Transit Priority to Improve Bus Running Time;

A Specific Case in Boston

Thesis for the Master Degree in

Transportation, Infrastructure and Logistics

by

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Abstract

This master-thesis analyzes the deployment of congestion protection strategies to improve the bus running time through a specific case; an intersection in the city of Boston, United States of America. At this juncture two bus routes, operated by the Massachusetts Bay Transportation Authority (the transit authority), suffer from congestion impacting on their travel time. Different congestion protection strategies –strategies that procure a sense of priority- are evaluated using a micro-simulation program. The results are presented in terms of the travel time and the delay suffered by the transit vehicle and other vehicle classes. To implement the proposed strategies at the intersection an analysis of the policies and actors, technology, and management tools is performed. Throughout the analysis several aspects, which have limited the deployment of congestion protection strategies in the city of Boston, are identified. The research concludes that in order to implement congestion protection strategies a shift in perception towards the dependency to use private vehicles and old common practices of priority is to happen in the United States of America. Furthermore an improvement in running time for the bus is achieved when the traffic signal control -fixed time- is changed to vehicle actuated. The report is concluded with suggestions for further research.

Preface

The work presented in this master-thesis is the result of months of research performed at Northeastern University in Boston, United States of America and at the Delft University of Technology in Delft, The Netherlands, which would have not been possible without the help of several people which I thank in the ensuing.

Dr. Peter Furth has given me the opportunity to conduct this research at the aforementioned institution in the United States of America. I would like to thank him not only for the opportunity but the insight, guidance, enthusiasm and the overall experience. Without him this work would have not been made possible. In addition, I apologize for the delay that was created to finalize this research. Furthermore, thank you to everyone at Northeastern University who provided me with their unconditional support, help and friendship during my time at the university. In specific I would like to thank Mr. Burak Cesme for his invaluable support, guidance, assistance and for those memorable times we had; "Baklava". I really learn and enjoyed my time at Northeastern University and in Boston, my gratitude goes out to everyone.

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To Mom, Dad and Diana, thank you for your understanding, enthusiasm and patience to make this possible. You have been there in so many ways that it is impossible to describe. To my family, who has also supported me in imaginable ways. I dedicate this work to you.

L.A. Kusters Viale
January 2010, The Netherlands

Executive Summary

This master-thesis focuses on deployment of transit priority to improve the bus running time, with particular attention to the intersection of Massachusetts Avenue and Beacon Street in the city of Boston, United States of America (USA). At this intersection, large traffic volumes generally create congestion impacting on two bus routes operated by the transit authority A solution to improve congested situations is possible by deploying congestion protection strategies. Procuring a sense of priority towards the public transportation vehicle they are implemented throughout the use of different strategies. However, despite their benefits they have seen limited deployment in the United States of America and the city of Boston. The report concludes that a change from fixed time to vehicle-actuated traffic signal program reduces delay and improves travel time for public transportation. Further benefits arise by the application of strategies such as a priority call or a bus lane over the Harvard Bridge. The benefits arise primarily from the elimination of the protected left turn from the control phase, improving primarily public transportation vehicles inbound and other vehicle classes. However, to deploy the congestion protection strategies requires a shift in perception of public transit and the dependence of private vehicles in the United States of America. These two issues can be considered as the initial constraints towards the limited implementation of congestion protection strategies.

Deriving from the problem definition, the research has centered on trying to answer the following research question:

> *"What are the necessary policies (changes or new), technology strategies and management tools that can work together to improve the running time by giving priority to public transportation in Boston?"*

This question is answered by firstly answering a series of sub-questions that have been established to deal with the various subjects addressed as part of the research process. The thesis is structured in four parts; Part I serves as the research demarcation and a brief discussion regarding public transportation, congestion protection strategies and the transit authority provided as background information. Part II proposes and evaluates different congestion protection strategies for deployment at the intersection in question. Part III analyzes the policies and actors, technology and management tools behind public transportation to implement congestion protection strategies. Part IV discusses the possibilities to implement the proposed strategies through a synthesis. The main findings of the research are discussed by answering the main research question along with the various sub-questions. Finally, the part and the report are brought to an end with suggestions for future research and a reflection from the author.

Part I Background

In *Chapter 1* the research demarcation describes the problem, problem owner, research objective, research questions and sub-questions and, the research scope and structure.

In *Chapter 2* the importance and role of public transportation and the impacts of congestion are described in terms of the benefits and impacts on society, image, reliability, the environment, non-users, and economic development among others. In the United States of America the car is still the preferred mode of transport while the perception of public transit is towards the less fortunate. The modes and network of the transit authority are briefly discussed. The Massachusetts Bay Transportation Authority, the fifth largest in the country with daily ridership over 1 million, serves 175 cities and towns operating a vast infrastructure and range of modes. The transit authority embarked in a bus service route (the Silver Line) deploying congestion protection strategies. Congestion protection strategies are slight modifications to the road geometry and or traffic control procuring a sense of priority towards the transit vehicle. Bus Rapid Transit (BRT) and Transit Signal Priority (TSP) are two of the most common congestion protection strategies deployed in the USA. BRT is a cost efficient and flexible alternative to rapid transportation. TSP, a feature of BRT and one of the most successful, is a tool to improve the running time of a bus by introducing a priority call within the traffic control phase. The Silver Line (SL) incorporates the basic elements of a BRT; implementing gates and or tunnels, and conditional Transit Signal Priority at a few intersections. The SL, illustrates the use of old common practices of priority –underground- which are still preferred despite the high investments and justifications compared with TSP. Regardless of the priority strategies, the Silver Line has been highly beneficial; reducing travel time, increasing ridership and improving the reliability of the bus service. Other transit authorities in the State of Massachusetts have successfully implemented congestion protection strategies at some intersections and or bus corridors.

In *Chapter 3* state-of-the-art cases from the USA and around the world are presented. Throughout the world different cases have delivered benefits and lessons to improve development and deployment. In the United States of America different cases are presented highlighting the priority strategy, characteristics, benefits and barriers that resulted from deployment. Within each case, a wide range of benefits resulted but the barriers can be considered as similar by all cases. Institutional barriers, such as high complexity given the number of actors and communication between actors, as well as other greater obstacles, which arise from the institutional barrier referring to coordination and communication between actors need to be addressed. These can be addressed through partnerships. In addition, the bureaucratic process in which these projects fall needs to be considered. Minimizing such process and the bureaucratic hurdle that comes with the project can be achieved through the leadership of one of the actors involved. In this particular case, through the Central Transportation Planning Staff –in charge of multimodal transportation planning and analysis-can provide such leadership to develop and deploy congestion protection strategies not only at the relevant intersection but also throughout the city of Boston. The agency can promote the necessary communication, coordination and partnerships between actors that will encourage the deployment benefiting the transit authority and its users.

Part II Site Evaluation

In *Chapter 4* the characteristics of the intersection of Massachusetts Avenue (Mass Ave) and Beacon Street subject to evaluation of diverse congestion protection strategies are described. To account for downstream and upstream effects other intersections are considered; Memorial Drive (downstream) and, Marlborough Street and Commonwealth Avenue (upstream) over Mass Ave. Massachusetts Avenue is a major north to south thoroughfare connecting the cities of Boston and Cambridge. To cross the Charles River, the Harvard Bridge is an important landmark between the intersections of Memorial Dr. and Beacon St. During baseball season, Mass Ave provides an excellent alternative to reach Fenway Park via Beacon Street. The intersection is chosen due to its characteristics; infrastructure surrounding (historical buildings and the Harvard Bridge), high traffic volumes, road geometry, location of bus stops and the traffic control program (protected left turn). All of these characteristics participate in the creation of congestion hampering the bus. Furthermore, they represent a constraint towards the different congestion protection strategies that can be deployed.

In *Chapter 5* the relevant intersections are analyzed in a quantitative manner. The intersections following the approach depicted in the Highway Capacity Manual are calculated in respect to their volume/capacity ratio, average delay and Level of Service. As observed in the field and resulting from the calculations several streams have a volume to capacity ratio higher than design levels impacting their Level of Service (LOS). Primarily, inbound -stream 11- over the intersections of Memorial Drive and Beacon Street are affected generating a queue. The cause can be attributed by protected left turn at Beacon St. and insufficient green time at Memorial Drive. Allocating longer green time by increasing the cycle time and or eliminating left turn possibilities by rerouting traffic are possible solutions to improve the performance of the intersections and increase their Level of Service.

In *Chapter 6* different congestion protection strategies are proposed through “scenarios” to improve/decrease the bus running time at the intersection of Mass Ave. and Beacon St. The scenarios are developed based on the characteristics of the relevant intersections as described in Chapter 4. The scenarios consider changes in the traffic signal control without making changes to the road geometry. Seven scenarios result. A “as-is” scenario is developed in order to compare the current situation with the proposed strategies. To incorporate Transit Signal Priority within the traffic control and evaluate all possible strategies the traffic control program is modify, fixed time to vehicle actuated. This resulted in two different scenarios. A scenario evaluates the possibility of actuated left turn by introducing it in the traffic control phase. The change in traffic control program eliminated protected left turn, reason for proposing this scenario. A scenario to increase the capacity of the intersection is proposed by modifying the lane markings. To improve the operational speed and performance of the bus a bus lane over the Harvard Bridge is proposed. This scenario is evaluated as well introducing a priority call to cross the intersection. Finally, to evaluate the future performance of the bus and other vehicles at the intersection, two scenarios are developed increasing the traffic volumes.

In *Chapter 7* the results of the scenarios –proposed strategies- modeled using a micro-simulation program are presented. The results are based on two performance indicators; delay –average delay over the travel section- and travel time –average travel time over the travel section. Introducing a priority call within the vehicle actuated traffic control program and or a bus lane represents one of the best congestion protection strategies for the bus with minimum impact over other vehicle classes to be implemented. Inbound and outbound movements are balanced and protected left turn eliminated as the traffic control program is changed. The change represents an improvement in the bus running time and minimization of the delay for the bus, even if congestion protection strategies are not preferred. However, there is a slight increase in delay for all vehicle classes and the effect over side streets is not considered.

Part III Policy, Technology and Management Tools

In *Chapter 8* the "carrots and sticks" for public transportation projects considering congestion protection strategies in the United States of America identified at the relevant intersection are analyzed. The "carrots", policies and programs provide the funds for public transportation projects. Notwithstanding the achievement of public transportation projects, the policies lack "sticks", penalties for none attainment of the project. Through an actor analysis the actors and their main objectives are analyzed, visualizing the interrelations between policies and actors. A reference framework is proposed towards setting thresholds as the initial step to compare the objectives with the results of any transit project, therefore, developing "sticks" for none attainment. A discrepancy exists at the policy level between rail and bus projects competing for funding. A distinction between modes is required. Funding resources are provided through Federal, State, and or local sources. Local shares of up to 50% are required for public transportation projects to qualify for other funds, e.g. Federal resources. The local share forces State and local agencies to go through long and difficult processes and or even find innovative ways to accomplish the required funds. Jurisdiction conflicts at the intersection arise given the large number of actors; they own, operate and maintain the roads, traffic signals, bus stops, the bridge and other infrastructure. Such conflict represents from the transit authority point of view one of the primary constraints to implement and deploy priority strategies. The number of actors requires agencies to create cooperative and well-built partnerships. In addition, communication channels need to be defined in order to achieve congestion protection strategies.

In *Chapter 9* the software and hardware required to deploy congestion protection strategies, more over, the technology for Transit Signal Priority (TSP) is described. The capabilities of the traffic signal in the United States of America are briefly discussed to analyze the available products offered by different manufacturers. The technology developments during the last decades have improved the systems in terms of their management, operation over networks and vehicles leading to a diversification of products, requiring standards. These standards regulate manufacturers and their products. Between products, primarily for TSP, there is still a strong relation between hardware and software capabilities. The information provided by the manufacturers is unclear in terms of the capabilities of their products. The products, communication capabilities between traffic signal controller and detection systems require in many cases the use of different products. Therefore, the use of a wide variety of products to achieve the priority strategy increases investment, threatening the project.

In *Chapter 10* performance measures as management tools used by transit authorities to fine-tune the operation and service quality are presented. The Massachusetts Bay Transportation Authority evaluates its operation and service through several performance indicators to make improvements or propose new services and their quality. Several performance indicators are used to evaluate the bus service. Nevertheless, the impacts of congestion over the bus or public transportation vehicle are not quantified. The MBTA is compared with other major transit authorities in the United States of America. The performance indicators for the MBTA and given the transit profile make the MBTA a productive and cost effective transit authority. However, its cost efficiency is one of the highest in the USA driving the budget of the authority to a deficit. An analysis of the key bus routes as defined by the transit authority is made in order to assess the impact of congestion (in minutes) over the bus. Accounting for other factors besides congestion, the delay suffered for all bus routes is considerably high primarily in the afternoon peak.

Part IV The End

In *Chapter 11* a synthesis, the main findings, recommendations and a reflection are presented. The synthesis discusses the possibility of implementing the proposed congestion protection strategies at the relevant intersection considering the actors, policies, technology, and performance measures. The primary constraint to deploy congestion protection strategies is given by the jurisdiction conflict. Actors need to overcome their preference over the car and the perception of public transportation. Further, partnerships and communication channels are required to achieve the implementation of priority strategies. Willingness and skepticism from the actors needs to shift recognized by the benefits of public transportation and congestion protection strategies. However, the proposed congestion protection strategies can be deployed if all actors, through the leadership of the CTPS and or the MBTA participate with the same objectives and enthusiasm.

The main conclusions reached are based on answering the main research question and sub-questions considering the objective of the research. Answering the main research question towards improving the running time of the bus in the city of Boston; 1) a policy focusing towards public transportation priority at a State level should fund transit projects while transit authorities over come their jurisdiction conflicts through cooperative programs and or partnerships. The policy should specify the “carrots and sticks” to implement such projects. 2) Technology manufactures should be able to provide more and specific information about their software and hardware. 3) Transit authorities should apply performance measures quantifying the impacts of congestion towards public transportation in order to provide information which can be used to generate sufficient pressure to deploy and fine-tune congestion protection strategies.

Further following the goal of this investigation, the limitations towards deploying congestion protection strategies need to be overcome by all of the actors involved. Among several identified limitations, two main limitations need to be addressed; public transportation perception and the reliance of old common priority practices. Recommendations for future research are proposed in the field of transportation policies, Transit Signal Priority and evaluating other congestion protection strategies at the intersection in question as well as other congested areas. In the city of Boston the Massachusetts Bay Transportation Authority in combination with the Central Planning Transportation Staff should continue to perform studies in the field of congestion protection strategies. Such studies could become the initial step towards a shift of public transportation and deployment of congestion protection strategies at conflict areas. The report is brought to an end with a reflection from the author.

Appendices are provided as background information to the different subjects dealt in this report.

About this Document

The report is written on the assumption that the reader has previous knowledge of public transportation, traffic signal control, Transit Signal Priority and micro-simulation programs (VISSIM) as well as the subjects dealt herewith. If the reader does not have previous knowledge off these subjects it might be a bit complicated to understand this report.

The report is structured in four parts to ease the flow of information and reading. Each chapter is provided with a small introduction and conclusions reached within the chapter. Figures are used for illustration purposes. Tables are used to present, as an overview, the information dealt within the chapter and support the main text. A list of figures and tables is provided. Throughout the report abbreviations are written in full length every time they are used for the first time and a list of abbreviations is provided at the end of the report. References are used when relevant. Appendices are provided at the end of the report to support and as additional information to the subjects dealt with.

In this report, congestion protection strategies, priority strategies, transit priority and public transportation priority are used synonymously. As well, mass transit, public transportation, public transit and mass transportation are used synonymously. In the context of this report congestion refers to the delay (effect on the travel time) a mass transit vehicle suffers.

The report is intended for research professionals, students, transportation managers and everyone involved with public transportation focusing on congestion protection strategies.

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Part I. Background

As a starting point to this report, Part I serves as the research demarcation discussing the problem at hand. Public transportation, modes, characteristics and the network of the transit authority for the city of Boston and strategies to improve the running time of the bus are discussed as background information.

The chapters presented in this part are:

- Chapter 1 Research Demarcation
- Chapter 2 Boston; a Public Transportation Capital
- Chapter 3 Global to Local Perspective

Figure 1: Logo of the Massachusetts Bay Transportation Authority

Source; www1

Chapter 1 Research Demarcation

1.1 Introduction

This chapter serves as the starting point, the introductory process, for the thesis report. It highlights the process by which the problem statement has been defined and the problem owner identified, leading to the formulation of the research question and sub-questions. The goal of this thesis research is to arrive at a conclusion by firstly finding answers to each of the sub-questions and finally answering the main research question. The research approach described below sets how the subjects of this research would be addressed. This thesis has been structured in four parts shown in an information flow highlighting the subjects of this research.

1.2 Research Problem

A problem can be perceived when there is a gap between the existing situation and the desired situation. In the case of this thesis, a gap has been identified between the existing and a decrease in circulating time or passenger travel time of public transportation in the city of Boston, Massachusetts (United States of America). A decrease in running time brings different benefits such as; improves reliability, saves money as fewer busses are needed, travel time for passengers is reduced and competitiveness with other modes. To accomplish an improvement can be done by either helping or hearting users. It is necessary to find the win-win situation. Arguably the cause of this gap is congestion, even though congestion protection strategies have been developed to narrow this gap. Worth noting that in urbanized cities in the United States of America (USA), large traffic numbers generally create congestion, which in turn, affects public transportation. Notwithstanding the benefits of congestion protection strategies and the fact that they generally procure a sense of priority by implementing different strategies, they have seen limited deployment in the United States of America and the city of Boston.

The problem statement in which this research is initiated is therefore as follows;

In major urbanized cities within the United States of America, why have congestion protection strategies seen such limited deployment as a solution to improve the running time of public transportation, which is significantly affected by congestion?

For example, in the city of Boston considering two bus routes (1 and CT1) running through a major thoroughfare encounter congestion cause by a diversity of issues that affect its operational speed. At a specific intersection, in this case Massachusetts Ave and Beacon St., the causes of congestion can be attributed to the high volume of traffic, the geometry of the intersection, the location of the bus stops, turning fractions and driving behavior. Therefore, impacting on the reliability, image, role and, ultimately, the perception of public transportation.

