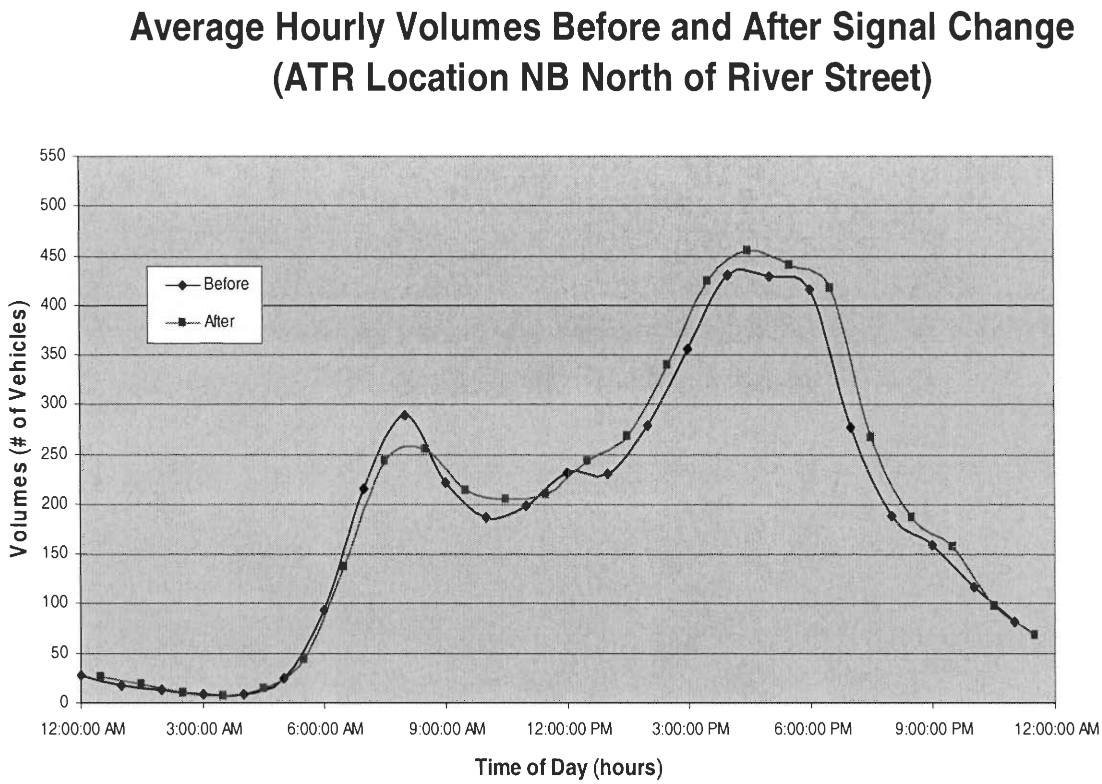


Figure 14: Average Hourly Volumes before and after signal timing change northbound north of River Street along Putnam Avenue.

4.1.2 Speed

The speeds recorded by the ATR's did not change significantly enough to say that the traffic signal change affected them. At the King School location northbound, both before and after showed average speeds between the low to mid 20's mph. The west of Magazine spot had averages in the mid 20's for the majority of the day. Lastly, in between River St. and Western Ave. speeds ranged from the mid to high 20's both pre and post experiment. The speeds varied at the three locations most likely because of the difference in road width. The King School and west of Magazine sites have a relatively close width, differing less than half a foot. However, the speeds were lower on average at the King School because of the fact that school was still in session. During the day the speed limit drops to 20 mph in that zone, slowing cars down as they pass over the ATR. Although there was no major change in the data, the hourly speeds were directly proportional to the volumes at those hours, i.e., the more volume the lower the speed on average. Our team feels that if data was collected for a longer period of time before and after the implementation, there may have been significant changes to conclude otherwise.

4.1.3 GIS Representation

A new GIS layer was created to represent our ATR data, in the hopes that more data could be added to it for other streets in Cambridge with the completion of further studies. For each ATR location, two arrows were inserted next to Putnam Avenue, one for each direction of travel. Data fields were created for each of these arrows to more succinctly represent the multitude of ATR data we received. Daily vehicle totals for each of the days in the “before” and “after” phases of our data collection were entered, along with daily speed averages.

In order to easily represent this data graphically, two sets of bar graphs were made. First, days of the week in the baseline and experimental phases were put side by side to compare Monday traffic volume before the signal change to Monday traffic volume afterwards, and so forth for each matching day. The same was then done for average speeds for each day of the week. Unfortunately, some ATR data was corrupted or was not retrieved, so not all data has a corresponding phase. This is evident in our GIS graphs.

A problem with this method was that our baseline and experimental data collection phases did not start and stop on the same day of the week. Therefore, while one phase may have a full day’s worth of volume data, the other may only have roughly half of a day’s worth of data. This was not a problem for our speed data, as we could just as easily average half a day’s data as a whole day’s. This volume data mismatch is noted with the 6 ATR GIS graphs shown in Appendix H: ATR Data GIS Representations.

4.1.4 Historical Comparison

Previous ATR studies have been performed on Putnam Avenue, specifically west of the Magazine Street intersection in 1997, 1999 and now in 2004. This data shows very interesting patterns over the last few years. From 1997 to 1999, the Average Daily Travel Volume decreased by almost 3000 vehicles, and stayed that way in 2004. Both the AM and PM K-factors rose by over 3 percentage points in the first two studies. After checking the ATR data after our study, we found that since 1999 the AM percentage dropped 1.5 points to 6.9%, and the PM only 0.6 points to 11.3%. These percentages are high for a collector street such as Putnam Avenue. This suggests that after 1997 there was an increase in commuters using Putnam Avenue as another route to get to and from work. Although the great differences in the 1997 data, it cannot be used validly because it was only one day's worth of data, and there could have been construction or another intervening variable affecting the numbers.

The D-factors for the west of Magazine Street had similar patterns to those that the K-factors showed. An average D-factor for a collector street is between 50%-60%, a low to high percentage respectively. The AM peak had slightly more southbound travel, and from '99 to '04 the percentage barely dropped to 52.8%, which is very healthy for such a street. However, between these two years, the PM D-factor decreased by over 3%, but is still extremely high for northbound travel at 68.6%. This means that during the 5-6 PM rush hour, 68.6% of traffic is traveling northbound. Although these percentages showed decline, both PM factors need to be addressed more seriously in the future in order to be reduced even more.

4.2 Turning Movement Counts (TMC's)

The Turning Movement Counts (TMC's) were only done during one day (a Thursday) before and after the traffic signal coordination. This could factor into our results in that the data could be random for one or both of the days that we recorded on. The time that was allotted to complete the project in greatly inhibited our team's ability to collect more than one day worth of data for this study.

4.2.1 Volume

The volumes recorded during these manual counts both increased and decreased randomly at all three locations on Putnam Avenue. There was no evident traffic pattern from our data collected during this study, but we did see slight changes between pre and post experimental data. There was a substantial decrease during the AM peak of vehicles continuing on Putnam through the River Street intersection, but almost no change at noon or the PM peak. At the Western Avenue and Putnam Street intersection, the before and after data remained almost identical. Finally, at the last place we counted, Magazine

Street, we found several fluctuations in volume depending on which turn was being made. Although there were changes between the pre to post experimental data, none were consistent enough to draw conclusions from. The results of the TMC counts before and after can be seen in Appendix I: Turn Movement Count Results.

4.2.2 Destinations

Besides for the slight decreases in AM travel at the River Street intersection, there were no major variations between the pre and post experimental data collected. At the magazine street TMC there were small increases during the PM peak showing similarities to that of Origin-Destination Study. In other words, it seems that travel increased during the afternoon peak, and decreased during the morning peak. This proves that in a week's worth of data there can not be a significant change seen, however, if it were to be analyzed for a few months, patterns could possibly form.

4.2.3 GIS Representation

Another GIS layer was created, and arrows were drawn in to clearly represent each turning movement for each of the three intersections. Each was labeled with a movement code, which notes where a car starts, where they make their turn (Western Ave., River St., or Magazine St.), and where they are going, via the intersection codes of those three locations. Six data fields were created for each arrow to store the total number of cars that made each movement during our 8:00-9:00am, 12:00-1:00pm, or 4:00-5:00pm data collection period, and during the baseline or experimental data collection phase. The totals were then paired as baseline and experimental data for each of the three time periods. To keep the graph simplified, only the turning movements with a significant (at least 20%) change in baseline and experimental data were graphed. These three graphs are shown in Appendix K: TMC GIS Representations.

4.3 Origin-Destination Study

The Origin-Destination Study (OD) was organized so that our team could analyze the different paths vehicles took when traveling on Putnam Avenue. There were three locations established, Magazine, Western and Mt. Auburn, as described previously. In the following section we will compare both the results, both before and after, to see what (if any) changes occurred.

4.3.1 Location

During rush hour traffic, between 4:30 and 6:30, Putnam Avenue sees most of its travel. Commuters use this collector to quickly access Western Avenue, and in turn exit the city. The focus was on northbound travel due to previous studies showing a heavier load during the PM rush hour. We were able to analyze the amount of cars coming from the Magazine intersection, turning onto Western, or continuing on Putnam until the end of the street at Mt. Auburn.

After comparing both sets of data, it is evident that the signal timing change did not affect vehicle travel patterns. Slight increases appeared in the percentage of cars continuing westbound on Putnam through the Magazine intersection to both Western and Mt. Auburn. The differences were so small that it could easily be normal day to day fluctuations. The amount of vehicles coming from Mt. Auburn and turning onto Western before the change was almost identical to after. These results were expected because the signals were changed from Magazine eastward, and this study was set west of this intersection.

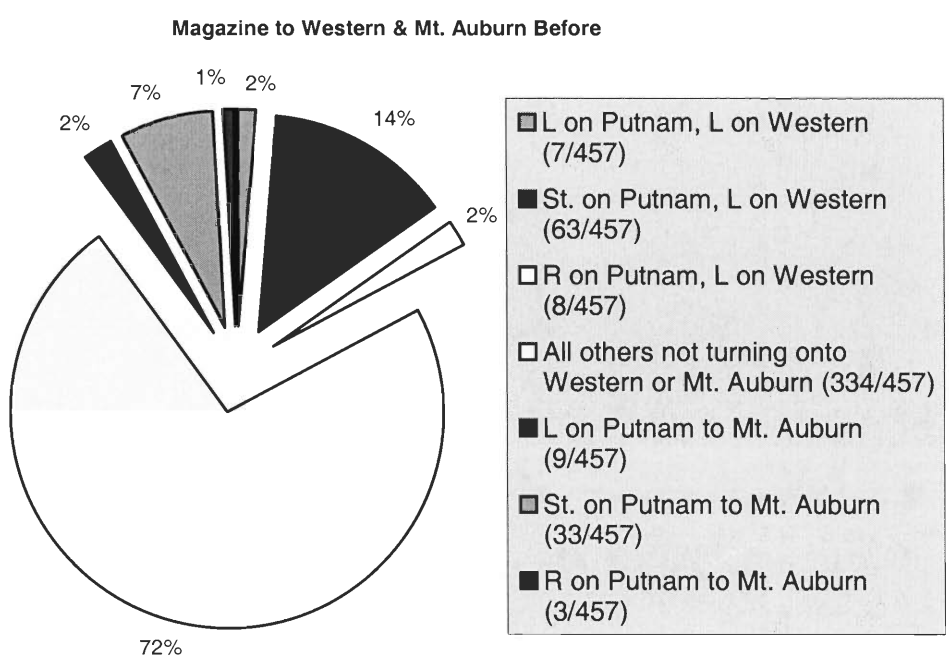


Figure 15: Pie Chart of Origin – Destination Percentages for Putnam Avenue before signal timing change.

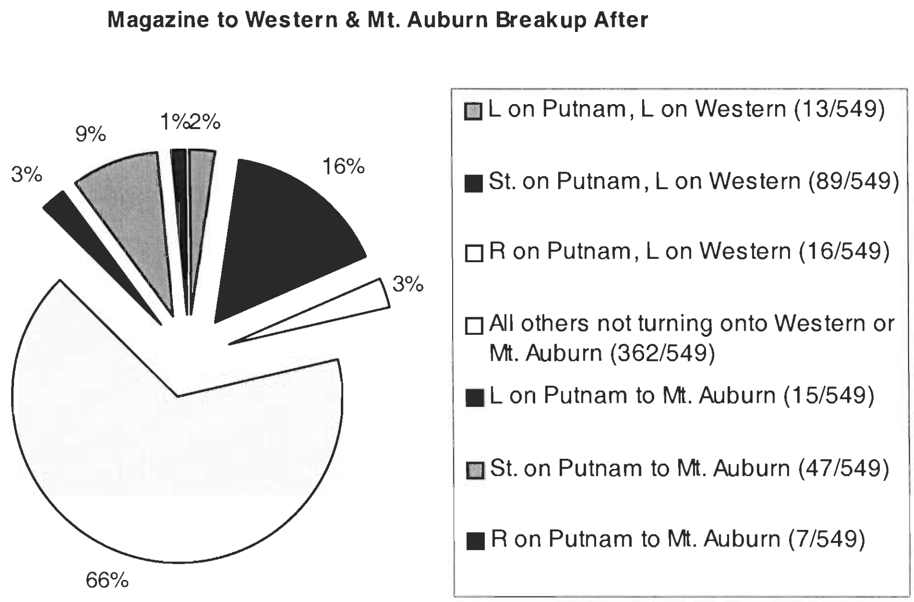


Figure 16: Pie Chart of Origin – Destination Percentages for Putnam Avenue after signal timing change.

4.3.2 GIS Representation

A new layer was created, on which we drew an arrow to represent the three basic movements, temporarily discounting the three ways a car could come from the Magazine St. intersection. Three fields were set up to now include the three movements of cars coming from Magazine, which used a 4-number movement code, much like the 3-number movement code of the TMCs. For the "Mt. Auburn to Western Ave." movement, the two unneeded fields were left blank.

Under each of these movement codes was listed the percentage of cars going through the area that traveled that movement path for both the baseline and experimental phases. The average travel time of each movement was also included for both phases, so we could see a relation, if any, between travel time and percentage of cut-through for our 3 segments or Putnam Avenue.

Two graphs were then made, pairing baseline and experimental data as in the previous two GIS representations: One to show percentage of cars traveling a path, and another to show the travel times of each path. These can be seen in Appendix K: TMC GIS Representations.

4.4 Travel Time Study

The main periods of time that were focused on during the travel time study were the AM and PM rush hours. During these times Putnam Avenue experiences the most traffic all day long. Since the signals were collaborated for southbound travel, the northbound side should see more red lights in succession. Increasing the travel time might get commuters off Putnam and on an alternate route to shorten their trip.

4.4.1 Peaks

After viewing both the before and after data collected through the Travel Time Study, our team has gathered sensible information. Both the AM and PM post experimental times for northbound increased after the signal change. Along with this, the southbound post experimental times decreased, likely due to the synchronization of lights in this direction. Appendix F: Travel Time Graphs shows all of the travel time graphs that were generated from the results, including the southbound direction.

