BOSTON PROJECT CENTER

Transportation Data Management in the City of Cambridge

An Interdisciplinary Qualifying Project
Submitted to the faculty of
Worcester Polytechnic Institute
in partial fulfillment of the requirements for the
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Abstract

This project has served to develop a basic foundation and framework for a traffic management tool for use by the Cambridge Traffic, Parking and Transportation Department in order to assist in decision-making. After reviewing current standards and practices, a standard for the collection and submission of traffic data to the department was determined and an electronic database was created to store and analyze traffic data. The usefulness of the tool was demonstrated through graphs and outputs of the database.

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Authorship

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

Specifically,

- *the Executive Summary and Introduction were written by all members as a group.*

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    2.1 The City of Cambridge – Kimberly
    2.2 Transportation In and Around Cambridge – Josh
    2.3 Traffic Laws & Regulations – Matt
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- *Methodology:*

    3.1 Evaluation of Current Traffic Management Practices – Matt
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- *Results and Analysis:*

    4.1 Validity of Data – Matt & Colleen
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    4.3 Adaptation of Existing Data to New Standards – Kim & Josh
    4.4 Demonstration of the Usefulness of the System by Interpreting Traffic Data – Kim & Josh

- *Deliverables and Recommendations* - Colleen

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EXECUTIVE SUMMARY

Each year the number of cars on the road and the miles they travel continue to grow as seen in Figure 1. This causes numerous problems for commuters and residents of urban areas everywhere; congestion and gridlocks plague many cities, hindering everyday travels and leading to problems of driver stress, road rage, and increasing air pollution. New roads, bridges, tunnels and bypasses are built in an effort to better manage the flow of traffic and expedite travel time for everyone. Traffic management has become an integral part of many cities in response to the demand and need for better transportation services.

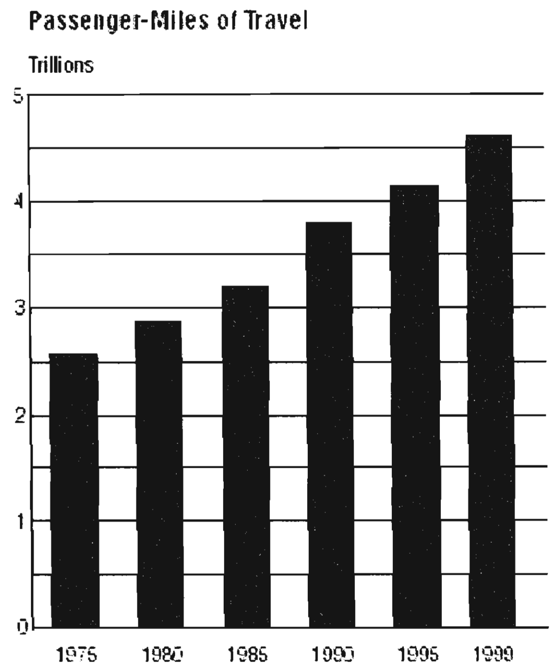

Figure 1: Passenger-Miles of Travel in the United States 1975-1999[1]

The City of Cambridge is part of a large and growing metropolitan area, experiencing thousands of trips by residents and commuters everyday. Significant changes in travel patterns have emerged over the past few years due to recent residential and commercial development in the City that increase traffic during both peak and off-peak hours. This is not a problem of Cambridge alone; urban planners and transportation managers around the world have been collecting and analyzing data in their struggle to relieve growing traffic problems. Cambridge is just one example of a city where transportation management has the potential to develop further and offer increasing benefits to its commuters.

The Cambridge Traffic, Parking & Transportation Department (CTPTD) was created to monitor the transportation system in the City and to make necessary changes to the infrastructure in order to meet ever-changing transportation demands. Over the years, the

[1] Bureau of Transportation Statistics. Transportation Statistics Annual Report 2000. US Department of Transportation. [Internet] 2000.[cited 2003 February 6]; 89. Available from: http://www.bts.gov/publications/tsar/2000/index.html

CTPTD has worked to gather pertinent information about the traffic situation in the City. The City Council enacted an ordinance requiring land developers to conduct traffic studies around the development area to determine the impact of increased traffic during and after construction and to ensure the extra traffic would not overburden the community. It became the responsibility of the CTPTD to define the study area for these projects, review the final reports for validity, and offer the Cambridge Planning Board its recommendation for approval of the development. Following the review, the Department keeps a copy of the report on file. These files, however, are often difficult to reuse in conjunction with other studies due to different formats in the collected data.

The Cambridge Traffic, Parking, & Transportation Department today retains an abundance of information about traffic patterns and volumes for different modes of transportation throughout the City. However, it is difficult for the CTPTD to use the information outside of the specific study for which it was acquired. Different consultants hired by land developers and the CTPTD utilize different formats in the presentation of their data to the Department. Figure 2 represents one of the many formats the data are represented by the consultants.

N/S Street : Portland Street
E/W Street : Broadway
City/State : Cambridge, MA
Weather : Clear

Accurate Counts
978-664-2565

File Name : 33290089
Site Code : 33290009
Start Date : 02/14/2002
Page No : 1

Groups Printed- Bikes

	Portland St From North			Broadway From East			Portland St From South			Broadway From West			
Start Time	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Int. Total
16:00	0	1	0	0	0	0	1	0	0	0	0	0	2
16:15	0	0	0	0	2	0	0	1	0	0	2	0	5
16:30	0	1	0	0	2	0	0	1	0	0	0	0	4
16:45	0	1	0	0	4	0	0	0	0	0	0	0	5
Total	0	3	0	0	8	0	1	2	0	0	2	0	16
17:00	0	2	0	1	6	0	0	2	1	0	0	1	13
17:15	0	0	0	0	5	0	0	1	0	0	0	0	6
17:30	0	0	0	1	3	0	0	2	0	0	0	1	7
17:45	0	0	1	0	3	0	0	1	1	0	1	1	8
Total	0	2	1	2	17	0	0	6	2	0	1	3	34
18:00	0	0	0	0	6	0	0	1	0	0	0	0	7
18:15	0	0	0	0	8	0	2	1	1	0	0	0	12
18:30	0	2	0	0	3	1	0	2	0	0	1	0	9
18:45	0	1	0	0	2	1	0	3	0	0	0	0	7
Total	0	3	0	0	19	2	2	7	1	0	1	0	35
Grand Total	0	8	1	2	44	2	3	15	3	0	4	3	85
Apprch %	0.0	88.9	11.1	4.2	91.7	4.2	14.3	71.4	14.3	0.0	57.1	42.9	
Total %	0.0	9.4	1.2	2.4	51.8	2.4	3.5	17.6	3.5	0.0	4.7	3.5	

Figure 2: Sample of Data Presentation[2]

It is not only incongruent arrangements of data that make them hard to compare to other studies even when all the necessary information may be available, but also because different departments and employees overseeing the studies maintain the data differently. If

[2] Vanasse & Associates, Inc. Transportation Impact Study / Special Permit Criteria Analysis; Proposed Office Building Expansion: 2 August 2002. Andover: VAI; 2002

the CTPTD were able to keep this information in a consistent and standardized format in one central location, the Department could extrapolate data to areas where no collections have been done and analyze trends in order to predict future travel patterns in growing areas of the City. The CTPTD, in conjunction with other departments, could make a more efficient use of all available data to produce more complete analyses for decision making.

The goal of our project was to analyze Cambridge's current and new traffic information in order to create standardized data gathering and submission procedures, allowing the City to maximize the use of the data it receives and in effect help the City alleviate current transportation problems. The team first reviewed existing data available to the City to assess the type and amount of information that is typically collected and how the current traffic management system works in Cambridge. By reviewing the current data our group extracted important information and organized it a way in which was useful for the CTPTD. From this information, we designed a standardized set of forms that allows the raw intersection data to be collected and evaluated their usefulness by using them in the field to collect new data. This helped the team establish what data could be reasonably collected in the field and was important to track for future data analysis.

Using this information, the project team developed a framework for the storage and organization of the data. This allowed us to demonstrate for the CTPTD the usefulness of such a system along with the many different functions it has. Information is easy to access and manipulate because it is stored in one central system. Utilizing GIS layers of the City, the Department, land developers, and other interested parties can click on their area of interest and find all pertinent traffic information and use it as they wish. This system also facilitates the identification of information gaps not previously recognized so that more new data can be collected as needed. As new data were found to be necessary, specifically in the Central Square area, the team went into the field to gather this data utilizing the new standards set forth by the system. This assisted the City in gathering necessary information while also served to validate the accuracy and convenience of our system.

As the system developed, a variety of more sophisticated applications of the tool were explored that provided further functionality to the system. Interactivity was added to make data entry and retrieval more user-friendly, using forms designed to enable the user to easily enter the traffic information in a format similar to which it was collected. Also, the system was made such that a standardized electronic version of consultant reports and data can be submitted and automatically stored for the CTPTD. The system was designed to be dynamic, allowing for future enhancements to increase its usefulness. For example, having this comprehensive system could allow the CTPTD to choose a study area for new developer reports that will not only reflect where traffic will change as a result of the development but also where the City needs to gather more information. Instead of repeatedly collecting information for one area, the City can request more information from a less studied area and none from the area where current data exists.

Effective traffic management is essential for growing urban areas that experience a large influx of non-residents daily. Cambridge, with just over 101,000 residents, has approximately 115,000 people who work in the City. In order to help alleviate the inevitable transportation problems, the City needs to be able to utilize existing traffic information to adjust laws, signals, and other regulations. Understanding the demands of the commuters and residents, the City can more effectively make decisions that will benefit everyone.

1 Introduction

In 2000 there were over one-hundred million passenger cars on the road in the United States[3], a number that makes effective transportation management essential for large cities. Since the 1800s, the transportation industry has evolved into an advanced network of private and public transportation that would be incomprehensible to our ancestors. Roads, highways, tunnels, and bridges are all built in an effort to help maintain a steady flow of traffic, yet traffic gridlocks unheard of 30 years ago have become commonplace to today's commuter. While the ability to be anywhere in the world in a matter of days has many advantages, it brings with it a number of problems. The large number of cars traveling through urban areas each day causes congestion and pollution, and creates an ever increasing demand for more efficient traffic regulators and pushes transportation services to their limits.

The city of Cambridge, Massachusetts is part of a large and growing metropolitan area that experiences thousands of trips by residents and commuters daily. Recent land developments in Cambridge have caused significant changes in travel patterns that place a strain on the capacity of the existing transportation system. Throughout the years, urban planners and transportation managers around the world have been collecting and analyzing data in their struggle to relieve growing traffic problems. Cambridge is just one example of a city where transportation management has the potential to develop further and offer increasing benefits to its commuters.

The Cambridge Traffic, Parking & Transportation Department has worked over the years to gather pertinent information about the traffic situation it the City. Ordinances set forth by the city government force land developers to conduct traffic studies to ensure the streets of Cambridge will not be overloaded with new vehicles entering the area. Once these studies are completed, the information is kept on file in the Department's office but is often difficult to use in conjunction with other studies due to different styles of collecting the data.

Currently, the City of Cambridge does not have a standard method for collecting and maintaining traffic information, and time is often spent recollecting information in a format that is comparable to existing data. Even though the City retains a wealth of information in regard to traffic and transportation, it is often useless outside of the specific study it was re-

[3] North American Transportation in Figures [Internet] US Census [cited 2003 January 28] Available at http://www.census.gov/econ/www/natf/natf.html

trieved for because the various agencies collecting the data have not utilized the same format. The City would like to be able to extrapolate traffic information from one intersection to the next but the lack of a congruent format of data presentation makes it quite difficult.

The focus of this project was to develop a standardized method for the City of Cambridge by which all data can be collected, stored, and easily retrieved. By analyzing the City's current information as well as new information they wish to acquire, we created a standardized data gathering and submission procedures that will allow Cambridge to maximize the use of the data it receives and help the City alleviate current transportation problems. The information was then stored in a database so the Traffic, Parking, and Transportation Department along with other departments, land developers, and the public can gain easy access to it. Data were collected in the Central Square areas to fill existing information gaps while observing the causes of inconsistent information.

2 Background

This chapter will introduce you to pertinent information about the City of Cambridge and its transportation infrastructure. Cambridge was settled in 1630 and has continually evolved into the dynamic city of today. Since its settlement, Cambridge has developed its own government system with a diverse group of departments created to run the City smoothly. One such department is the Cambridge Traffic, Parking & Transportation Department which was created to allow the transportation infrastructure to meet an ever-increasing demand. Background research was conducted in areas such as the historical background and demographics of Cambridge, traffic laws and regulations, local transportation, and traffic management to help form a solid understanding of the study area and the important factors that affect the way transportation works in the city of Cambridge.

2.1 The City of Cambridge

The City of Cambridge has a rich history that began in 1630 when 700 men, women and children set sail from England to settle in Massachusetts.[4] Upon arrival, John Winthrop and his associates determined the best place for the capital would be atop a hill where the Charles River was wide enough to sail their ships, yet protected the City against any who did not know the waters. Originally named Newtowne, the residents quickly set to work creating their City. They laid out the streets in squares, each meeting the others at right angles, with the center square reserved for a market place. It was not until 1638 that the City of Newtowne officially changed its name to Cambridge.[5]

2.1.2 Cambridge: The City of Today

The City began as a small farming community, moved into the heavy industry of the 19th and 20th centuries, and currently is a growing hub of innovative technology. With a population of 101,355, Cambridge's cultural and social diversity gives it a unique character. One in five of Cambridge's residents are foreign born from more than sixty different coun-

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[4] A Brief History of Cambridge [internet] :[updated 2002 January; cited 2003 Jan 15], <http://www.ci.cambridge.ma.us/info/history.html>.

[5] Ibid

tries; if one were to walk down the streets of Cambridge more than fifty languages could be heard.[6]

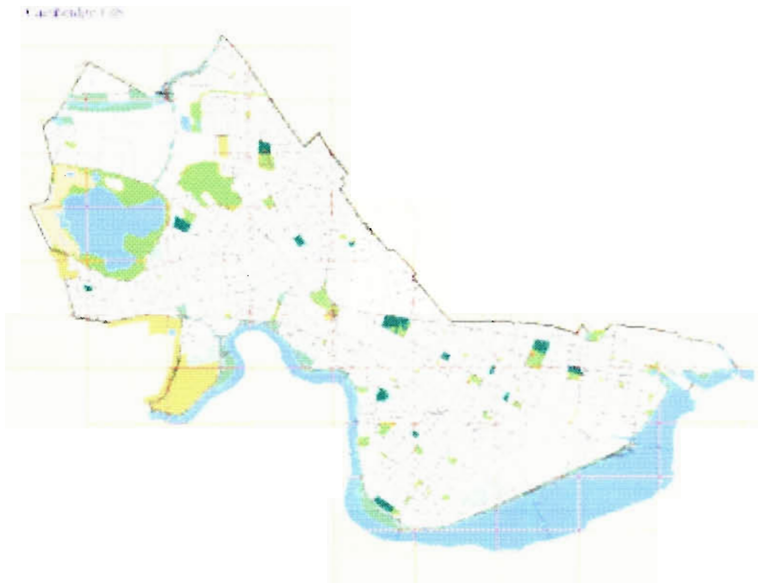

Figure 3: Map of Cambridge[7]

The figure above shows a map of the City of Cambridge. One can see from this picture that Cambridge has a wealth of roads and waterways. Home to some of the most prestigious universities in the world, including Harvard University and The Massachusetts Institute of Technology, nearly ¼ of the residents of Cambridge are students and $^1/_6$ of the City jobs are involved with higher education. Over the last decade the population of Cambridge has increased 5.8% with 16,217 people per square mile.[8]

2.1.3 The Government of Cambridge

The government of Cambridge consists of a city manager, city council, deputy city manager, and a mayor. Under the city manager there are several departments including Public Safety. This branch of government is the one under which the Traffic, Parking, and

[6] Cambridge: Middlesex County, "Transportation" [Internet]. [Updated 2001; cited 2003 Jan 26], <http://www.state.ma.us/dhcd/iprofile/049.pdf>.