Through congestion protection strategies the intersection crossing for the bus can be improved. However, implementing congestion protection strategies, generally in the United States of America and particularly in the city of Boston might require a shift in perception towards public transportation and the current preference of cars. These, among other reasons make it difficult to implement congestion protection strategies. The benefits of congestion protection strategies have proven highly beneficial where deployed. Hence, this research will focus on policies, technology and management tools to aid the deployment of congestion protection strategies in order to improve the running time of the relevant bus routes.

1.3 Research Problem Owner

The Massachusetts Bay Transportation Authority (MBTA) has been identified as the problem owner. Due in fact that as the transit authority renders public transportation services over the city, it would be the primary beneficiary from the deployment of congestion protection strategies as these focus on the transit vehicle.

1.4 Research Objective

Relating to the problem statement and the research question, this research will try to accomplish the following objective:

Identify the reasons that have limited the deployment of congestion protection strategies considering the policies, technology and performance measures involved in public transportation to increase the running time (operational speed) of the bus in the city of Boston.

As part of the objective, it is intended to identify the necessary balance required between policies, technology and performance measures to deploy congestion protection strategies in order to increase the operational speed of public transit. This will be achieved by considering an intersection in Boston which, given its characteristics, provides the necessary insight to uncover some of the reasons that have limited the deployment of congestion protection strategies.

1.5 Research Questions

A research question has been formulated based on the problem statement in order to find alternatives or solutions and serving the purpose of this thesis:

> *"What are the necessary policies (changes or new), technology strategies and management tools that can work together to improve the running time by giving priority to public transportation in Boston?"*

The research question is centered among four subjects, and to find a unified answer it has been subdivided in a series of simpler questions. Categorizing by subject and answering the sub-questions individually, provides the necessary information to achieve a solution. The sub-questions are:

1. Policy
    a. Which are the transportation policies for public transportation in the United States of America? Do any acknowledge or promote the use of congestion protection strategies for public transportation projects? What are the funding possibilities derived from the transportation policies for public transportation projects?
    b. Who are the actors involved?
    c. What are their expectations / goals towards public transportation and priority strategies?
    d. Is there a need for new or improved policies relating to public transport focusing on priority strategies?

2. Technology
    a. What technology applications and products does the market offer to deploy congestion protection strategies?
    b. What developments of technology are needed to have solutions at a local level?
    c. What is the current state-of-the-art in congestion protection strategies deployed in the city of Boston, the United States of America and other countries?

3. Management Tools
    a. Which performance measures exist to evaluate the performance of the transit modes?
    b. What performance measures does the relevant transit authority use? Do any consider the impact of congestion?
    c. Can we predict the cost – benefit efficiency over the congestion impact?

4. Boston
    a. Which strategies of congestion protection can be deployed at the site being evaluated?
    b. Are these strategies particular to a conflict area? Should they focus to other conflict areas?
    c. Which priority strategy would benefit the bus and other vehicle classes at the intersection under evaluation?

1.6 Research Approach

The research approach in this investigation is partly empirical and model based. Literature review, interviews and input from observed situations, form the base for the development of the analysis (actor, performance measures, and state-of-the-art cases), the concepts further in this thesis, and ultimately the findings of the investigation. The use of software such as a micro-simulation program provides the source to model diverse situations creating a framework to validate different scenarios. The selected research approach allows gathering information and achieving a level of understanding in order to evaluate the problem –based on a hypothesis and a range of possible solutions.

1.7 Research Scope

The research focuses on; public transportation with particular consideration towards the bus, as one of the modes of public transport, the transit authority -Massachusetts Bay Transportation Authority- congestion and congestion protection strategies – primarily Transit Signal Priority and Bus Rapid Transit. Furthermore, consideration has been given to transportation policies in the USA that encourage or fund public transportation projects and congestion protection strategies. Technology to implement these strategies and the management tools used to evaluate the performance of the bus by the problem owner are also regarded. A specific site is modeled considering only the intersections of Massachusetts Avenue with Memorial Drive, Beacon Street, Marlborough Street and Commonwealth Avenue in the city of Boston.

1.8 Research Outline

The report is divided in four parts. Each part contains different chapters discussing in an orderly manner the subjects of the investigation (see Figure 2). The parts and their respective chapters are as follows. Part I – Background, presents a discussion over the role of public transportation and the impacts of congestion (paragraph 2.2), the transit authority characteristics and modes (paragraph 2.3) and its network (paragraph 2.4). Further, this Part defines congestion protection strategies (paragraph 2.5) and analyses the strategies deployed in the city of Boston and other cities in the State of Massachusetts (paragraph 2.6 and 2.7) respectively. Different strategies have been deployed in other cities around the world, which are subject of Chapter 3 highlighting the benefits and barriers (paragraph 3.2). In addition, this chapter discusses the bureaucratic hurdle and the leadership to be provided (paragraph 3.3) in order to deploy a preferred congestion protection strategy at the relevant site.

Part II –Site Evaluation- evaluates a specific intersection in the city of Boston to evaluate and different congestion protection strategies. Downstream and upstream are included in the evaluation where in (paragraph 4.2) the characteristics of the intersections are discussed.

Calculations for each of the intersections are performed (paragraph 5.2). Considering the characteristics of the relevant intersection different congestion protection strategies – scenarios- are proposed (paragraph 6.2) and simulated using a micro-simulation program. The results of the simulated congestion protection strategies are discussed in relation to the performance indicator; travel time and delay (paragraph 7.2 and paragraph 7.3 respectively).
Part III –Policy, Technology and Management Tools- analyzes these subjects towards the deployment of congestion protection strategies in the city of Boston. The transportation policies within the United States of America and the actors identified at the site evaluation (paragraph 8.3) are analyzed through an actor analysis (paragraph 8.4). The traffic signal in the USA and its characteristics (paragraph 9.2) are presented. Transit signal priority the considerations, products and detection technologies are discussed in (paragraph 9.3 to paragraph 9.5) order to deploy and accomplish such strategy. Transit authorities fine-tune their operations and service quality through performance measures which are dealt in (paragraph 10.2). The performance of the transit authority in the city of Boston is analyzed and compared with other transit authorities (paragraph 10.3). Performance measures do not account for the impact of congestion towards the bus; therefore, an analysis (paragraph 10.4) of such impact over some bus routes in the city of Boston is performed.
Part IV –The End- presents a synthesis (paragraph 11.2) and the main findings of the research (paragraph 11.3). The chapter and the report conclude with recommendations for future research (paragraph 11.4) and with a reflection (paragraph 11.5).

In order to guide the reader into the subjects dealt within every chapter a brief introduction is provided. In addition, each chapter is brought to a close with a conclusion reached over the relevant chapter.

The appendices provided at the end of the research present a further discussion over the subjects dealt with and serve as an illustrative guide.

1.9 Research Structure

The subjects dealt within this research are depicted in the following information flow chart. This is done in order to lead the reader through the parts of the report and illustrate the interrelation between the subjects dealt herewith.

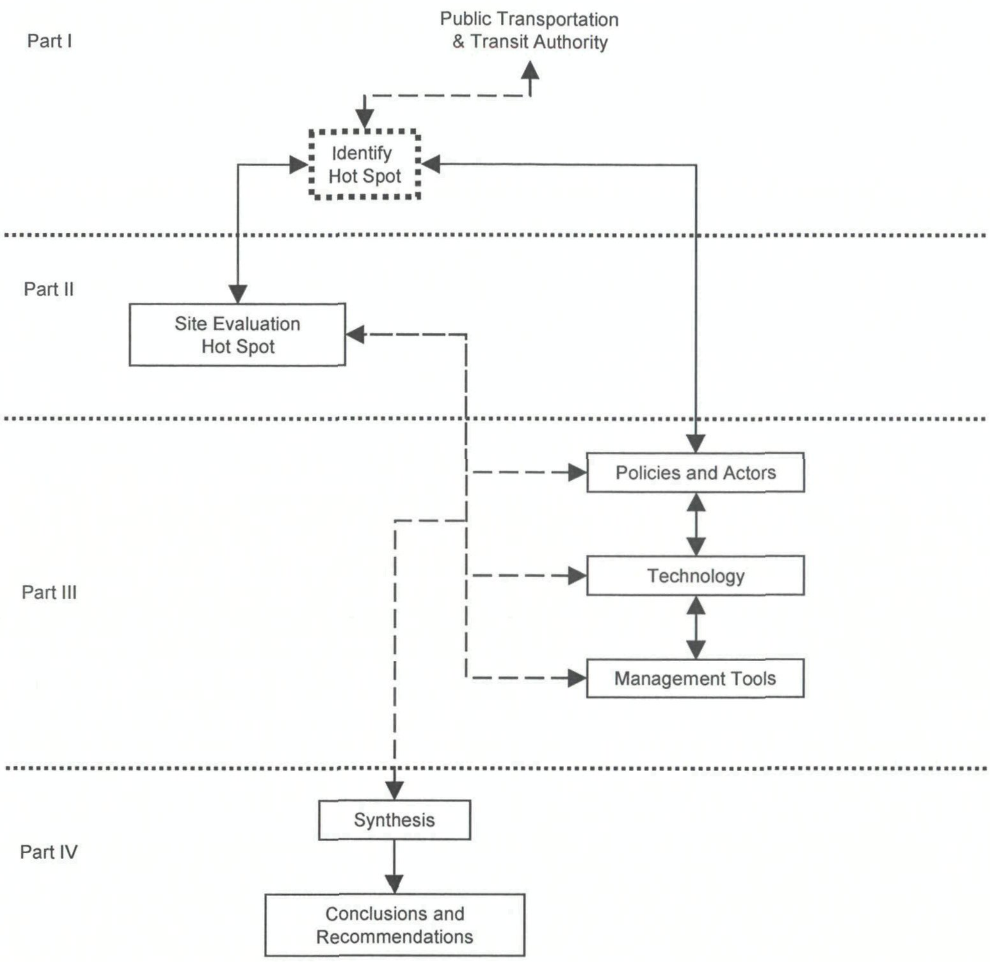


Figure 2: Research information flow

The initial step is to identify a "Hot Spot", which is a conflict area where congestion protection strategies are to be analyzed for and further deployed. This step initially identifies the transit authority. The site is evaluated based on the characteristics of the relevant intersection, which determines the strategies –scenarios- to be assessed in relation to the congestion protection strategies that can be implemented. The policies and actors, technology and management tools are those identified within and for the intersection. The dotted line provides the link between Part II and Part III. This link is made through state-of-the-art cases in the United States of America. The case, the site evaluation, identifies the benefits and barriers of congestion protection strategies, while by the analysis of the actors, technology and management tools allows through the identified barriers to further evaluate the possibilities for deployment. The synthesis presents a discussion of how deployment of preferred congestion protection strategies at the site evaluation can be achieved. Finally, the conclusions and recommendations resulting from the analysis performed throughout the previous chapters are discussed. This thesis intends to provide an understanding on how to improve the running time (or operational speed) for buses in the city of Boston; a consequence of this would be an improvement of the public transportation system, which ultimately impacts on the society as a whole.

Chapter 2 Boston; a Public Transportation Capital

2.1 Introduction

This chapter initially addresses several concepts and defines the subjects that serve as background information to comprehend the research at hand. The Massachusetts Bay Transportation Authority (MBTA) has a long history in the city of Boston; operating several modes it serves over 4.5 million inhabitants. It is the 5th largest operating transit authority in the USA. The characteristics and the range of modes it operates through a vast network are further discussed in this chapter.

Further, the chapter discusses a solution to improve congestion situations primarily in urbanized cities affecting public transportation. Congestion protection strategies are briefly defined and analyzed. In combination with the latter, the transit authority has deployed several congestion protection strategies throughout the city with the development of a Bus Rapid Transit; the Silver Line. Other transit agencies have also realized congestion protection strategies in the State of Massachusetts; these are also briefly discussed.

2.2 Public Transportation versus congestion

In this paragraph public transportation and congestion will be defined and subsequently the role of public transportation and the impacts of congestion will be depicted. First, public transportation individually or combined provides greater mobility, access, opportunity, and choice for all users. Defined as "*transportation by a conveyance that provides regular and continuing general or special transportation to the public…*" [1] by Federal government of the United States of America, it renders means of transportation to all citizens communities of all sizes. Public transportation includes modes like; bus, subway, rail, trolleys (tram and or streetcars), monorails, cable cars, light rail, and ferryboats. Paratransit services (Demand Responsive Transport, DRT) for elderly and disable, van pool services, taxis and other subcontracted services provided by the transportation authority are also considered public transportation.

Second, traffic congestion means "*there are more people trying to use a given transportation facility during a specific period of time than the facility can handle with what are considered to be acceptable levels of delay or convenience*" [2]. A bus suffering from congestion could mean, under this definition the following. The bus and therefore bus route is able to provide mobility and accessibility. This being true, at certain points of the route the bus will face delays, interruptions or a decrease in convenience. The combinations of different factors working all together generate congestion -factors such as; capacity, driving behavior, traffic signals, and road geometry amongst many others- affecting all vehicle classes. A wide variety of innovative solutions have been implemented effectively to minimize the impact of congestion over public transportation. The impacts of congestion over public transportation can be minimized by slight changes and or modifications to the factors generating congestion. In addition the user, public transportation employees and transport policies, technology and management tools, among other indirect factors surrounding the system should be considered.

From a society, image, reliability, environment, economic development and non-users point of view public transportation plays a key role, which could be heavily impacted by congestion. In Table 1 the role of public transportation and impact of congestion are discussed.

Table 1: Role of Public Transportation versus Impact of Congestion

	Role Public Transportation	Impact of Congestion
Society	Mobility for all members helps build richer social networks	High operation costs, communities developed under the premise of the private car, limited mobility.
Image	Accessible, comfortable, fast, a good transportation alternative	Slow, crowded, long running times, delays and perception as inaccessible to perform all daily activities.
Reliability	Well planned systems (high frequency), operation and service processes related to the network and modes	Bad planning, inefficient services, driving behavior and unbalance in road capacity.
Economic Development	Thrives economic development as it promotes smart growth, caters for shift in market demands and lifestyle. A public transportation node can help to attract development.	Scarce resources to develop public transportation systems. Public transportation has returns to scale, highways and streets decrease the returns of scale
Environment	Green alternative to mobility (pax/per vehicle) and low emissions; alternative fuels (CNG)	Gas-guzzlers and high traffic volumes generate higher emissions; vehicles stand idle for long periods.
Non-users	Convenient and less expensive alternative to transport, creates a modal shift, reduces congestion	Private vehicle dependency is high where public transportation systems must provide an efficient and genuine alternative to cars, a challenge in urbanized cities.

Public transportation also plays a role in case of emergencies as it can transport large number of people and or save numerous lives. For example, in New York City when the attack to the World Trade Center (9/11) buses where used to evacuate the city, providing a transportation alternative.

2.3 The Transit Authority: Massachusetts Bay Transportation Authority

The Massachusetts Bay Transportation Authority, MBTA, (locally known as the "T") was one of the first combined regional transportation planning and operating agencies to be established in the USA, August 3rd, 1964 [www1]. However, the first transportation mode in the city of Boston dates from 1897 considered as light rail.

Figure 3: Subway entrance sign at Back Bay

Source; www1

A political body and subdivision of the Commonwealth, the MBTA has grown to service more than 175 cities and towns of the Massachusetts Bay area with a total population of approximately 4.7 million. It is the fifth largest mass transit system in the USA in terms of daily ridership with 1.1 million passenger trips (weekday and all modes) [www1]. In Boston, 55% of all work trips and 42% of all trips into downtown are made by transit [3]. The MBTA system serves the area in a largely hub-and-spoke network. The MBTA is one of the few agencies in the USA regulated at a State level where all 175 cities have decision-making ability towards transportation programs and or plans operated by the transit authority. Therefore the agency encounters a few difficulties in terms of accomplishing public transportation projects (new or improvements and developing programs) as well as funding. Further analysis of the policies and programs for the MBTA (refer to Chapter 8 and Appendix B -) discusses several issues to be addressed in order to fulfill its objectives.

The MBTA is in constant management of projects. Some of the projects, aimed to increase ridership and benefit riders, fall into high investment costs. Boston is typical of many metropolitan areas struggling to maintain or increase their ridership while keeping their transit deficits under control [4]. Many of the projects managed by the MBTA focusing on improvements or new services make use of one of the oldest practices of "priority": grade separation – underground. Many transportation planners and decision-making agencies relate to this as "the priority strategy" for public transportation. Notwithstanding this solution as one of the best, it comes with high investment costs and is quite difficult to justify.

Despite its costs and justification, subway lines are still being developed representing an optimal solution to traveling faster. The MBTA has been trying and pushing among its stakeholders, agencies, and governing towns and cities involved for further deployment of congestion protection strategies. Although a priority strategy has been successfully deployed in the Silver Line (described in paragraph 2.6) it has been difficult for the transit authority to achieve congestion protection strategies for other bus routes due to several factors; primarily the effect of priority on the surrounding routes and traffic congestion [INT1].

2.4 The Transit Authority Network

The Massachusetts Bay Transportation Authority operates and maintains approximately 185 bus routes, three Bus Rapid Transit lines, 5 streetcar routes, 4 trackless trolley lines and 13 commuter rail routes. It also operates inner-harbor ferries and commuter boats, and has para-transit services sub contracted to a third party [www1, 3]. The MBTA owns some of the commuter rail routes but a coordination-relation to operate these lines exists with Amtrak[1].

The rapid transit system, as the subway lines are labeled, the bus rapid transit and bus service, commuter rail, para-transit and commuter boat, are briefly described in Table 2. In Figure 10 the rapid transit and key bus routes network map is depicted. In addition some commuter rail lines and commuter boat lines are shown in this network map.

[1] Signals and dispatch are operated by Amtrak, as well as it provides service in other routes.

Table 2: Transit modes operated by the MBTA

Rapid Transit System

Four rapid transit lines (Red, Orange, Green and Blue) are operated in approximately 408 heavy rail vehicles over 38 miles of heavy rail routes and 53 stations and 2 streetcars (Green Line and Mattapan line) in approximately 26 miles of rail routes serving 78 stations with a fleet of approximately 207 light rail vehicles

Figure 4: Blue line vehicle, Rapid Transit Lines

Bus Rapid Transit

The Silver Line is a BRT project serving 14 stations, operating in an exclusive bus-lane only on portions of Washington Street, South Station to the South Boston Seaport District, and a direct service to Logan Airport

Figure 5: Silver Line vehicle

Bus Service

With over 175 bus routes and a fleet of over 991 buses (564 diesel buses, 360 CNG and 2 prototype alternative fuel buses) bus services cover more than 763 route miles with a frequency approx. of 5 to 10 minutes in peak hour and 15 to 20 off peak. Additionally, four bus routes operate in the urban core areas a frequent schedule express service to and from downtown Boston and manage six local service subsidy programs.