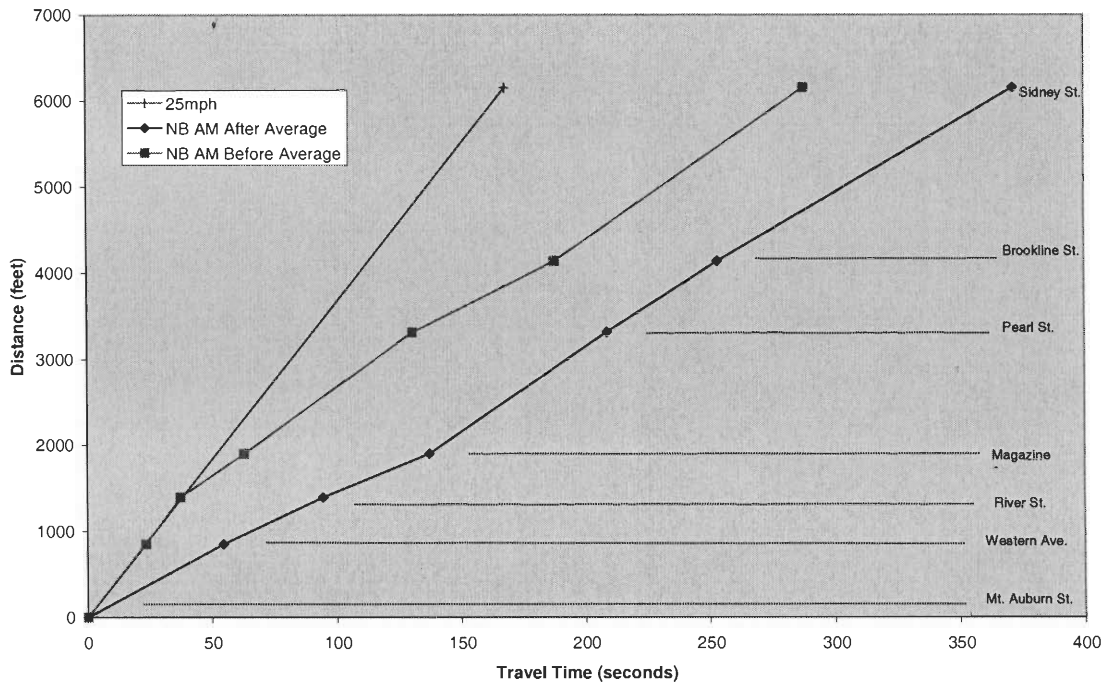


Figure 17: Chart of Travel Time Averages on Putnam Avenue during AM Peak traveling Northbound

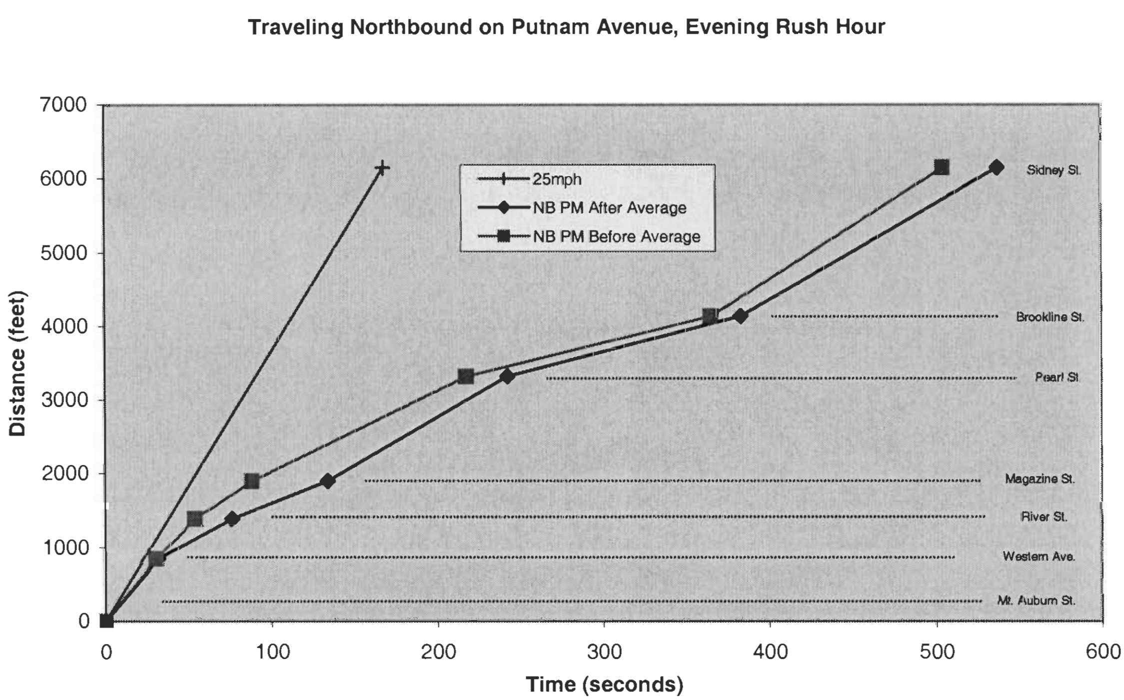


Figure 18: Chart of Travel Time Averages on Putnam Avenue during PM Peak traveling Northbound.

4.4.2 Statistical Comparisons

The travel times can be compared using an ANOVA test. The comparison of each of the peak time periods (AM and PM) before and after the signal change give insight to the overall effect the change had. The result printouts from the SPSS program are shown in Appendix X. The comparisons overall do not show any large significant difference when comparing the direction and time total travel time. The calculation however for the northbound PM peak total travel time before and after is close to having a significant difference. We hav concluded that this could be a result that is hint a soon to come significant change in the traffic for the northbound direction during the peak time period or just a variation between weeks. Only time will tell which way the results will go and if the signal timing change had a significant impact. Furthermore when comparing the differences between the signal timing changed intersections before and after it is very easy to see a substantial change. This is expected since the signals are coordinated and timed to unfavorable progression through them. Table 2 below shows the total travel time averages from River St. to Sidney St. This section of Putnam Avenue would be the most impacted by the signal change.

Total Travel Time → Time of Day ↓	Before (seconds)	After (seconds)	Difference (seconds)
AM Peak	254.50	495.17	**240.67**
Midday	260.25	413.00	**152.75**
PM Peak	391.83	484.83	**93.00**
AVERAGES	302.19	464.33	**162.14**

Table 2: Table of Total Travel Times from River Street to Sidney going Northbound Before and After the signal timing change.

As seen above, the travel times before and after between River Street and Sidney Street increase on average overall about 2 and half minutes. There are significant changes for each time period of the day, each with at least 1 minute and a half differences. The results here show that the signal change was successful in making it take longer to travel through these four intersections. With this increase travel time at this end of the street we hope that it will further discourage drivers from using Putnam Avenue as a cut-through route.

4.4.3 GIS Representation

A new layer was created, and an arrow was drawn for each segment of the street between traffic signals for each direction of travel. Each arrow was then given data for the average time it took to travel that path in the morning and evening rush hour time periods, for both baseline and experimental phases. These 4 data were then graphed for each segment in the same fashion as our other layers. To see more detail, the street was split up into two sections, so two graphs are seen in Appendix L: Travel Time GIS Representations.

4.5 Speed Study

The Speed Study was conducted at the same places our ATR data came from, in order to see the actual speed break-up of individual cars, not just an hourly average. The speed limit on Putnam Avenue, although not posted, is 30 mph. The team was hoping to see sort of a bell shaped curve when plotting speed vs. frequency, where most vehicles were traveling within a 20-30 mph range. Our results proved this point exactly.

At the King School location before the change was implemented, the main peak of speeds that vehicles were traveling at was between 23-27 mph. However, after the change was made, this peak slowed drastically to between 18-22 mph. Similar patterns were seen at the Magazine location, where the peak went from 20-24 mph down to 19-22 mph. Although this decrease in speed was not as deliberate as seen at the King School, it was still worth noting. Finally, between Western Avenue and River Street something different happened. The small speed peak rose from 24-26 mph to 27-30 mph. A few vehicles traveled in the high 30's, with one car reaching 40 mph. These speeds were higher than the other two locations due to the lane width increasing by almost 3' in both directions. This shows that the signal timing difference had little or no effect on the cars traveling between Western and River.

5. Conclusion

The five studies that were conducted incorporated many aspects of traffic patterns that are evident in today's travel. The baseline that our team formed covered many areas that interested us, as well as the Cambridge Traffic, Parking and Transportation Department. Focusing on volume, speed, travel time and the directional pattern of vehicles allowed us to, with little human error, form conclusions based on our findings.

When addressing volume, both the ATR and TMC data come into play. After reviewing both sets of figures, the volume has slightly decreased in the AM peak, but increased during the PM peak. This is probably due to a randomness of traffic during the days studied. However, this small change could be the beginning of a larger trend that will occur if the site is continued to be studied for the next several months.

The two studies that incorporated speed in their collection were the ATR's as well as the speed study. It was very interesting to see the average speeds compared to that of individual vehicles traveling along the street. West of Magazine Street showed a great decrease in individual speeds by almost 5 mph, proving that the signals had an affect on vehicle speeds. This was only performed one time before, along with one time after the synchronization was in place, unlike the ATR's which counted for a whole week, showing that it could just be randomness of days.

During the travel times after, it was clearly evident that the traffic signal change had done what was expected. It slowed down the northbound time over the four streets that were changed, and sped up the southbound time incredibly. Although this was achieved as planned, it still did not discourage the inappropriate use of commuters using the road as a "cut-through." With a more drawn out study over several months, these changes might have been seen.

Lastly, the directional pattern of traffic was mapped using the Origin-Destination Study and Turning Movement Counts in GIS to see what routes vehicles were taking. After entering both the pre and post experimental data there was no overwhelming pattern evident. The slight increase in traffic on Putnam Avenue coming through the Magazine Street intersection was not prominent enough to draw strong conclusions from.

Although the studies did not prove that the signal change had a real effect on traffic, our goals for the project were met. We have a detailed understanding of traffic patterns on Putnam Avenue, unlike when we had first arrived in Cambridge. Also, a database was created along with GIS layers that can be expanded upon in the future with upcoming traffic studies done anywhere in the city. There is now a method of comparison established for traffic signal change experiments. Finally, the CTPTD now has solid data for three points on Putnam Avenue for comparison with future studies carried out on this street.

6. Recommendations

By completing this study on Putnam Avenue, our group has learned many things that could aid the CTPTD in future studies similar to this one. The first thing needed to be changed in our study was the overall length. If we had more time to gather an accurate baseline, and also more after the implementation, the results would be solid and conclusive. Also, if we had known going into the study that only 4 out of 7 lights would be synchronized, the focus would have shifted towards the southern end of Putnam, not the whole thing. Making a study more focused and lengthy for data collection purposes would be two main considerations for future studies.

Another recommendation would be for the CTPTD to continue using our established measurement and analysis process so that streets can be compared to one another. Along with this, would also be to create a congestion index which would account for all the aspects studied into one overall score or rating. By comparing streets with a number, it would help show the public which streets need improvement the most, because their rating would be the worst. If these recommendations are taken into consideration, our team feels that the Cambridge Traffic, Parking and Transportation Department would benefit greatly in the future.

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Appendix A: Sponsor Background

The purpose of the Cambridge Traffic, Parking, and Transportation Department (CTPTD) is to provide the city with services related to Public Safety. Historically in Massachusetts, most traffic departments never really existed as a separate entity. The departments usually would fall under the responsibility of the Department of Public works. It was not until the 1964 that the City of Cambridge separated the Traffic Department from the Public Works. The CTPTD was created and charged with the responsibility for making sure both motorized and non-motorized transportation along the city's streets is safe. The challenge the department has is to meet the transportation demand for the city's residents, businesses, and institutions (City of Cambridge, 227). The departmental goals are: Increase the public safety of the transportation facilities, support transportation needs for the City of Cambridge, enhance customer service orientation, and increase the efficiency of the department operations and procedures (About Traffic, 1).

The CTPTD is a public organization that falls under that category of Public Safety. A hierarchy of the city of Cambridge is shown in figure 1. The CTPTD is highlighted with a red box. The CTPTD is funded publicly and also privately. The budget for the CTPTD overall is about $7.6 million for Fiscal year 2004 (City of Cambridge, 227). The funding for the organization comes from various areas.

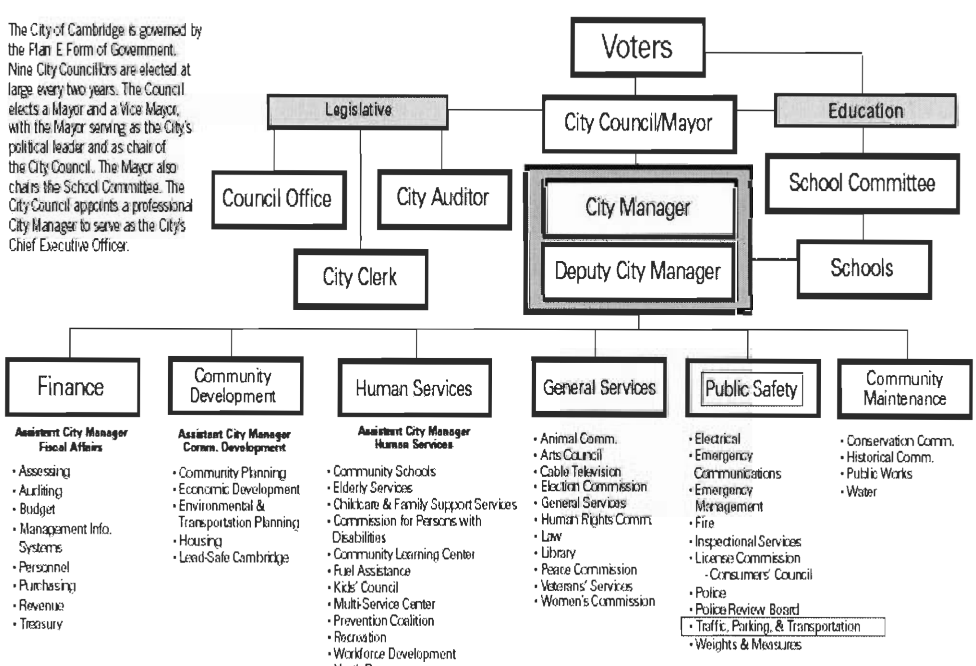


Figure 19: Organization Chart of the City of Cambridge (Living in Cambridge, 27)

Taxes are partially what fund the organization. Over half of the budget is financed by other means. Nearly $5 million comes from the following:

Source	Amount
Street Meters	$127,500
Fines	$4,789,190
Parking Usage	$2,658
Interest Earnings	$10,745
Private Donations	$50,000

Table 3: Financing Plan for the CTPTD, Fiscal Year 2004 (City of Cambridge, 228).

The budget for the department is split among its three divisions. To understand how each of the divisions uses its budget we first need to understand the organization of the CTPTD.

The CTPTD is split into three divisions, the divisions are: traffic control, parking control, and support services (City of Cambridge, 227). The purpose of the traffic control division is to install and maintain all of the traffic control devices. Furthermore the division coordinates with other city departments and agencies on development proposals (City of Cambridge, 230). The parking control division is responsible for the parking meters, parking garages and enforcement of parking regulations (City of Cambridge, 233). The support services division is responsible for the administration of the entire department. The division coordinates between the other two divisions as well as within each of the divisions (City of Cambridge, 236).

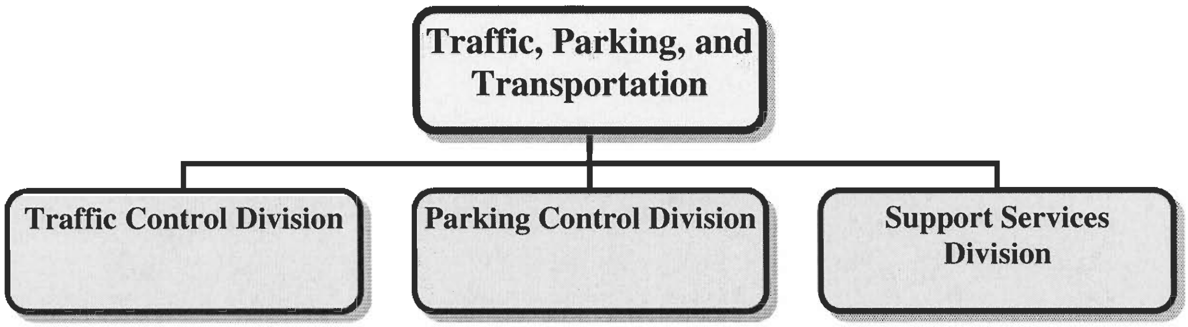


Figure 20: Organization of the CTPTD

The budgets of the divisions are split up among each division's purpose and responsibilities. The budget breakdown is shown in table 2.