[7] City of Cambridge Massachusetts. [Internet]. [Updated 2002; cited 2003 Jan 25], <http://www.ci.cambridge.ma.us/>.

[8] City of Cambridge: At a Glance. [Internet]. [Updated 2003; cited 2003 Feb 5], <http://www.ci.cambridge.ma.us/cambglance.cfm

Transportation Department exists. The basic organization of the Cambridge government can be seen in Figure 28 located in Appendix B.

The city council is a board of nine members who are elected every two years, including the mayor. Collectively these members are the policy setting, legislative branch of Cambridge's government. The board authorizes public improvements and expenditures, adopts regulations and ordinances, levies taxes and adopts the annual budget.[9] The city council also reviews and authorizes any reports for development in the City. Without this authorization developers are not allowed to begin construction. These reports provide free traffic studies and information for the City.

2.1.4 Cambridge Traffic and Transportation Department

The City of Cambridge created the Traffic, Parking and Transportation Department (CTPTD) to help the City adapt to the ever-increasing demands on its transportation system. The Department seeks to meet the transportation needs of the people within the City while reducing the number of single occupant vehicles and effectively lessening the amount of pollutants in the air. This Department has four specific goals including:

1. Increase the public safety of our transportation facilities
2. Support the transportation needs of residents, businesses, institutions and other City departments
3. Enhance the Department's customer service orientation
4. Increase the efficiency of the operations and procedures of the Department [10]

2.1.4.1 Responsibilities of Transportation Department

The CTPTD has a number of responsibilities that help them achieve their goals. They are in charge of signal placement, currently in 122 locations, curb regulations, signs, permits, and closing or special use of streets. They are also responsible for the marking of the 1,700 crosswalks and 900 stop lines located around the City. Along with dealing with the logistics of traffic management, the CTPTD also conducts studies to observe how they could make their transportation system more efficient. Some of the studies they conduct

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[9] City Council, City of Cambridge [Internet]. [Updated 2002; cited 2003 Feb 3]. <http://www.ci.cambridge.ma.us/ccouncil.cfm>.

[10] Cambridge: Middlesex County, "Transportation" [Internet]. [Updated 2002; cited 2003 Jan 25], <http://www.state.ma.us/dhcd/iprofile/049.pdf>.

deal with traffic, access, and safety.[11] The Department is also responsible for parking issues around the City, including monitoring meters, resident permit parking, and ticketing.[12]

2.2 Transportation In and Around Cambridge

Cambridge provides a transportation system with a wide array of public transit options and a sound infrastructure for private transportation. The "T" is an appealing form of transportation to both local residents and commuters. The "T" allows for commuters to avoid traffic and the hassle of parking in the City. While Cambridge is home to a little more than 101,000 people,[13] there are about 115,000 who spend their workday there.[14] Since the resident population of Cambridge includes children, college students, retirees, residents working outside of the City, and other non-working citizens, we can conclude that many people need to commute into Cambridge for work. Cambridge would like to expand the public transportation system by way of the City's Transportation Demand Management programs (TDM). These programs encourage commuters to use the public transit system as well as private modes of transportation to travel in and around the City.[15] Cambridge hopes to reduce the number of single occupant vehicles in order to allow for an increase in mobility throughout the City.[16] The TDM programs provide commuters with a number of alternatives to driving alone.

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[11] About The Traffic, Parking and Transportation Department, City of Cambridge [Internet]. [Updated 2002; Cited 2003 Jan 14], <http://www.ci.cambridge.ma.us/~Traffic/about.html>.

[12] Ibid

[13] U.S. Census Bureau Profiles of General Demographic Characteristics, 2000 Census of Population and Housing [Internet]. [place unknown]: U.S. Census Bureau; c2001 [cited 2003 Jan 24]. Available from: http://www.census.gov/prod/cen2000/dp1/2kh25.pdf

[14] Employment and Training Data for Cambridge [Internet]. [place unknown]: Commonwealth of Massachusetts, Division of Employment and Training (US); [cited 2003 Feb 20]. http://www.detma.org/lmi/local/Cambridg.html

[15] Cambridge Transportation Demand Management Services [Internet]. Cambridge (MA): City of Cambridge, MA (US); c2002 [cited 2003 Feb 20]. Available from: http://www.cambridgema.gov/~CDD/envirotrans/tdm/index.html

[16] About the Traffic, Parking and Transportation Department of Cambridge [Internet]. Cambridge (MA): City of Cambridge, MA (US); c2002 [updated 2000 Apr 18, cited 2003 Feb 20]. Available from: http://www.cambridgema.gov/~Traffic/about.html

For years, the City of Cambridge has pushed for a higher quality of life for City residents through City ordinances, transportation programs and other measures aimed at decreasing traffic. They have also worked to improve travel for all transportation modes, particularly high occupancy and non-motorized modes, such as walking, bicycling, ridesharing, and public transit.[17]

2.2.1 Public Transportation

The Massachusetts Bay Transportation Authority (MBTA) controls most of the public transportation in the greater Boston area. The MBTA service includes four subway lines, thirteen commuter rail lines, five boat routes, and 170 bus routes servicing approximately 3,244 square miles, maps of which can be viewed in Appendix C. Service is provided to 175 cities and towns that comprise the MBTA's district in eastern Massachusetts, serving over 1.1 million riders each day.[18]

Within Cambridge, the MBTA manages several rail and bus services. Two subway lines run through the City making a total of six stops. The Red Line runs north-south through the City and includes five stops along the way: Kendall Square, Central Square, Harvard Square, Porter Square, and Alewife. The other line is the Green Line which ends at Lechmere Station in Cambridge near the eastern boarder of the City. Multiple bus routes are provided by the MBTA and stop at each of the stations throughout much of the day (5:00am - 1:30am). These bus routes also provide service to neighboring communities. There are approximately 30 different fixed bus routes throughout the City. The MBTA provides commuter rail service via the Fitchburg Commuter Rail, which makes connections with the Red Line at Porter Square station and runs from Fitchburg to Boston's North Station.[19]

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[17] Cambridge Environmental & Transportation Planning Division [Internet]. Cambridge (MA): City of Cambridge, MA (US); c2002 [updated 2002 Dec 12; cited 2003 Feb 20]. Available from: http://www.ci.cambridge.ma.us/~CDD/envirotrans/index.html

[18] Massachusetts Bay Transportation Authority: Traveling on the T [Internet]. Boston: Massachusetts Bay Transportation Authority; c2002 [cited 2003 Feb 20]. Available from: http://www.mbta.com/traveling_t/schedules_index.asp

[19] Boston / Your Town [Internet]. Boston: Boston Globe Electronic Publishing Inc.; c2001 [cited 2003 Feb 20]. Available from: http://yourtown.boston.com/town/cambridge/transport.shtml

2.2.2 Private Transportation

Cambridge is accessible via highways and routes that run through and around the City. Within Cambridge there are five state and U.S. routes. These principal highways traveling through and around Cambridge add to the traffic trouble in the City because traffic is entering through several different areas. State Routes 2, 2A, 16, 38, and US Route 3 all pass through Cambridge as seen in Figure 4. The Massachusetts Turnpike (Interstate 90) travels along the Boston side of the Charles River, which is the southern border of Cambridge.[20] Interstate 93 also passes along the eastern border of Cambridge, on the Somerville side. All of these highways make Cambridge easily accessible to those who live in the suburbs and do not want to use public transportation, but the constant inflow of cars off these routes contributes to the daily traffic problems in and around the City which it cannot directly control or regulate.

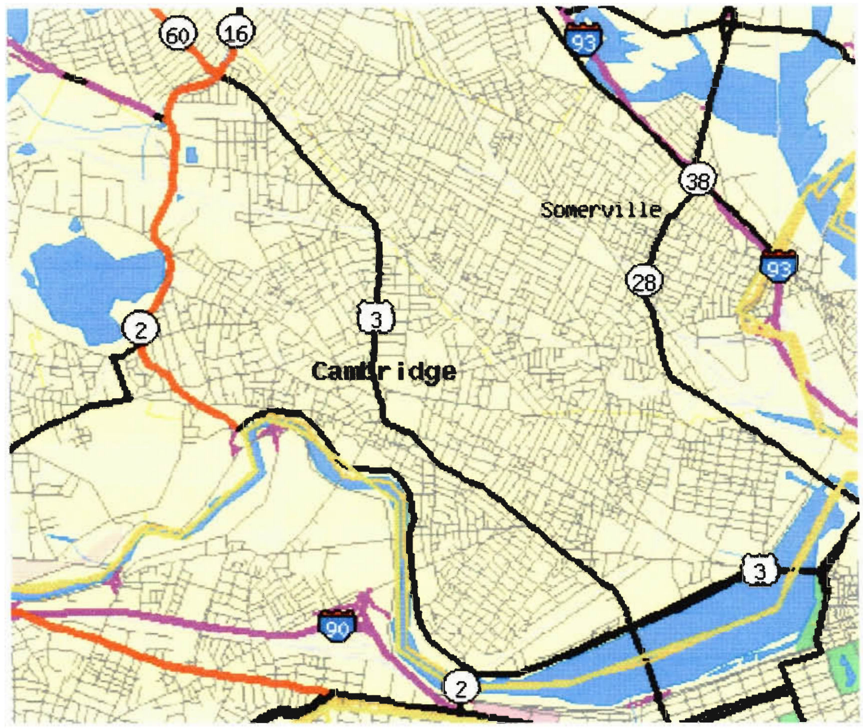

Figure 4: Highways of Cambridge

2.3 Traffic Laws & Regulations

The understanding of traffic laws and regulations is an essential topic for the understanding and development of traffic management systems. With knowledge of the traffic laws, a more effective design of the management system can be planned where relevant gaps in the current data could be spotted and designed into the system to prevent this gap in the future.

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[20] Boston / Your Town [Internet]. Boston: Boston Globe Electronic Publishing Inc.; c2001 [cited 2003 Feb 20]. Available from: http://yourtown.boston.com/town/cambridge/transport.shtml

2.3.1 Current Traffic Laws in Cambridge

Understanding traffic laws in Cambridge is essential to knowing how the system works. The laws that dictate how and when traffic data should be collected are important to the validity of data collected. These laws allow for consistencies in the results of studies even if the same person did not conduct them.

2.3.1.1 Consultant Reports

When a developer decides to build a structure in Cambridge, it may fall under a category of "Project Review" if it meets certain criteria within building zoning laws. Project Review falls under article 19.000 of the City of Cambridge Zoning Ordinance[21]. Section 19.23 of the Cambridge Zoning Ordinance depicts the requirements of a building that is subject to Project Review—part of the table of the requirements is shown below in Table 1.

Thresholds for Required Traffic Study by Land Use Type [22]	
Land Use Category	**Threshold**
Standard Threshold: All Land Uses Set forth in except as enumerated below	50,000 sq ft
Transportation Communication & Utility Uses	
a. Bus or railroad passenger station	Required
b. Automobile parking lot or parking garage for private passenger cars	150 parking spaces
c. Railroad freight terminal, railroad yards and shops	50 acres
d. Truck or bus terminal, yard or building for storage or servicing of trucks, trailers, or buses; parking lot for trucks	Required

Table 1: Thresholds for Required Traffic Study

For instance, if a building is larger than 50,000 square feet, the structure would be subject to Project Review. Once in this state, the developer must go through an application process, which includes conducting a Traffic Impact Study (TIS). The purpose of the TIS is to determine if the development will adversely affect traffic in the City:

> Where a Traffic [Impact] Study is required as set forth in Section 109.24 (3) above the Planning Board shall grant the special permit only if it finds that

[21] City of Cambridge, Massachusetts Zoning Ordinance [Internet]. [updated 2002; cited 18 February 2003]. Available from http://www.ci.cambridge.ma.us/~CDD/commplan/zoning/zord/index.html

[22] City of Cambridge, Massachusetts Zoning Ordinance Section 19.23 [Internet]. [updated 2002; cited 18 February 2003]. Available from http://www.ci.cambridge.ma.us/~CDD/commplan/zoning/zord/zo_article19_project_review.pdf

> the project will have no substantial adverse impact on the city traffic within the study area as analyzed in the Traffic [Impact] Study.[23]

A TIS is based on certain values called Traffic Impact Indicators that determine if the development will have an effect on the study area traffic system or not. The indicators are:

> (1) Project vehicle trip generation weekdays and weekends for a twenty-four hour period and A.M. and P.M. peak vehicle trips generated; (2) Change in level of service at identified signalized intersections; (3) Increased volume of trips on residential streets; (4) Increase of length of vehicle queues at identified signalized intersections; and (5) Lack of sufficient pedestrian and bicycle facilities. The precise numerical values that will be deemed to indicate potentially substantial adverse impact for each of these indicators shall be adopted from time to time by the Planning Board in consultation with the TPTD, published and made available to all applicants.[24]

A consultant is hired to perform the actual TIS and the report is submitted to the Cambridge Transportation Department who then certifies the document of its validity and makes recommendations for the approval of the development. From there, the Planning Board makes the decision as to whether or not the developer may continue with the structure.

2.3.1.2 Transportation Demand Management

The Traffic, Parking and Transportation Department is one of several City departments working together with the objective of improving the transit options available to Cambridge. The group is responsible for improving the City's quality of life by planning improvements to the City's transportation system.

The City's Transportation Demand Management (TDM) programs began in 1998 and are designed to improve mobility and access throughout the City, as well as reduce congestion and air pollution, and increase safety. These programs work to reduce the number of single-occupant vehicles by promoting walking, bicycling, carpooling, public transportation, and other alternative modes. The City works cooperatively with citizens, businesses, and institutions in Cambridge and the Boston area to implement TDM measures. Employers can

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[23] City of Cambridge, Massachusetts Zoning Ordinance Section 19.25.1 [Internet]. [updated 2002; cited 18 February 2003]. Available from http://www.ci.cambridge.ma.us/~CDD/commplan/zoning/zord/zo_article19_project_review.pdf

[24] City of Cambridge, Massachusetts Zoning Ordinance Section 19.25.11 [Internet]. [updated 2002; cited 18 February 2003]. Available from http://www.ci.cambridge.ma.us/~CDD/commplan/zoning/zord/zo_article19_project_review.pdf

have a significant effect on the commuting behavior of their employees by offering financial incentives and promotional programs.