Figure 6: Bus service vehicle

Commuter Rail

Commuter rail routes provide long haul linking the outer regions with downtown Boston with over 80 commuter rail locomotives and 410 commuter rail coaches servicing 131 stations on 11 commuter rail lines.

Figure 7: Commuter Rail vehicle

Para-transit

Named "THE RIDE" is a door-to-door demand response para-transit program. Operates 453 vehicles in over 62 cities and towns with monthly average trips of approximately 115,000 providing the elderly and disable with transportation.

Figure 8: The RIDE Para-transit vehicle

Commuter Boat

Service is provided over several routes between Boston and various points in the inner Boston Harbor area and three terminals on the south shore. It owns two of the ferry boats while the rest are subcontracted to third parties

Figure 9: Silver Line vehicle

Source; information and figures adapted from www1 and [6]

Figure 10: Massachusetts Bay Transportation Authority Rapid Transit and Key Bus Routes Network map

Source: www1

2.5 A Solution for Public Transportation: Congestion Protection Strategies

Delays aggravate the travel times for the users and drivers impacting on the reliability of the entire public transport system. When a driver (in a private vehicle) encounters a congested zone or situation will quickly try to look for alternative routes to by-pass the congested area. However, a bus or public transportation vehicle runs over a fixed infrastructure or route without having the capabilities to by-pass the congested area. It must wait until it can properly pass the congested area or congestion disseminates. Therefore, congestion protection strategies have been developed and deployed.

A bus requires much less road space for the same number or passengers commuting by car. Congestion protection strategies offer a solution to by-pass congested areas focusing towards the mass transit vehicle by developing and deploying techniques, which are simple measures that procure a sense of priority maintaining its travel time. To procure a sense of priority is especially important when the vehicle shares a right-of-way. Priority strategies have proven extremely cost effective and a simple solution to improve the reliability, image and service of public transportation.

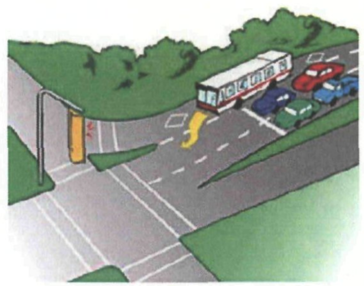
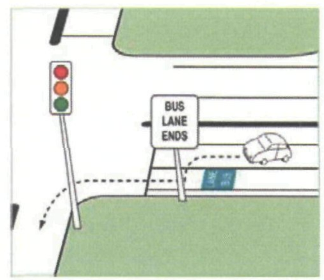
The strategies to protect the transit vehicle from congestion they include physical improvements, operating changes, and regulatory changes. A single strategy not always "fits-all" congested situations. As every congestion situation is different it is necessary to consider the circumstances and characteristics of the area and or transit system in order to determine the strategy to be adopted. Therefore, it is not possible to assess or deploy one strategy in itself but rather a combination of strategies to achieve the desired situation. Congestion protection strategies present a mean to integrate all existing strategies. Examples of congestion protection strategies are briefly described and illustrated here below.

Where do Congestion Protection Strategies come from?

Congestion Protection Strategies derive from the combination of Dynamic Traffic Management (DTM) measures. Dynamic Traffic Management is a set of different strategies such as traffic control being one of the possible ways to manage the use of infrastructure [7]. The purpose of the measures is to [7];

- Improve travel comfort;
- Improve utilization of infrastructure;
- Reduce travel time;
- Improve reliability of the transport system and;
- Influence route (mode) choice.

Table 3: Examples of Congestion Protection Strategies

Bus only roadways; this design pertains to the BRT strategy where single or dual bus lanes in each direction are reserved and platforms are at the center, e.g. Bogota  Figure 11: Congestion Protection Strategy; Bus roadway Source; www2	**Counter flow lanes**; this design provides the bus with a lane flowing in opposite direction than traffic, e.g. Mexico City  Figure 12: Congestion Protection Strategy; Counter Flow Lanes Source; www3	**Bus lanes**; this design distinguishes a bus lane by markings in the pavement, e.g. Seoul  Figure 13: Congestion Protection Strategy; Bus lanes Source; www4
Median or roadside reservation; this design provides buses with their own roadway, e.g. Washington D.C.  Figure 14: Congestion Protection Strategy; Median Road Reservation Source; www5	**Queue jump lane**; this design provides with an extra lane at the intersection only for the bus, with sufficient length for the bus to clear the queue and reach the stop line, get ahead of the queue, e.g. Ottawa.  Figure 15: Congestion Protection Strategy; Queue jump lanes Source; www6	**All-but approach lane with pre-signal**; it is the inverse of a queue jump lane, acts as a buffer lane to the bus but at the intersection the bus runs in mixed traffic, e.g. New Zeeland.  Figure 16: Congestion Protection Strategy; All but approach lane with pre-signal Source; www7

Gates; this design restricts the access to only buses, like a tunnel or separate right-of-way, e.g. Boston.

Figure 17: Congestion Protection Strategy; Gates and or Tunnels

Source; www2

Transit Signal Priority; provides a priority call when a detector mounted on the street detects a vehicle, e.g. Ottawa.

Figure 18: Congestion Protection Strategy; Gates and or Tunnels

Source; www6

Reversible lane (by signal only); The use of signal for a bus lane, which can be used in either direction depending on the time of day and with no reservation or separate right-of-way, e.g. Montreal.

Figure 19: Congestion Protection Strategy; Reversible lane

Source; www8

Curb extension and ordinances to yield for public transportation by motorists can be considered as alternatives of congestion protection strategies. Several strategies oriented within and or to the transit vehicle, e.g. fare box collection methods, accessibility to the vehicle (kneeling buses), and traffic enhancements and calming strategies can also be considered as congestion protection strategies. Fare box collection methods expedite dwell times when passengers acquire a prep-paid card, for example. Traffic enhancements and calming strategies are made to sections of the route such as lower curbsides or curb alignments for vehicles, while accessibility to the vehicle is smoother through low-floor vehicles or kneeling buses (when boarding a bus or tram with steps the dwell time increases).

A number of authors and agencies have recognized several strategies and adopted those that best fit. The transit authority from the city of Portland, Oregon, TriMet[2] can be cited as one of the pioneer agencies in the USA in terms of priority for public transportation, it has deployed several congestion protection strategies throughout its network. Through its Transit Preferential Streets Program, five bus priority strategies are recognized; Queue Bypass, Queue Jump lane, Curb Extensions, Fare Collection Change and Traffic Signal Priority [8].

One of the most successful congestion protection strategies for buses is Transit Signal Priority (TSP). TSP is one of the features of Bus Rapid Transit (BRT). The thesis will further focus in these two congestion protection strategies, described further here below.

2.5.1 Bus Rapid Transit

Bus Rapid Transit (BRT) is "a rapid mode of transportation that can provide the quality of rail transit and flexibility of buses" as defined in part by the Federal Transit Administration [9].

BRT has been developed and deployed in different cities worldwide. Its potential lays in the provision of flexible and cost effective alternatives to rapid transit systems. Bus rapid systems provide a combination of routing options with the flexibility to accomplish a route within metropolitan areas. The essential elements of BRT make it an alternative to transit with characteristics of light-rail and even heavy rail systems. In a nutshell, it is a bus (rubber-tired vehicle) with the flexibility to form a rapid transit system combining stations, vehicles, and technology elements in an integrated manner.

Since 1999, the Federal Transit Administration (FTA) began deploying as a demonstration program Bus Rapid Transit throughout the United States of America. The federal agency identified a number of primary features of a BRT system.

2 Concerning Traffic Signal Priority this agency has undertaken several projects to asses the applicability and effectiveness of TSP through early green phase or green phase extension.

These included the following [9]:

- Bus lane-related right-of-way enhancements;
- Bus signal preference and preemption;
- Vehicle design;
- Stop spacing and design;
- Fare collection;
- Marketing, information, and Automatic Vehicle Location (AVL) and other ITS features; and
- Land use policy.

Recent policies provide funds for public transportation projects that incorporate features of BRT without specifying the criteria that defines such strategy (e.g. speed, control tactics). The Federal Transit Authority to evaluate the effectiveness and cost of the BRT features identified several performance measures (transit travel time and delay) related to operational performance, costumer satisfaction and traffic. The performance measures benchmarked from other cases are established based on the results of the previous cases without distinguishing a threshold or an operational objective, such as speed higher than or travel time reduction and or ridership increase of minimum... Benefits are considered when the Bus Rapid Transit evaluation attracts ridership and decreases delay or travel time. In paragraph 8.4.1 a frame of reference is proposed to develop thresholds evaluating BRT projects and their benefits.

2.5.2 Transit Signal Priority

Signal priority is one of the most important features of Bus Rapid Transit (BRT) [10]. Transit Signal Priority (TSP) is not solely deployed in BRT projects but can also be deployed independently. TSP is a tool that can be used to help make transit service more reliable, faster and more cost effective [11]. Basically, TSP implements a control strategy at traffic signals providing the public transit vehicle with extra green time (green time extension) or reduce the red time (red truncation) from the opposite approach, amongst other control strategies.

The management of TSP can be done at the intersection level or at the system level, distributed or centralized respectively. The priority call from an approaching bus at the intersection is defined as distributed, while centralized is given from a traffic management center as the bus approaches the intersection. The focus will be on distributed priority calls.

TSP control strategies are simply the method to implement priority by interfering in numerous ways with the traffic signal control sequence. These not only involve the traffic signal but also other detection technologies affecting the timing control through variant algorithms and detectors. TSP strategies have been defined in different ways. Vincent, Cooper and Wood suggested the following four; priority extension or green extension, priority call or red truncation, compensation green to the cross street if the priority call extended beyond the normal maximum green, and inhibit placed on priority call during cross street green, following a granted priority call [12].

Furth and Muller [13] define transit priority at signalized intersections in three broad dimensions; 1) distinction between active or passive priority; 2) categorizing priority as full, partial and relative; and 3) choice of conditional or unconditional priority. In the USA, the most common are partial priority and conditional priority. Partial priority, green extension and early green start are allowed; conditional priority refers to vehicle request priority while behind schedule. Other priority strategies are also used in rare cases, e.g. phase skipping [14].

The United States of America Department of Transportation, ITS America, handbook on TSP defines control strategies in passive, active priority and real time [11]. Under active priority, five strategies are defined; green extension, early green, actuated transit phases, phase insertion and phase rotation. Real time TSP is defined through the use of adaptive signal priority and adaptive signal control systems. This type of priority is not very common as the systems are very sophisticated and complex. Still in early developments, however, they might be the trend of the future.

Following the definition and classification from the ITS America handbook on Transit Signal Priority the traffic signal control strategies will be further described.

Passive Priority

This type of priority operates continuously and does not require the software and hardware of active and real time. The priority call is given based on the route and ridership patterns and does not detect / request a priority call. This strategy is used when operations are predictable with understanding of the routes, ridership, schedule and or dwell times. A green wave at a corridor where a bus runs and the schedule is known is an example of passive priority.

Active Priority

This type of priority operates under the premise of detection / request for priority. Various types of active priority can be implemented.

Green extension: a green phase within the control sequence is extended as a vehicle is detected and the priority requested. This strategy requires the traffic signal phase to be green. It is the most effective form of TSP.

Red Truncation (also called early green); this strategy shortens the red phase (expedites green phase), having an impact on the other streams when the traffic signal phase is green. The request needs to be while the red phase.

The figure below illustrates the concept of green extension and red truncation at an intersection.

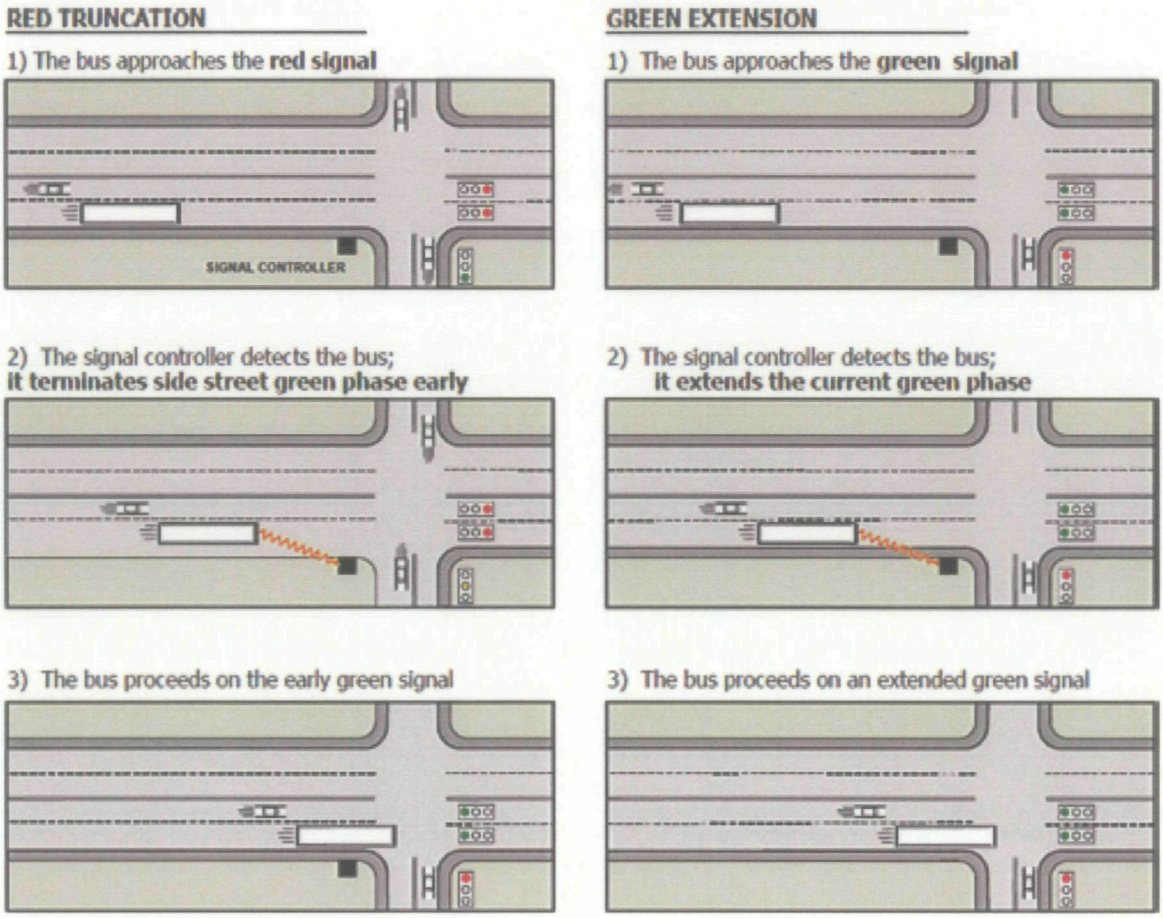


Figure 20: Green Extension and Red Truncation

Source; www9

Generally these two strategy types are combined when TSP is applied. Other strategies possible within active priority are:

Actuated transit phases: the signal phase is actuated by a public transport vehicle only as it approaches and requests a priority call, then the traffic signal is displayed, e.g. a dedicated left turn for public transport vehicles only.

Phase insertion; a special priority phase is inserted within the normal sequence phase. It is inserted as the priority call is received.

Phase rotation: rotates the control sequence, meaning it rotates a lagging phase to a leading phase in order to serve a priority call.

Real time

This type of strategy works within very sophisticates and complex systems that are not yet common, i.e. adaptive signal control systems (provide a priority call while trying to optimize traffic performance) and adaptive signal priority (considers the trade-offs between transit and traffic delay and adjusts the signal timing by adapting the transit vehicle and the traffic conditions).

A common misunderstanding is made between signal priority and signal pre-emption. These two terms are often used as synonyms, while in fact their control strategy is different. Within the control sequence, signal priority extends or truncates the sequence when a priority call is active, while signal pre-emption (generally for emergency vehicles) simply extends or interrupts the sequence when a call is active.

In order to implement Transit Signal Priority and define the strategy to be deployed at any intersection the following variables need to be considered. The variables are:

- Traffic volumes;
- Queue length;
- Intersection capacity;
- Type of transit vehicle (bus or tram);
- Stops, its location (near or far-side)[3];
- Dwell times;
- Headways, frequency and cycle length;
- Number of priority calls to be requested;
- The effects of priority calls on side streets and on pedestrians;
- The cycle phase when priority is requested;
- Road speed (minimum speed limit)
- Preceding intersections (upstream and downstream).

Flexibility within the system shall provide for the TSP strategy realizing the priority call. Deployment of the strategy as a tool has proven successful. The success of TSP is due to its minimal influence on other traffic streams, its cost-effective approach and the increase in reliability of the public transport system as well as the provision of mobility.

In the United States of America, several cases [10] have been deployed with proven outstanding benefits, although there is still skepticism regarding their effectiveness. An analysis over the policies, technologies and management tools will further try to determine the reasons behind the skepticism and the possibilities to deploy priority strategies. An intersection where the bus encounters congestion is subject of evaluation to analyze the impact of Transit Signal Priority (applying either green extension or red truncation as the TSP strategy) and other congestion protection strategies.

[3] A nearside stop refers to locating the bus stop upstream of the intersection, while far side locates the bus stop downstream of the intersection.

2.6 The Silver Line an example of Congestion Protection Strategies

The Silver Line (SL) is a three-phase project in the City of Boston adding a fifth rapid transit line to downtown. The SL incorporates the essential elements of a BRT project through tunnels and Transit Signal Priority, conditional priority at some intersections. In Table 4 the Silver Line protection congestion strategies and costs are presented.