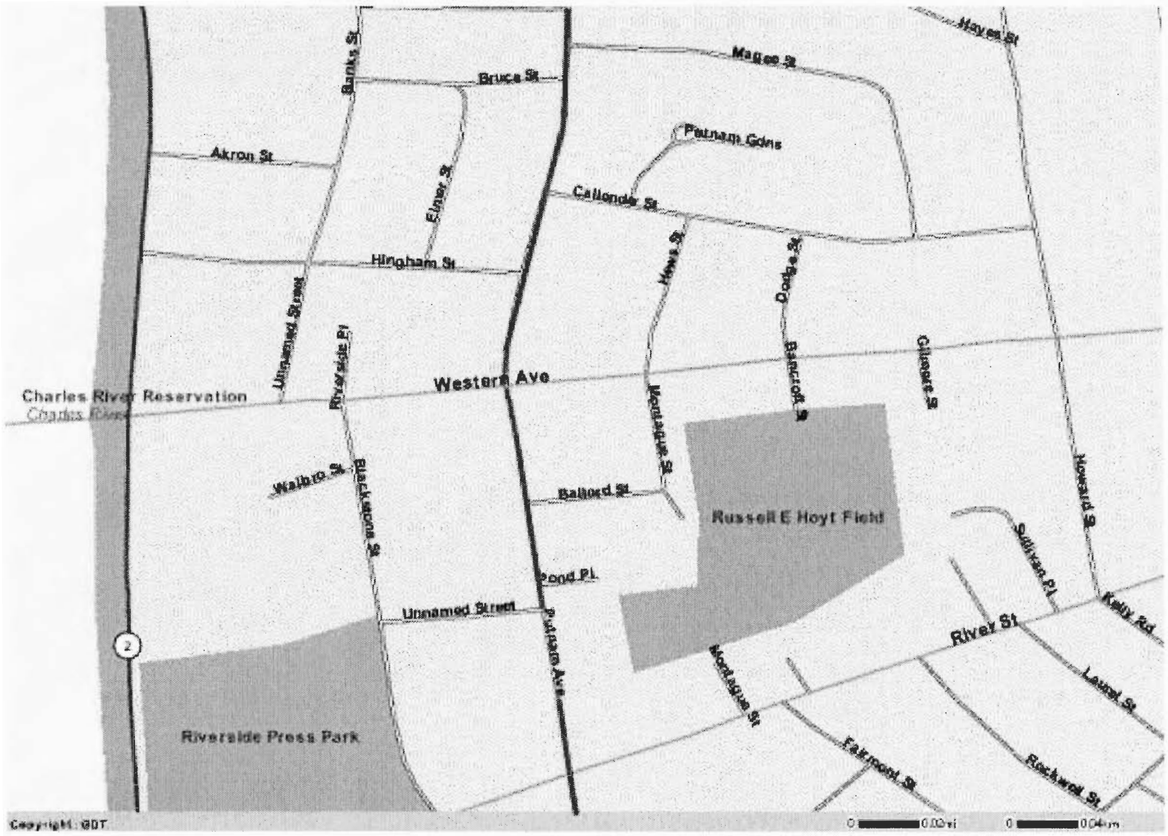
Division	Purpose	Amount
Traffic Control	Traffic Signal Maintenance	$426,385
	Traffic Engineering	$419,075
	Pavement Markings and Sign Posting	$682, 075
	TOTAL	**$1,527,525**
Parking Control	Parking Services	$1,925,340
	Parking Meter Maintenance	$585,930
	Off street Parking	$787,350
	Parking Enforcement	$2,156,595
	TOTAL	**$5,455,215**
Support Services	Administration	$653,605
	TOTAL	**$653,605**

Table 4: Budget Breakdown of the division of the CTPTD Fiscal Year 2004 (City of Cambridge, 230, 233, 236)

The CTPTD has wide-ranging responsibilities for transportation in the City of Cambridge: It must have focus on public safety and traffic efficiency in its decisions and actions. From traffic studies to parking issues the Cambridge Traffic Department goals are consistent to provide the city with safe and efficient travel for motorized and non-motorized methods of transportation.

Appendix B: Detailed Maps of Putnam Avenue

Putnam Avenue is highlighted in pink.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Riverside Pl
Bancroft St
Gilmore St
Charles River Reservation
Charles River
Western Ave
Montague St
Walbro St
Blackstone St
Balfour St
Russell E Hoyt Field
Howard St
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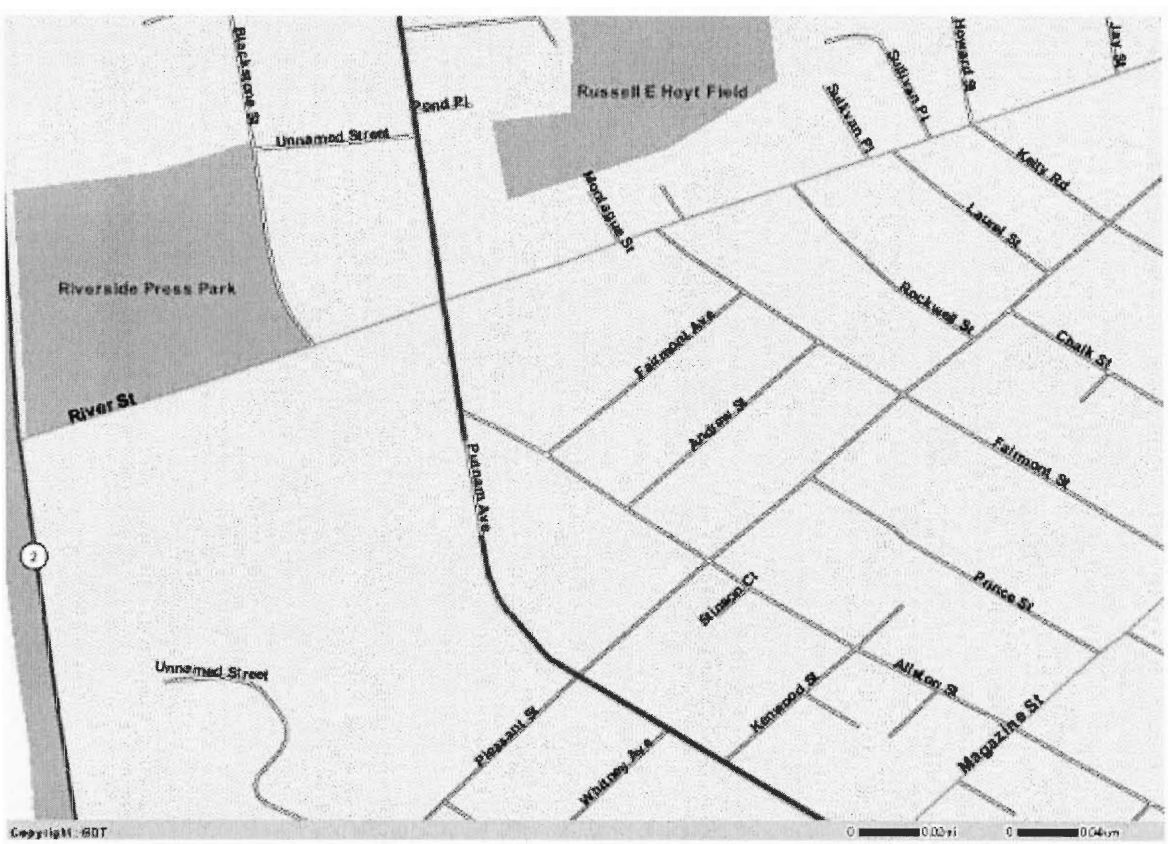
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Chalk St
Fairmont Ave
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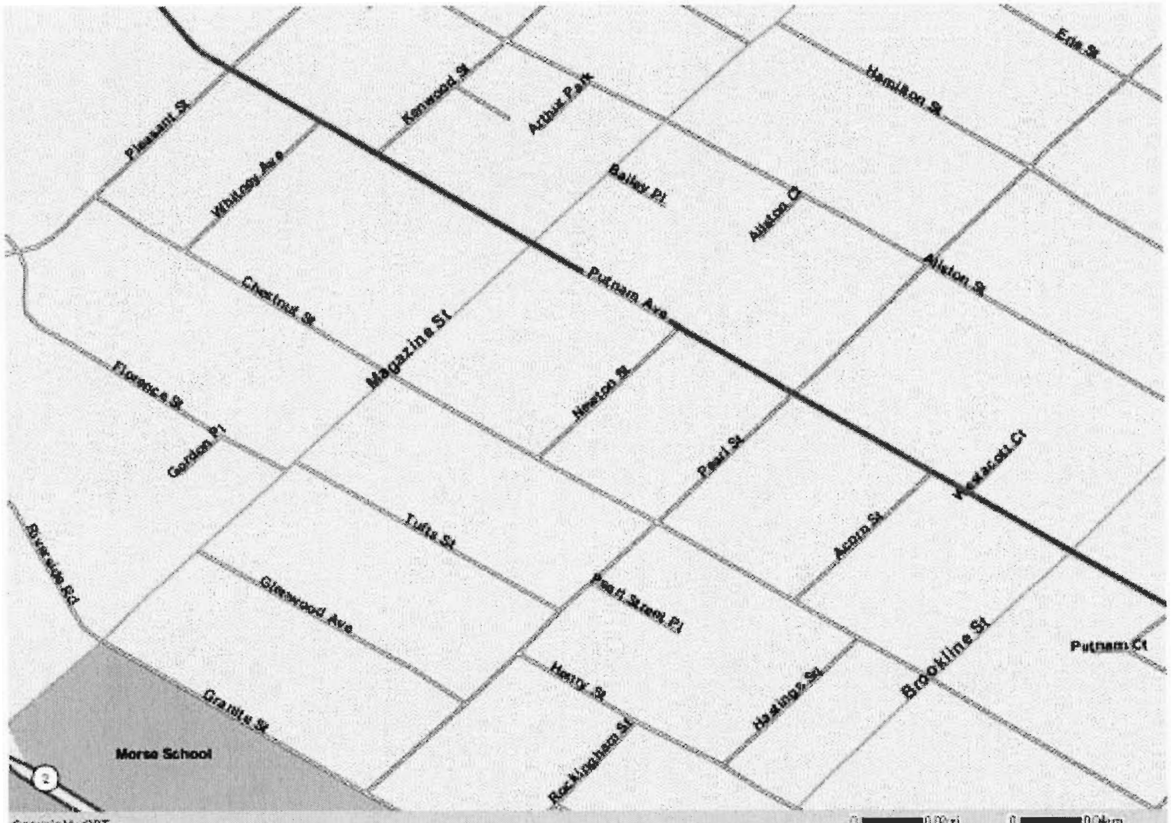
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Gordon Pl
Pearl St
Acorn St
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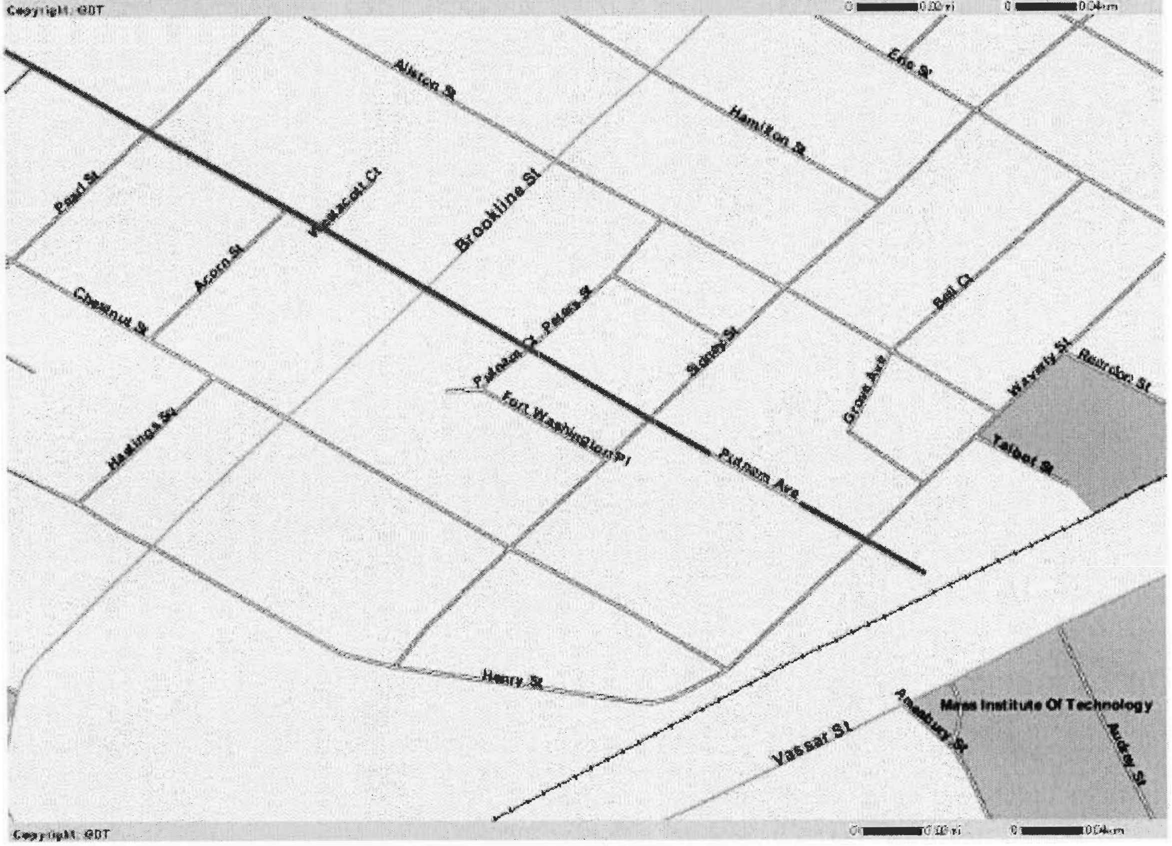
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Waverly St
Hastings St
Fort Washington Pl
Putnam Ave
Grove Ave
Talbot St
Henry St
Mass Institute Of Technology
Vassar St
Amesbury St
Audrey St
Copyright, GDT

Appendix C: Traffic Calming Selection Criteria

The following is the project selection criteria used by the City of Portland in choosing traffic calming along collector streets.

PROJECT SELECTION CRITERIA

Criteria	Points	Basis Point Assignment
Speed	0 to 30	Extent by which traffic speeds exceed 35 mph (2 points assigned for every 1 mph)
Volume	0 to 25	Average daily traffic volumes (1.667 points assigned for every 1,000 vehicles per day)
Residential Density	0 to 20	4 points assigned for every 100 dwelling units per mile
No Sidewalks	0 to 10	10 points assigned if there is not a continuous sidewalk on at least one side of the street
Elementary School Crossing	0 to 10	10 points assigned if marked school crossing exists.
Pedestrian Generators	0 to 5	5 points assigned if pedestrian generators (retail commercial uses, institutional uses, parks, or other schools occur along or within 1,000 feet of the street
Total Points Possible	**100**	

Speed is given the most importance, since high speed usually affects safety and livability the most. It is also the condition that can be most improved by traffic calming devices.

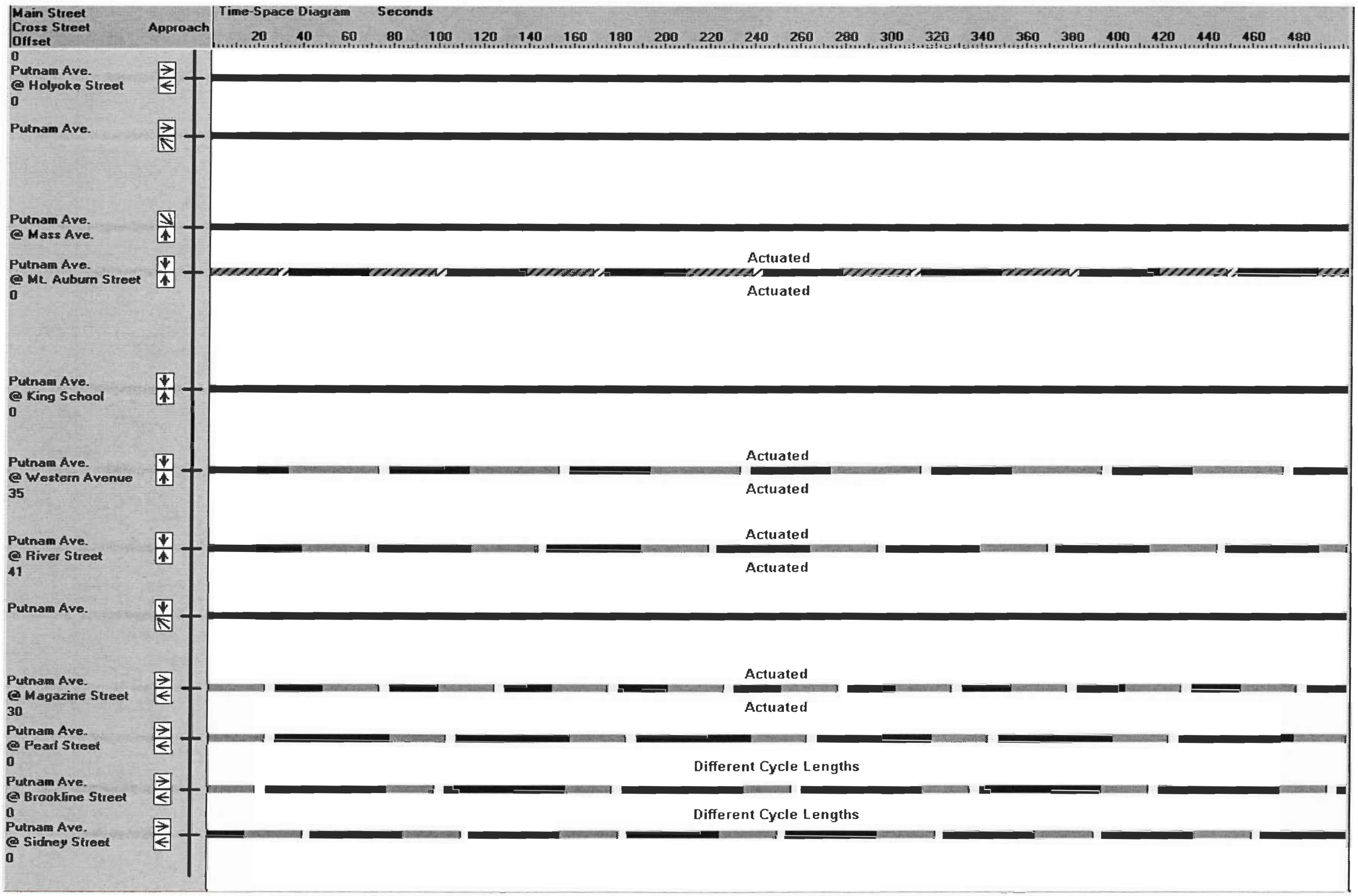
Volume is considered because it contributes to the general traffic conditions on the street. For example, conditions on a street with both high volumes and speeds will be worse than on a street with high speeds but lower volumes.