Walking and biking are popular ways of getting around for many people who live in cities. Almost fifty-percent of Cambridge's residents who work in the City walk or bike to work.[25] The TDM promotes both walking and bicycling as healthy alternatives to the other modes of transportation.

The City has also implemented traffic calming projects to improve traffic conditions and increase safety. This involves the creation of physical and visual cues, such as speed tables, sidewalk neck downs, and roadway markings creating a safer environment for all modes of transportation.

2.3.1.3 Parking and Transportation Demand Management

The Parking and Transportation Demand Management (PTDM) Ordinance expands on the TDM program in that it aims at controlling pollution from automobiles. Section 10.18.040 describes the registration of all parking spaces so that a person cannot "create" a new parking area that might lead to cars being blocked in[26].

The Vehicle Trip Reduction Ordinance is also aimed at cutting traffic congestion and pollution. Section 10.17.110 describes the regulation against idling cars and trucks to help maintain air pollution while the following section of the ordinance explains the effort to improve the accessibility of taxicabs so people will have more opportunities to take advantage of public transportation.

2.4 Traffic Management

As the number of vehicles on the road continues to increase everyday, there is a continually growing strain on the transportation infrastructure of cities around the world. Construction, accidents and weather conditions coupled with an excessive amount of vehicles cause increased traffic problems in addition to the everyday ones that are in need of a solution. Basic traffic control measures such as lights, signs, and travel limitations have been around for over a century and have become antiquated in many situations. Today's fast-

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[25] 1990 US Census Journey to Work Data [Internet]. http://www.ci.cambridge.ma.us/~CDD/data/jtw/jtw-alltracts.html

[26] City of Cambridge Community Development Department, Environmental & Transportation Planning Division [Internet]. Chapter 10.18: Parking and Transportation Demand Management Planning; Parking Space Registration; [updated 24 September 2001; cited 1 February 2003]. http://www.ci.cambridge.ma.us/~CDD/envirotrans/ptdm/ordinance.html

paced society needs comprehensive traffic management systems that can help travelers get to where they want to go as quickly as possible.

2.4.1 Traffic Data Collection Practices

The basic element of traffic management is up-to-date traffic information. Data can be collected at various times of day, days of the week, and months of the year to get an understanding of how traffic functions in different areas. There are several different aspects to traffic data collection, each one providing a different type of information about the traffic situation. Within each aspect of data collection, there are different methods to collecting the same data that will yield different results but utilize different technology for collection.

2.4.1.1 Turning Movement Counts

Turning movement counts (TMCs) are one type of traffic data collected that record not only the volume of traffic in an intersection but also where the traffic is going. At a four-way intersection of all two-way streets, each automobile or bicycle can turn left, right, or drive straight through from each approach, allowing for twelve possible turning movements for the intersection. The path that the vehicle ultimately takes is recorded as the turning movement for that vehicle. Information on pedestrians crossing the street can also be recorded during the TMC. Data are collected in fifteen-minute intervals by a person on-site at the intersection. Collection in these shorter intervals allows for alternative data manipulation and aggregation during analysis. The peak hour can easily be established from the 15-minute counts as well as hourly averages and comparisons. Also, when pedestrian data are collected, it can be used to examine critical sums and the interference of pedestrian and vehicular traffic. There are many different methods used in collecting TMCs; each method is used usually depending on budget, since more advanced systems are more expensive.

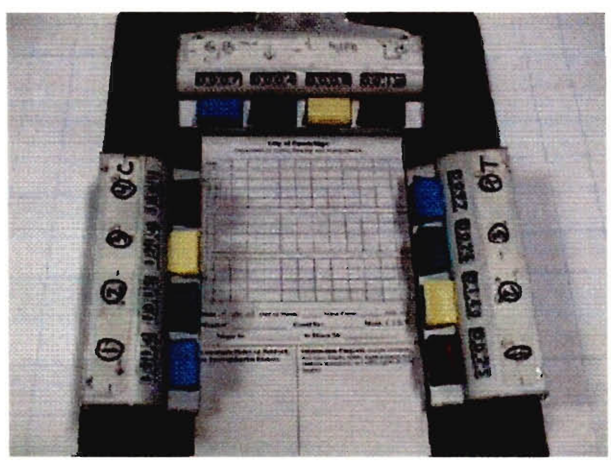

Figure 5: Three-clicker TMC Owned and Used by the Cambridge Traffic, Parking and Transportation Department

The simplest way to collect TMC data is by using clickers as seen in Figure 5 and Figure 6. With these tools, the person collecting data simply assigns a turn or pedestrian movement to a button and clicks the button whenever a vehicle, bicycle, or pedestrian makes that movement. Then, when a time interval is reached, the person must record the values on the clickers, and then continue the counts. At the end of the count, the data collector would have to manually transcribe the counts at each interval to some other summary sheet, or even type them into an electronic database.

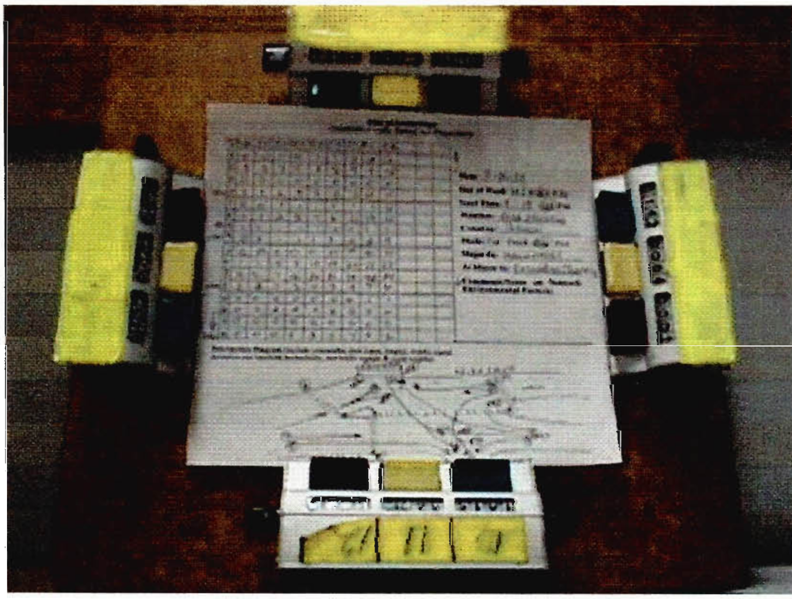

Figure 6: Four-clicker TMC Owned and Used by the Cambridge Traffic, Parking and Transportation Department

Modifications of TMCs usually involve an electronic version of the clickers. A dedicated electronic TMC device would behave in the same way as conventional clickers, but also may be internally programmed to automatically separate the counts into the correct time intervals. An example of these counters, made by Jamar Tech, can be seen in Figure 7. Laptops can also be used on the field to collect TMCs. Laptops would require a TMC program to help collect and extract the data. All electronic forms of TMCs are most useful because the traffic data can be automatically downloaded and sorted in digital form.

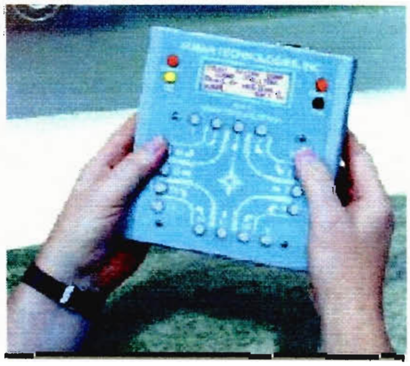

Figure 7: Electronic Turning Movement clicker made by JamarTech

2.4.1.2 Automatic Traffic Recorders

Briefly described in Section I.2.a of the TIS Report in Appendix , collecting general traffic information on vehicle volumes, speeds, type, and sometimes even occupancy is done with Automatic Traffic Recorders (ATRs). ATRs collect data on vehicles that pass over a given point. Typically they are kept out for a period of 48 to 72 hours but only one day is used for the analysis. One type is the traditional ATR, as seen in Figure 8, which consists of two hollow tubes that are placed perpendicular to the road. When the vehicle runs over the tubes, a pulse of air is sent back to the recorder which resides in a locked box on the side of the road. By measuring the time between the tires of the automobile pass over each tube, the recorder can determine vehicle type based on the chart in Appendix . Another type of ATR is the Vehicle Magnetic Imaging (VMI) Traffic Counters pictured in Figure 9. These ATRs sense an interference with the Earth's magnetic field when an automobile passes over it. The VMI Traffic Counters can determine vehicle count, the presence of a stopped vehicle, speed, length, and even occupancy[27].

Figure 8: Traditional Automatic Traffic Recorders Being Placed

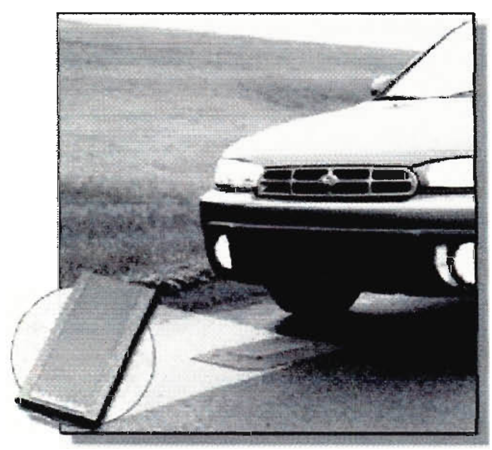

Figure 9: Nu-metrics Vehicle Magnetic Imaging Traffic Counter

[27] Nu-Metrics. Vehicle Magnetic Imaging Traffic Counter / Analyzers. Uniontown, 1995.

2.4.1.3 Measuring Wheel

In order to measure lengths along streets, curbs, and crosswalks, a measuring wheel, like the one pictured in Figure 10, is used. The wheel rolls along the ground and measures distance in feet and inches. The device can be reset to zero by pushing a button on the front face. The measuring wheel allows for a reasonably accurate measure of distances, such as the length and width of crosswalks.

Figure 10: Measuring Wheel

2.4.2 Development of Traffic Management

Traffic management begins with understanding where people are coming from, where they want to go, and when they are trying to get there. Data collection and analysis is the foundation on which traffic management is built. Traffic patterns indicate important information as to why congestion occurs and how traffic can be redirected or better managed to prevent it in the future. The most basic management systems include a systematic collection and storage of data for regular analysis to aid decision-making. With this information, cities can designate certain roads as "one-way" or only allow some actions during less congested hours. From this base, cities can expand with technology and create even better management systems.

2.4.2.1 Intelligent Transportation Systems

Popularized in the 90's, Intelligent Transportation Systems (ITS) are developing into the resolution to many transportation issues. ITS combines new technologies with existing traffic control tools to create a system that can monitor traffic, implement real-time changes and even signal the deployment of emergency vehicles. In 1991, Congress legislated the ITS program to the U.S. Department of Transportation and it has continued to evolve since then. By monitoring traffic through various methods, including video surveillance, ITS can detect congestion and divert traffic through variable message boards placed in strategic locations in the city or change the regularity of light changes to reflect the amount of traffic passing through an intersection[28].

One of the ultimate goals of Intelligent Transportation Systems is the integration of Intelligent Vehicles into the overall system. Intelligent vehicles would be able to access the real-time data being collected by the ITS and offer on-board motorist assistance for route choices along with safety features to attempt to lessen the number of accidents[29].

Advancing technologies open a world of opportunities for development of all-inclusive systems that can control traffic with minimal effort and tremendous benefit to the traveler. Although ITS comes as a major cost to the cities themselves, in the long run it can pay off in the form of more efficient control and safer roadways. The traffic management systems of the future will ask us where we are coming from and where we are going to and get us there safely exactly when we want to arrive.

2.4.3 Current Traffic Management System in Cambridge

Under article 19.000 of the City of Cambridge Zoning Ordinances, developers in Cambridge must conduct traffic analysis of the roadways and major intersections near the development area to prove to the city planning board that the current traffic infrastructure can handle the increased volume that would occur during and after the project completion. These reports, submitted to the Cambridge Traffic, Parking & Transportation Department for review and approval, are one of the main sources of traffic data kept by the City. Although each of these studies contains hundreds of pages of valuable information, organizing and managing it in order to utilize it in different applications has been troublesome due to the varying submission formats.

2.4.3.1 Data Collection and Storage Methods

Currently the Cambridge Traffic, Parking & Transportation Department conducts a minimal amount of their own traffic data collection. When assessing roadway, signal, and sign changes, the City either conducts its own study or hires a consultant firm to gather the data. Similarly, developers needing to fulfill the ordinance requirements typically hire outside

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28 Intelligent Transportation Systems [Internet]. Washington, D.C.: United States Department of Transportation; [cited 2003 January 25]. Available from <http://www.its.dot.gov/faqs.htm>

29 Intelligent Vehicle Initiative [Internet]. Washington, D.C.: United States Department of Transportation; c2002 [updated 2002 May 13; cited 2003 January 25]. Available from <http://www.its.dot.gov/ivi/ivi.htm>

consultants to conduct their traffic studies. Once these studies are completed and the necessary information extracted, the hard copies are shelved within the Department and rarely accessed for comparison to later or similar studies. Several attempts have been made in creating a database to store all the received information such that it is more easily accessible, however; a comprehensive database has yet to be developed.

2.4.3.2 Problems with Current Traffic Management System

The problems with the traffic management system in Cambridge are that data from study to study and even intersection to intersection are not always consistent or standardized due to the various sources from which the data comes. Each consultant submits their data analysis in a different format and only submits the hard copy to the City. This makes it difficult to organize and merge similar data. It also makes it difficult for developers or the City to access data that already exists for their study area from past studies.

2.4.3.3 Existing Data

In previous studies, traffic data were obtained by the Cambridge Traffic, Parking & Transportation Department in several different forms. Approximately 30% of the data are collected in-house by or at the request of the CTPTD. Within that 30%, approximately 33% of the data are collected manually by the CTPTD or Community Development Department and the other 67% by hired traffic counters and consultants. These studies are conducted after constituent complaints in the area, the need for roadwork, resignalization considerations, or in zoning/planning studies.

The other 70% of data are from developers within the City who must comply with the Cambridge Zoning Ordinances. Article 19 stipulates that developers must analyze five main areas: trip generation, level of service, lane queues, bicycles and pedestrians, and residential street volumes. Appendix C shows the current CTPTD guidelines for these reports and the more specific information that is required.

3 Methodology

The goal of this project was to develop standardized procedures for the City of Cambridge for gathering and submitting data, and to design and prototype a computerized system that will allow the City of Cambridge to consistently and efficiently enter, maintain, manipulate and display information to help find ways to alleviate current transportation problems. The team has used new and existing data to aid the Cambridge Traffic, Parking, and Transportation Department in analyzing travel patterns and problems that have developed over the years.