Table 4: The Silver Line Congestion Protection Strategies and Costs

SILVER LINE Phase	Congestion Protection Strategy	Cost
Phase I	Bus Tunnel with 1.1 miles (2 km) in length running between South station and the Water Front	$ 600 million
Phase II	2.2 miles (3.5 km) in length of curbed bus lanes between Dudley Square and Downtown Boston	$ 50 million
Phase III	Bus tunnel corridor between South station and Washington Street	$700 million

The Silver Line BRT project incorporates several technologies. The MBTA will stager these instead of unveiling them in a full BRT system. The buses are equipped with onboard communication systems to enhance schedule adherence and dispatch capabilities (CAD/AVL). Passenger information is provided at stations via talking stations and passenger information kiosks. The SL articulated 60-foot long dual-mode electric and low-pollution fuel buses operate at 40 to 80 second headway during peak periods. It is estimated by the Central Planning Transportation Staff that by 2025, when completed 65,000 riders will be attracted to the system [10].

The congestion protection strategies deployed at the Silver Line, primarily, are bus tunnels and conditional priority (priority when bus running behind schedule) at some of the intersections over Washington Street. To achieve this service, Washington Street needed to be redesign to incorporate a reserve bus lane and the bus tunnels designed to be similar to an LRT line. However, the Silver Line is a case where old common practices of priority and the perception of public transportation come to play. This project has cost the city and federal government millions of dollars to accomplish tunnels and underground stations. Bus Rapid Transit as described previously is a cost efficient alternative to rapid transit. The key reason for selecting BRT is "*the ability to directly reach a much broader service area without major additional investments*" [9]. But the reason behind the applicability of a bus tunnel as stated in the TCRP Report 90, Volume 1, BRT Case Studies – Boston, MA Silver Line is *"the concept of a BRT tunnel in congested areas affords promise where essential to provide desired service reliability – especially in large cities"* [10]. As this is true in many cases other solutions providing priority to bus fixed routes have proven beneficial at lower investment costs. In order to avoid high investment costs and justifications simply required a compromise to be made between private cars and public transportation.

The Silver Line has been beneficial and highly regarded from its users in terms of reliability. Reported benefits have been several; its running times are nearly or slightly below scheduled running times, ridership has increased 24% in the overall public transit to the airport [10]. The SL has provided a new image and identity in terms of bus service in Boston, according to the FTA Silver Line Project report [15]. A survey from the Central Transportation Planning Staff conducted in 2006, showed the 80% of those surveyed rated safety, travel time and directness of the Silver Line Waterfront service as above average or excellent and 70% rated service reliability above average or excellent [3].

2.7 Transit Signal Priority in other cities of the State Massachusetts

A side from the Silver Line in Boston other cities have successfully implemented TSP on one or several bus routes. This is the case of the City of Springfield, where the Pioneer Valley Transit Authority implemented one of the first TSP in the region. The authority through four different fixed route operators carries nearly 10 million passengers per year [16]. The control strategy, green extension or red truncation is provided by the use of optical based transmitters emitting visible and infrared light and a receiver detects the optical transmission. To overcome the disruption of the precisely timing of the traffic signal network along the bus route, a new algorithm governs the signal timings and a wireless GPS system maintains accurate time reference between intersections.

Funding for this project was granted through the Congestion Mitigation and Air Quality program due to its air quality improvement. The deployment of TSP brought to the City of Springfield and the Transit Authority the following results: travel time on the green line service was reduced by nearly 15 minutes, ridership has increased by 8% (shifted demand) and the performance is in line with the authority's other express routes [16].

The deployment of the TSP in the city of Springfield acknowledges the necessity to foster the relation between the different entities to be successful. The actors concerned needed to set the mutual benefits since the beginning. Allowing communication and information resources to flow by creating interagency agreements was one of the key successful factors. In addition these agreements allow implementing in the future TSP in other corridors.

2.8 Conclusions

Public transportation plays a key role in society as it renders transportation services to all members of society. The benefits of public transit are impacted by the generation of congestion. Congestion created by a multitude of factors working together. In Boston, public transit vehicles suffer from congestion impacting on the image and reliability of the system and even of the transit authority. The Massachusetts Bay Transportation Authority (MBTA) is in this research the problem owner. The MBTA operates a large number of vehicles over a vast infrastructure. Serving 175 cities and towns in the Massachusetts Bay Area the MBTA renders subway, bus, commuter, ferry, and paratransit service to over 1.1 million riders' daily.

Different strategies have been developed as a solution to minimize the impacts of congestion. These strategies are called congestion protection strategies. Congestion protection strategies assist the transit vehicle to by-pass or avoid congested situations by procuring a sense of priority. Congestion areas are site specific, for this reason the congested area needs to be evaluated in order to select the appropriate congestion protection strategy. There are different congestion protection strategies among which Bus Rapid Transit (BRT) and Transit Signal Priority (TSP) are the most deployed. The transit authority embarked into a BRT project to propose an alternative mode of rapid transit in the city. The Silver Line overcame several conflicts, such as policies, funding and public transportation perception in order to be achieved. In addition, it deploys priority controls through tunnels and conditional priority in some intersections over a small corridor. The BRT service serves as an example to illustrate how old common practices of priority –underground- are still preferred despite the high investment costs and required justifications. Despite the priority strategies deployed the Silver Line benefited it users and attracted non-users. However, this project as well as others has driven the budget of the transit authority into deficit.

Other transit authorities in the State of Massachusetts have deployed TSP in one or several bus route corridors. The Pioneer Valley Transit Authority deployed TSP in the City of Springfield, which resulted in benefits to riders and non-users. The authority recognizes the importance of inter-agency cooperation to accomplish this type of projects. A conflict, further discussed, which occurs given the large service area (increase number of actors) and agencies involved within the transportation system and the site to deploy congestion protection strategies.

The information provided in this chapter will serve as background information in order to analyze and present the discussion of the subjects dealt in Part II and Part III.

Chapter 3 Global to Local Perspective

3.1 Introduction

This chapter presents a state-of-the-art in congestion protection cases in the United States of America as well as from other countries around the world. Describes the benefits of deployment through different cases where congestion protection strategies, primarily Transit Signal Priority (TSP) have been deployed. Further it discusses the barriers to be overcome and the measures of effectiveness, which are considered as the main issues towards implementation. Implementation involves the bureaucratic process that can be overpowered through an agency providing the necessary leadership.

3.2 State of the Art – Cases and Benefits

Throughout the world there have been several countries that have implemented congestion protection strategies. Regarding Transit Signal Priority, several have been the experiences where TSP is operational, making a classification of the TSP techniques, identifying their benefits and other lessons learned from implementation. Some of the cases where Transit Signal Priority and or other strategies have been deployed are discussed hereafter.

In Europe, different countries focus primarily on public transportation applying priority controls, strategies and measures in comparison with other countries. Eindhoven, Vicenza, Dublin, Brussels, and Zurich [18] are some of the cities in Europe where different congestion protection strategies and or systems are either in full operation or have been tested.

Asian countries are focusing more on developing better public transportation systems as their cities grow. For example Shizouka City, Japan [19], a bus priority lane provided a solution to congestion creating a modal shift. In Latin America the focus has been in priority for public transportation through developing BRT systems. The pioneer in this system is the city of Curitiba in Brazil [10, 20]. Other cities have attempted to copy this model with mixed results, e.g. Mexico City. In Bogota, Colombia, a similar system, with slight modifications being site specific, has proven outstanding benefits [20].

In the United States of America, there are different cases that applied a priority strategy. In relation to traffic signal priority, some only involve a few intersections where others have incorporated almost their entire network. Different strategies to improve buses and fixed routes have been applied. In Cities like; Boston, Massachusetts; Minneapolis, Minnesota; Seattle, Washington; Portland, Oregon; Eugene, Oregon; Los Angeles, California; Houston, Texas among many others, traffic signal priority, BRT, Rapid Transit and or other strategies of priority have improved the service and reliability of the public transportation network.

Houston Metropolitan Transit Authority is one of the transit authorities with the highest number (1,563) of signalized intersections with priority controls [11] in the United States of America. Other transit agencies with signalized intersections where priority controls are operational range from two to even 600 intersections.

It is worth noting that the uses of TSP controls, in most of the USA cases hereafter, were deployed as demonstration projects. Funding, skepticism, lack of information, coordination, willingness, and or other issues could be acknowledged as the probable causes for limited deployment. Despite this, several cases in the USA have been realized with extraordinary results.

Below a short overview of several USA cases is given. The overview illustrates the benefits, strategy and the obstacles encountered by the transit agencies when implementing congestion protection strategies. An overview of state-of-the-art cases in Europe, Asia and The Americas, is provided in Appendix E.

The state-of-the-art cases have been adapted from several sources: report published by the TCRP in 2003 BRT Case Studies [10], The Transit Signal Priority (TSP): A Planning and Implementation Handbook [11], The Bus Rapid Transport Policy Center Database [www20] and literature review from different journals with information ranging from 2001 to 2007.

Table 5: Overview of State-of-the-Art Cases in the states of California and Washington

	AC Transit, Oakland, CA	King County Metro, Seattle, WA
Corridor	One - San Pablo Corridor	Three
Congestion Protection Strategy	Early green or green extension	Green extension and red truncation
Traffic Signal Priority	Conditional	Many traffic-related conditions, not based on schedule adherence
Institutional Barriers	TSP low importance to some jurisdictions	Number of jurisdictions involved and complexity
Reported Travel Time Savings (min)	9% time savings	25-34% reduction of average intersection delay for eligible buses; 14-24% reduction of stops at intersections; 35-40% reduction of trip travel time variability; 5.5-8% reduction in travel time during peak hour
Measures of effectiveness	Extrapolation of data, attempting to develop software feedback loop	Average intersection control delay; average minor movement delay; minor movement cycle features; Bus travel times; schedule reliability; average intersection bus delay; Average person delay; vehicle emissions; accidents
Greatest obstacles	Adequate software design	Specifications and operations acceptable to the stakeholders due to jurisdiction
Keys to success	Standardization of equipment; simplicity of TSP objectives	Maintaining communication

Table 6: Overview of State-of-the-Art Cases in the states of Washington and Oregon

	Tacoma, WA	TRIMET, Portland, OR
Corridor	Six Corridors	Phase I complete 8 corridors, phase II adds corridors and other intersections
Congestion Protection Strategy	Developed strategies that include, green extension and red truncation, only phase insertion for a queue jump developed on one downtown arterial	Green Extension and Red Truncation
Traffic Signal Priority	Unconditional, emitter always on	Conditional based on four criteria
Institutional Barriers	There was not much communication between traffic and Transit agency in the beginning	No due to great communication. TSP implementation still requires time. An intergovernmental agreement (IGA) has to be signed with each suburb for future expansion, and this takes 6 – 18 months, which is longer than anticipated in TIP
Reported Travel Time Savings (min)	TSP is an effective tool and significantly reduces signal delay and improves transit speed and reliability. Delay reductions for general public as well as Transit	Reduced recovery time and increased reliability. For Line 4 in Nov 2000 TriMet was able to avoid adding one more bus. There are also benefits on-time performances for transit vehicles.
Measures of effectiveness	Comprehensive before and after studies; travel time; stop and signal delay; fuel savings; air quality benefits; public schedule changes; operating resources required and signal delay significantly increases transit travel time	TriMet MOE was reduced variability. As variability is reduced, recovery time can be reduced as well. Because of lack of data from controller actions, TriMet is unable to assess directly the impact of specific strategies on reduced variability and running time.
Greatest obstacles	Convincing traffic engineers of the need of TSP and keeping everyone focused on working on same project and communication open. On the whole public is unaware of TSP.	For Tri Met; Getting activation points into TriMet data, Define usage parameters. For the City; Controller upgrade and software, deployment or installation problems.
Keys to success	Develop strong jurisdictional partnerships for project coordination and implementation. Provide measurable and quantifiable project results and outcomes	Stakeholder Partnerships. Extensive inter-agency cooperation and trust, pitching the right ideas from the beginning

Table 7: Overview of State-of-the-Art Cases in the states of Illinois, California and Virginia

	Pace, Chicago, IL	MTA, Los Angeles, CA	Fairfax, VA
Corridor	One	9 equipped, 19 other planned, BRT Corridors	One
Congestion Protection Strategy	TSP Requested by all buses	Early green, green extension and phase hold	Signal priority is not dependent on the bus lateness. Green extension.
Traffic Signal Priority	Early green and green extensions	Conditional base don headway management	Green Extension
Institutional Barriers	DOT reluctant in support due to significant adverse impact on traffic operations from transit priority. CTA reluctant as it was pursuing other priorities and approaches	Minimal LADOT instigated the project	System ownership and maintenance (VDOT vs. Fairfax County) is a problem. Also internal Fairfax County logistics since two departments (EMS and Fairfax DOT) share same equipment.
Reported Travel Time Savings (min)	15% reduction in running time, Pace realized savings of one weekday bus while maintaining same frequency of service	19 to 25% reduction travel times, 4-40% increase ridership depending on line	-
Measures of effectiveness	Average vehicle delay, average vehicle speed, average bus delay and average bus speed all bases on TraF-NETSIM output	Reduce travel time and increased delay to motorists	Queue. Number of cycles to clear a queue. Queue on mainline. Delay to vehicles. Reduction in accidents. Travel time for buses. Reduced accidents
Greatest obstacles	Support from all agencies and collection of data	Rapid deployment of new technology and bureaucratic limitations to implementation. 86 cities involved to request implementation agreements of the technology, green time precious	-
Keys to success	Cooperation, enthusiastic support of at least some agencies, Econolite support to change firmware	Extensive technology evaluation and selection of a reliable technology and continuous and ongoing monitoring of performance. "Dare to be Simple"	Communication, and keep moving ahead despite the obstacles

The benefits of congestion protection strategies are several. They range from reduction in travel time to improvements of traffic flow. These results also translate to savings in infrastructure and costs. However, to implement and deploy these strategies as well as other cases has come at a price. There are two important aspects to consider here; the institutional barrier and great obstacles. Institutional barriers range from importance given to the project, to the high complexity of actors involved and communication between actors. Derived from the institutional barriers, there are greater obstacles to get through. Given the large number of actors involve requires their coordination and communication. The latter is perhaps the most important obstacle to be addressed. Jurisdictions involve in many cases a large number of actors, where information, data and the bureaucratic process just make it more difficult for the project to be developed and deployed. On the other hand, the measures of effectiveness have been so diverse that the information they provide is, to a certain point, limited to only the case at hand. This is, each of the cases has selected the measures of effectiveness from which they will evaluate their project. The most common; travel time and vehicle delay. The way in which the measures are evaluated is unknown. However, there are no thresholds towards these measures. A simple reduction in travel time is already considered a benefit. The results are presented in a wide variety of ways that lack to provide the necessary information to seize in reality what the benefits are.

To implement the congestion protection strategies at a local site evaluation requires, therefore, an analysis of the actors. The analysis also proposes different thresholds in order to evaluate the performance of a congestion protection project. Furthermore, implementation involves considering the technologies behind Transit Signal Priority. As the strategies focus towards the transit vehicle it is necessary to know what management tools are used by the transit authority. The site evaluation and characteristics are presented in Part II, while Part III analyzes the policies, actors, technologies and management tools. Notwithstanding, the result of the site evaluation, implementation and or deployment involves overcoming the bureaucratic hurdle.

3.3 Bureaucratic Hurdle and Leadership for Implementation

The previous paragraph provided several state-of-the-art cases highlighting the benefits and barriers towards development and deployment of congestion protection strategies. However, for implementation and or deployment it is necessary to overcome the bureaucratic hurdle. The bureaucratic process in which the project –public transportation deploying congestion protection strategy- needs to go through is, in some cases, endless. Considering the amount of information, reports, data, debates and consensus amongst many other aspects required to fulfill such project threaten it. Even more when there is skepticism, lack of information or even the perception towards the mode in question can jeopardize the entire project. To defeat the bureaucratic hurdle and even perhaps the institutional barriers calls for leadership.

Leadership towards guiding the project, providing the necessary information and promoting it does not necessary come from the transit authority -although in many cases it does as it is the primary beneficiary. In the case discussed in this report, such leadership can come from the Central Transportation Planning Staff (CTPS) of the Metropolitan Planning Organization (MPO). As it is discussed in Part III and in Appendix C, the CTPS is in charged of multimodal transportation planning and analysis for the MPO. Through the agency different programs and projects can be accomplished. This actor can be seen as the link to promote the cooperation required between agencies. The cooperation, as mentioned before and identified in the latter parts of this report plays an important role. Therefore, the CTPS, not only has the ability to promote cooperation but it also has the necessary power and interest towards support and encouragement to deploy projects that involve congestion protection strategies.

3.4 Conclusions

This chapter presents a state-of-the-art of cases in the United States of America where different congestion protection strategies have been implemented. Furthermore, it identified the benefits and barriers of deployment and how allocating the appropriate leadership can defeat the bureaucratic hurdle.

Despite the institutional barriers and measures of effectiveness, which are two aspects to consider in the implementation of congestion protection strategies, diverse project have had outstanding benefits. The benefits translate to a decrease in travel time and delay to savings in infrastructure and operational costs. Congestion protection strategies benefit public transportation users as well as non-users. However, coordination and communication have been identified as the major obstacles towards deployment. Coordination and communication lack is caused due to the large number of actors and the jurisdiction conflict.

The bureaucratic process is in many cases endless. Moreover, when trying to implement and or deploy a project that is seen with skepticism, a lack of enthusiasm or perception the hurdles are more difficult to overcome. Through leadership, however, appointing an actor with the sufficient interest and power the bureaucratic process and barriers can be minimized. In the case of this report, for example, the Central Transportation Planning Staff, has the sufficient power and interest to promote, support and encourage public transportation project that deploy congestion protection strategies in the city of Boston.

The information in this chapter serves to highlight the interrelation between the site evaluation (Part II) and the analysis performed to the actors, policies, technology and management tools (Part III), towards finding the benefits, barriers and obstacles of deploying the preferred congestion protection strategy at the site evaluation.

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Part II. Site Evaluation

Bus route 1 and CT1, a key bus route and express bus route running along Massachusetts Avenue, a major thoroughfare in Boston, encountering congestion at different intersections. At the intersection of Beacon Street before crossing the Harvard Bridge congestion effects hamper all vehicles, specially the bus. Throughout several scenarios different congestion protection strategies will be modeled with the help of a micro-simulation program.