Residential density also affects general traffic conditions. For example, higher densities tend to generate more pedestrians and vehicle turn movements. In addition, projects on high-density streets benefit more people than projects on lower-density streets.

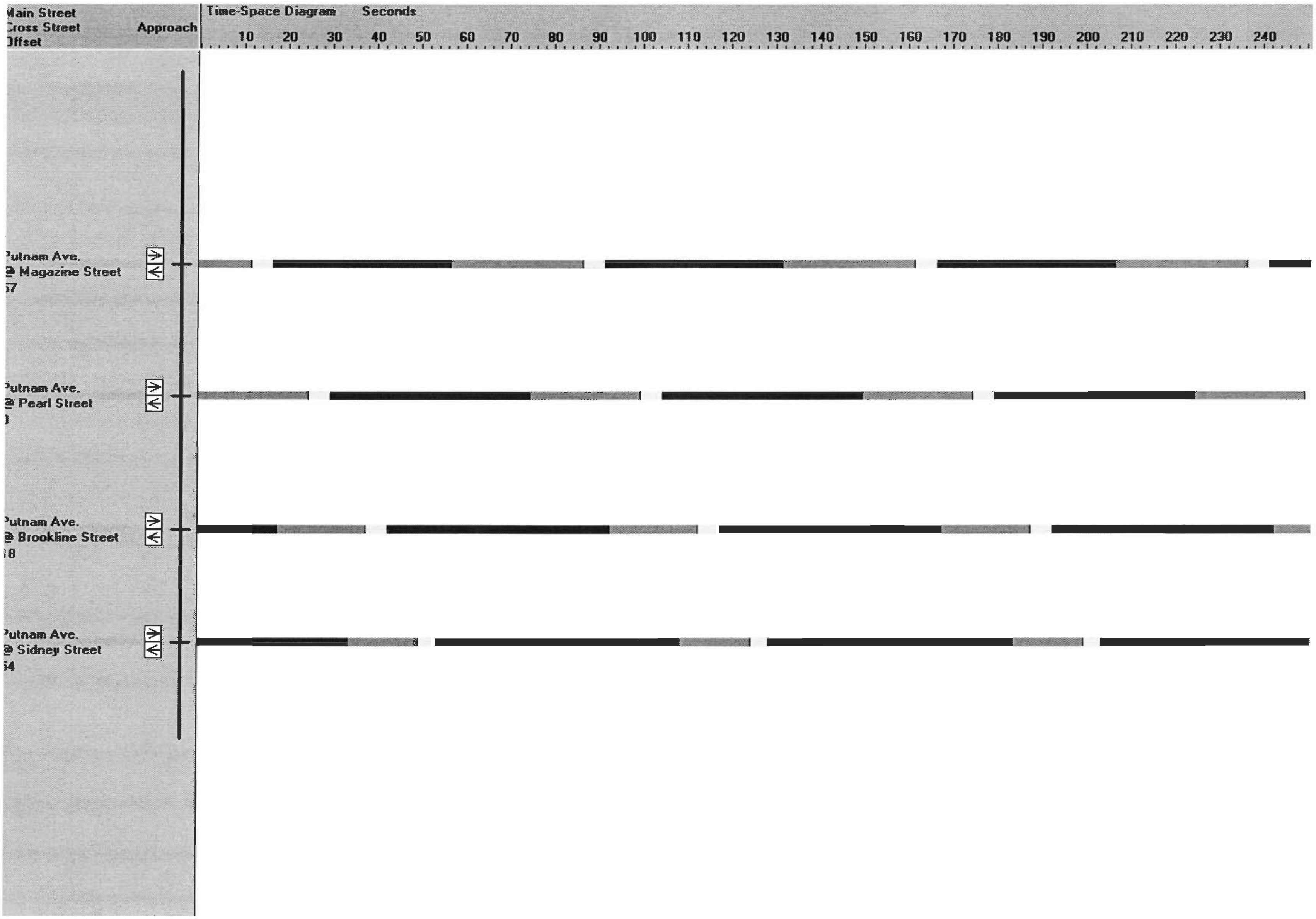
The other criteria - sidewalks, elementary school crossings, pedestrian generators - are important considerations because they relate to pedestrian safety.

Appendix D: Syncro Time – Space Diagrams of Signal Changes on Putnam Avenue

BEFORE

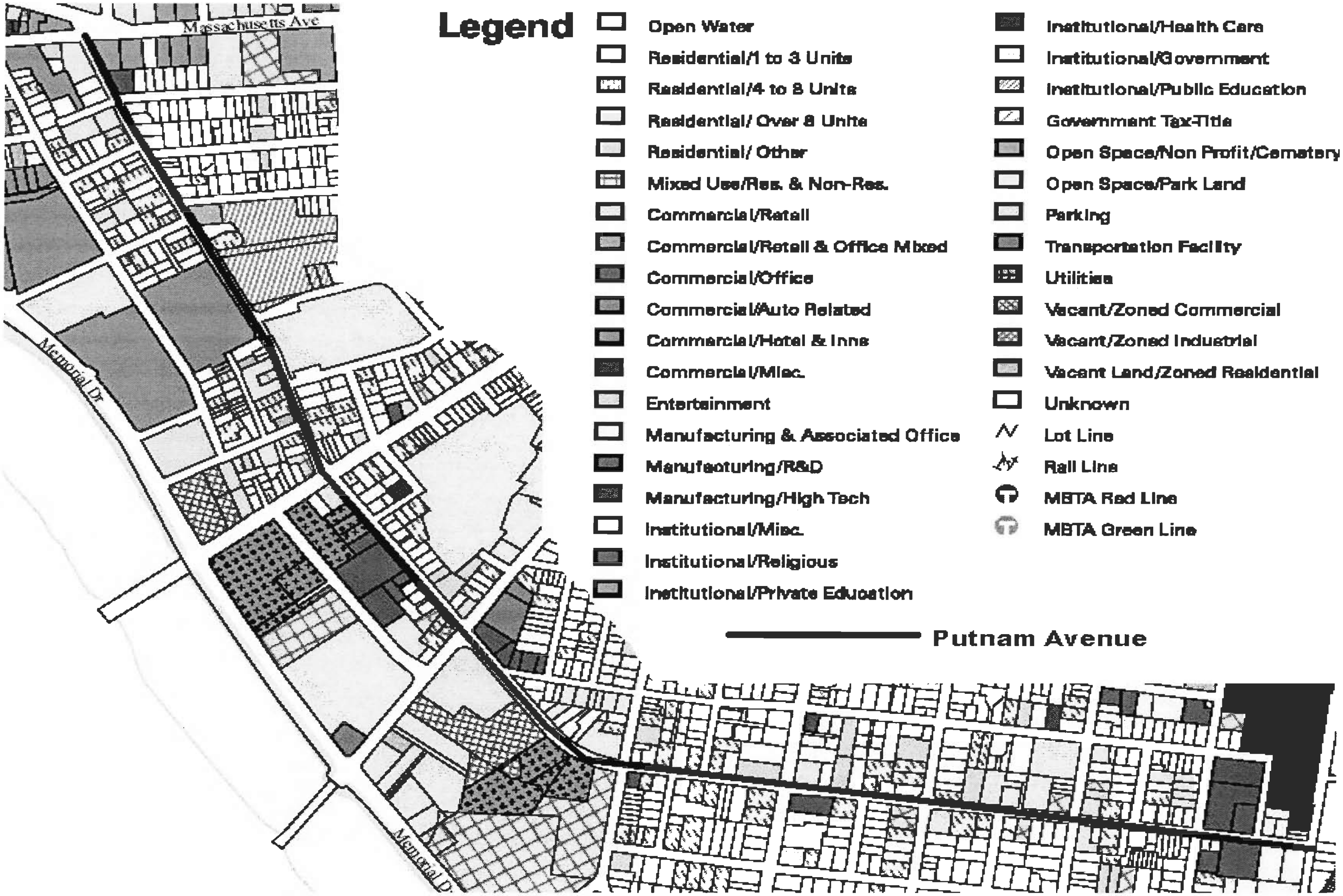


AFTER



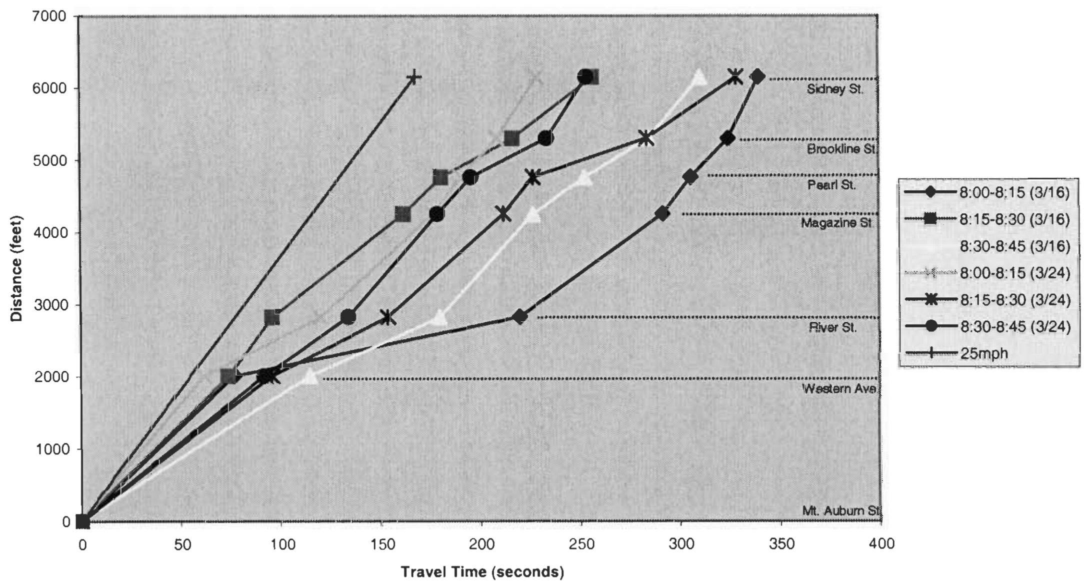
Main Street
Cross Street
Offset
Approach
Time-Space Diagram
Seconds
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240
Putnam Ave.
@ Magazine Street
Putnam Ave.
@ Pearl Street
Putnam Ave.
@ Brookline Street
18
Putnam Ave.
@ Sidney Street

Appendix E: Zoning Map of Putnam Avenue Area

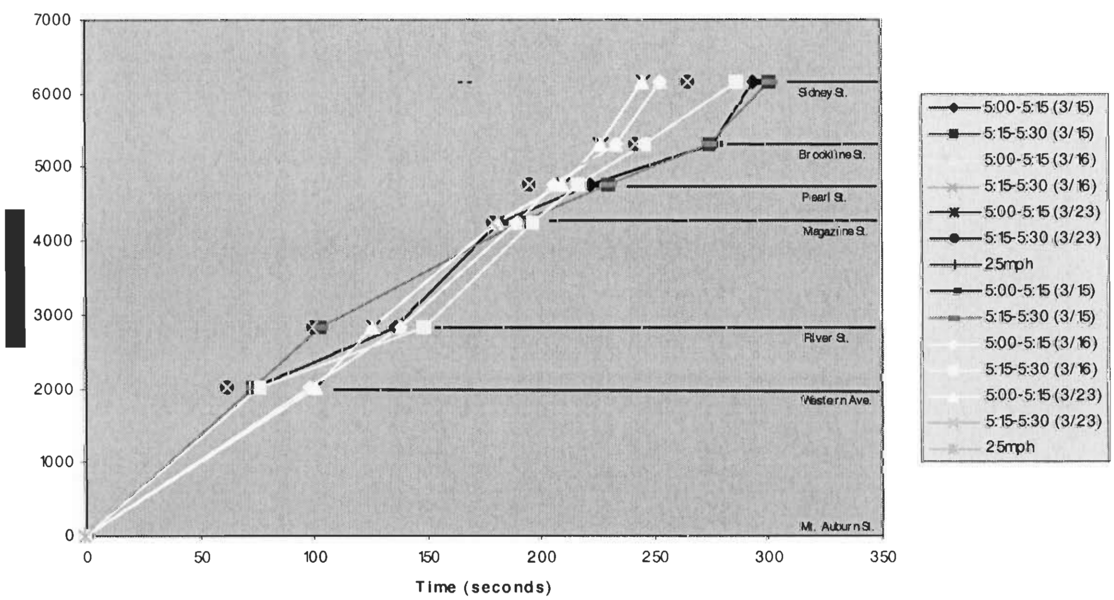


Appendix F: Travel Time Graphs

Traveling Southbound on Putnam Avenue, Morning Rush Hour



Traveling Southbound on Putnam Avenue, Evening Rush Hour



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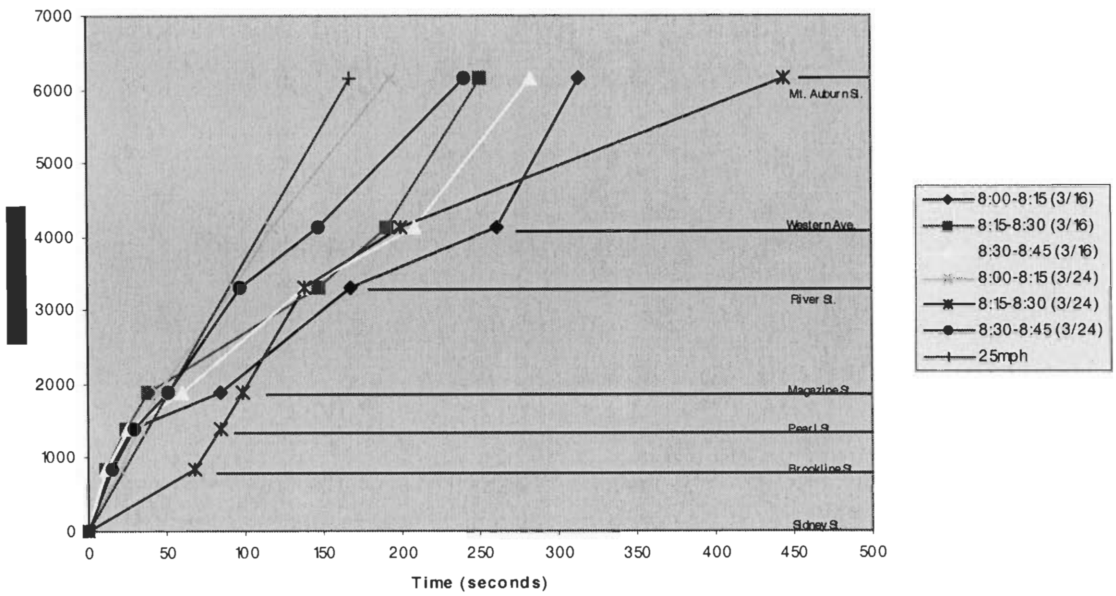
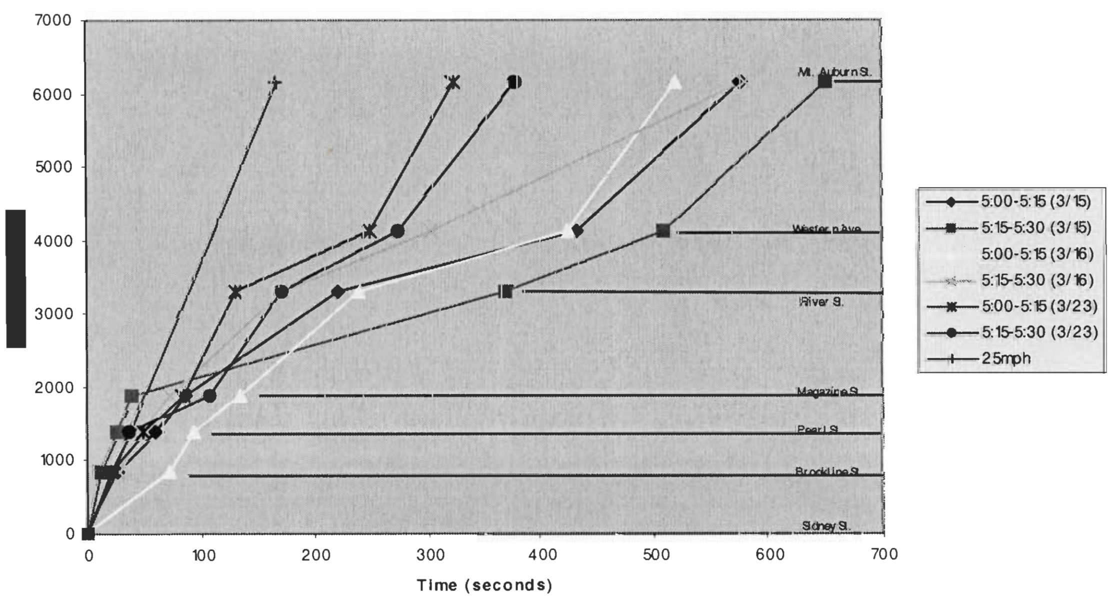
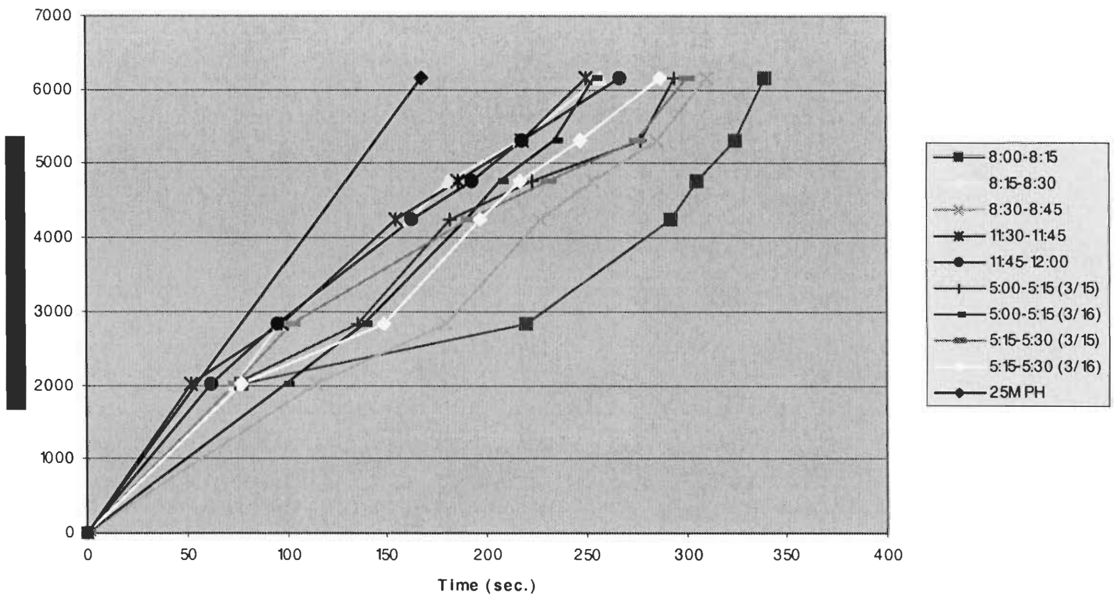