Specifically, this project has:

1. Evaluated the current traffic management practices
2. Developed and tested standardized methods for gathering and submitting traffic data
3. Adapted existing data to newly developed standards
4. Demonstrated the usefulness of the system by interpreting traffic data

This project is unique in that it was difficult to distinguish between methodology, results, and deliverables since they all essentially involved the traffic management database as the central topic. Due to this, the results section focuses on the actual design and format of the database and the deliverables and recommendations section on enhancements that could be made to the database. The methodology focuses on the steps and reasoning leading to the development of the traffic management tool, and more specifically on the following:

- 3.1 Evaluation of Current Traffic Management Practices includes details on the assessment of the current situation in the City
- 3.2 Development and Testing of Standardized Formats describes how forms and standards were created and tested through fieldwork
-
- 3.3 Adaptation of Existing Data to New Standards describes the development of the traffic management to tool and population of it with data

3.1 Evaluation of Current Traffic Management Practices

The City of Cambridge currently has several sources from which data are received as described in Section 2.4.3.3 Existing Data. Guidelines in place through the Cambridge Zoning Ordinances determine the format in which data must be submitted as well as the amount and type of data. Appendix D and Appendix E contain the full text of the submission guidelines of the CTPTD and Section 19 of the Cambridge Zoning Laws, respectively.

The project team has examined the data are collected and studied how it are utilized in managing traffic throughout the City. This was accomplished by analyzing the existing reports kept by the CTPTD as well as interviews with members of the CTPTD and Community Development Department to determine how they use traffic data as well as what information they hope to get from reports and studies conducted.

Evaluating the current practices in place has facilitated the development of standardized forms and procedures because the team better understood how the data needed to be presented and what data needed to be easily and consistently accessible. This also allowed the team to understand what areas more data could be necessary for further collection.

3.1.1 Collection of Data

Data were collected from both existing reports and new counts in the field. This data were used to fill in our database and verify its accuracy and usefulness. Data were collected in the field as deemed necessary by the CTPTD in areas where minimal data existed and changes in the roadway structure were anticipated.

Based on the type of data, the information was organized in the appropriate manners. Consultant, or developer, reports were reviewed and organized based on content. Manually collected data were organized using the database developed by the team and explained in detail in Section 4.3 Adaptation of Existing Data to New Standards.

3.1.1.1 Organization of Consultant Reports

Familiarizing ourselves with the types of information that a report should contain and looking for similarities in the types of data shown from report to report began the organization of consultant, or developer, reports. Once we had looked at each report in detail we began to color tab the pages on our own criteria. We placed and labeled a blue tab on any pages that contained information that we deemed important for a standardize format. A green tab was placed on pages that contained information that was required by the current report guidelines but that we do not see as critical to understanding the impact of a development on traffic. A yellow tab signifies useful summary sheets that are distributed throughout the report, and a pink tab is used to show redundancies in data as well as any graphs or tables that are inconsistent with other areas of the report. By placing these tabs throughout the different reports we created a visual representation of the layout of each report which helped us understand how each developer creates a report and what they include in them.

The initial data ranking outlined in Appendix F, shows that certain types of data are more useful than others. Tier 1 explains the most important elements of the data collection process. The first element, trip generation, is the number of additional vehicle, bicycle, and pedestrian traffic that the development will bring to the study area. The second element is the level of service of an intersection. An algorithm determines the level of service by evaluating intersection data and computing a letter grade ranging from A through F. The third element is the average weekly volume on residential streets, which is the same as the trip generation described above, only for cars that move through residential neighborhoods. The fourth element the data on how many cars become lined up at an intersection on a red light, called queues. The fifth element is peak hour turning movement counts, which is the highest volume of traffic to pass through the intersection within one hour of the day. Primary and Regular turning counts depict the detailed data of the vehicles, bikes, and pedestrians moving into and out of the intersection.

The second tier of elements are ones that are required or used by those preparing the reports, but not necessarily useful to the CTPTD in their data management efforts. The breakdown of traffic into the 13 Federal Highway Administration Classifications, available in Appendix G, is the seventh element. The data collectors sometimes use this information in order to categorize their data, however, typically the CTPTD need only know the difference between cars and trucks and not distinguish into all the categories. The eighth and ninth elements of the list, Public Transit and Parking Availability, are required by the CTPTD guidelines and are useful for understanding how increased volumes of people into the new development area will be handled. All these items have been put on the second tier because they do not directly indicate how traffic volume is increasing in different areas and where it is going and coming from, which is one of the main concerns of the City.

3.1.2 Available Reports and Studies

We received three different reports conducted by developers in throughout the City as examples of the type and format of the data that is submitted by consultants. Vanasse & Associates, with Accurate Counts as the sub-consultant conducting the actual traffic counts, compiled two of the reports. The Charles Stark Draper Laboratory, Inc. report was submitted in August of 2002 and included a Traffic Impact Study (TIS) and special permit criteria analysis. The second, for Technology Square LLC, was submitted in February of 1999 and included a TIS and Planning Overlay Special Permit (IPOP) Analysis. A third report was submitted in September of 1998 as a traffic impact assessment for Cambridge Research Park.

We also reviewed a binder of different traffic counts done by the Cambridge Traffic, Parking & Transportation Department in 1998. The binder contained a number of studies done for individual streets and was evaluated to determine what types of studies are conducted and what formats are useful for the Department. Since this study is broader than the specific developer reports, it assisted us in identifying major information gaps for the City. Also, this data provided seven consecutive days of counting on most streets, offer us the necessary information to help analyze the variations of traffic data from day to day. The Department also maintains a large number of speed checks done on various streets throughout the City. Although many of them are somewhat dated, we were able to retrieve speed checks done on several of the streets in our study area.

3.2 Development and Testing of Standardized Formats

After evaluating the current traffic management practices, the team was more knowledgeable of what information is necessary for the Cambridge Traffic, Parking & Transportation Department to make better use of collected data. With this knowledge, we have evaluated the existing reports received from developers along with the current guidelines in place for the submission of their reports to design and recommend a new standard by which the data were formatted and submitted to the CTPTD. The feasibility of this format was evaluated through the adaptation of current data to this format as well as the collection of new data by the project team in areas for which minimal data exists. New forms were also created using input from those who collect data and previously used forms. The team used the forms when out in the field to collect their own data and verify the usefulness of such forms.

3.2.1 Fieldwork

Fieldwork was conducted on-site at Central Square in East Cambridge at the intersections of Massachusetts Avenue and Brookline Street, Massachusetts Avenue and Douglass St., both pictured in Figure 11, and Massachusetts Avenue and Essex Street. Data were also collected at the cluster of intersections including Massachusetts Avenue, Main St, Columbia St., and Sidney St, which can be seen in Figure 12. We were able to document the turning movements for the vehicles, bikes, and pedestrians for all the intersections. We collected the data for the Massachusetts Avenue/Main Street intersection on March 20, 2003 and all other intersections on both March 25 and 26, 2003.

Figure 11: View from Mass Ave and Brookline/Douglass Intersection Counting Station

This area was chosen by the Cambridge Traffic, Parking & Transportation Department because of the on-going heavy development in and around the area and also lack of current traffic data. A map of the area where our team manually collected data is shown here in Figure 13:

Figure 12: Aerial Photo of the Roadway Intersection at Mass Ave and Main St.

Figure 13: GIS Layer of Central Square

Our team collected data in the field to test different collection methods and to explore the ease of using different formats for data collection. Data were collected from 7am to 9am and again from 4pm to 7pm on each day to capture the AM and PM peak hours. The team chose counting stations at each intersection used the same stations during each collection period on each day to minimize variability due to changing locations. Used the manual turning movement counters described and pictured in Section 2.4.1.1 Turning Movement Counts, the team tracked car, truck, bicycle, and pedestrian movements on all intersections. Car and trucks were tracked independently on intersections where the team felt comfortable counting them separately without it becoming to cumbersome. The team opted not to track the directionality of the pedestrians because accurately recording the large amount crossing multiple crosswalks simultaneously was a burdensome task in itself.

3.3 Adaptation of Existing Data to New Standards

Once the standardized forms were determined, a database for easy storage of the information was developed in order to organize all the information for analysis and manipulation. When this was complete, the team used this method to organize existing data and determine data gaps.

3.3.1 Creation of a Electronic Storage Format

Electronic storage of the traffic information is an essential tool that the Cambridge Traffic, Parking & Transportation Department will use to help make better traffic planning decisions. The electronic storage format was a database implemented using Microsoft® Access XP. In addition, the Access database was linked with GIS layers that visually show the turning movements of the traffic flow. The GIS layer of the turning movements will be viewed using ArcGIS®'s ArcMap 8.2 or MapInfo.

After analyzing the current traffic management and analysis practices of the CTPTD, the team began designing the framework for the traffic database. Reviewing the data collection forms and developer reports submissions, and talking with members of the CTPTD, the team established the information that was important to include in the traffic management system in order to allow for comprehensive analysis of all the traffic data. Data collected by the team were used to begin the population of database and verify its accuracy and usefulness.

In order to create the primary output of the database, our team built upon existing GIS layers that the Cambridge Traffic, Parking & Transportation has developed. Specifically, we used a major transportation layer that displays the actual pavement dimensions of the roads. A centerline layer that displays the centerline representation of the roads, crosswalk layer, and a building dimensions layer were also used. The existing identification numbers from the intersections and street segments of these layers were used within our access database so they linked to the existing GIS layers. New identification numbers for crosswalks were developed utilizing the street segment number the crosswalk is on and a letter assigned from north to south.

Current traffic information that is in paper format was manually entered into the Access database. Similarly, current traffic information that is in a digital format was imported into the Access database.

3.3.1.1Importing Existing Data

Collecting traffic data is the process of collecting large quantities of numbers, all of which are divided into many fields. The goal of the database is to store all the traffic data for the City of Cambridge in one central location—one file. Also, an extreme amount of traffic data has already been collected by the Cambridge Traffic, Parking, & Transportation Department. However, the only information entered into our newly created database is the information our team collected on the intersections of the major street, Massachusetts Avenue, and minor streets: Essex, Brookline, Douglass, Main, Columbia, and Sidney. Ideally, the CTPTD wants to populate our database with as much existing traffic data as possible.

First, for the database to be somewhat effective, the existing traffic data need to be in a digital format of some kind. This can be a tab delimited text file at its lowest form. If the digital data are already in a spreadsheet, please skip to the next paragraph. A tab delimited text file is one in which the columns and rows are divided up by tab characters. To import this file into the database, an intermediate step with a spreadsheet such as Microsoft® Excel is required. The first step is to copy all or portions of the text file that is to be entered into the database. The copy portion is then pasted into a spreadsheet. For a tab delimited text file, the copied text should automatically paste itself into the appropriate cells in the spreadsheet rather than incorrectly pasting all the text into one cell. This pasting function has been tested and proved true with Microsoft® Excel. Now, the text from the tab delimited file is into a spreadsheet, with each column and row correctly inserted into each corresponding cell of the spreadsheet.

The second step is to then format this spreadsheet so that it correctly matches the setup of the database. This step is taken after the spreadsheet has been created from the tab delimited text file, or the digital data have already been received in spreadsheet form. As a reference, the destination table within the database should be viewed in order to see the layout of the fields. The spreadsheet then needs to be formatted so it matches the layout of the database exactly—with the same fields in the same locations. The leftmost field which corresponds to the database field labeled "auto-number," should be left blank so the database can modify this field itself. Also, the column headings should be removed to avoid pasting these text cells into the database.

The final step is to import the spreadsheet into the database. The raw form of the destination table needs to be open; this is different from the interface from which a user would manually enter in the data. To open the raw tables, press "close" on the opening menu of the database interface. Once the destination table is located, select the last line marked "auto-number", and paste all the contents from the spreadsheet here. The database now contains all the digital data from the spreadsheet, correctly auto-numbered.

Importing digital data into the database is tricky. Different programs used to collect traffic data often output the data into different formats. Therefore, every program outputs its data in a slightly different way. This degree of variance in formats forces human intervention when importing the data into the database. The formats all need to be altered to match the database. Ideally, if there was one standard format for digital files, a single macro could be written to modify these files so that they would fit perfectly into the database. If there was a standard format, all digital traffic data files could be imported automatically. Since all digital files slightly differ in format, and human intervention is required to make the format compatible, the time it takes to import the data drastically increases as opposed to letting the macro automate the import. Depending on the speed of the user and the size of the file being imported, it could take a significant amount of time to import a single digital file. However, if a macro could be written to format the data, the time to import a file would be significantly less. One option is to create a single macro for each of the different formats that need to be imported. This translates most of the labor into programming the macro, however, significantly reduces the time to import the data since the macro only needs to be written once for a specific format.

4 Results & Analysis

The main result of this project is the traffic information database that will be used to manage existing and newly collected traffic data from all the sources supplying the Cambridge Traffic, Parking, and Transportation Department. Standard formats have been created for data collected by the CTPTD and the guidelines for the submission of consultant reports will be adjusted accordingly to reflect a format compatible with our database.

4.1 Validity of Data

Sources of error can exist in all aspects of data collection and research. Data collection techniques, data entry, and general assumptions about traffic data can all be sources for errors or misinterpretation of the legitimacy of data. The data collected must be met with some degree of internal validity in order to certify that the data are within a reasonable range of accuracy. The project team felt it was important to validate different assumptions about traffic data as well as analyze various sources of error that could occur in order to develop a comprehensive analysis system that could possibly identify incongruent data that might represent an invalid dataset or mistakes in data entry.

4.1.1 Threats to Internal Validity

A significant threat to internal validity that affected our data occurred on Tuesday, March 25, 2003 during the data collection at Massachusetts Avenue and Brookline Street, Massachusetts Avenue and Douglass, and Massachusetts Avenue and Essex Street. During the morning rush hour shift, a fire broke out in the Necco building just a few blocks down Massachusetts Avenue. A section of Massachusetts Avenue was closed around 8:15am and was not reopened until 9am, forcing us to assume that traffic on Massachusetts Avenue was altered. A decision was made to collect data on these two intersections the following day to help identify and analyze if the data were in fact atypical and understand how the street closure ultimately affected volume. However, the fire also occurred during the first two hours of data collection on that intersection when several other variables could have also affected the data that were collected during that time. Unquantifiable variables such as inexperience in our data collection techniques and large buses and delivery trucks stopping and moving slowly in front of our counting stations could also have contributed significantly to the variation of the data during that time.

In order to examine the effects of such variables like inexperience on the data, the team had hoped to place ATRs near the intersections in our study area in order to verify the numbers we collected. Even without the fire occurring, the ATR would have allowed us to see if we were reasonably accurate with our turning movement counts. If the numbers were similar, the Necco Fire would have been the most probable result of the traffic variation. If the numbers where not similar, then it can be said that the variation of traffic was a result of inaccurate data due to some of the variables mentioned above. However, the counters were not ready to be placed in time to meet our schedule for data collection in the field. An analysis on the data collection on March 25th and March 26th can be found in Appendix J.