The chapters in this Part are:

- Chapter 4 A Specific Case; Massachusetts Avenue
- Chapter 5 Analyzing Massachusetts Avenue
- Chapter 6 Scenarios at Mass Ave and Beacon St
- Chapter 7 Results at Mass Ave and Beacon St

Figure 21: Cartoon of bus driver on bus lane

Source;www44

Chapter 4 A Specific Case; Massachusetts Avenue

4.1 Introduction

Part I has described the research demarcation, the transit authority and congestion protection strategies. The previous chapter described the benefits and barriers of deployment of congestion protection strategies encountered by several cases primarily in the USA. This chapter focuses on a specific case in the city of Boston. In the relevant city several intersections could be labeled as “Hot Spots” for public transportation vehicles due to the congestion effects encountered impacting on their running time. One of these “Hot Spots” is the intersection of Massachusetts Avenue and Beacon Street where the combination of different factors creates congestion. At the intersection two bus routes operated by the transit authority as well as regular traffic suffer a delay and or increase in travel time. To alleviate the bus routes from congestion different congestion protection strategies will be assessed. However, this intersection represents a challenge given the characteristics of the intersection and the surrounding infrastructure described in the ensuing.

4.2 Intersection Characteristics

Located in the Back Bay neighborhood the intersection of Massachusetts Avenue and Beacon Street will be evaluated assessing different congestion protection strategies to improve the running time of two bus routes.

Massachusetts Avenue (Mass Ave) is a major thoroughfare in the city of Boston with an approximately length of 24 km or 15 miles [www10] running north – northwest connects the city of Boston to the city of Cambridge and other towns and south – southeast towards Suffolk. Mass Ave is a 2x2 lane for traffic flow and a parking lane (in some sections) by the curb.

Beacon Street is another mayor thoroughfare running east to west, through the Back Bay neighborhood of Boston and other towns with five-lanes, until it reaches Kenmore Square (approximately 0.4 miles or .62 km to the west) where then three lanes accommodate flowing traffic and the other two lanes by the curb are for parking.

To account for spillbacks and other effects other intersections over Mass Ave. are considered; downstream (Memorial Drive) and two upstream (Marlborough Street and Commonwealth Avenue). The intersection of Memorial Drive is located opposite of the Charles River in the city of Cambridge. Marlborough Street is a small side street, while Commonwealth Avenue is a major thoroughfare. The corridor of intersections is depicted in Figure 22.

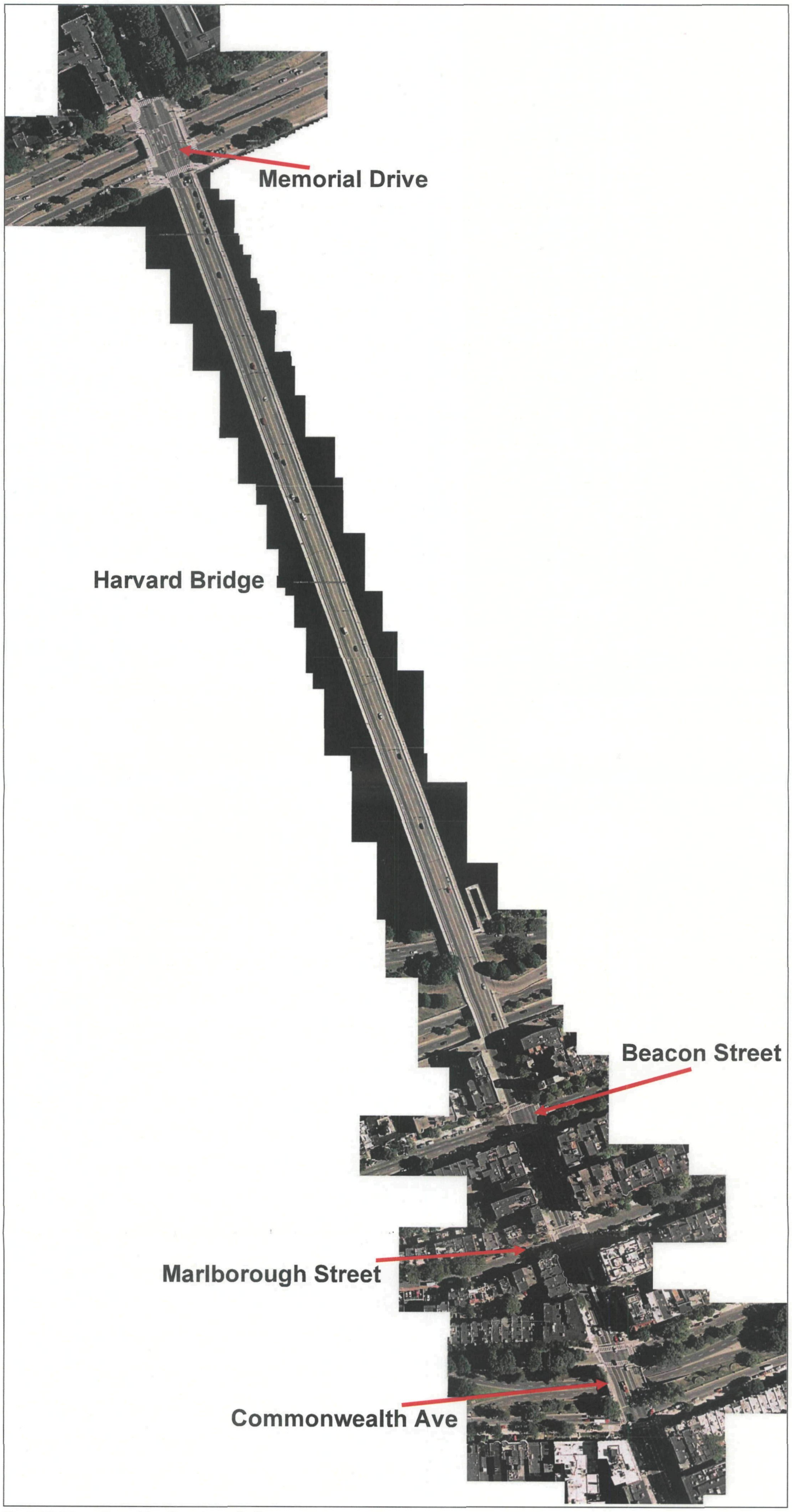

Figure 22: Intersections of the site under evaluation

Source; www10

Through Mass Ave two important bus routes operated by the Massachusetts Bay Transportation Authority (MBTA) render a service. Bus route "1-Harvard-Dudley via Massachusetts Avenue and Boston Medical Center" runs mostly along Massachusetts Avenue, from Harvard, past the Massachusetts Institute of Technology, over the Charles River via the Harvard Bridge into Boston, continuing to Boston Medical Center. Route "CT1-Central Square, Cambridge – B.U. Medical Center", offers a service running through Mass Ave with limited stops. Basically route CT1, follows a similar path of bus route 1, being considered by the Massachusetts Bay Transportation Authority an express service –with limited stops. The frequency of bus route 1 and CT1 considering the schedule effective 03/22/08 is; at peak hours up to 6 buses per hour for route 1 and 3 buses per hour for CT1 and at non-peak hours 4 buses and 2 buses respectively.

The following characterize the "Hot Spot" and are considered the reasons for selection. 1) The "Hot Spot" is located at the edge of the Harvard Bridge. The Harvard Bridge (also known as the M.I.T. Bridge or Mass Ave Bridge) is the bridge that connects Cambridge and the Back Bay area, being the longest bridge crossing the Charles River with a length 659.82 meters on the roadway and 620 meters on the sidewalk [17]. The bridge has 2x2 lanes for vehicles, a bicycle lane and pedestrian sidewalks on each side. Given the history and importance of the bridge, congestion protection strategies to be deployed present a challenge, as it is almost impossible to change the road geometry.

2) Beacon St. has a considerable volume of traffic, primarily during baseball season as it offers one of the few alternatives to access Cambridge and Fenway Park. As vehicles turn (right) from Mass Ave (Cambridge) after the bridge into Beacon St. the turning ratio is considerably high compared to other days, even on peak hours. Vehicles coming from the south of Mass Ave, turn left (protected left turn) into Beacon St. having an effect over traffic running through Mass Ave inbound and outbound.

3) The problem of congestion has increased in recent years throughout the city due to a higher number of private vehicles. The congestion conflict present at this intersection is in some instances severe impacting on drivers, buses, pedestrians and cyclist. Congestion causes observed at the corridors involved faulty traffic signals, protected left turns, driver behavior and parking lanes. The Harvard Bridge serves as a buffer allocating a considerable amount of vehicles primarily inbound. Downstream of Beacon Street other intersections are also at capacity and turning fractions (left turns allowed, reducing the lane capacity to one) create congestion upstream. Outbound, before arriving to the mentioned intersection, a similar conflict created by turning fractions exists. However, the primary cause of congestion affecting the bus is driving behavior. Drivers stand in through lanes, double park, stand at bus stops, delivery trucks are idle on through traffic lanes, right turn on red from side streets,

merging possibilities between vehicles, lack of buffer space to vehicles turning are among the many causes of congestion observed.

4) A bus stop at the intersection of Beacon St. is located (near side) for inbound and outbound. The buses suffering from congestion given the location of the stop (by the curb) have led bus drivers to apply diverse strategies to overcome these situations. For example, as observed, some bus drivers dwell passengers at the middle lane without reaching the curb due to limited possibilities (right-of-way) to merge back after stopping and crossing the intersection (see intersection layout in figure below). Effects such as bus bunching also occur, as both bus routes run on a short headway between each other's schedules and most stop at Beacon St. bus stop.

5) Finally, at the relevant intersection different actors have a jurisdiction, creating a jurisdiction conflict when developing and deploying congestion protection strategies. The jurisdiction conflict is further addressed and depicted in Chapter 8.

Figure 23 presents a sketch of the intersection of Massachusetts Ave and Beacon St. highlighting the streams, lanes, markings and bus stops. In Figure 24, an old aerial snapshot, it can be seen a 3 lane configuration, markings, different from the current markings. In addition, a bus dwelling at the center line between two lanes for inbound (stream 11). Outbound a bus bay allows buses to dwell by the curb, where no vehicles are allowed to stop or park here (although these situations occur). It can be noted how after crossing the intersection from three lanes it is reduced to 2 lanes for inbound and outbound.

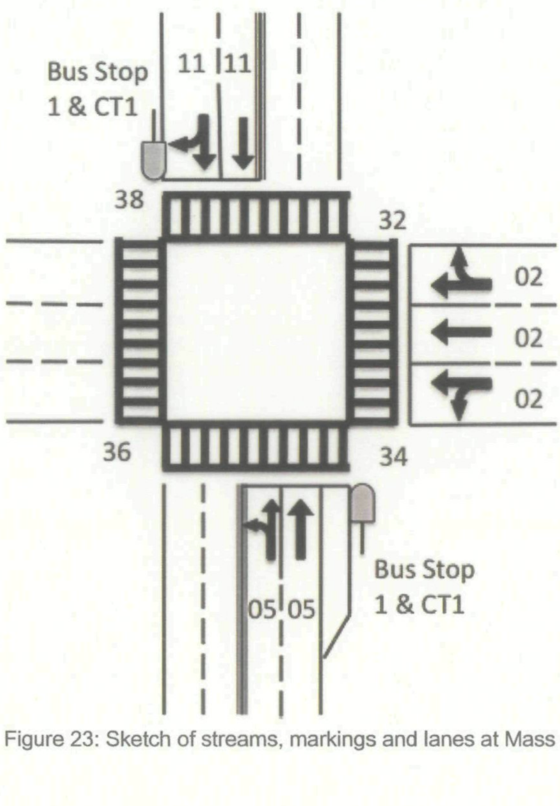

Figure 23: Sketch of streams, markings and lanes at Mass Ave. and Beacon St.

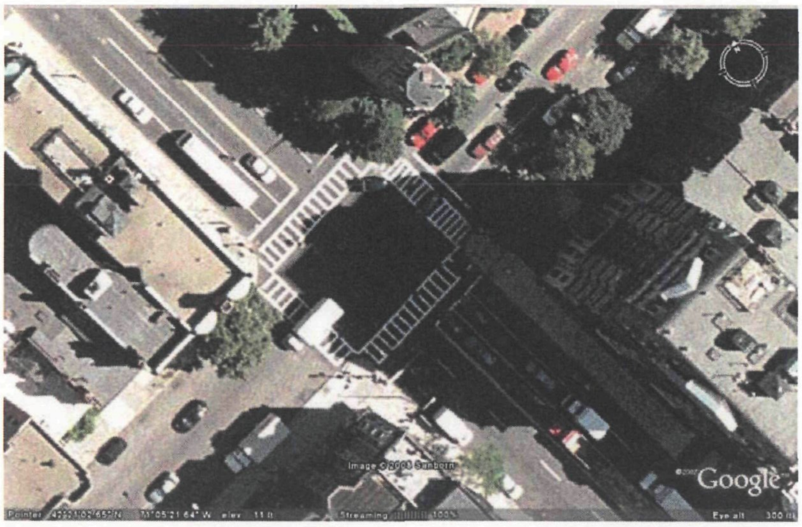

Figure 24: Old satellite picture of Mass Ave and Beacon St. showing three lane markings inbound
Source; www11

Measuring the Harvard Bridge
The Harvard Bridge is 364.4 smoots +- one ear long on the sidewalk [18]. Smoots are a measurement adopted after a fraternity of M.I.T. students measured the bridge using one of its members (by laying him down) on the eastern sidewalk. A smoot is a nonstandard unit of length named after Oliver R. Smoot who was five feet and seven inches or 1.7018 meters. The bridge

4.3 Conclusions

The "Hot Spot" an intersection in the Back Bay neighborhood where Massachusetts Avenue and Beacon Street meet is an ideal candidate to assess congestion protection strategies.

Massachusetts Avenue is a major thoroughfare where two bus routes run suffering from congestion, especially at the relevant intersection impacts on the running time of the bus. Congestion primarily caused by driver behavior and capacity intersection. In addition, other conflicts affect such as high traffic volumes (peak and seasonal), turning fractions, road markings and geometry as well as the infrastructure surrounding the area. The intersection is at the edge of the Harvard Bridge, a landmark in the city, connecting the city of Boston and Cambridge. Due to the causes of congestion and the geometry of the intersection represent a challenge to develop and deploy congestion protection strategies in the City of Boston. Moreover, as the layout of the intersection can not be altered. .

The information contained in this chapter will serve as the initial input to develop scenarios (Chapter 6) to evaluate congestion protection strategies previously discussed. As well it identifies the policies and actors (Chapter 8) comprehended at the relevant intersection, define technology (Chapter 9) and performance measures (Chapter 10).

Chapter 5 Analyzing Massachusetts Avenue

5.1 Introduction

An analysis of the intersections comprehended in the site evaluation in a quantitative manner is performed in this chapter. The calculations are performed evaluating the concepts of volume/capacity ratio, minimum green time, average delay and Level of Service per stream. The results render the current situation in order to identify if any stream is above acceptable levels of volume to capacity ratio, delay and Level of Service.

5.2 Intersection Calculations

Calculations performed for each of the intersections follow the parameters and approach formulas of the Highway Capacity Manual [21] and the lecture notes from CT4822 [7]. The input data is obtained from traffic volumes, cycle time of the traffic signal and intersection characteristics described in Appendix E. In Figure 25 to Figure 28 a sketch of each intersection depicts the stream numbers and lane markings. Table 8 to Table 11 provides the results obtained from the calculations for each of the intersections.

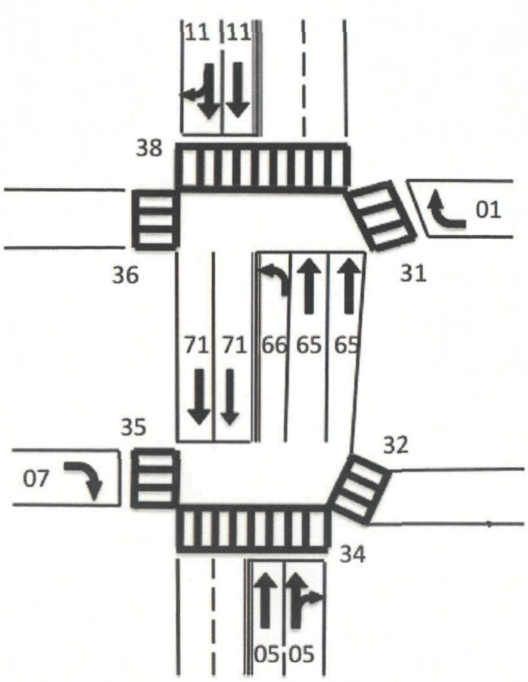

Figure 25: Streams and markings at Memorial Drive

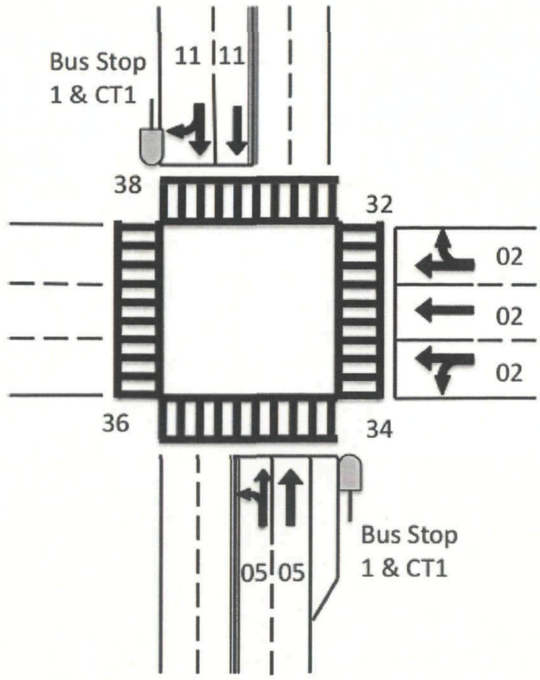

Figure 26: Streams and markings at Beacon St.