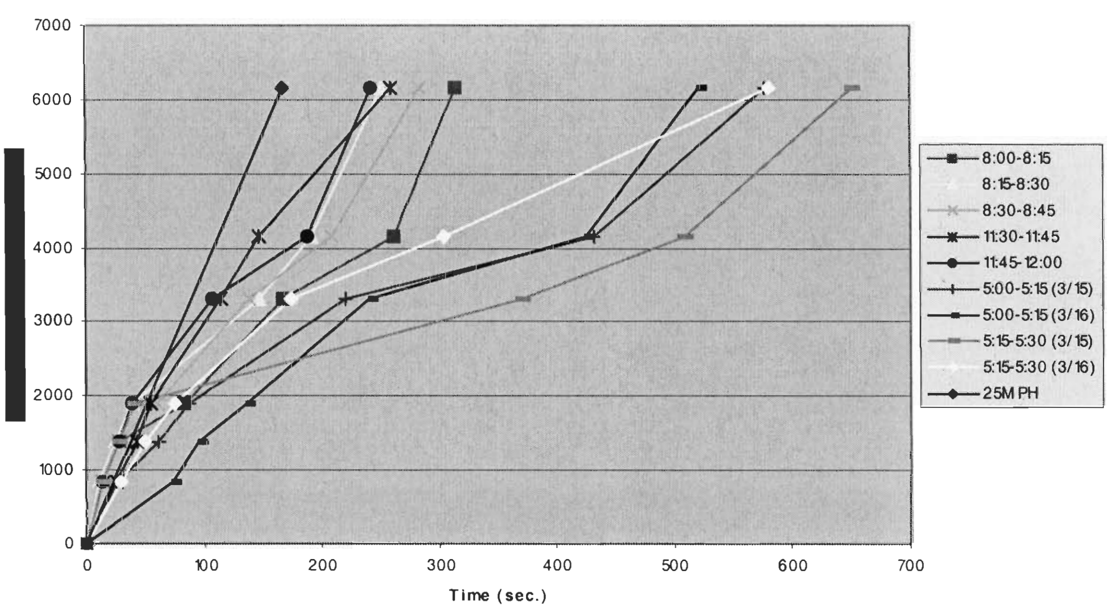
Traveling Northbound on Putnam Avenue, Evening Rush Hour



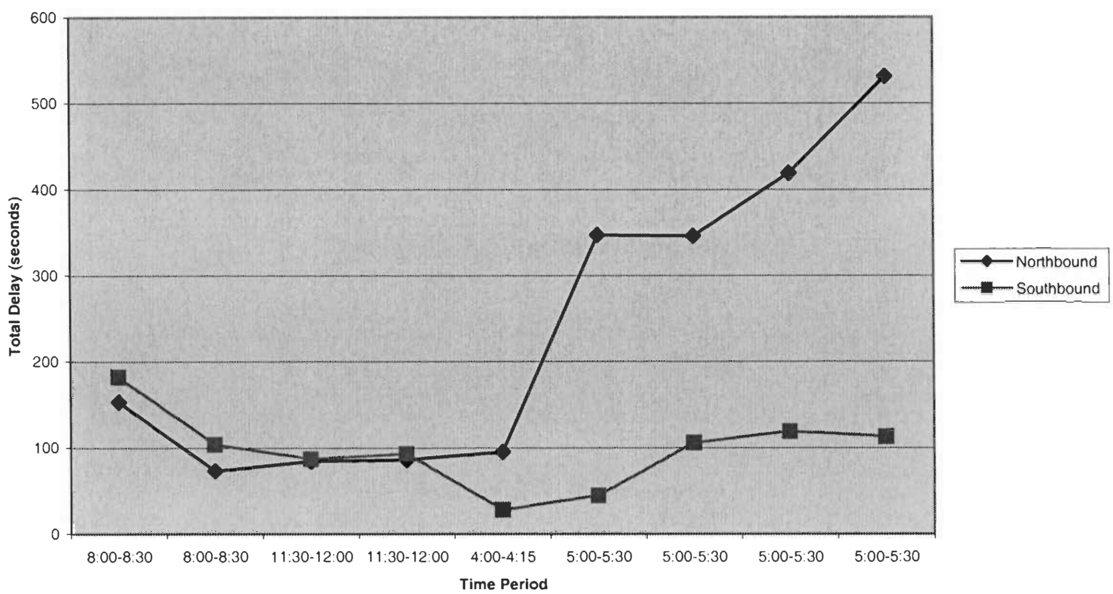
Southbound on Putnam Ave.



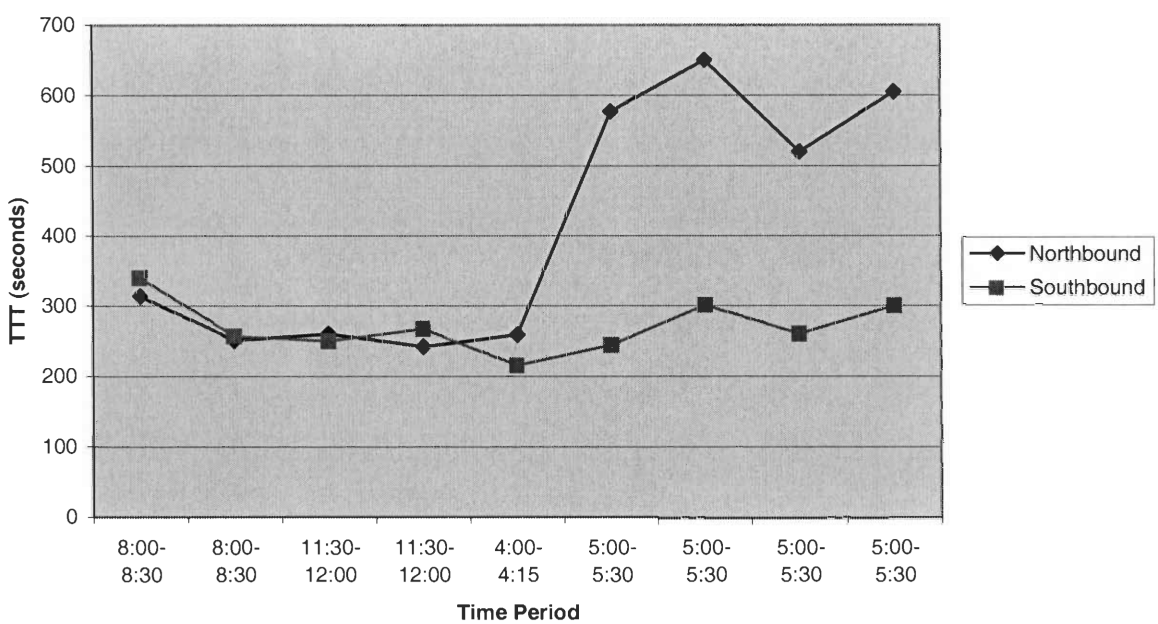
Northbound on Putnam Ave.



Delay vs. Time of Day Before Signal Change

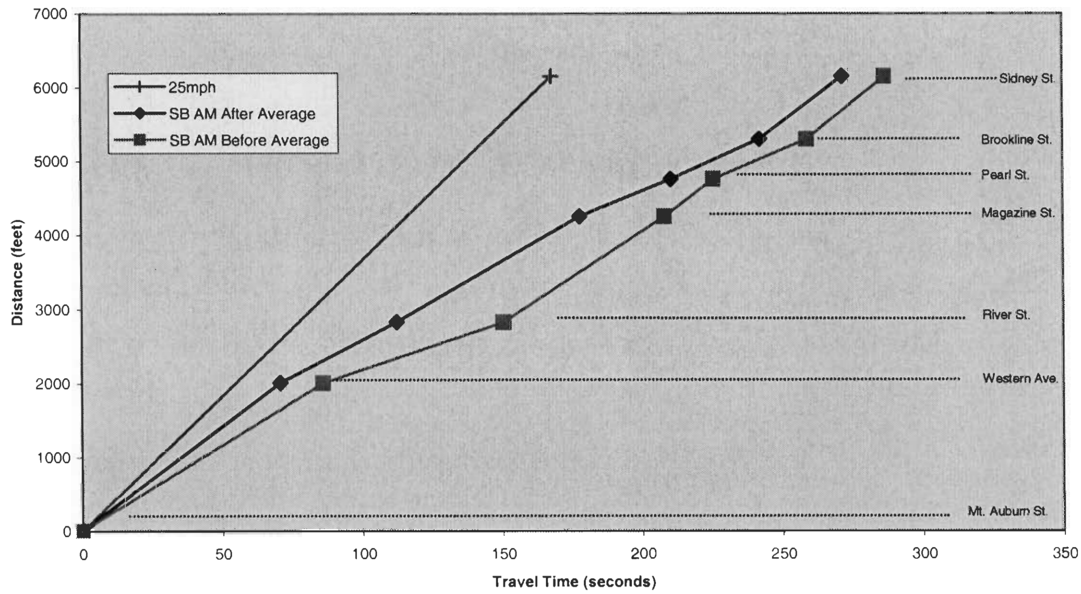


Total Travel Time vs. Time of Day Before Signal Change

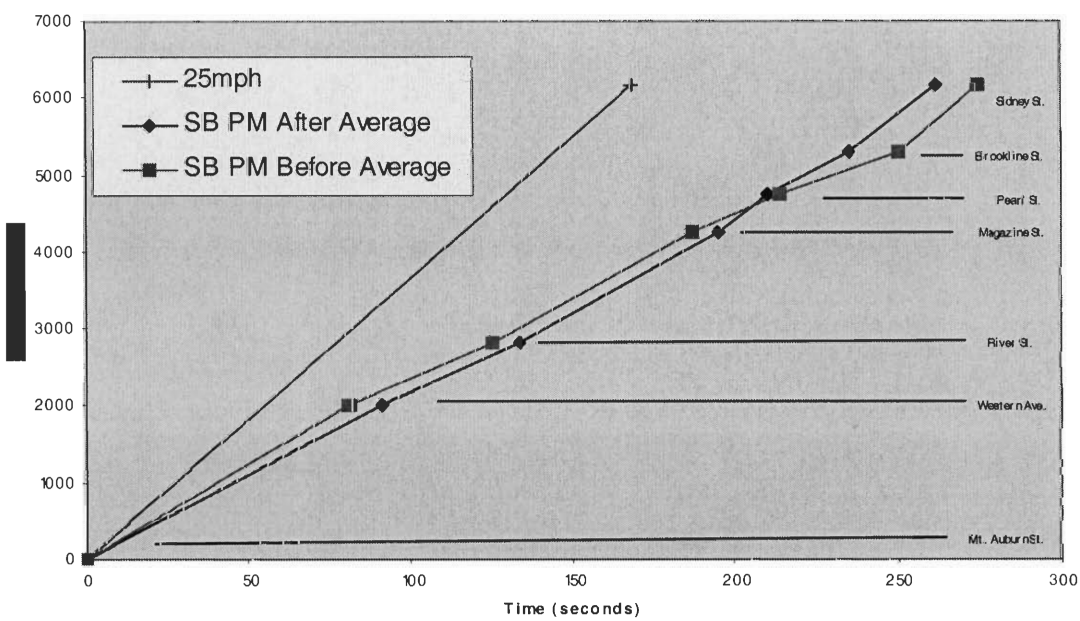


Appendix G: Time Travel Average Graphs

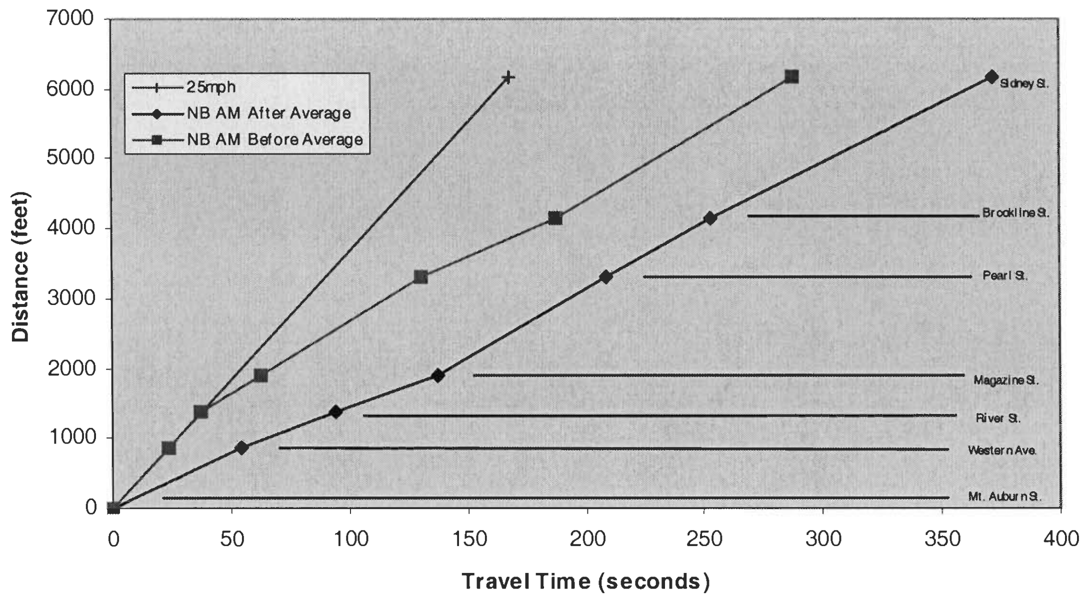
Traveling Southbound on Putnam Avenue, Morning Rush Hour