During data collection of turning movements, it was found that the congested traffic on the narrow Massachusetts Avenue proved difficult to have perfect visibility of the intersections. At times views were totally obstructed due to buses and other large vehicles that were either queued at a red light, or parked along the side of the road, making it impossible for a direct line of sight to the intersection. To minimize this error, our team did our best to gain a better position on the intersection to keep line of sight and our turning movements accurate.

Despite all these probable sources of error, it is also reasonable to assume that these sources of human error exist during all data collection efforts. Physical limitations are always a problem, and even though we were only novices at collection, later comparison with historical data showed that our data were within a reasonable range to make the assumption that it was in fact accurate.

4.1.1.1 Verification of Assumptions with Traffic Data

There are several common assumptions that are made about traffic data. The first is that the variation from day to day of traffic volume is always within $^{+}/_{-}$ 10% during the week. Understanding the validity and accuracy of this assumption was necessary in order to examine such things as abnormalities of traffic flow during the Necco fire described in the previous section. Verifying such information will also help in the future development of the advanced features of our traffic management tool. Another assumption is that traffic data collected on a Monday or Friday is inherently flawed due to unique changes in traffic patterns and flow on those days.

In order to analyze the assumptions on the variability of data, the team utilized data from city-wide Cordon Counts conducted in 1998, which are the most recent consecutive day counts available at the CTPTD and described in greater detail in Section 3.1.2 Available Reports and Studies. The data were analyzed during the time of 5am to 7pm on Monday through Friday in order to evaluate the $^{+}/_{-}$ 10% assumption. The data were also used to examine the whether data collected on Monday and Friday were uncharacteristic of daily averages as is typically assumed.

Data for Cambridge St. and Binney St. were entered into an excel spreadsheet. The data were analyzed by the hourly volumes. The maximum and minimum values for the volume during Monday-Friday were extracted and then the maximum and minimum values from Tuesday-Thursday only were obtained. The average volume per hour for Monday-Friday was then calculated. All graphs showing the summary of these volumes and findings can be found in Appendix J. The graph in Figure 14 shows one summary graph for traffic traveling westbound on Cambridge St.

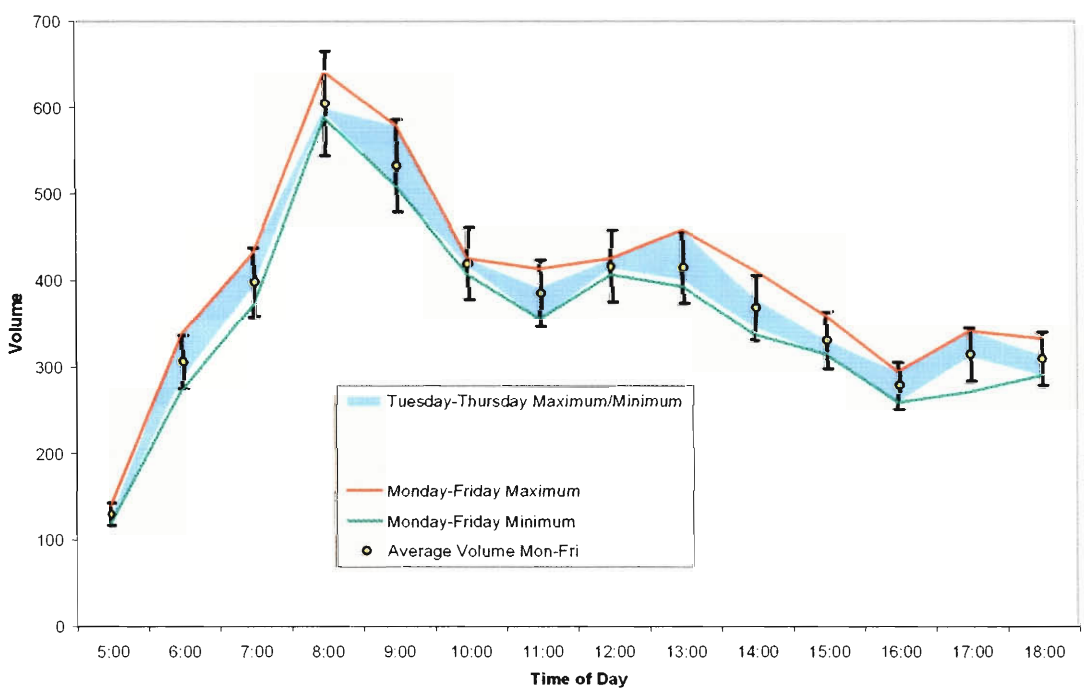


Figure 14: Summary of Traffic Traveling Westbound on Cambridge St

The black bars extending from the Average represent the +/- 10% variation that would represent accurate datasets. The blue shaded area is contained completely within the error bars displaying that the Tuesday-Thursday data are accurate. However, the red and green lines, representing the maximum and minimum values when Monday and Friday are included are not always contained entirely within the bars and are often at the extremes if they are within the limits. This proves that Monday and Friday data significantly skew the data, not allowing it to be within 10% from day to day. Therefore, both assumptions can be considered true but are dependent on each other in order to verify that assumption.

The team also examined a recommendation made by Kathy Watkins of the Community Development Department in which it was proposed that recording "exact" numbers from the turning movements or ATRs represent a false sense of accuracy. It was suggested that data need only be kept in even increments of 5 or 10 to appropriately represent the data collected.

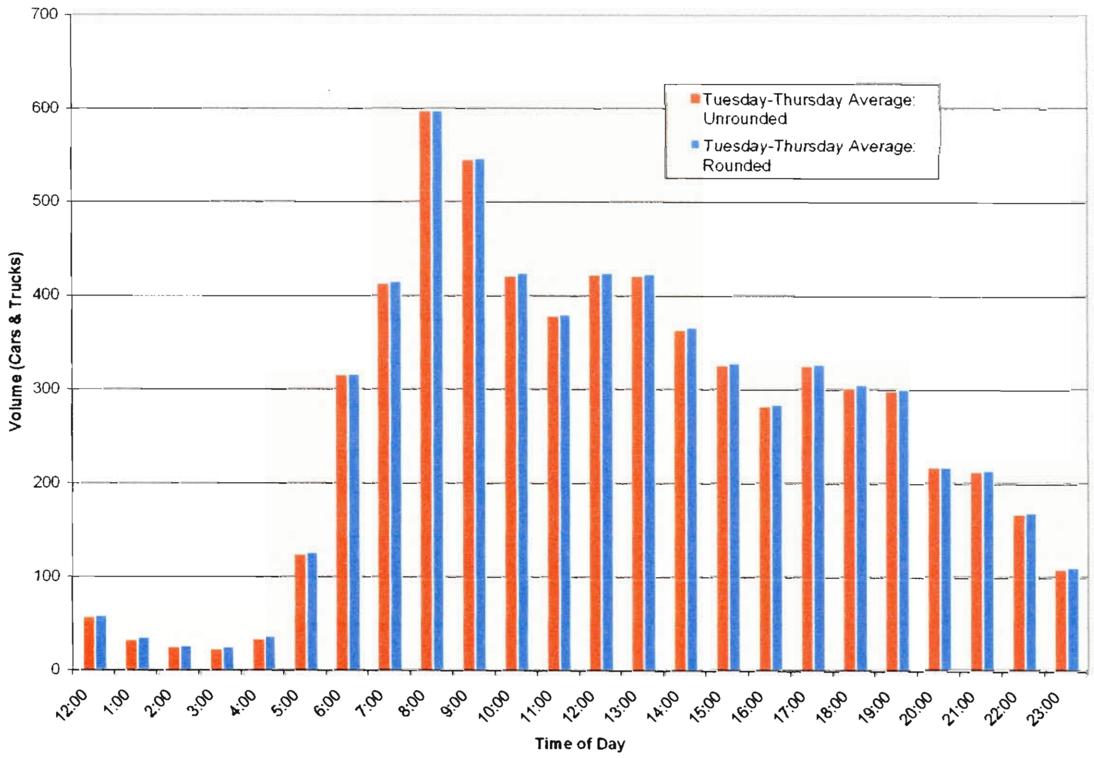


Figure 15: Summary of Traffic Traveling Westbound on Cambridge St. Comparing Rounded and Unrounded Averages

Figure 15 shows the Tuesday-Thursday Hourly Averages both in their exact form and rounded, represented by the red and blue bars respectively. The rounded data were always rounded up to the nearest 5; such that 67 cars would become 70 and 71 cars would become 75. As the graph shows, the data are always close, such that it would not affect the data for analysis purposes. The averages of the rounded numbers will never be more than 4 cars off from the averages of the exact numbers, so with the exception of small volumes, the data will remain within the 10% variation while not giving a false expectation of accuracy.

4.1.1.2 Analysis of the Necco Fire Street Closure

As mentioned above, data collected on Tuesday, March 25th 2003 was considered in accurate during the 8am to 9am hour due to a fire at the Necco Building located at 254 Massachusetts Avenue, down the street from where the team was stationed. Figure 16 shows a map of where the fire occurred, represented by the flames, relative to the two data collection stations from that day, represented by the red crosses.

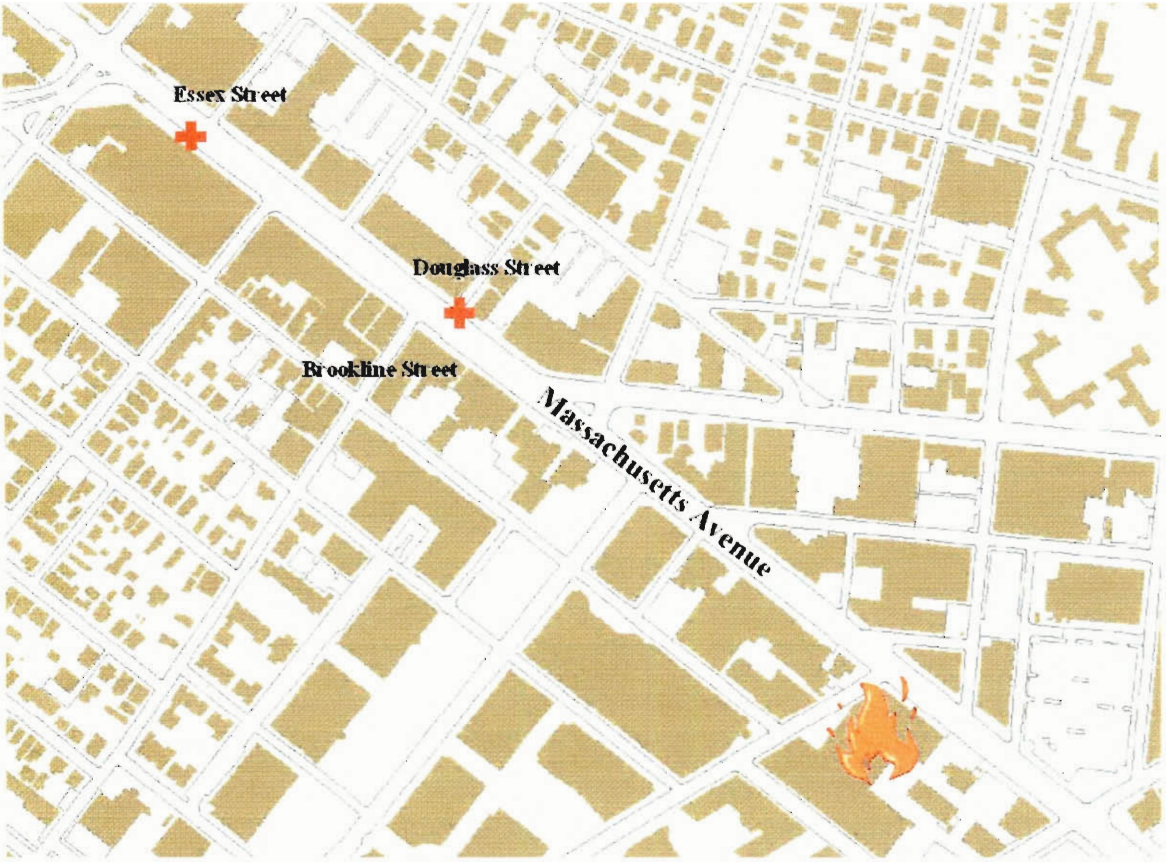


Figure 16: Map of Counting Stations Relative to Necco Building Fire

Based on the verification of assumptions from the previous section, we were able to compare the data collected on March 25th and 26th to analyze the effects that the closure of a portion of Massachusetts Avenue had on our data collection. The data were collected on a Tuesday and Wednesday, meaning both sets should have been accurate representations of the data. If the data from the morning of the fire were invalid, it would not be within 10% of the following day's data and we conclude that the street closure caused our data to be inaccurate.

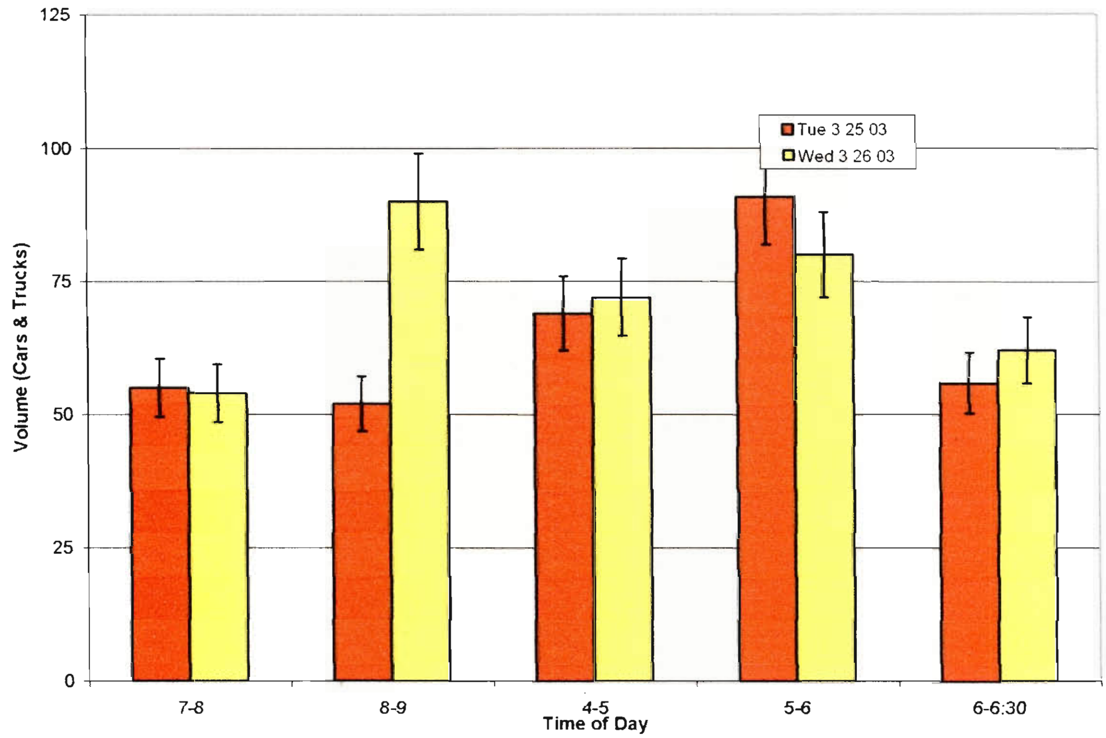


Figure 17: Traffic Traveling Westbound on Mass Ave Turning Right onto Essex St. on March 25th

As displayed in Figure 17, traffic during the 8-9am hour does not fall within the $^{+}/_{-}$ 10% range. This graph is representative for the majority of vehicular traffic from that day. Some of the bicycle data were harder to examine, due to the extremely small number of bikes for some hours. The pedestrian data during the fire seemed to not be affected at all, because the street was not closed to pedestrian traffic. As mentioned above, the graphs from the day of the fire can be found in Appendix J.