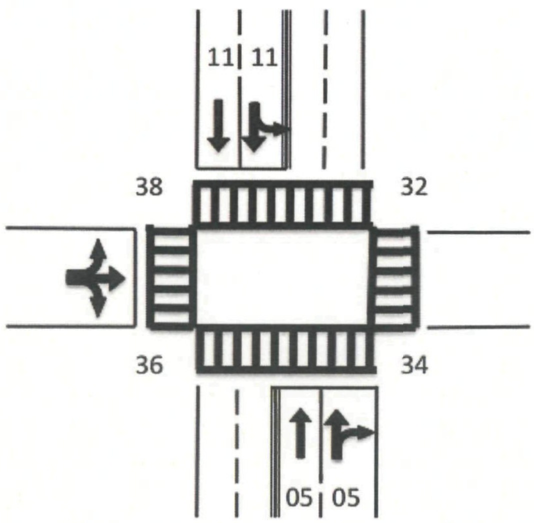

Figure 27: Streams and markings at Marlborough St.

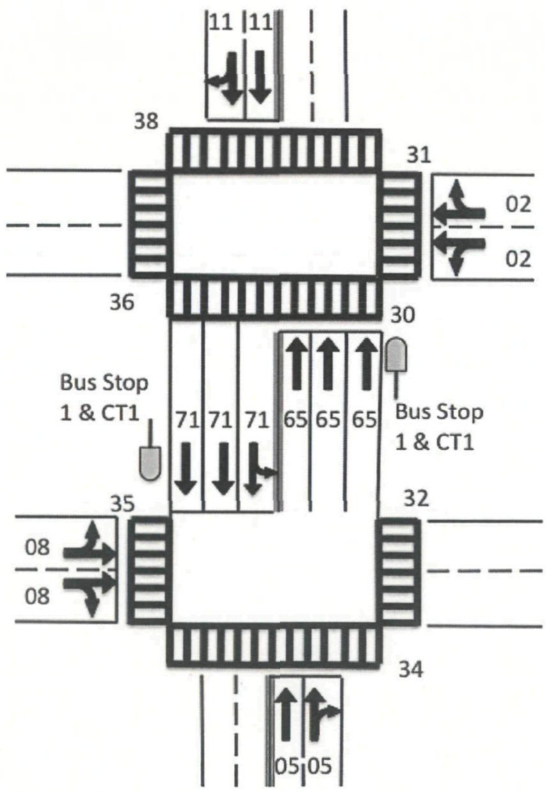

Figure 28: Streams and markings at Commonwealth Ave.

Table 8: Intersection Calculations at Memorial Drive

Memorial Drive and Mass Ave

Concept	Formulas	1	5	7	11	65	66	71
Lanes		1	2	1	2	2	1	2
Saturation Flow (veh/hr/ln)	So	1800	1800	1800	1800	1800	1800	1800
Adjusted Saturation Flow	S= b1 * So	1523	2815	1523	2939	2985	1523	2985
Volume		148	985	398	862	558	133	793
Flow ratio v/s	Volume/S	0,10	0,35	0,26	0,29	0,19	0,09	0,27
Cycle length C (sec)		100	100	100	100	100	100	100
Green time G (sec)		18	47	34	29	53	13	35
Yellow time Y (sec)		3	3	3	3	3	3	3
Lost time L (sec)		4	4	4	4	4	4	4
Effective red r (sec)	C-G-Y+L	83	54	67	72	48	88	66
Effective green g (sec)	G+Y-L	17	46	33	28	52	12	34
Minimum green (sec)	C * v/s	10	35	26	29	19	9	27
Green ratio g/C	g/C	0,17	0,46	0,33	0,28	0,52	0,12	0,34
Capacity (veh/hr)	S*(g/C)	259	1295	503	823	1552	183	1015
Volume / Capacity	Volume/(S*(g/C))	0,57	0,76	0,79	1,05	0,36	0,73	0,78
Resulting Delay								
d1 (sec)	0,5*C*((1-g/C)^2)/(1-(Vol/Cap*g/C))	38,15	22,43	30,39	36,68	14,17	42,43	29,66
d2 (sec)	900*0,25*((Vol/Cap-1)+ SQRT((Vol/Cap-1)^2 + (8 *0,5*Vol/Cap /(Cap*0,25))))	8,87	4,25	12,08	44,51	0,65	22,29	5,98
Total Delay D (sec)	d1 + d2	47,03	26,68	42,47	81,18	14,82	64,71	35,64
Level of Service LOS		D	D	D	F	B	E	D
LOS Intersection					D			

Table 9: Intersection Calculations at Beacon Street

Beacon St and Mass Ave.

Concept	Formulas	2	5	11
Lanes		3	2	2
Saturation Flow (veh/hr/ln)	So	1800	1800	1800
Adjusted Saturation Flow	S= b1 * So	3765	2205	2457
Volume		732	952	1174
Flow ratio v/s	Volume/S	0,19	0,43	0,48
Cycle length C (sec)		110	110	110
Green time G (sec)		38	65	42
Yellow time Y (sec)		3	3	3
Lost time L (sec)		4	4	4
Effective red r (sec)	C-G-Y+L	73	46	69
Effective green g (sec)	G+Y-L	37	64	41
Minimum green (sec)	C * v/s	21	47	53
Green ratio g/C	g/C	0,34	0,58	0,37
Capacity (veh/hr)	S*(g/C)	1266	1283	916
Volume / Capacity	Volume/(S*(g/C))	0,58	0,74	1,28
Resulting Delay				
d1 (sec)	0,5*C*((1-g/C)^2)/(1-(Vol/Cap*g/C))	30,07	16,93	41,44
d2 (sec)	900*0,25*((Vol/Cap-1)+ SQRT((Vol/Cap-1)^2 + (8 *0,5*Vol/Cap /(Cap*0,25))))	1,93	3,91	135,15
Total Delay D (sec)	d1 + d2	32,00	20,83	176,58
Level of Service LOS		D	C	F
LOS Intersection			E	

Table 10: Intersection Calculations at Marlborough Street

Marlborough St and Mass Ave

Concept	Formulas	5	8	11
Lanes		2	2	2
Saturation Flow (veh/hr/ln)	So	1800	1800	1800
Adjusted Saturation Flow	S= b1 * So	2734	2152	2667
Volume		944	78	798
Flow ratio v/s	Volume/S	0,35	0,04	0,30
Cycle length C (sec)		110	110	110
Green time G (sec)		66	25	78
Yellow time Y (sec)		3	3	3
Lost time L (sec)		4	4	4
Effective red r (sec)	C-G-Y+L	45	86	33
Effective green g (sec)	G+Y-L	65	24	77
Minimum green (sec)	C * v/s	38	4	33
Green ratio g/C	g/C	0,59	0,22	0,70
Capacity (veh/hr)	S*(g/C)	1616	469	1867
Volume / Capacity	Volume/(S*(g/C))	0,58	0,17	0,43
Resulting Delay				
d1 (sec)	0,5*C*((1-g/C)^2)/(1-(Vol/Cap*g/C))	14,06	34,88	7,06
d2 (sec)	900*0,25*((Vol/Cap-1)+ SQRT((Vol/Cap-1)^2 + (8 *0,5*Vol/Cap /(Cap*0,25))))	1,55	0,76	0,72
Total Delay D (sec)	d1 + d2	15,61	35,65	7,78
Level of Service LOS		B	D	A
LOS Intersection			B	

Table 11: Intersection Calculations at Commonwealth Avenue

Commonwealth Ave and Mass Ave

Concept	Formulas	2	5	8	11	65	71
Lanes		2	2	2	2	3	3
Saturation Flow (veh/hr/ln)	So	1800	1800	1800	1800	1800	1800
Adjusted Saturation Flow	S= b1 * So	2241	2726	2105	2724	4343	4191
Volume		198	795	418	833	947	813
Flow ratio v/s	Volume/S	0,09	0,29	0,20	0,31	0,22	0,19
Cycle length C (sec)		110	110	110	110	110	110
Green time G (sec)		40	55	40	55	62	62
Yellow time Y (sec)		3	3	3	3	3	3
Lost time L (sec)		4	4	4	4	4	4
Effective red r (sec)	C-G-Y+L	71	56	71	56	49	49
Effective green g (sec)	G+Y-L	39	54	39	54	61	61
Minimum green (sec)	C * v/s	10	32	22	34	24	21
Green ratio g/C	g/C	0,35	0,49	0,35	0,49	0,55	0,55
Capacity (veh/hr)	S*(g/C)	795	1338	746	1337	2408	2324
Volume / Capacity	Volume/(S*(g/C))	0,25	0,59	0,56	0,62	0,39	0,35
Resulting Delay							
d1 (sec)	0,5*C*((1-g/C)^2)/(1-(Vol/Cap*g/C))	25	20	29	21	14	14
d2 (sec)	900*0,25*((Vol/Cap-1)+ SQRT((Vol/Cap-1)^2 + (8 *0,5*Vol/Cap /(Cap*0,25))))	1	2	3	2	0	0
Total Delay D (sec)	d1 + d2	26	22	32	23	14	14
Level of Service LOS		D	C	D	C	B	B
LOS Intersection					C		

In the tables above b1 factors the parameters of each stream, such as adjustment for parking lanes, turning fractions, bus stops and or slope. Following the Streetscape Guidelines for Boston's Major Roads [22] all intersections (fixed time control) should satisfy a volume to capacity value of .85 and a Level of Service (LOS) of "D" or better. However, for certain streams the volume to capacity ratio is below acceptable levels. For stream 11, inbound, at Memorial Dr. the volume to capacity ratio is 0.20 higher than acceptable. The green time of this stream is 29 seconds and the minimum time is also 29. This means that not all vehicles are able to clear the intersection creating a queue. At the "Hot Spot" for this stream a queue build-up, dissolving at the next cycle, was observed in different occasions. A solution would be to reduce green time from stream 66 and or increase the cycle time to 110 to generate new traffic timings. The latter would help to have the same cycle time at all of the intersections and probably coordinate their time sequence. Currently, the intersections of Beacon St., Marlborough St. and Commonwealth Ave. are coordinated, creating a green wave effect.

At Beacon St. stream 11, inbound, has a lagged start of 23 seconds, protected left turn, from stream 05 (outbound). Stream 11 is saturated, as green times are not sufficient to cross the intersection creating a queue. The volume to capacity ration is 0.43 above acceptable. The elimination of the protected left turn would have simultaneous movement for both streams improving the flow of stream 11. At peak hours queues were observed, in some cases reaching the intersection of Memorial Drive, a length of more than 600 meters.

The Level of Service rates the performance of the intersection based on the total delay vehicles experience. Acceptable levels are a delay of 25 seconds or less. The delay caused at the previously discussed stream affects the LOS of the intersection of Beacon St., LOS "E". The remaining intersections have a level of service "D" or better.

To alleviate both streams, previously mentioned, can be done by improving their traffic control, a proposed solution is to change from fixed time to vehicle actuated. Vehicle actuated control is the mode of operation where all approaches have detectors and all green phases are controlled by means of detector information [7]. Modeling of the site will be done using vehicle actuated traffic control as it allows introducing a priority call into the control phase.

5.3 Conclusions

Following the approach of the Highway Capacity Manual [35] and the lecture notes of CT4822 [7] the intersections at the site are analyzed in a quantitative manner. The results of the calculation draw the following conclusions. According to the Streetscape Guidelines for Boston's Major Roads [40] and the Highway Capacity Manual for the intersections each approach should have a volume to capacity ratio below 0.85 and Level of Service (LOS) of

"D" or better. For Memorial Drive and Beacon St. stream 11 is above design standards. The green time of this stream in both intersections is not sufficient saturating the intersection. At Beacon St. the cause of the queue forming over the Harvard Bridge is due to the green time lagged between stream 05 (protected left turn) and stream 11. Eliminating the left turn and allocating turning traffic through side streets will balance both movements improving inbound traffic. Stream 66 at Memorial Drive, a cycle time of 100 and all pedestrian phase could be changed to provide stream 11 with a few more seconds of green time.

The Level of Service evaluates the delay of the intersection. Despite the high delay of stream 11 at Memorial Drive, the Level of Service of the intersection is "D". For Beacon St. the Level of Service is considerably low, LOS "E". Both Levels of Service could be improved by changing the traffic control program and or reconfiguration of the signal timings to allocate more time to through traffic and less to turning movements. The intersections of Marlborough St. and Commonwealth Ave. perform within acceptable design levels with a LOS of "B" and "C" respectively.

The information contained in this chapter is used to comprehend the situation of the site subject of evaluation and in coordination with the information discussed in previous chapters develop different scenarios to propose a solution to improve the running time of the bus at the "Hot Spot"

Chapter 6 Scenarios at Mass Ave and Beacon St

6.1 Introduction

In order to deploy congestion protection strategies to improve running time of public transportation requires modeling diverse strategies. Evaluating them presents the necessary information to comprehend and assess which strategy will provide the best benefits. At the "Hot Spot" different congestion protection strategies will be modeled using a micro-simulation program to further propose the most appropriate congestion protection strategy towards improving the running time of bus route 1 and CT1.

In Appendix E information about the software program, input parameters and other relevant information required to perform the simulation of the "Hot Spot" are discussed.

6.2 Intersection Scenarios

Based on a range of congestion protection strategies several scenarios are developed for the "Hot Spot". The scenarios focus on strategies to improve the travel time of bus route 1 and CT1 by simply modifying the traffic signal control strategy and/or other protection congestion strategies at Mass Ave and Beacon St. The congestion protection strategies that can be developed are limited by the existing road geometry and the importance of the infrastructure surrounding the "Hot Spot" (refer to Chapter 4). Modifications to the layout of the intersections (e.g. adding an extra lane or widening the Harvard Bridge) are impossible. The latter resulted in seven different scenarios listed here below and further described in the ensuing paragraphs:

- Base Scenario
- Vehicle Actuated Scenario
- Vehicle Actuated with Priority Control Scenario
- Three Lane Scenario
- Vehicle Actuated Left Turn Actuated
- Bus Lane Scenario
- Bus Lane with Priority Scenario

In the future an increase in traffic will occur. Therefore, 2 scenarios were developed to examine the impact of an increase in traffic over the site –Base Scenario 10% and Vehicle Actuated 10%. In all scenarios, except the base scenarios, the adopted traffic control strategy is vehicle actuated control for all intersections. Vehicle actuated control allows to introduce priority calls for public transport integrated into the traffic control phase.

6.2.1 Base Scenario

Called the base scenario, this scenario is the “as-is scenario”. The control program for the traffic signals throughout the relevant intersections is fixed time. With a cycle time of 110 seconds (100 seconds for Memorial Drive), this scenario will be used as base case to develop, evaluate and compare alternative scenarios that will try to improve the situation at the “Hot Spot”.

A screen shot of the intersection of Beacon Street in 3D from the simulation program is shown in Figure 29.

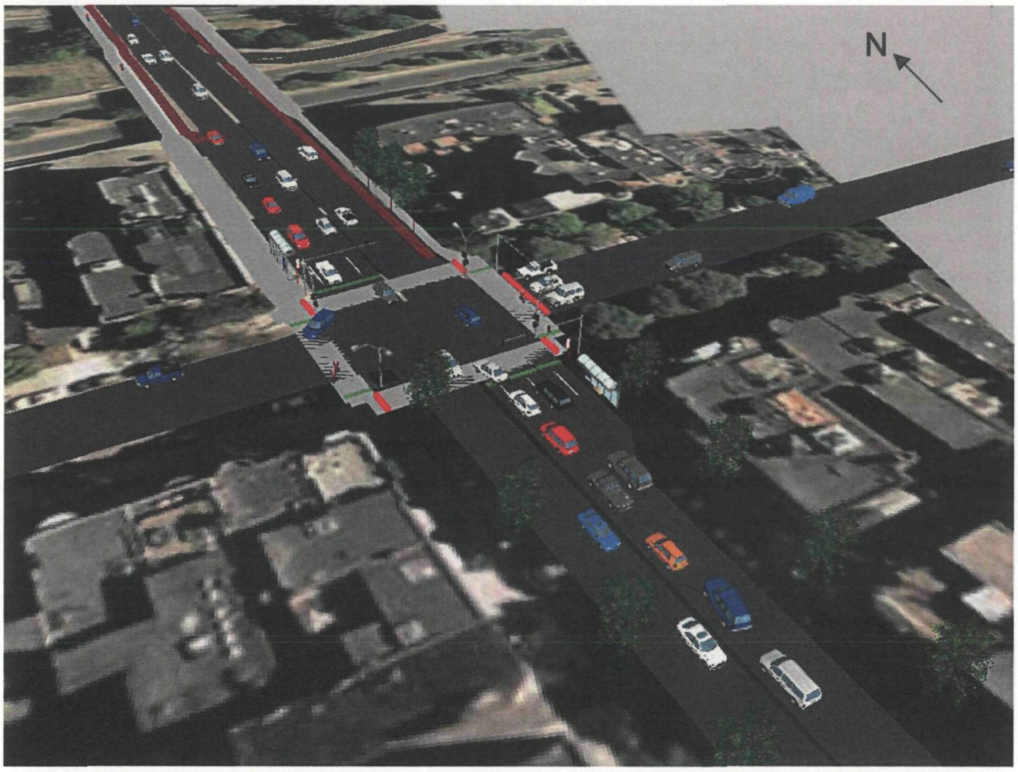

Figure 29: Screenshot of Base Case Scenario in 3D for the intersection of Mass Ave and Beacon St.

6.2.2 Base Scenario 10%

Based on the “as-is scenario”; this scenario considers an increase by 10% of the traffic volume (vehicle counts) at the site. As traffic will increase in the coming years, the assumption of an increase in traffic volumes helps to comprehend what would be the impact if no priority strategies are considered. Although, a 10% increase in traffic might not happen in the near future such a high increase allows a considerable assessment into analyzing the reliability and future conditions of the “Hot Spot”.

6.2.3 Vehicle Actuated Scenario

The traffic signal control program in this scenario is changed from fixed time to vehicle actuated. By setting detectors in the pavement, traffic at the intersection flows as vehicles occupy the detector area where a control sequence provides green to those streams occupied following a control sequence previously determined for each intersection.

It is necessary to change fixed time control to vehicle actuated in order to integrate priority strategies to the traffic control. This scenario serves as the base scenario to develop congestion protection strategies.

6.2.4 Vehicle Actuated Scenario 10%

The scenario is based on the vehicle actuated scenario (all things being equal) considering an increase of 10 % in traffic volume (vehicle count). Base scenario 10% provides insight behind the increase in traffic volumes.

6.2.5 Vehicle Actuated with Priority Control Scenario

This scenario incorporates a traffic signal priority control for buses at Mass Ave and Beacon St. The priority call allows buses to cross the intersection by either green extension or red truncation.