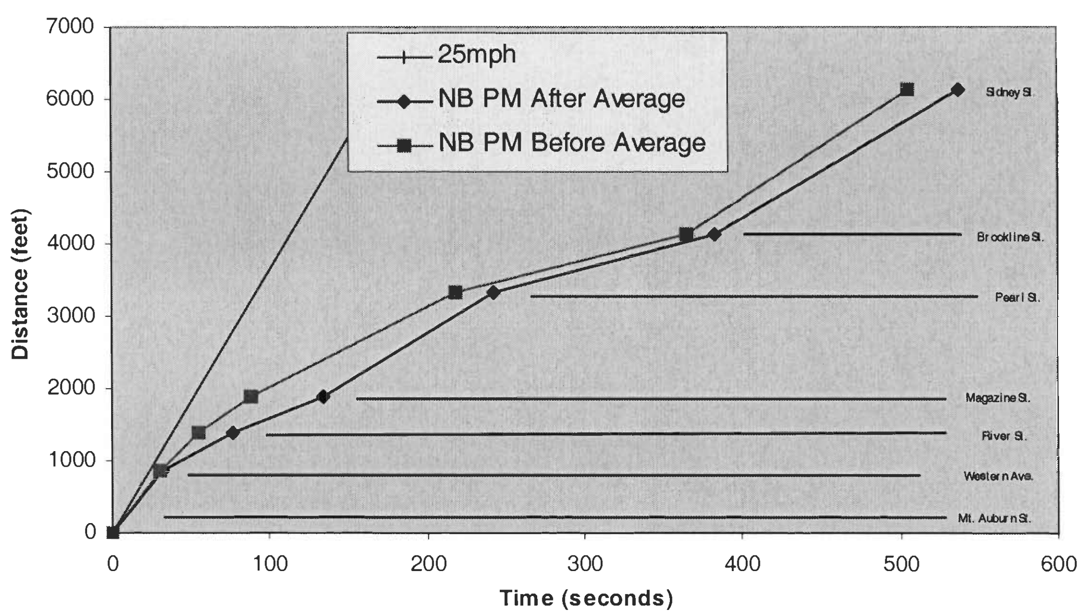
Traveling Southbound on Putnam Avenue, Evening Rush Hour