4.2 Development of Standardized Forms and Procedures

In order to standardize data entry, forms were developed that will serve as a template for all data that is gathered. This way, when data is collected by members of the CTPTD, it will be consistently organized and easily entered into the traffic information system. Existing forms were recreated in the computer for easier reproducibility and updated to reflect changes and information deemed important to collect during traffic studies.

4.2.1 Raw Data Collection Sheets

Sheets for recording the raw data were developed to ensure that the appropriate information was collected and to facilitate the recording process. Sheets were developed for both manual turning movement count (TMC) boards owned by the CTPTD. One board had 3 sets of clickers with 4 buttons each. The other board has 4 sets of clickers with 3 buttons each. The recording sheets have a row for each clicker data to be recorded at 15-minute intervals. It also contains spots for the data collector to identify themselves, record environmental variables, temporal information, as well as diagram the intersection in detail and make any special notes about the condition of the network or environment at the time of the count. Both of these raw data collection sheets can be viewed in Appendix H.

4.2.2 Data Summary Sheet

A sheet for the summary of raw data was developed in a similar format to an existing sheet used by the CTPTD to gather information and can also be found in Appendix H. Often in counts, there are several counters at one intersection. Rather than having to file the raw data in several sheets for each section, it was decided that a summary sheet could gather all pertinent information for easy maintenance of the raw data along with facilitated entry of information into the database. The sheet has all the same information as the raw data sheets but contains room for twelve vehicular movements, twelve bicycle movements, and crosswalk volumes all in one central area. This also allows for easier manual entry of data into database because all information is contained on one central sheet.

4.3 Adaptation of Existing Data to New Standards

Storage of the data was computerized in the form of a database system which allows the user to perform various functions to extract useful information. Functions such as searching, sorting, extrapolating, interpreting and graphing of trends have been implemented to assist the user in manipulating, analyzing and updating transportation data.

4.3.1 Creation of an Electronic Storage Format

Our database contains nine interconnected tables as shown in Appendix I. The relationships between these tables allow for all information that is entered to be crosschecked for validity. Information about each intersection is stored in our *Intersection* table. The information in this table defines an intersection as the crossing of two roadway centerlines, as shown in Figure 18:

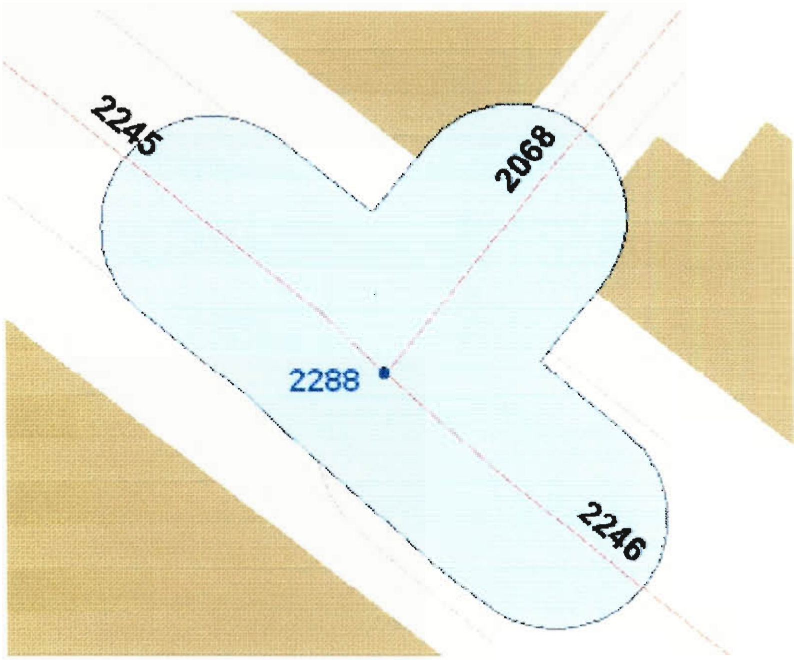


Figure 18: Link Intersection

This concept of intersection is consistent with previous GIS datasets thus making the two systems compatible. The *GIS Node Intersection* table is composed of the following fields: *IntersectionNodeID, IntersectionID, Signal Control ID, Traffic Control,* and *SignalControllerID*. The *IntersectionNodeID* field is the primary key of the Table. "The primary key of a relational table uniquely identifies each record in the table."[30] Each *IntersectionNodeID* is related to number that is used as a node ID in our GIS layers. The *Signal Controller ID* is a foreign key and serves to relate this table to a *SignalController* table. This field serves to uniquely identify each signal controller within the City. The *Traffic Control* defines what classification the signals of an intersection are. *IntersectionID* is a foreign key in the *Intersection* table used to relate the *Intersection* table with the *Roadway Intersection* table. "A foreign key is a field in a relational table that matches the primary key column of another table. The foreign key can be

[30] Chapple, Mike. What you need to know about databases.
http://databases.about.com/library/glossary/bldef-primarykey.htm

used to cross-reference tables."[31] Having the *IntersectionID* as a foreign key in the *GIS Node Intersection* table allows access to check each table to make sure the ID's are valid.

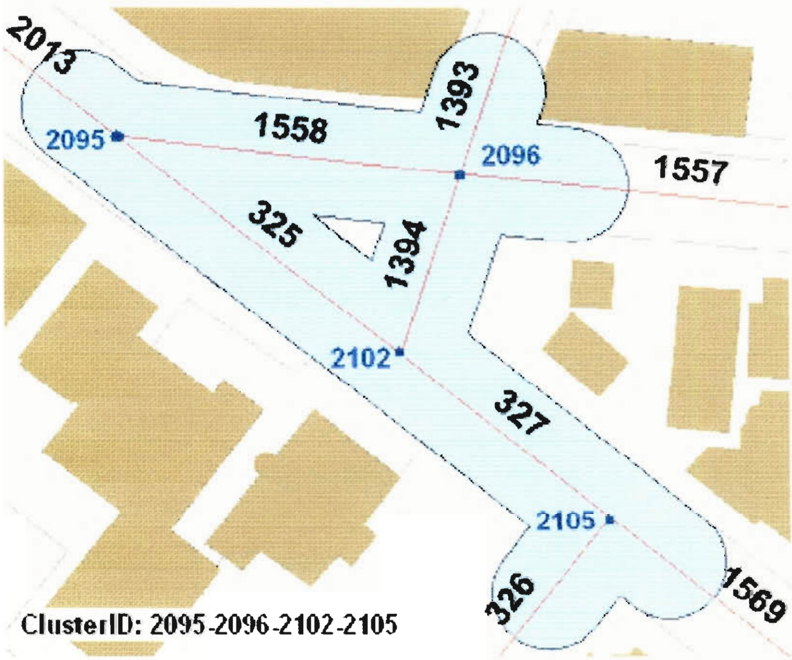


Figure 19: Clustered Intersection

The second table pertaining to intersections is called the *Roadway Intersection* table. This table defines an intersection as a group of convening roadways that may consist of two or more intersecting roadway centerlines, as shown in Figure 19. This table will allow for a more comprehensive analysis of closely related intersections. The *Roadway Intersection table* consists of an *IntersectionID* field. This field is the primary key of the table and serves to link this table with the *GIS Node Intersection* table as will as *Traffic Counts for Roadway Intersections*. The *IntersectionID* is a number comprised of all the node ID's within that intersection. Each node ID within a roadway intersection will be put together with hyphens to comprise the *IntersectionID*.

The traffic count table, *Traffic Counts for Roadway Intersections* stores the most recent vehicular turn movement count data. This table includes the following fields: *StudyID, IntersectionID, Date, Time, Primary, Secondary, Bikes, From Link ID, To Link ID, Movement Code,* and *Volume*. The *StudyID* is the primary key for this table and is stored as an auto number field within our database to prevent any duplication. The *Date* and *Time* show precisely when the study was done. The *Primary, Secondary,* and *Bike* fields are yes/no options indicating the type of study done. If total vehicular volumes are being studied the *Primary* and *Secondary* fields may be chosen together to indicate total vehicular volumes. The *From Link ID* and *To Link ID* fields designate the movement from segment to segment and allows for directionality.

[31] Chapple, Mike. What you need to know about databases.
http://databases.about.com/library/glossary/bldef-foreignkey.htm

The *Movement Code* is a combination of the *From Link ID* and *To Link ID* including any *SegmentID's* in between. *Volume* is the field where all traffic count numbers are stored.

The database also includes a *Pedestrian Count* table which stores all current pedestrian movement counts for each crosswalk. This table includes the following fields: *PedCountID*, *Date*, *Time*, *CrossWalkID*, and *Volume*. The *PedCountId* is the primary key for this table and is also set as an auto number field. *Date* and *Time*, as in the above tables, shows precisely when the study was done. *CrossWalkID* is a foreign key in this table and serves to relate the *Pedestrian Count* table with the *Crosswalks* Table. Finally the *volume* field displays the numerical volumes for each crosswalk.

Permanent information about each crosswalk in the City is stored in the *Crosswalks* table. The fields included in this table are: *CrosswalkID*, *IntersectionID*, *SegmentID*, *length*, *handicap access*, *Signal Type* and *Pattern Type*. The *CrosswalkID* is the primary key for this table and is comprised of the SegmentID of the segment it is on as well as a letter with the most northern crosswalk having an "A". *IntersectionID* shows the user where the crosswalk is on the segment. The *SegmentID* illustrates an overall picture of where the crosswalk is located and allows for crosswalks that are not in an intersection to be included within the database. *Handicap Access* as well as *pattern type* serves to better illustrate the kind of crosswalk identified.

Two of the tables within our database store information on each segment of roadway within the City. In our database as well as in GIS a segment is defined as a link of roadway connecting two intersecting roadway centerlines. The first of these, the *Segments* table stores all permanent information for each segment. The fields in this table include: *SegmentID*, *From IntersectionID*, *To IntersectionID*, *StreetName*, and *Speed Limit*, *Speed Limit Posted*. The *SegmentID* is the primary key for this table and is consistent with GIS ID's. The *StreetName* field contains the name that encompasses all segments of a particular street. The *Speed Limit Posted* field is a yes/no field indicating placement of signs. The *Speed Limit* indicates the posted speed limit.

The second of the segment tables, the *Segment Speed Studies Table* includes all current speed studies done for each segment. The fields in this table include: *Speed Study ID*, *SegmentID*, *From IntersectionID*, *To IntersectionID*, *Date*, *Time*, *Min Speed*, *Max Speed*, *85% speed*, *95% Speed*, *Ave Speed*. *Speed Study ID* is the primary key for this table and is set as an auto number field. *SegmentID* is a foreign key and serves to link this table to the *Segments* table. The *Date* and *Time* fields tell the user when the study took place and the *Min Speed*, *Max Speed*, *85% speed*, *95% speed*, and *Ave Speed* provide additional segment speed information.

The Automatic traffic recorder table is connected to the Segment table through the *SegmentID*. This table includes the following fields: *AtrID*, *SegmentId*, *From IntersectionID*, *To IntersectionID*, *Date*, *Time*, and *Weather*. The primary key of this table is the *AtrID* and provides a unique identifier for each study done. The *SegmentID* is the foreign key within the table and serves to link this table to the segment table. *From* and *To IntersectionID* show directionality and the *date*, *time*, and *weather* give more detail to each study.

Our database also includes tables that store information on the signals around the City. The first of these tables is the *Signal Controller* table contains the following fields: *SignalControllerID*. The *SignalControllerId* is the primary key of this table and uniquely identifies all signal controllers within the City. The second of these tables is the *SignalHeads* table. This table includes *SignalHeadID* and *SignalControllerID*. *SignalHeadID* is the primary key and defines a specific head within the City. The *SignalControllerID* is a foreign key and serves to relate this table to the *SignalControllerID*, by doing this there cannot be a signal head that can be entered without a corresponding signal controller.

Each table within our relational database is linked to another in order to reduce the number of redundancies and errors that occur in data entry. In order to link two tables the primary key of the first table is placed as a foreign key in the second. For example, the primary key of the Intersection table, *IntersectionID*, is linked to the *From IntersectionID* in the *Segment* table as a foreign key. This means that when any new segment is introduced into the *Segment* table it must have a corresponding *IntersectionID* in the *Intersection* table. In this way a segment can not exist without an intersection. The *Segment* table has one primary key, the *SegmentID*. This key allows for a unique identifier within the table. While the *IntersectionID* field links to the *Segment* table, the *SegmentID* is placed as a foreign key within the *Segment Speed Studies* to insure that each respective speed study has a corresponding segment. Within our database each table has a primary key and that key is then placed in an adjacent table as a foreign key. In this way each table is linked to another as shown in Appendix I.

4.3.2 Development of an Interface for Data Entry

The interface that was created for data entry was based on the standardized data collection sheets seen in Appendix H. We began by exploring the different ways data could be entered into our database. One way of entering data is to open each table and enter the information in the corresponding fields. While this may be the simplest design for a database, it allows room for error such as accidentally editing of past records. In order to prevent this, an interface was made so that the user can enter information into the system without viewing or having direct access to past records. There are four forms that the user can use to enter in new traffic data including Pedestrian Counts, Traffic Counts, Segment Speed Studies, and Automatic Traffic Recorders.

The Pedestrian Counts form allows the user to enter new records without being able to edit historical ones. This form can be seen in Figure 20, it contains all the information within the Pedestrian table. The *PedCountID* field is grey because the user may not change the number within it to help eliminate any error as well as prevent duplicate ID's.

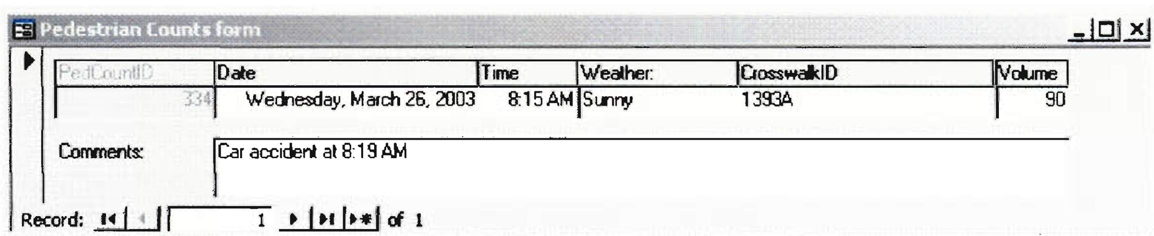


Figure 20: Pedestrian Entry Form

The Traffic Counts for Roadway Intersections entry form includes all the fields within the Traffic Counts table with the addition of one extra field. The *Time Interval* field was added to make the data entry process easier. When the "Copy to New Record" button is used to create a new record, each field within the form is copied to the next record to eliminate the need to enter redundant data. A picture of this form can be seen in Figure 21. The *StudyID* appears on the form but can not be altered by the user this is shown by the gray background of the box. When the "Copy for New" button is pressed the *Start Time* field is incremented by the amount (in minutes) of the *Time Interval*. All of these provisions were made to help eliminate some human error. Once the user has entered a number of records they can be reviewed by pressing the button arrows at the bottom of the screen. The button on the bottom with an arrow and asterisk will create a brand new record when different numbers need to be entered. This allows the user to look back through each record and check for errors. If an error is found within the records the user may change it or if the record should not have been added they can delete it by pressing the "toilet" icon.