When a bus is detected (detector occupied) the control sequence provides a green extension if the sequences is in progress or a red truncation of the phase in progress changing to the phase that made the call returning to the subsequent phase after the priority call ends. This would not be possible with fixed time control.

The location of the bus stop becomes a limitation in relation to the stop line, the traffic signal and the detector. The detector needs to be placed or programmed to request a priority call after the bus has dwelled. This is one of the reasons why far side bus stop locations are preferred. Several studies have shown that priority calls work better if the bus stop is downstream and not upstream of the intersection [10]. In order to evaluate this possibility the bus stop would have to be relocated. However, at the intersection of Mass Ave and Beacon it is impossible due to policies and actors and the infrastructure[4] (historical buildings and parking spaces) surrounding the intersection.

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[4] Opposite from the bus stop (outbound) an old church building is located where the dimensions of the sidewalk over Mass Ave are considerably small to relocate the bus stop. As well after this building the Harvard Bridge begins without sufficient buffer area.

Figure 30 shows the bus (in pink) being granted priority to cross the intersection. Notice the green bus further downstream. This bus is bus route 1 and the pink bus is CT1. Both were granted priority to cross the intersection, green extension. This caused long queues over Beacon St. and illustrates the effect of bus bunching between both bus routes.

6.2.6 Vehicle Actuated Left Turn Actuated Scenario

One of the situations observed at the "Hot Spot" is the queue generated by cars turning left on Mass Ave to Beacon St. In the base scenario the first 23 seconds of the fixed time control sequence allow a protected left turn, after this time turning is possible at the discretion of the driver, creating a bottleneck. Therefore, this scenario incorporates left turn phase to the control sequence (adding stream 06), a dedicated lane, in order to have an actuated left turn. This lane will be provided with sufficient length to accommodate certain number of vehicles turning left. Although it has been mentioned that road layout and geometry cannot be changed due to the characteristics of the intersection, this scenario only considers removing one and maximum two parking places to be accomplished[5] without affecting the capacity of the intersection. The bus bay lane (lane by the curb) would have to be increased upstream to allow through going cars to use it. This will mix the bus and therefore the bus with other vehicles at the bus stop. In Boston, it is not possible to park or use the bus stop areas for other vehicle classes. Figure 31 shows a screenshot of the lane configuration and traffic flow at Beacon St. in this scenario.

6.2.7 Three-Lane Scenario

In this scenario a three-lane configuration to cross the intersection of Beacon St. and Mass Ave. for streams inbound and outbound (streams 11 and 05, respectively) without changing the layout and or road geometry is proposed. For stream 11 the right lane is sufficiently wide to have two lanes (resulting in a 3 lane configuration as previously shown in Figure 24, page 30) at the stop line. The right lane would allocate buses and cars turning right. At Mass Ave. outbound, cars make use of the right lane (where the bus stop is located) allocating the right lane and the middle lane for cars and buses going through. The left lane is for protected left turns. This scenario tries to assess if an increase in capacity (without major modifications to the layout) with a protected left turn for 05 would have a significant decrease in congestion (cycle time smaller than V/C ratio) at the "Hot Spot". In addition, increasing the capacity for stream 11 where long queues were observed during peak hours would reduce running time of the bus.

Merging of the bus after crossing the intersection becomes a setback towards realizing this scenario, as there is a reduction in lanes from 3 to two. In the simulation the bus has a priority to merge as soon as possible having a minimal impact over the bus.

[5] It is assumed that if the results of this scenario are highly beneficial, removing one or two parking spaces to decrease congestion might be possible.

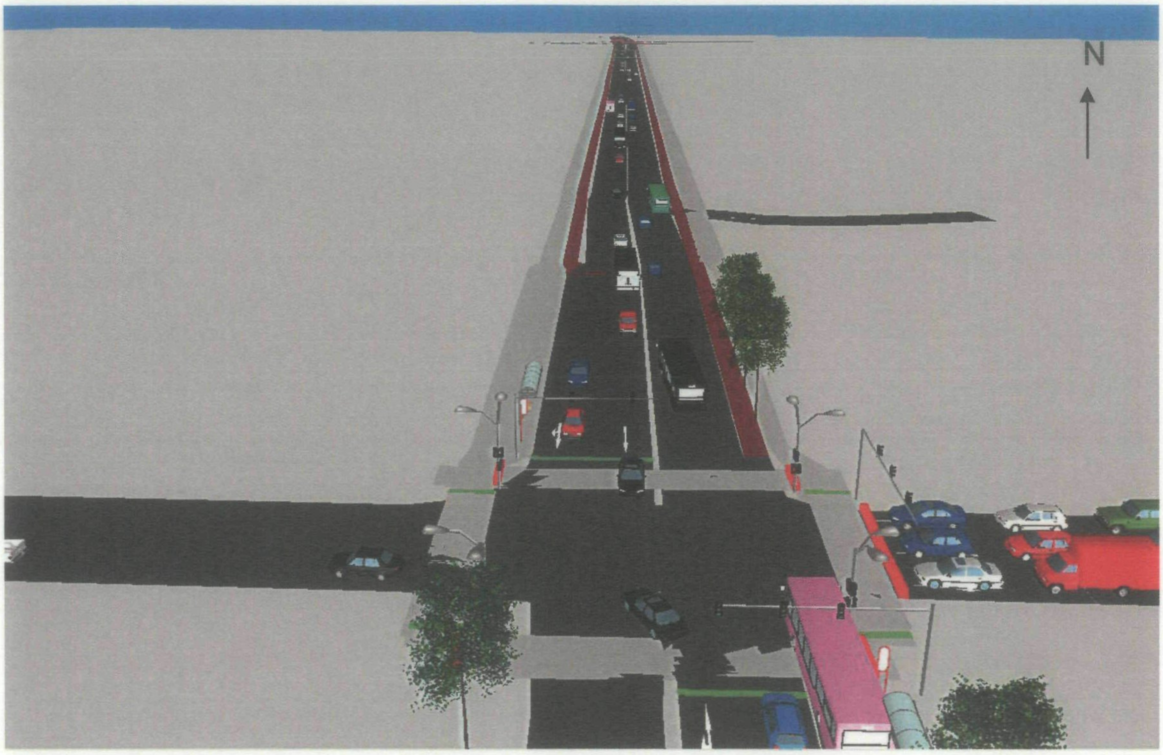

Figure 30: Screenshot of Vehicle Actuated with Priority Scenario at Mass Ave and Beacon St.

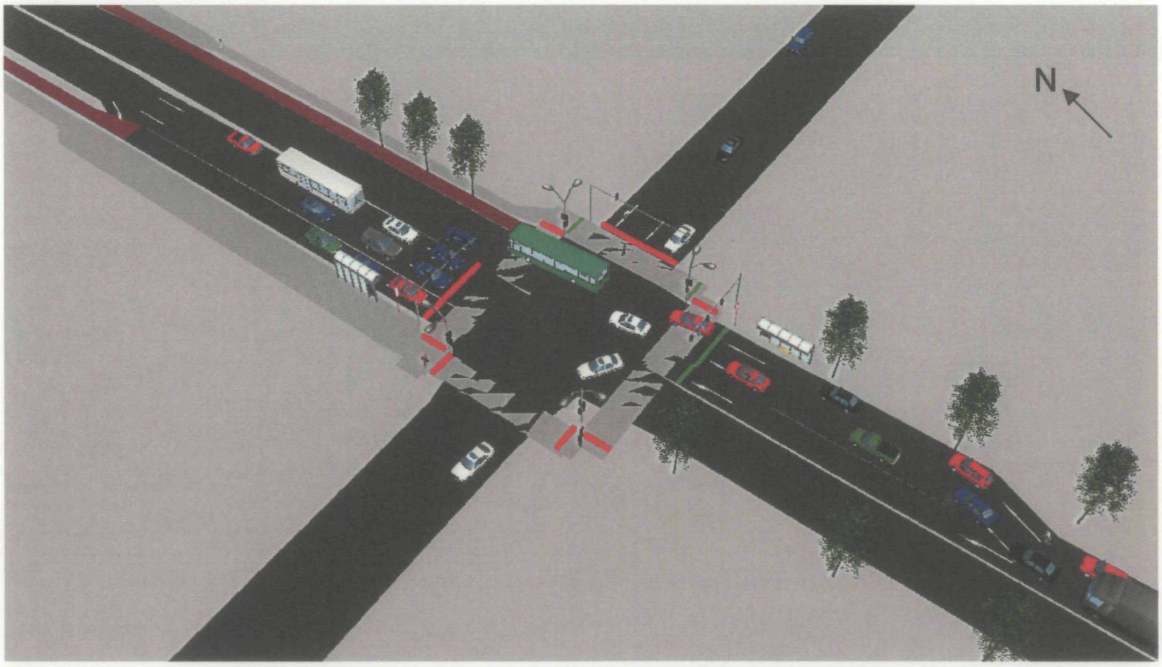

Figure 31: Screenshot of Vehicle Actuated Left Turn Actuated Scenario at Mass Ave and Beacon St.

6.2.8 Bus Lane Scenario

The length of the Harvard Bridge can be considered sufficient to incorporate a dedicated bus lane or intermittent bus lane[6] as a priority strategy. A dedicated bus lane along the Harvard Bridge for both directions could provide the bus with fewer delays. To keep the capacity of both intersections "as-is" incorporating a bus lane requires to start after crossing the intersection and end a few meters before the stop line of the intersection downstream. This scenario does not affect the capacity over the bridge. For outbound, stream 05 at Beacon St. the bus lane can be easily established. However, inbound, stream 11 becomes slightly more difficult to accomplish due to the bridge width and the layout of the intersection at the end of the bridge.

In Figure 32, the markings where the bus lane begins and ends at the intersection of Beacon St. are depicted.

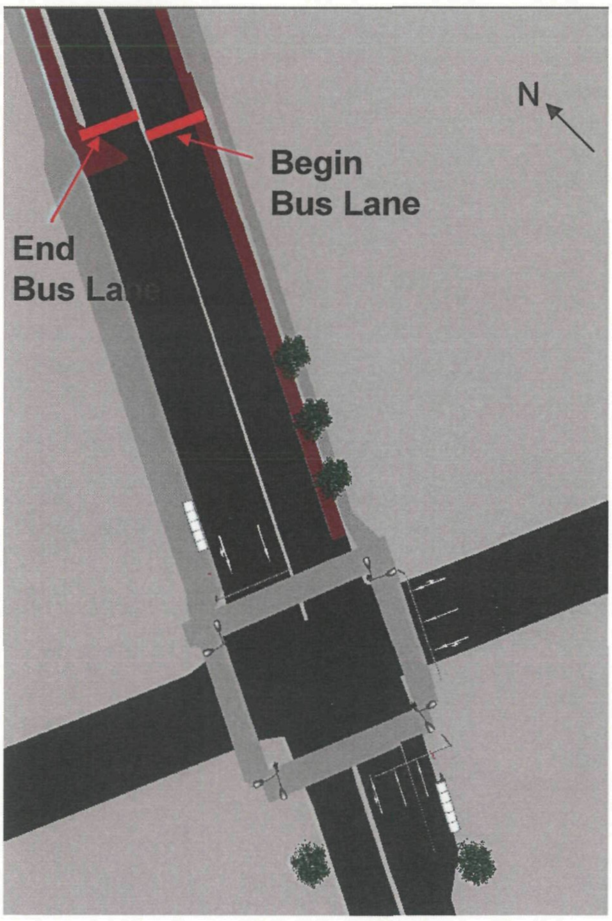

Figure 32: Bus Lane markers for Bus Lane Scenario

[6] The Intermittent Bus Lane [23], still in research trials uses a lane within a section of roadway for buses where road design changes are possible. When a bus approaches this lane through a traffic signal the lane changes to a dedicated bus lane. After the bus has traveled along the section, the lane is set back to mixed traffic. Mixed traffic can also flow behind the bus but on certain specific cases.

At begins and ends, buses run in mixed traffic were priorities are set to allow the bus to merge with ease. As cars would require merging, all merging possibilities are considered in advance and done as soon as a gap is available with minor or almost non-observed bottleneck situations.

6.2.9 Bus Lane with Priority Scenario

This scenario incorporates a priority call to reach the bus lane at the intersection of Beacon St. The scenario is a combination between vehicle actuated with priority scenario and bus lane scenario. A set back, for stream 11 (inbound) occurs given the road geometry and right turn. The bus lane ends at the end of the Harvard Bridge, where right turning vehicles use the right lane to turn right. Vehicles waiting to turn right occupy the bus stop and hamper the bus from reaching the bus stop. All buses make a stop at the bus stop. Placing the detector at the end of the bus lane did not provide enough time for the bus to dwell and cross the intersection. Therefore, the detector was placed between the bus lane and the bus stop. Locating the bus stop far side would allow the bus to cross the intersection with less delay.

6.3 Conclusions

In this chapter seven developed scenarios are proposed with the objective to improve the running time of the bus routes 1 and CT1 when reaching the intersection of Mass Ave and Beacon St. The scenarios consider different congestion protection strategies without making changes or modifications to the geometry of the intersection due to the characteristics of the "Hot Spot" (surrounding historical buildings and infrastructure).

To compare the proposed strategies with the current situation an "as-is scenario" (base scenario) is developed. In the base scenario the traffic control is fixed time. In all proposed scenarios the traffic control is modified to vehicle actuated. This allows incorporating a priority call within the control phase. Two scenarios evaluate the situation of the intersection when an increase in traffic volumes is to occur. In addition, congestion protection strategies such as Transit Signal Priority and a bus lane are formulated. The scenarios are modeled using a micro-simulation program to assess their effectiveness and performance in reducing travel time and or delay. In Chapter 7 the results from the simulated scenarios using travel time and delay as performance indicators are discussed.

The information in this chapter is used as input to simulate different congestion protection strategies at the "Hot Spot" in order to improve the running time of bus route 1 and CT1.

Chapter 7 Results at Mass Ave and Beacon St

7.1 Introduction

The previous chapters presented the characteristics of the "Hot Spot", performed intersection calculations and developed scenarios to simulate different strategies of congestion protection at the intersection of Mass Ave and Beacon St. Seven scenarios were modeled using a micro-simulation program. Each of the scenarios analyzes a different strategy of priority with potential to be implemented at the aforementioned intersection. In Appendix E - the parameters and simulation input data are presented. The result of the simulation, in this chapter, presents in a visual manner the outcome of the following performance indicators: delay and travel time. In paragraph 7.2 the travel time and in paragraph 7.3 the delay results for all scenarios are discussed.

The performance indicators are calculated as follow: delay -by averaging the delay over the travel sections- and travel time -by the average travel time for each travel section- differentiating between all vehicle classes and bus route one and CT1.

The travel time and delay results described hereafter are made on the basis of the deployed strategies impacting over the intersection at Beacon St. without considering (specific) situations that occur at other intersections, such as turning right at Marlborough Street for example. The results are provided for the travel sections over Mass Ave from Commonwealth Avenue to Memorial Drive. It is assumed that all things being equal the priority strategies affecting Beacon St. have an impact over other preceding intersections, allowing to quantitatively asses the effects of the priority strategies at the relevant intersection.

7.2 Travel Time Results

The results based on the performance indicator –travel time- for all vehicle classes and for bus route 1 and CT1 are presented in Table 12. The table compares the base scenario with the proposed scenarios providing the difference in travel time for all vehicle classes and bus route 1 and CT1 outbound and inbound (to and form MIT). The negative values represent a reduction of seconds in travel time.

Table 12: Difference in travel time between base scenario and proposed scenarios

SCENARIO	All Vehicles Mass Ave Outbound (sec)	Bus Rte 1 & CT1 Mass Ave Outbound (sec)	All Vehicles Mass Ave Inbound (sec)	Bus Rte 1 & CT1 Mass Ave Inbound (sec)
Vehicle actuated	22	-5	-28	-79
Vehicle actuated with priority	33	-12	-27	-88
Vehicle Turn Actuated	59	7	0	-48
Three lanes	5	-10	-33	-105
Bus lane	28	-11	-21	-83
Bus Lane with priority	29	-14	131	-32

Outbound (to MIT, stream 05) there is an increase in travel time for all vehicle classes while a decrease in travel time occurs for all other streams and classes. The increase in travel time to MIT can be explained by the following. The base scenario traffic control is fixed time and lags the start of this stream (protected left turn), which in turn creates a queue for stream 11 as there is insufficient time to cross the intersection (see chapter 5). In all of the scenarios the traffic control is changed to vehicle actuated. The traffic control balances both streams as it provides simultaneous movement. The bus under this scenario experiences a considerable reduction in travel time, primarily for stream 11. The reduction is even greater when a priority call is introduced. Stream 05 however, does not experience such a reduction in travel time due to the queue that builds up to turn left. In addition, when the priority call is introduced all vehicle classes suffer an increase of 33 seconds in travel time. The left turn queue effect can also be seen in the travel time result of the three-lane scenario. There is a slight increase in travel time for stream 05 for all vehicles as they queue behind the left lane but a reduction of 10 seconds for the bus occurs. Three-lane scenario represents the best alternative, which is a more or less expected result, as an increase in capacity improves crossing the intersection. Primarily, it benefits all vehicles outbound. The scenario bus lane increases the travel time by 28 seconds inbound due to the geometry of the intersection and the short distance to incorporate the bus lane. Vehicles need to merge from right to left after crossing the intersection to avoid the queue of left turning vehicles. Bus lane with priority affects the travel time for vehicles inbound (increase of 131 seconds) due to the geometry of the intersection, the location of the bus stop and right turning fractions. Despite these reasons the bus sees a reduction in travel time; however, it is relatively low to the decrease obtained in the bus lane scenario. The benefits of adding a priority call to this scenario might not justify the investment to deploy such strategy. Without considering scenario three lanes, vehicle actuated with priority and or bus lane scenario become one of the most beneficial strategies to improve the travel time of the bus.

To assess the situation of an increase in traffic volume at the intersection the base scenario 10% scenario and vehicle actuated 10% scenario were develop. In Table 13 the results of these scenarios is depicted.