Northbound Travel on Putnam Avenue, Morning Rush Hour



Traveling Northbound on Putnam Avenue, Evening Rush Hour



Appendix H: ATR Data GIS Representations

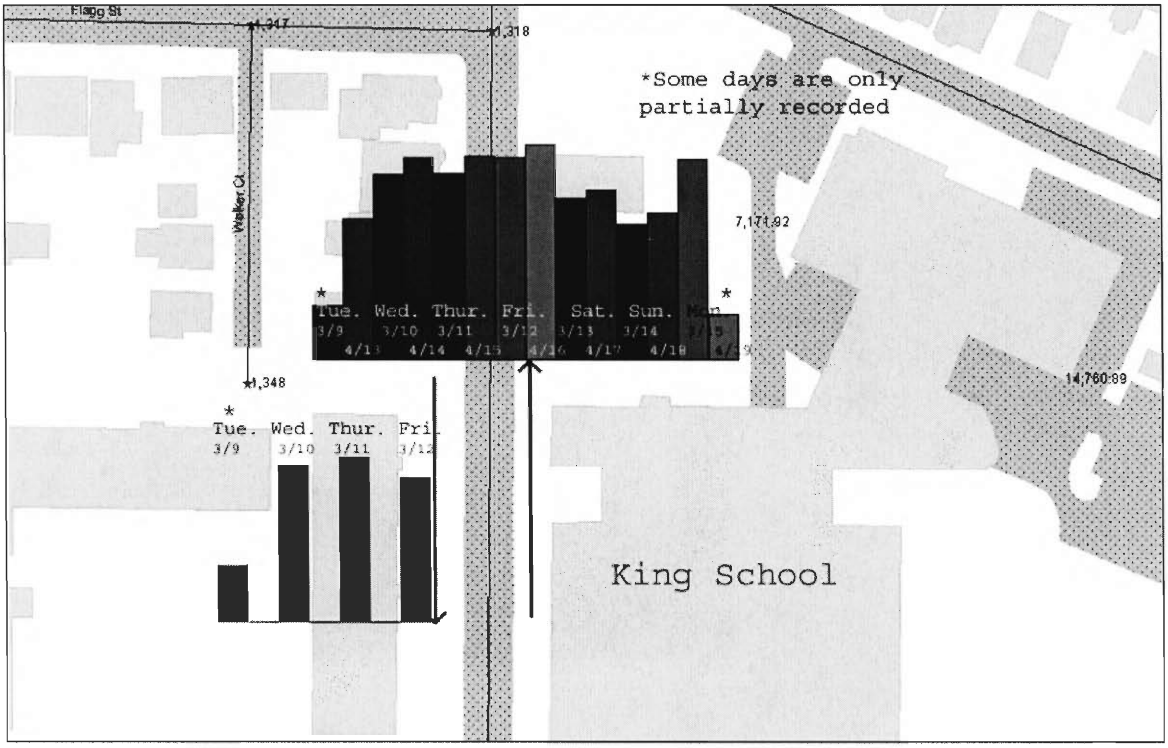


Figure 21: ATR Volume Data for King School Location

Figure 22: ATR Volume Data for North of River St. Location

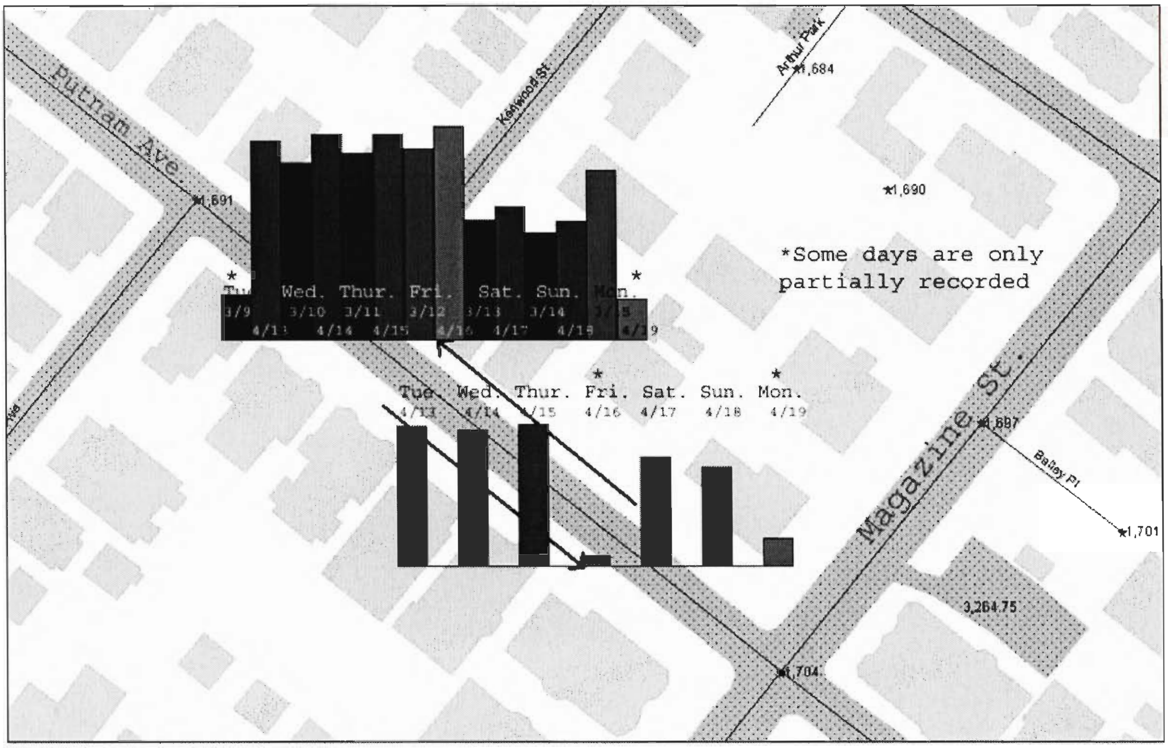


Figure 23: ATR Volume Data for West of Magazine St. Location

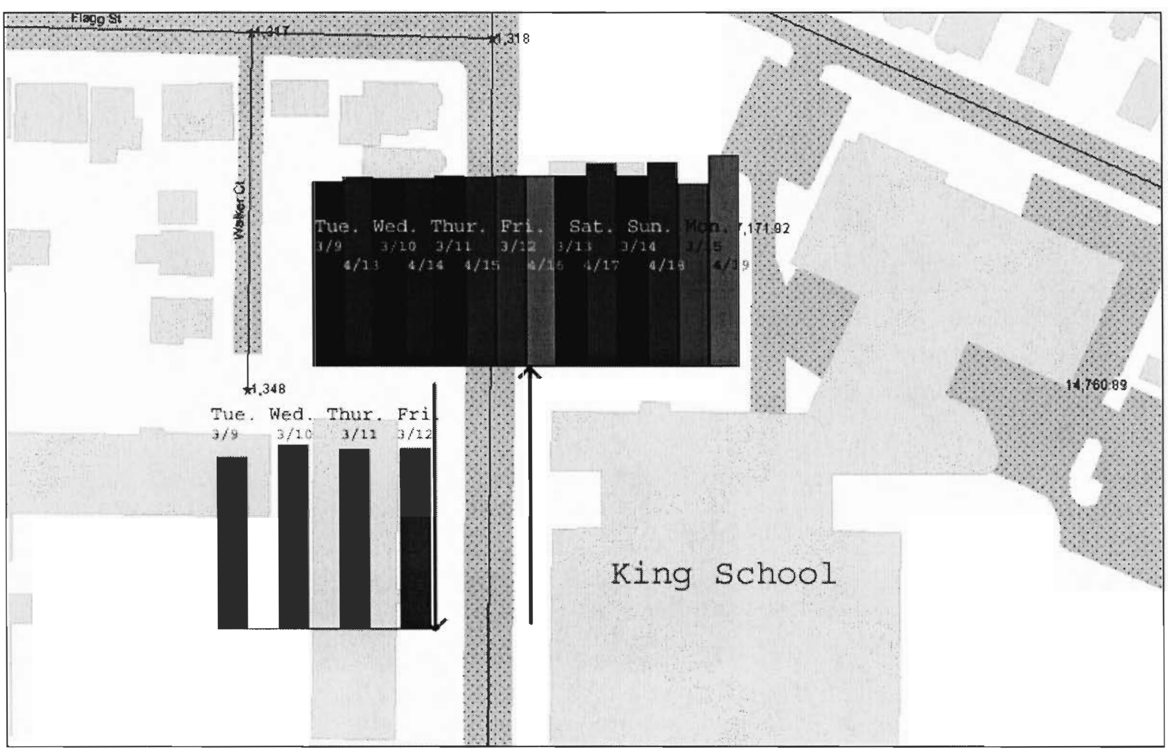


Figure 24: ATR Speed Data for King School Location

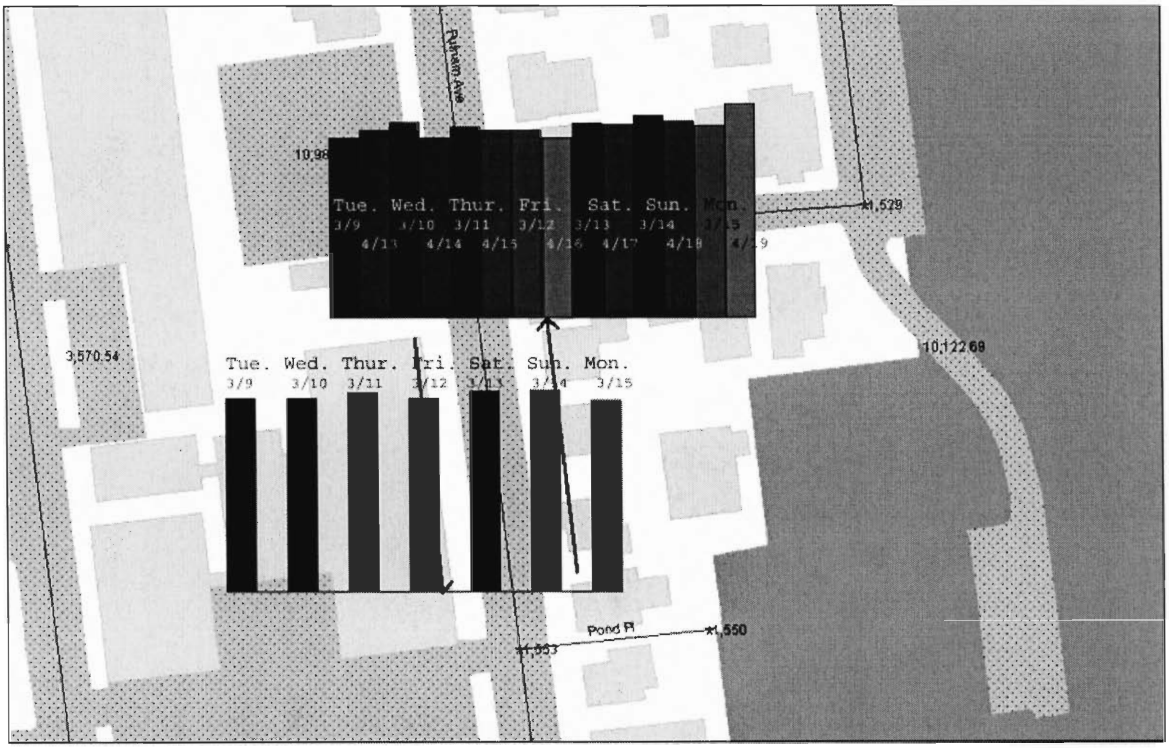


Figure 25: ATR Speed Data for North of River St. Location

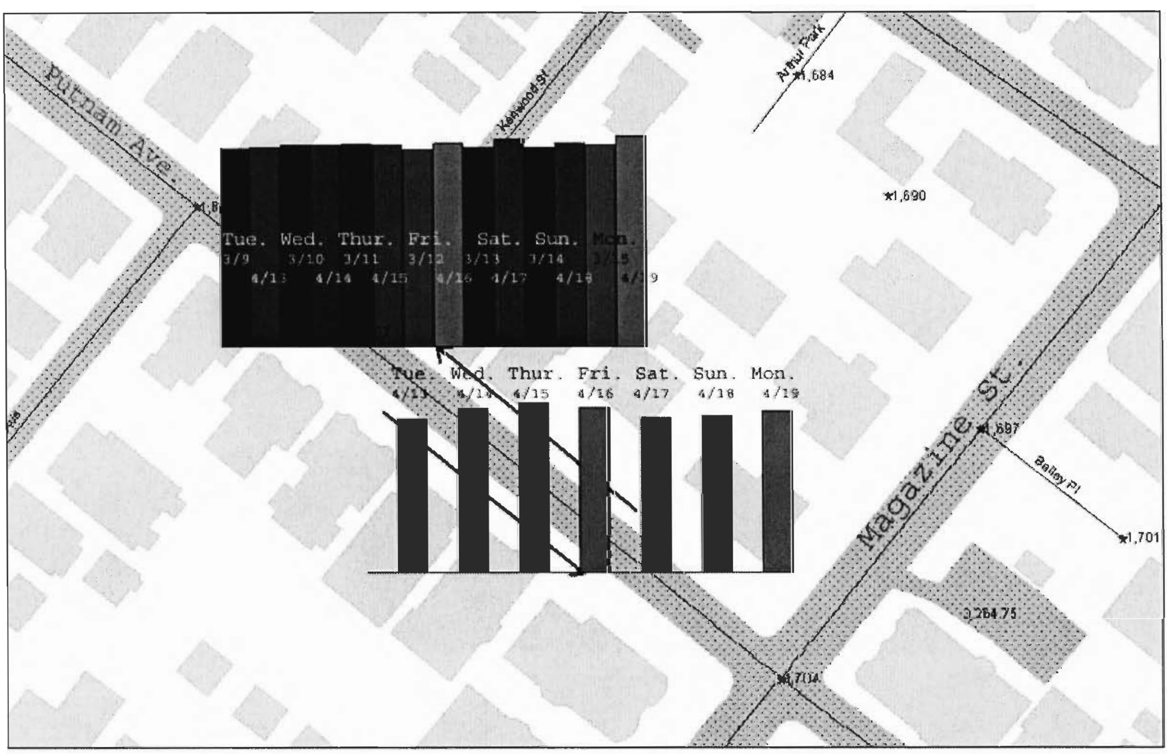
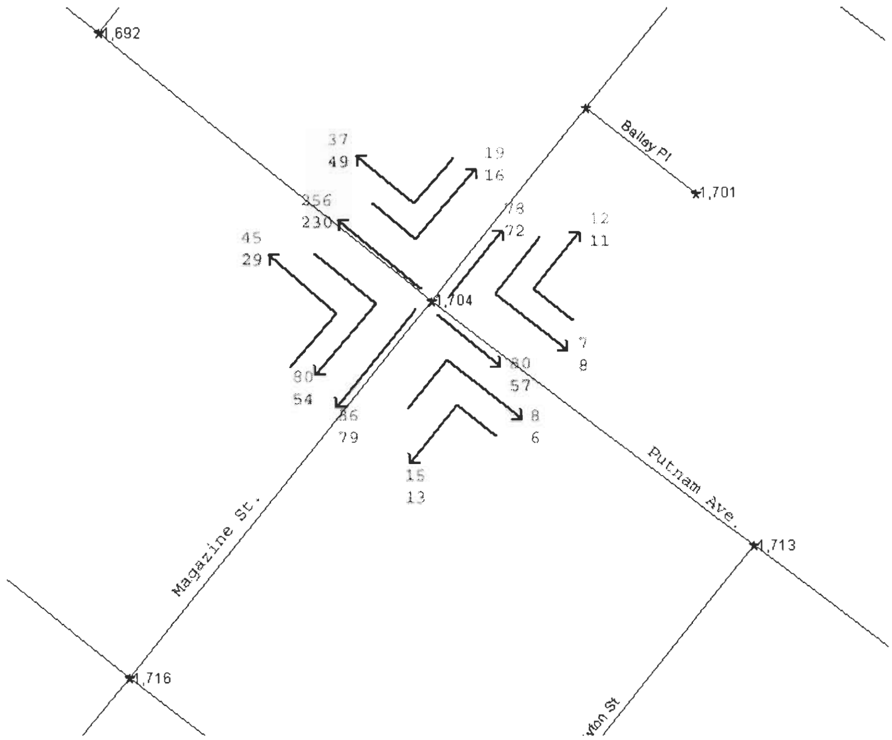
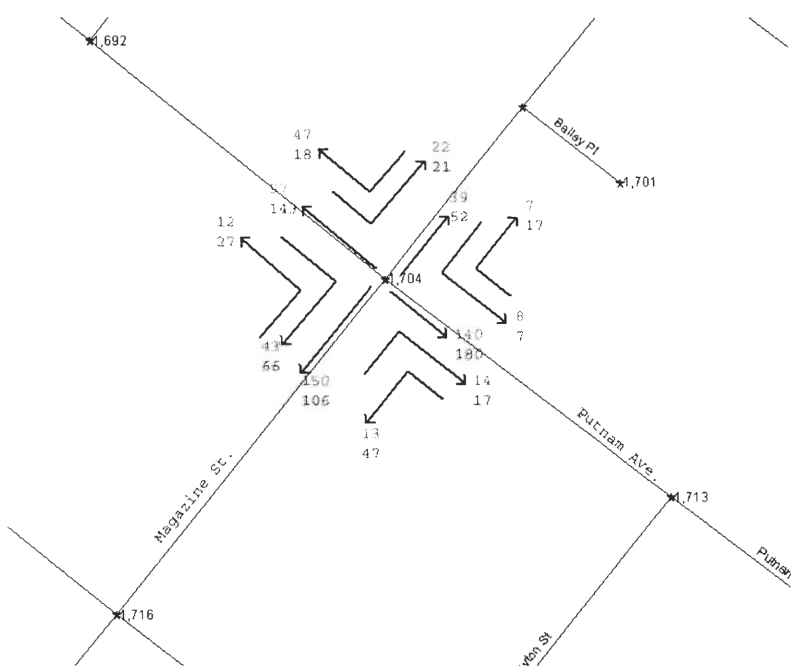
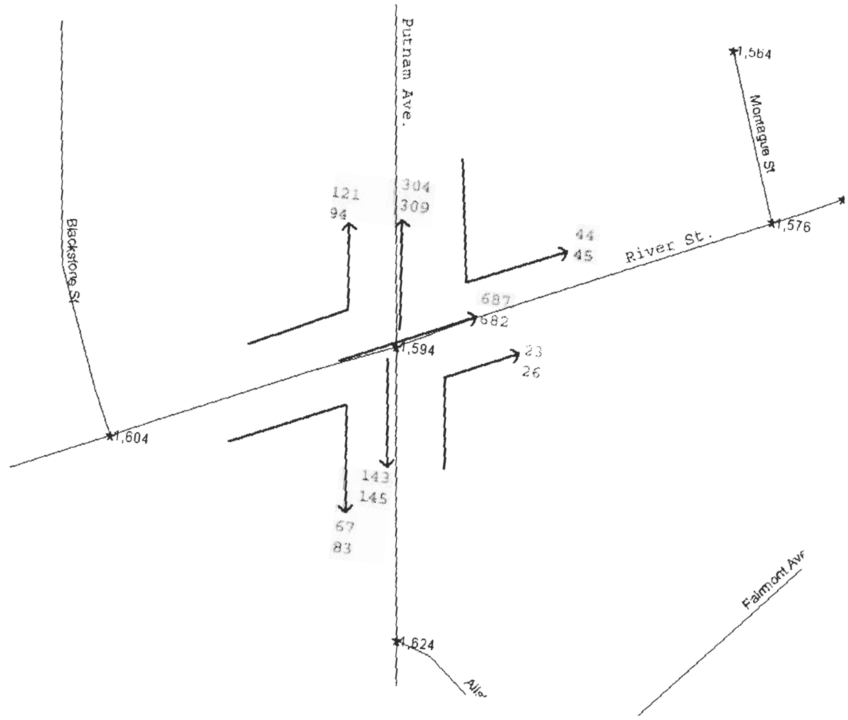


Figure 26: ATR Speed Data for West of Magazine St. Location

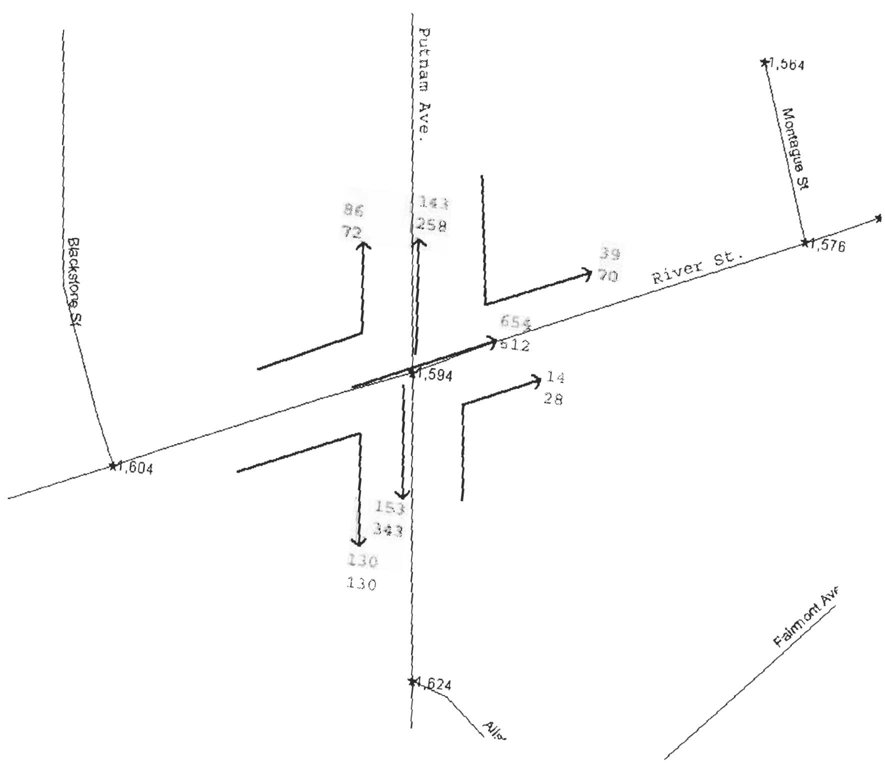
Appendix I: Turn Movement Count Results







Putnam Ave.
Blackstone St
Montague St
River St.
Fairmont Ave
1,564
1,576
1,594
1,604
1,624
121
94
304
309
44
45
687
682
23
26
143
145
67
83



Putnam Ave.
Blackstone St
Montague St
River St.
Fairmont Ave
1,564
1,576
1,594
1,604
1,624
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72
143
258
39
70
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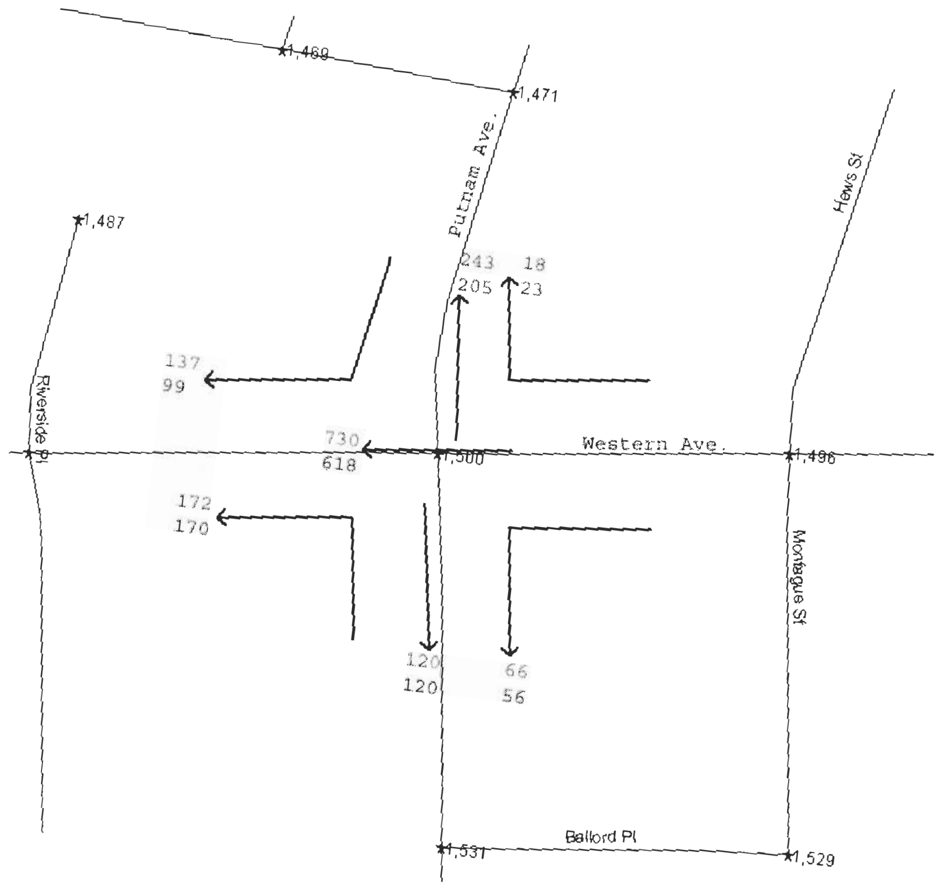
28
153
343
130
130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1,471
Putnam Ave.
Hews St
1,487
243
205
18
23
137
99
Riverside Pl
730
618
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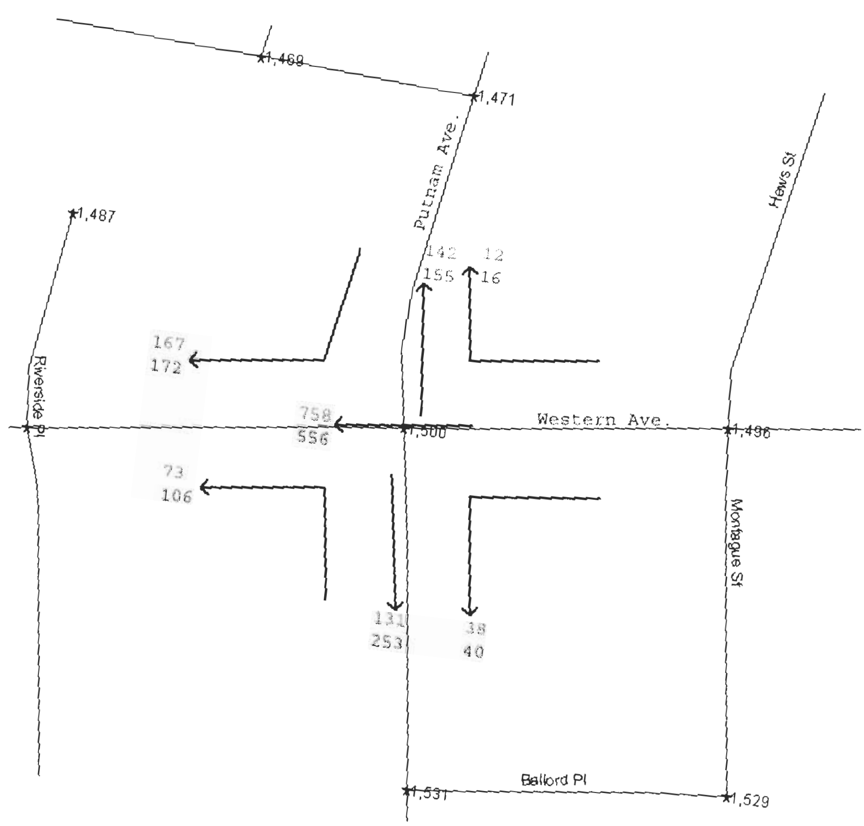
Western Ave.
1,496
172
170
Montague St
120
120
66
56
Ballord Pl
1,531
1,529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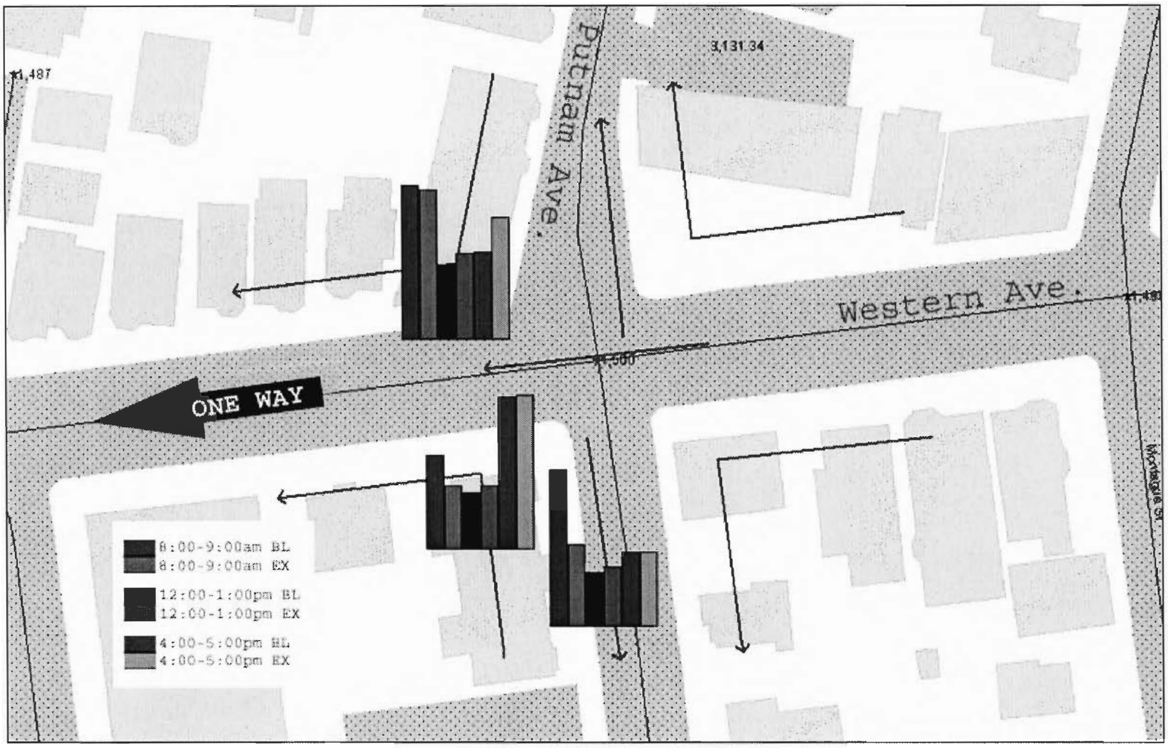
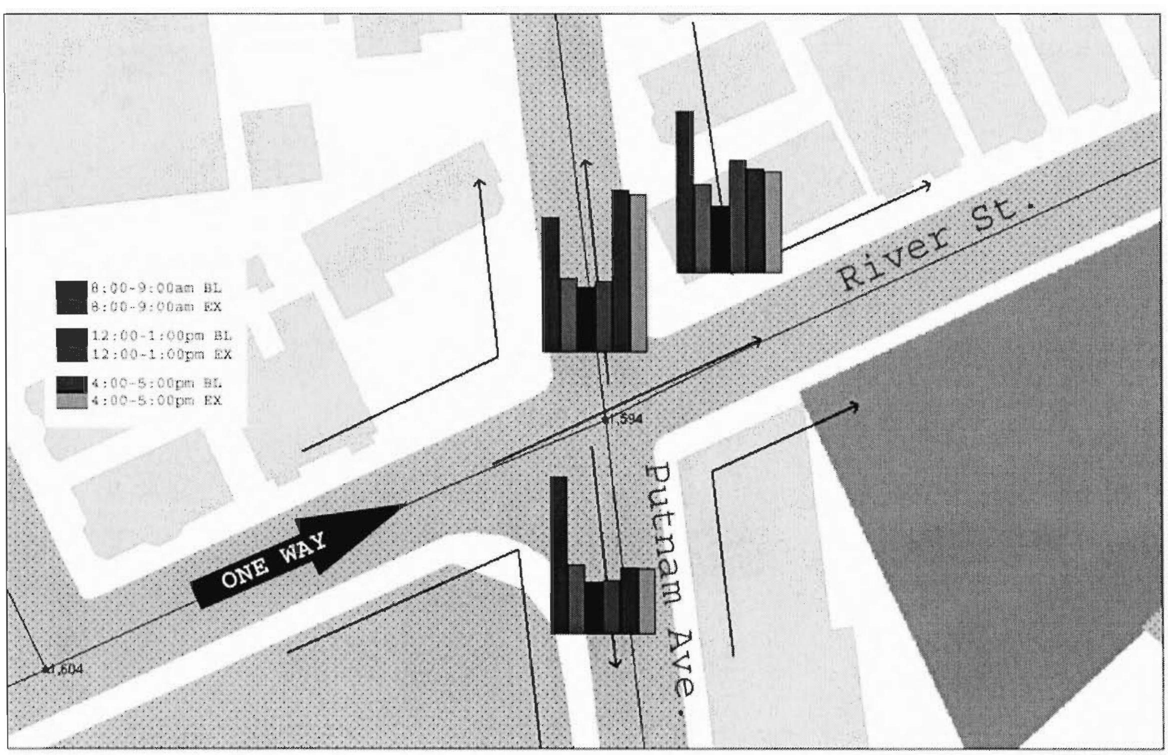
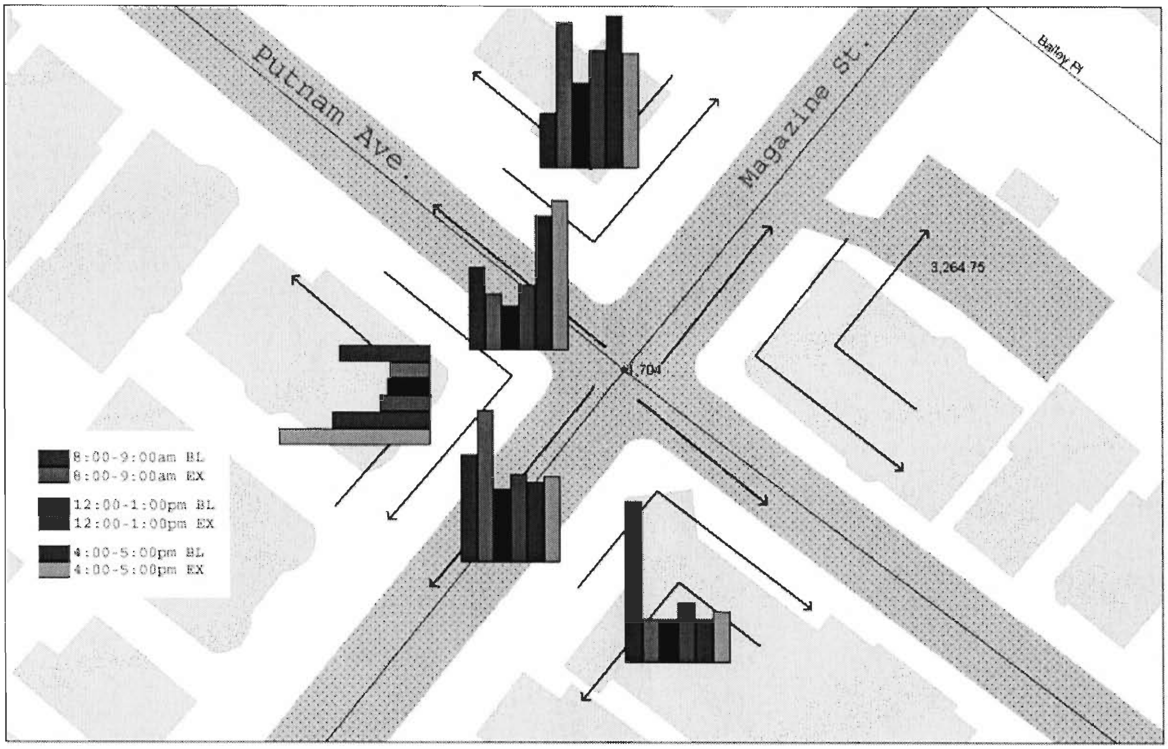
1,471
Putnam Ave.
Hews St
1,487
142
155
12
16
167
172
Riverside Pl
758
556
1,500
Western Ave.
1,496
73
106
Montague St
131
253
38
40
Ballord Pl
1,531
1,529