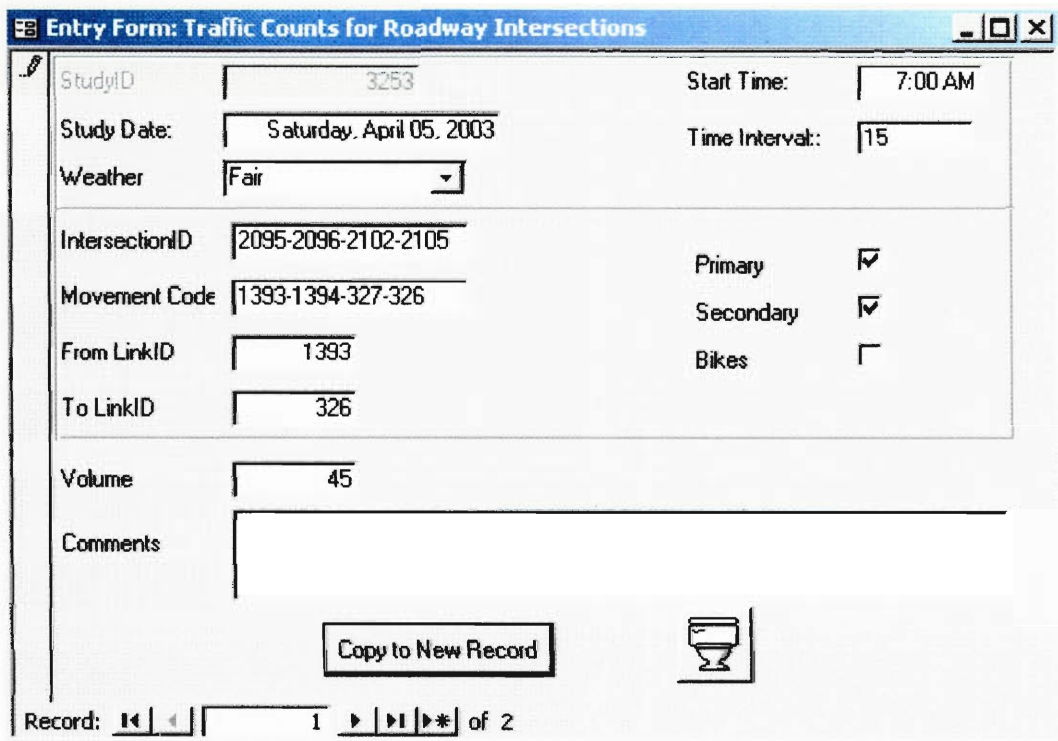


Figure 21: Traffic Counts for Roadway Intersections Entry Form

The third form made for data entry is the Segment Speed Studies Entry Form. This form contains all information within the Segment Speed Studies Table. The fourth form is the Automatic Traffic Recorder Entry form which contains all the information in the Automatic Traffic Recorder table and allows the user to enter in all desired information and then look through them for any possible errors. Each of these forms looks similar to the figures above. Once these forms are closed they are saved in the tables despite the fact that the user never sees them. If a mistake was made on any particular record they may open up the table in edit mode in order to make desired changes.

4.4 Demonstration of the Usefulness of the System by Interpreting Traffic Data

The project team used existing data in the storage system developed in order to manipulate it in manners desired by the Cambridge Traffic, Parking, and Transportation Department for their use in traffic management. We also used new data to verify and validate the system we have created to prove its usefulness to the Department. This has displayed for the Department the importance of having and maintaining such a system and also give rise to opportunities to explore areas of the system that could be expanded on to include more advanced tools.

4.4.1 GIS Integration

In order for the information in the database to become useful for any user, the data have been integrated with GIS layers of Cambridge using Map Info 7.0 and viewable in both that program and ArcGIS®'s ArcMap 8.2. This way, a more visual approach to data analysis is obtained, allowing for more accurate decisions to be made on traffic flow adjustments.

As described in Section 3.3.1 Creation of a Electronic Storage Format, existing GIS layers of the City's major transportation, centerline, crosswalks, and buildings were combined with our intersection layer which depicts a buffer of each intersection in our study area. The intersection layer acts as a study area marker, showing the user exactly what intersections have turning movement data for them. A second layer was created which contains the arrows that depict the turning movements as well as labels over each arrow that show the volume of that move. An example of a turning movement layer for vehicles is shown below in Figure 22.

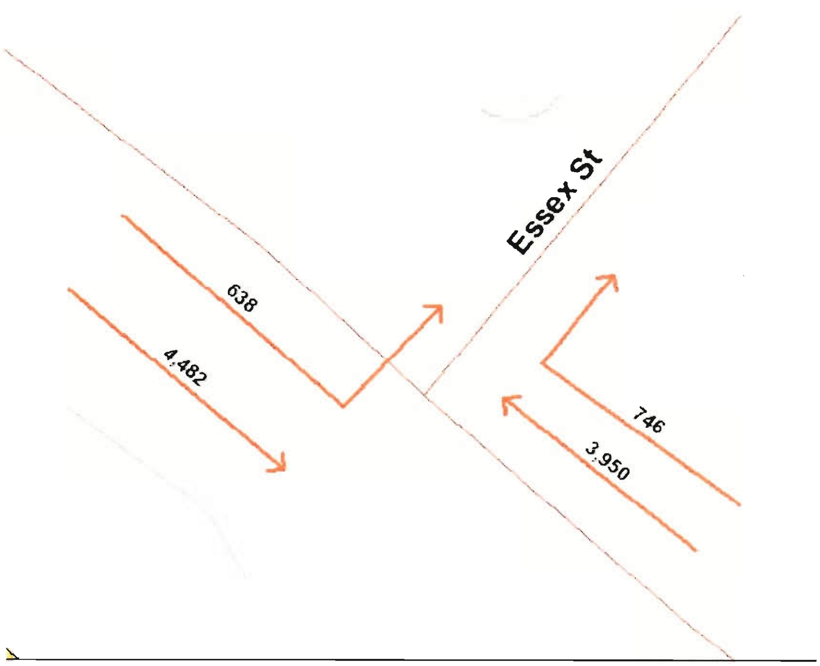


Figure 22: Turning Movements for Vehicles

The lines were created by hand-drawing lines over the street layer that represented the turning movements. The lines were traced in the direction of how the cars traveled—this means that the lines were always drawn from back to front. The lines were positioned to make sure they did not overlap length-wise with other lines. Arrows, which were not hand-drawn, then needed to be inserted on the lines. Since the lines were always drawn from back to front, the lines could be formatted to be arrows instead of lines—with the arrowhead always being placed at the front of the line.

The layers were created using MapInfo because that program offers an extensive amount of thematic maps and functionality that can enhance the visual aspects of the layers. Figure 23 depicts a layer that shows on of the many thematic maps that can be displayed by MapInfo. This figure shows an example of pie charts that can be placed over the lines to show the user the percentage of cars, trucks, and bikes that made the specific turning movement. However, the Cambridge Traffic, Parking, & Transportation Department heavily relies on a mapping program made my ArcGIS® called ArcMap 8.2 and the following describes how the MapInfo layers can be imported for use with ArcMap. The layers created in MapInfo were saved as a combination of files that work together to create the layer. These files, which consist of a .sbn, .sbx, .shx, and the two main files, the shape file (.shp) and database file (.dbf), were simply transferred over to MapInfo. This was done by simply clicking "add data" and selecting the shape file (.shp), and setting it to the correct projection. The projection is the coordinate system location within the world that the layer is set. The correct projection category the layer needs to be set in is:

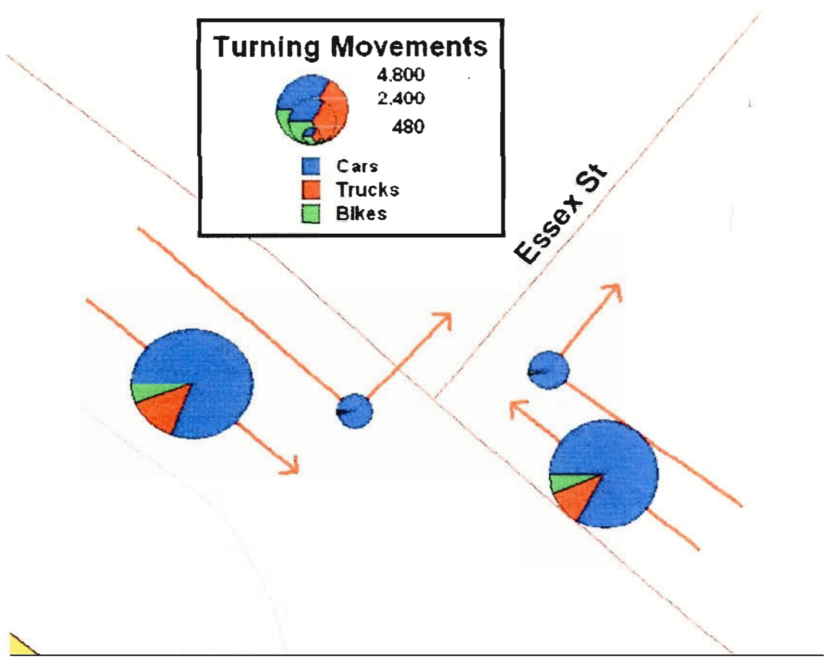
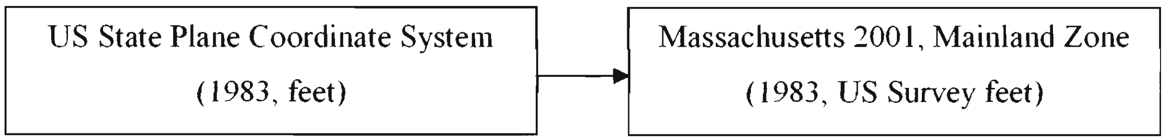


Figure 23: Turning Movements in MapInfo with Pie Charts Summarizing Data



Using almost this same method, layers can be created in ArcMap as well. Creating the turning movements would consist of the same process as in MapInfo—hand-drawing the lines and setting them as arrows.

To link the turning movement layers to the database, the process is almost identical on both the MapInfo and ArcMap programs. Our database described in Section 3.3.1 Creation of a Electronic Storage Format, would be connected to the program. Within the database, there is a table that has fields for movement code, and the volumes of cars, trucks, bikes, and vehicles. To display the volumes on the layer itself, the appropriate label is selected to show what the user wants.

4.4.2 Graphical Outputs of Database

Analysis of traffic data is important to the CTPTD so it was essential for the database to produce data that can be quickly extracted and viewed for analysis. This allowed us to demonstrate for the department the usefulness of our database. Figure 24 shows a graph produced for the historical analysis for the intersection of Sidney and Massachusetts Ave. Such analysis was desired to show traffic volume and turn movement trends, and more specifically a before-and-after analysis of an intersection or road that has undergone changes. This graph will also aid the CTPTD in analyzing the potential for change. The Department is looking to change the intersection to make Sidney a through street to Columbia. By looking at this graph they can look at the changes in traffic volumes over time. This graph was produced from data that were extracted via a query and manipulated to make graphs that would aid the CTPTD.

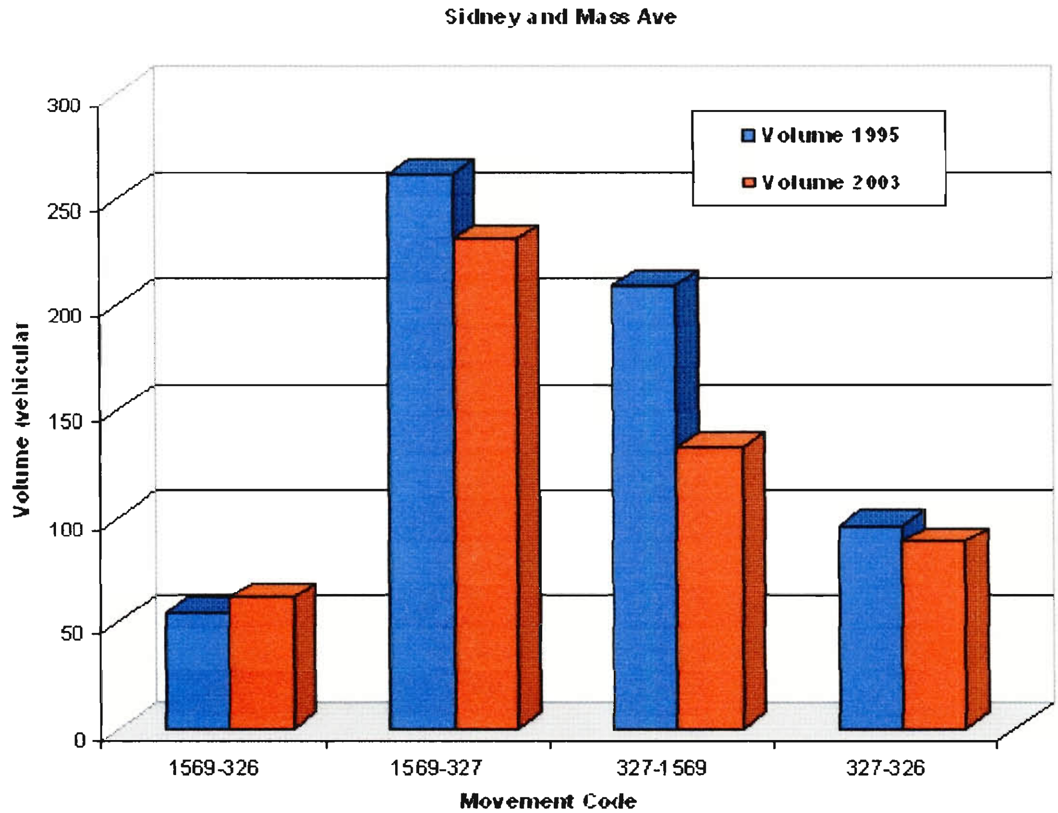


Figure 24: Historical Analysis of Intersection

A second graph that was produced using the data within our database can be seen in Figure 25. Each bar within the graph represents a different intersection the blue indicates all volumes for the intersection of Brookline, Douglass, and Mass Ave. The red bar shows volumes for the intersection of Mass, Main, Columbia, and Sidney. Finally the yellow bar shows volumes for Mass and Essex. These volumes are the hourly sums starting at 7AM. By looking at this graph the CTPTD can identify peak hours as well as compare consecutive intersections volumes. While the bars can be used for easy visual comparisons, the exact numbers can be seen in the table below the graph.