Appendix J: TMC GIS Representations

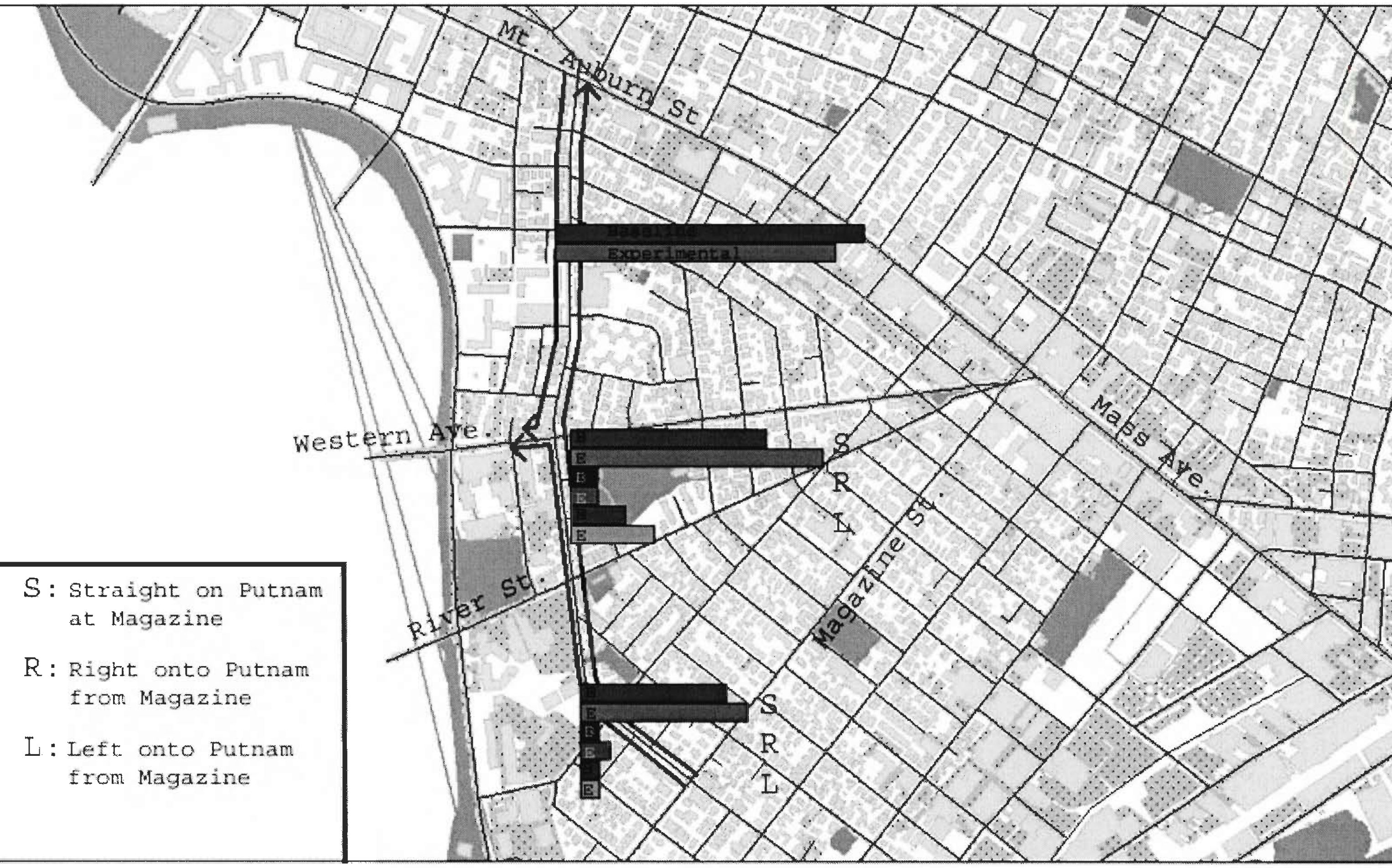






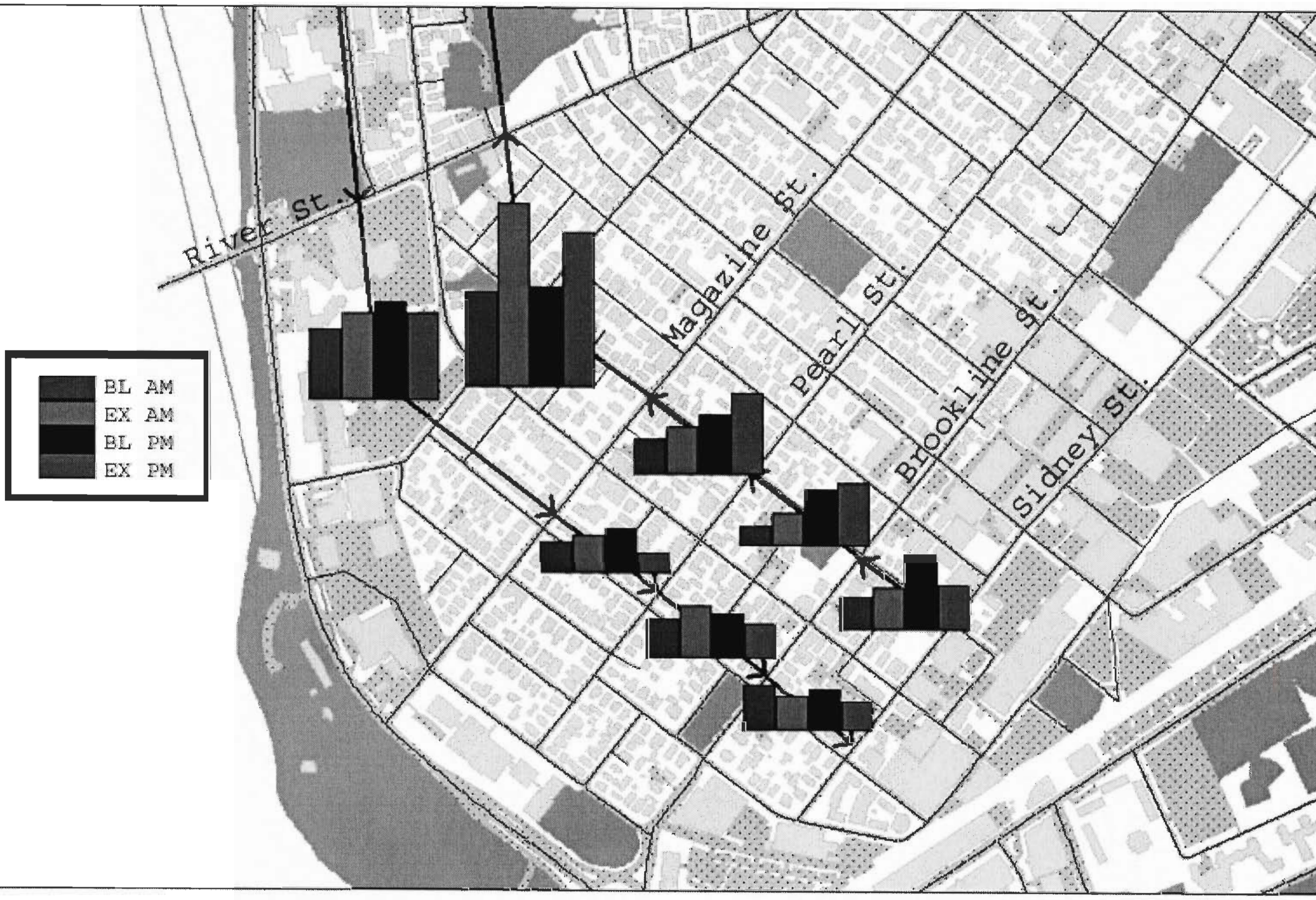
Putnam Ave.
Magazine St.
Bailey Pl
3,264.75
1,704
8:00-9:00am BL
8:00-9:00am EX
12:00-1:00pm BL
12:00-1:00pm EX
4:00-5:00pm BL
4:00-5:00pm EX

Appendix K: TMC GIS Representations




BL AM
EX AM
BL PM
EX PM
Mass Ave.
Western Ave.
Magazine St.

Appendix L: Travel Time GIS Representations



River St.
Magazine St.
Pearl St.
Brookline St.
Sidney St.
BL AM
EX AM
BL PM
EX PM

Appendix M: SPSS Output for Travel Time Comparisons

Between-Subjects Factors

		Value Label	N
PHASDIRC	1.00	Southbound Before	16
	2.00	Northbound Before	16
	3.00	Southbound After	16
	4.00	Northbound After	16
TIMEDAY	1.00	AM Peak	24
	2.00	Midday	16
	3.00	PM Peak	24

Descriptive Statistics

Dependent Variable: TRAVTIME

PHASDIRC	TIMEDAY	Mean	Std. Deviation	N
Southbound Before	AM Peak	286.6667	45.82867	6
	Midday	256.2500	9.35860	4
	PM Peak	274.5000	22.63405	6
	Total	274.5000	32.19317	16
Northbound Before	AM Peak	287.8333	87.12386	6
	Midday	247.0000	22.93469	4
	PM Peak	505.0000	127.04015	6
	Total	359.0625	148.02859	16
Southbound After	AM Peak	271.5000	31.89201	6
	Midday	255.0000	51.34848	4
	PM Peak	261.8333	21.56309	6
	Total	263.7500	32.66905	16
Northbound After	AM Peak	371.6667	38.13485	6
	Midday	313.5000	21.91651	4
	PM Peak	537.5000	124.06571	6
	Total	419.3125	123.25838	16
Total	AM Peak	304.4167	65.27128	24
	Midday	267.9375	38.69964	16
	PM Peak	394.7083	154.70884	24
	Total	329.1562	116.06897	64

Levene's Test of Equality of Error Variances(a)

Dependent Variable: TRAVTIME

F	df1	df2	Sig.

4.005	11	52	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a Design: Intercept+PHASDIRC+TIMEDAY+PHASDIRC * TIMEDAY

Tests of Between-Subjects Effects

Dependent Variable: TRAVTIME

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	614189.854(a)	11	55835.441	12.379	.000
Intercept	6412867.741	1	6412867.741	1421.761	.000
PHASDIRC	214229.271	3	71409.757	15.832	.000
TIMEDAY	177782.708	2	88891.354	19.708	.000
PHASDIRC * TIMEDAY	175802.083	6	29300.347	6.496	.000
Error	234546.583	52	4510.511		
Total	7782742.000	64			
Corrected Total	848736.438	63			

a R Squared = .724 (Adjusted R Squared = .665)

Post Hoc Tests

PHASDIRC

Multiple Comparisons

Dependent Variable: TRAVTIME

	(I) PHASDIRC	(J) PHASDIRC	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Southbound Before	Northbound Before	-84.5625(*)	23.74477	.004	-147.5835	-21.5415
		Southbound After	10.7500	23.74477	.969	-52.2710	73.7710
		Northbound After	-144.8125(*)	23.74477	.000	-207.8335	-81.7915
	Northbound Before	Southbound Before	84.5625(*)	23.74477	.004	21.5415	147.5835
		Southbound After	95.3125(*)	23.74477	.001	32.2915	158.3335
		Northbound After	-60.2500	23.74477	.066	-123.2710	2.7710
	Southbound After	Southbound Before	-10.7500	23.74477	.969	-73.7710	52.2710
		Northbound Before	-95.3125(*)	23.74477	.001	-158.3335	-32.2915
		Northbound After	-155.5625(*)	23.74477	.000	-218.5835	-92.5415
	Northbound After	Southbound Before	144.8125(*)	23.74477	.000	81.7915	207.8335
		Northbound Before	60.2500	23.74477	.066	-2.7710	123.2710
		Southbound After	155.5625(*)	23.74477	.000	92.5415	218.5835
Bonferroni	Southbound Before	Northbound Before	-84.5625(*)	23.74477	.005	-149.6933	-19.4317

	Southbound After	10.7500	23.74477	1.000	-54.3808	75.8808
	Northbound After	-144.8125(*)	23.74477	.000	-209.9433	-79.6817
Northbound Before	Southbound Before	84.5625(*)	23.74477	.005	19.4317	149.6933
	Southbound After	95.3125(*)	23.74477	.001	30.1817	160.4433
	Northbound After	-60.2500	23.74477	.085	-125.3808	4.8808
Southbound After	Southbound Before	-10.7500	23.74477	1.000	-75.8808	54.3808
	Northbound Before	-95.3125(*)	23.74477	.001	-160.4433	-30.1817
	Northbound After	-155.5625(*)	23.74477	.000	-220.6933	-90.4317
Northbound After	Southbound Before	144.8125(*)	23.74477	.000	79.6817	209.9433
	Northbound Before	60.2500	23.74477	.085	-4.8808	125.3808
	Southbound After	155.5625(*)	23.74477	.000	90.4317	220.6933

Based on observed means.

* The mean difference is significant at the .05 level.