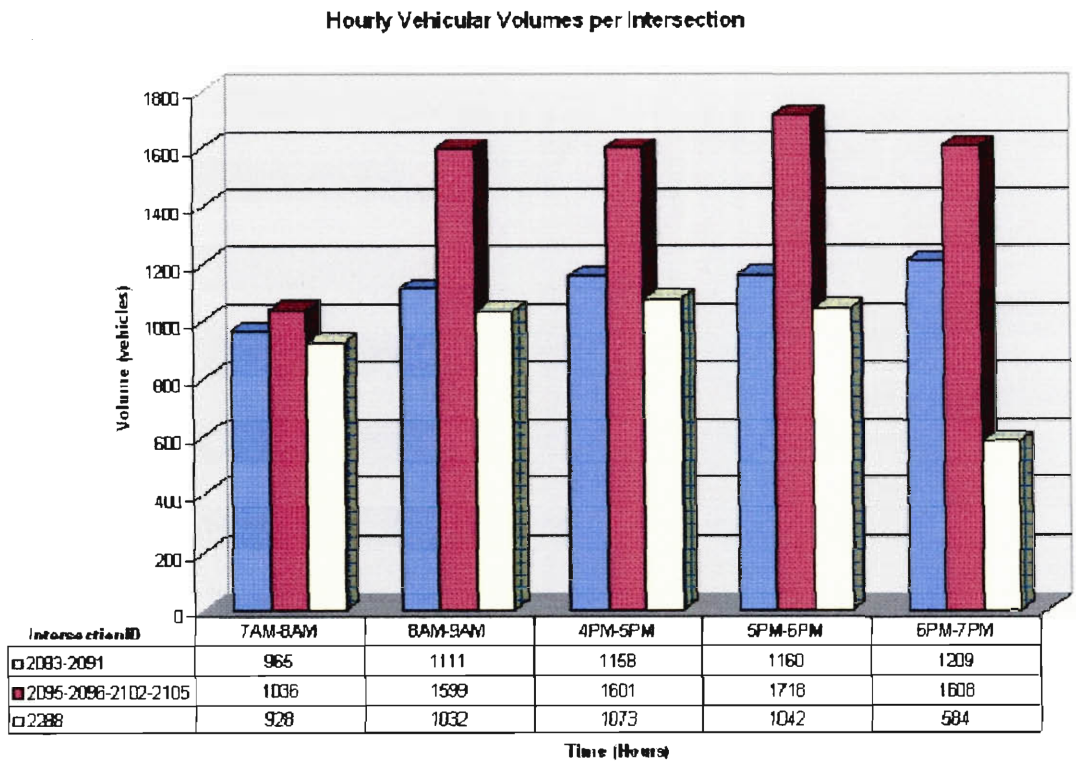


Figure 25: Volumes per Intersection

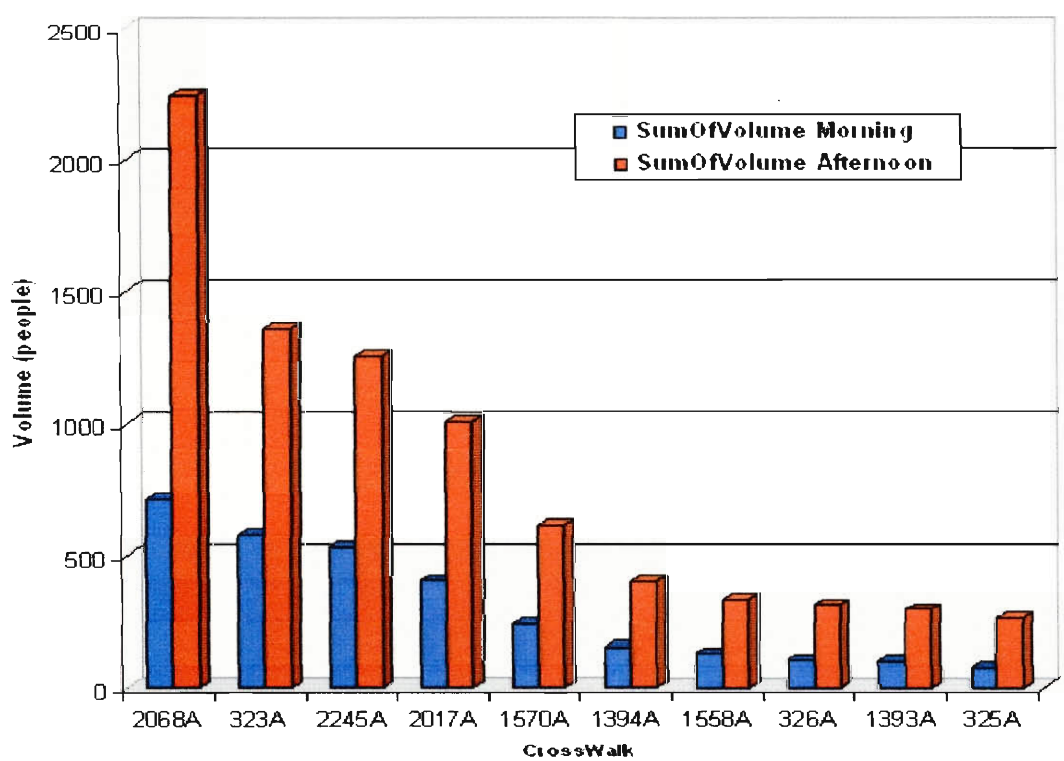


Figure 26: Top 10 Busiest Crosswalks

Figure 26 shows a graph of the top 10 busiest crosswalks for the morning and afternoon volumes with the busiest crosswalks on the left side. The crosswalks can be viewed any way a user wishes however, we specifically made this graph to show the busiest crosswalks on the left. The crosswalk ID's are listed across the bottom of the graph and their volumes depicted by the bars. From Figure 26 we can see that often times more than double the volumes of people use crosswalks in the afternoon than in the morning. The top 10 busiest intersections for bikes and vehicles can also be analyzed using graphs similar to the one shown in Figure 26.

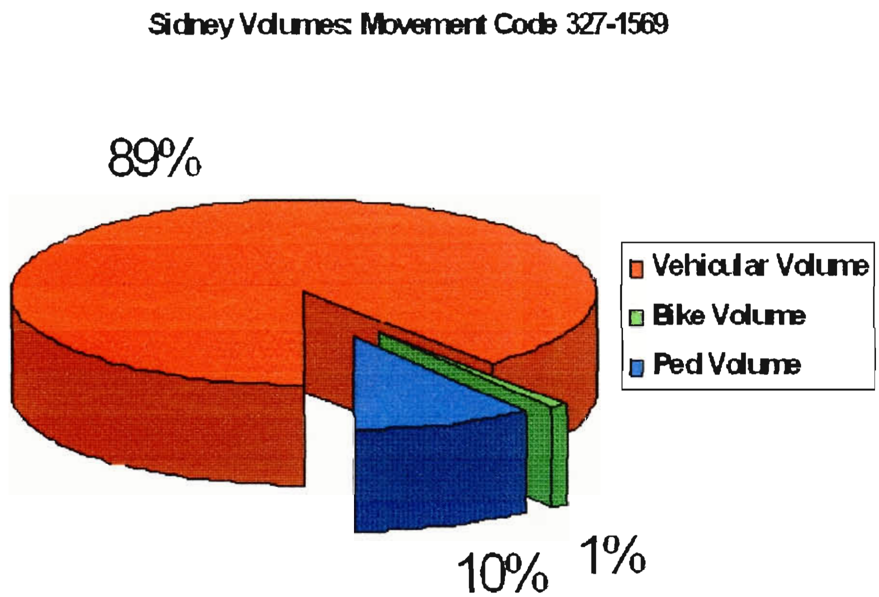


Figure 27: Modes of Transportation

The pie chart above shows the breakdown of volume for a given movement code. The movement code broken down here is the movement from Sidney to Mass Ave eastbound. Although this particular pie chart shows the breakdown for one movement code, it can be used for an entire intersection if desired.

5 Deliverables and Recommendations

The end deliverable of this project is a comprehensive traffic management tool framework that allows the Cambridge Traffic, Parking and Transportation Department to have a single, electronic location for the maintenance and manipulation of traffic data. This database, in its most basic form, is able to manage all current traffic information as collected by the CTPTD but is also dynamic and able to support future changes and adaptations that will occur as the City grows and changes.

5.1 Advanced Options for Traffic Management Tool

This project has served to develop a basic foundation and framework for a traffic management tool for use by the Cambridge Traffic, Parking and Transportation Department. However, with continued work and development, the tool could be expanded to allow for greater functionality and use across different departments and applications. The following sections describe ideas for additional features and functionality that our traffic management tool is prepared to handle and allow for in the future as well as recommendations for the database in its current condition.

5.1.1 Increased Interactivity of GIS Layers

In its current state, the traffic management tool allows the user to zoom into an area of the GIS layer in the ArcMap or MapInfo software application and automatically view updated traffic information for the intersections in view. Further interactivity could be added to these GIS layers, allowing the user to select other data representations to view than the standard turning movement arrows currently available.

Another element of interactivity that could be added would be dynamic study areas. Currently, the CTPTD selects a study area for developers within which they must conduct their traffic studies. However, some of these areas are heavily overlapping, creating a situation where data are repeatedly collected in one area and nearby areas have little or no data. Using existing Access queries which can identify intersections that have recently had multiple studies conducting on them, the CTPTD could develop the ability to select study areas for new developer reports based on where studies have previously occurred. By selecting the intersection on the map nearest where the development would be built, the tool could color-code nearby intersections based on the number of recent studies conducted and the study area could be customized to maximize the useful information gathered by the reports.

5.1.2 Integration with Existing Databases

In order to get more functionality and diverse uses for the traffic management tool, it is recommended that other databases already existing within the CTPTD be integrated with this new database, allowing information to be simultaneously extracted for analysis. An example of such a database would be the existing traffic crash database. Thousands of records in this database locate crashes within Cambridge based on the streets on and near which they occurred. This could be valuable information when analyzing traffic flow along a segment or at an intersection. In order to link it with our existing database, it would need to be linked by the street name. However, because each street name was manually entered in the crash database, many are misspelled and not in a standardized format, making data extraction extremely difficult. In its current form, the crash database is not easily linked to our database and GIS layers, and would take a considerable amount of time to alter the street name field to be the standard, accessible names.

It is recommended that a data entry interface be implemented for the crash database, and any other databases, that would allow for drop down menus to select the streets and intersections, standardizing information entry and making later retrieval easier. If all this information is maintained using the same foundation, it can all be integrated into a more comprehensive tool.

5.1.3 Cross-Departmental Applications

Although this traffic management tool was created specifically for use by the CTPTD, as it develops it would be a straightforward way to maintain and share data collected by different departments and assist with planning across departments. An example would be the upkeep of painted lines on a crosswalk. The crosswalk table in our database stores such information as crosswalk type, or pattern, length and width. Information could be added that stores the type of paint use on the crosswalk, the average life of the paint on the street, and the date last painted. During budget planning, the database could be consulted to view the number of crosswalks that would be due to be painted that year, the type of paint, and the amount needed based on the square-footage of the crosswalk itself. The

CTPTD could more properly prepare for occurrences and anticipate scheduling the field work with the Public Works department in advance.

5.2 Standardization of Consultant Reports

Currently, guidelines from the Cambridge Zoning Laws and the CTPTD, as described previously in the report, stipulate what information must be gathered and interpreted in order for the development to be approved by the Cambridge Planning Board. In order to maximize the ease of maintaining data collected through consultant reports in the newly created traffic management tool, it is recommended that the city of Cambridge require all raw data collected in support of the reports be submitted electronically in a standard format that is easily transferable to the database. Along with the electronic submissions, the 'site code' reference in the raw data files must be standardized to a value that is acceptable and practical for the CTPTD in identifying the area studied and reading into the database.

In is recommended that the TIS Guidelines in Appendix be appended as follows:

III. Reporting Procedures

...

2. <u>The TIS Report shall be printed double-sided and distributed as follows</u>:

   a. Two (2) copies to the Cambridge Traffic, Parking & Transportation Department;

   b. Two (2) copies to the Cambridge Community Development Department; and

   c. One (1) copy directly to the Cambridge traffic consultant or other designated representative for peer review.

   d. One (1) electronic copy of all volume and turning movement counts in a Microsoft Excel file in the following format:

      i. Standardized site code will be the intersection ID or intersection cluster ID available from the Cambridge, Traffic, Parking and Transportation Department

      ii. A traffic count setup that matches the database with the fields as follows:

         i. StudyID
         ii. IntersectionID
         iii. Date
         iv. Time
         v. Primary

vi. Secondary
vii. Bikes
viii. From LinkID
ix. To LinkID
x. Movement Code
xi. Volume

iii. A pedestrian count setup that matches the database with the fields as follows:

i. PedCountID
ii. Date
iii. Time
iv. CrosswalkID
v. Volume

5.3 Creation of Numbering System for Non-Street Segments

In order to identify turning movements while facilitating linking our traffic management tool with GIS, existing segment ids were extracted from the GIS tables and integrated into our database. However, there are many 'segments' throughout the city of Cambridge that are unnumbered because they are not designated streets. Driveways and entranceways to parking lots are examples of areas where a large amount of turning movements can occur and need to be accounted for in studies. Especially in larger developments that may be creating larger employee parking areas or parking garages and must account for increased trip generation by new employees, it may be necessary to conduct studies on these non-street segments. A numbering system must be developed and implemented for these non-street segments such that the data can be appropriately entered into the database. The database currently allows for the user to add new records and a new street segment could easily be added. As well, the segment could be identified and numbered in the GIS layer so that is can be placed spatially on the map and data retrieved in the same manner as other turning movements.

5.4 Development of a Key for Intersection and Segment Identification

Currently, the intersection and segment IDs that are the basis for data entry and linking the database with GIS are only available from the GIS layer at the CTPTD. Therefore, in order for developers and consultants to access these numbers for standardization of their reports they would need to go through the CTPTD. However, a key could be developed to identify segments, intersections, and roadway intersections and made available to those developing the reports in order to facilitate the process. This would make it easier to request the standardization of electronically submitted files and save time in having to adjust the files to the appropriate IDs after the data are submitted. This key could also include the standard street names to be used when identifying streets to keep from alternate names being used. By creating this standard key that must be utilized by the developers, it would prevent them from collecting data at unrecognized street segments or areas without discussion with the CTPTD.

5.5 Backup and Recovery of Database

The concept of maintaining all traffic data in a single area can be useful but also has its drawbacks. In the event that the computer on which the database is stored crashes or the file is infected with a virus or otherwise compromised it is important that a recent backup copy of the database be available. It is recommended that a system for creating regular backup copies of the database be created to avoid such a problem from occurring. The database should be stored on the network where it is accessible to all necessary users and can more easily be saved in several locations.