Table 13: Difference in travel time between base scenario and proposed scenarios with an increase in traffic volumes

SCENARIO	All Vehicles Mass Ave Outbound (sec)	All Vehicles Mass Ave Inbound (sec)
Base scenario 10%	16	304
Vehicle actuated 10%	23	-28

An increase in traffic of 10% at the relevant intersections increases for stream 11 (inbound) with fixed time control the travel time 304 seconds for all vehicles classes. The increase can be explained by the layout of the road as discussed previously. An increase in travel time of 16 seconds for stream 05 also takes place. Vehicle actuated traffic signal control increases the travel time for stream 05 while reducing it for stream 11. The traffic control for both streams balances the movements, therefore, the reduction of minus 28 seconds bound from MIT and the increase of 23 seconds outbound. The reason behind this is the elimination of protected left turn from the control sequence. However, vehicle actuated control with an increase in traffic results in long periods of movement for the streams over Mass Ave. The effect on side streets, the queues generated, were quite considerable. Subsequently, the increase in traffic over the site would have a considerable effect on all vehicle classes including the bus.

The travel time of all vehicle classes and the bus is improved when deploying different priority strategies. An improvement in travel time means an improvement in the speed experienced by all vehicles, particularly the bus. This is shown in Figure 33.

The average speed depicted in Figure 33 is the operational speed for bus route 1 and CT1 considering dwelling and stops at congested points and bus stops. The increase in speed over the site subject of evaluation for the bus improves the running time of route 1 and CT1. Notwithstanding this increase in speed and the mix results in travel time the bus still suffers from congestion and encounters queues. The result of the delay encountered by the bus and all vehicle classes is discussed hereafter.

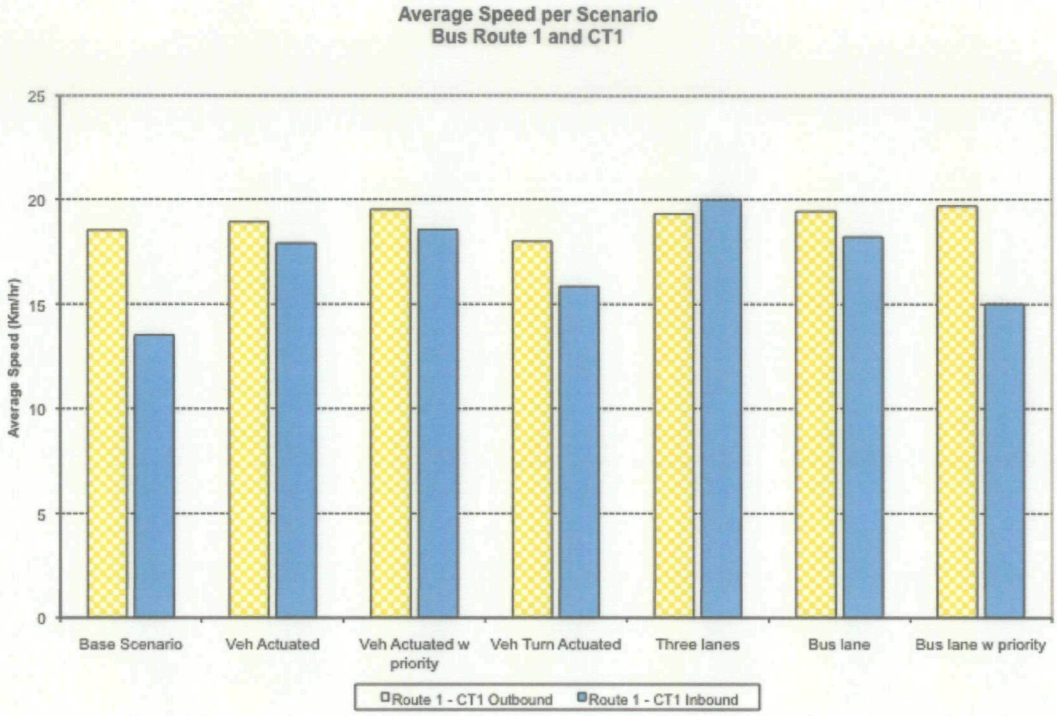

Figure 33: Average Speed per Scenario for Bus Route 1 and CT1 on Mass Ave

7.3 Delay Results

The results based on the performance indicator –delay– for all vehicle classes and for bus route 1 and CT1 are presented in Figure 34 and Figure 35, respectively. Figure 36, depicts the results of the simulation where an increase in traffic flow was considered.

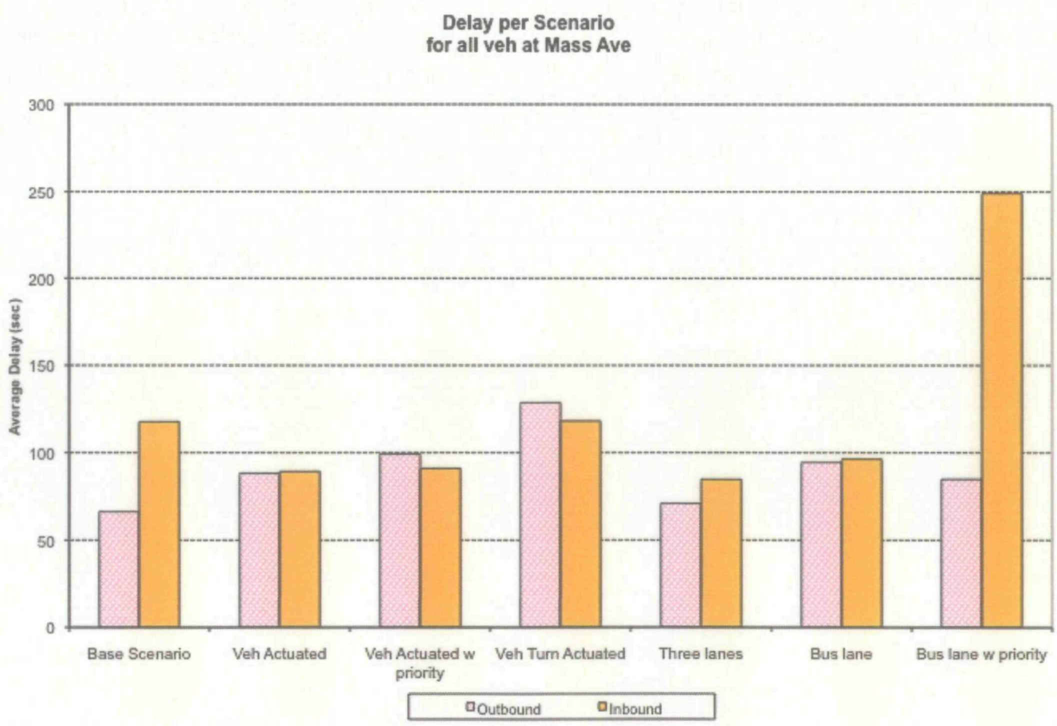

Figure 34: Average Delay for all vehicle classes on Mass Ave

The encountered average delay for all vehicle classes is slightly increased in all scenarios. Evaluating each bound per scenario, the delay for inbound is decreased whilst outbound is increased. This shift in delay could be explained by the change in the control sequence affecting all of the intersections at the site. Scenario vehicle actuated balances the delay experienced by both streams. The protected left turn is taken away from the control sequence. In vehicle turn actuated scenario, the introduction of an actuated left turn increases the delay for through traffic. Introducing a priority call for the bus increases the delay for both streams. Traffic outbound sees an increase in delay due to the queue forming of vehicles to turn left on the left lane, which reduces the capacity for this stream to one lane. Increasing the capacity of the intersection to three lanes seems to be the scenario with the smallest effect in delay.

The increase in delay can also be explained by the strategies in relation with the geometry of the intersection, right turn volumes and the location of the bus stop. The latter are the reasons behind the extremely high delay values of the bus lane with priority scenario. The geometry of the intersection does not allow to properly designing this strategy affecting all vehicle classes. The bus lane scenario has hardly any impact over the capacity of the bridge as it increases slightly the delay compared with the vehicle-actuated scenario, merging capabilities are the cause of such delay. It is worth remembering that delay caused at other intersections is also accounted for in these results. Consequently, the effects of the proposed congestion protection strategies also affect the intersections downstream and upstream.

The priority strategies focus towards reducing the delay of bus routes 1 and CT1 besides the effect over all other vehicle classes. The delay results for vehicle class bus route 1 and CT1 are depicted in Figure 35.

A situation encountered in the field and seen in the simulation was bus bunching at the intersection of Beacon St. It is worth remembering that bus route 1 and CT1 run over the same segment with very short headway. Despite this effect, there is a considerable decrease in average delay encountered by the bus. Primarily, the bus routes benefit from the congestion protection strategies inbound as the delay is considerably reduced. The reason behind this is the elimination of the protected left turn for outbound. Vehicle turn actuated scenario increases the delay (compared with vehicle actuated scenario) due to left turn in the control phase. A priority call reduces delay for the bus despite the geometry and location of the bus stop. Three-lane scenario represents the scenario with minimal delay effects.

The delay for scenario bus lane with a priority call for inbound (from MIT) is extremely high due to the geometry of the intersection and the location of the bus stop. These two factors constrain the location of the detector required to provide the priority call. Notwithstanding this effect the scenario decreases the delay for the bus routes compared to the “as-is” situation.

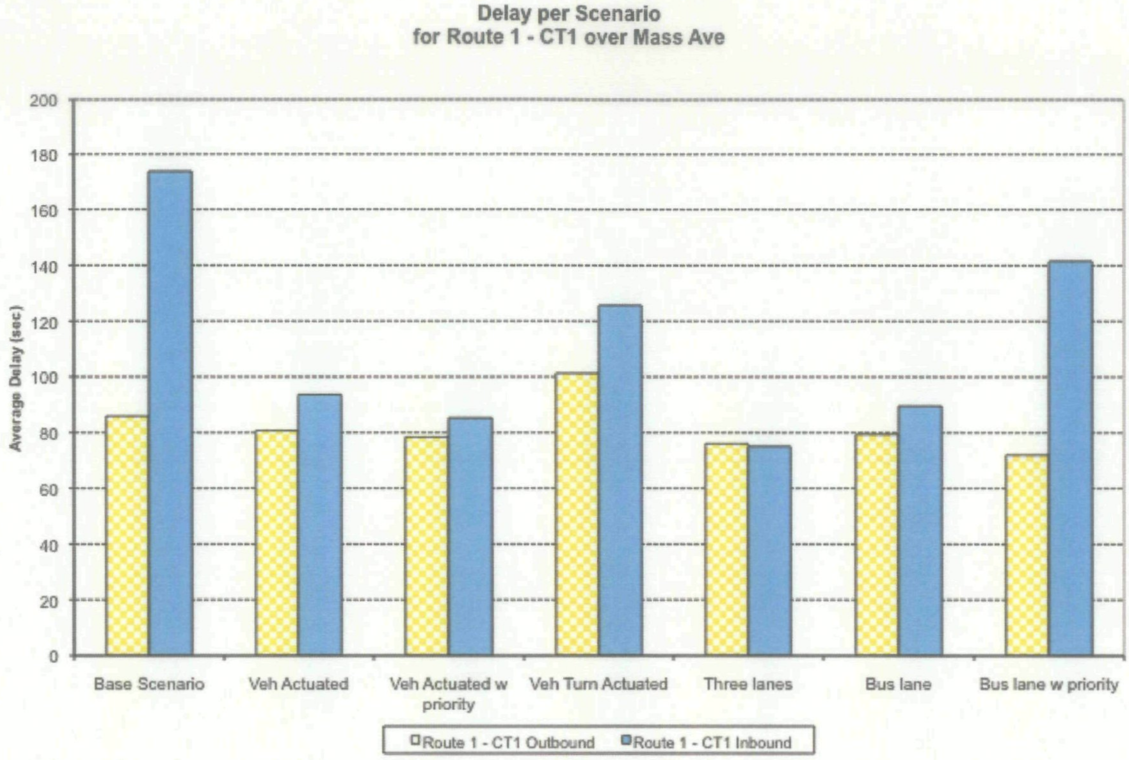

Figure 35: Average Delay per Scenario for Bus Route 1 and CT1 on Mass Ave

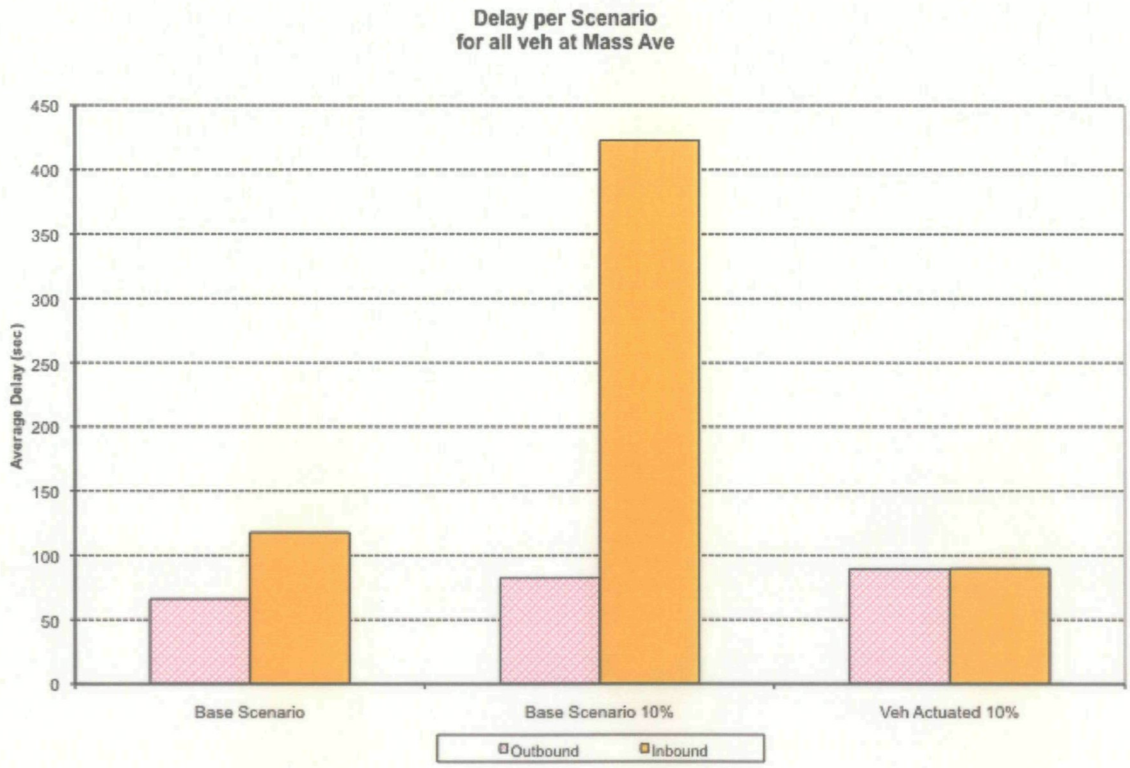

Figure 36: Average Queue per Scenario for all vehicle classes on Mass Ave with a traffic increase

An increase of 10% in traffic considerably increments the average delay, especially, inbound 360% increase while for the opposite bound the increase was 24%. The effect of an increase in traffic helps to highlight what the delay effects will be in the future.

Once more it can be mentioned that the cause of such effect is protected left turn within the traffic control. On the other hand the increase in delay for vehicle actuated scenario is 35% for outbound, while inbound sees a decrease in delay. The latter is caused by balance in the control phase as both streams provide movement simultaneously. Effects over side streets are not considered. However, observations reveled long queues as vehicle actuated provided long movement times for the streams over Mass Ave.

Taking into consideration the performance indicators, scenario vehicle actuated becomes a beneficial strategy. In addition, the deployment of congestion protection strategies has mixed results. To change the traffic control sequence might be the required approach towards a solution to improve the running time of bus route 1 and CT1 if priority strategies are not preferred. Side street effects are not considered as the research focus is on improving the running time of the bus by proposing different congestion protection strategies.

7.4 Conclusions

At the "Hot Spot" seven scenarios were modeled using a micro-simulation program assessing different congestion protection strategies to improve bus running time. This chapter presents the results from the simulation through two performance indicators: travel time and delay
In relation to travel time performance, the scenarios showed an increase in travel time outbound (to MIT – stream 05) while reducing travel time for the opposite bound. The reason behind the mixed results can be explained by the change in traffic control -fixed time to vehicle actuated. Stream 05 has a lagged start of 23 seconds in fixed time for protected left turn. Vehicle actuated balances the movements of both streams, eliminating the protected left turn. The latter is also the cause of the results for the delay experienced at the "Hot Spot". Delay is slightly increased outbound, while decreasing it inbound. Bus route 1 and CT1 experience a reduction in travel time and in average delay. The delay currently suffered by the bus can be attributed to the traffic control program. A change in traffic control program reduces considerably the delay experienced by the bus.

Considering the scenario vehicle actuated to compare the other proposed scenarios delivers mixed results as well. Notwithstanding the effect over other vehicle classes, an increase in capacity at the intersection, which is to be expected, presents the best results. However, this might be difficult to accomplish. Therefore, not considering the latter scenario, vehicle actuated with priority or bus lane scenarios are the most suited scenarios to improve the running time of the bus. The geometry of the intersection, protected left turns and the location of the bus stops make it difficult to implement a congestion protection strategy at this "Hot Spot" in order to reduce the travel time and delay of the bus with minimum effect over other vehicle classes.

The priority strategies proved beneficial towards the bus and mixed results towards other vehicle classes. If congestion protection strategies are (or not) preferred the required approach to improve the bus running time might be the change in traffic control program and elimination of protected left turn at the intersection. Turning vehicles could be re-routed by turning right at Marlborough St. reaching Beacon St. through backside streets. It is recommended to further analyze the latter considering the effects over all side streets and vehicle classes.

Research is recommended to assess the possibilities to change the road geometry and or eliminating parking possibilities in order to model other congestion protection strategies. Furthermore, other intersections over Massachusetts Avenue (primarily towards the south) and the effects of bus bunching should also be included.

The information provided in this chapter is used in the main conclusions towards proposing which congestion protection strategy best suits at the "Hot Spot" to improve the running time of bus route 1 and CT1. As well, suggestions for future research are made based on the information from this chapter.

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Part III. Policy, Technology and Management Tools

Part III presents an analysis of the policies, technology and management tools towards improving the bus running time through deploying congestion protection strategies. The site identified the policies and actors individually, which are analyzed by means of an actor analysis. The technology to develop and deploy priority strategies is discussed. Finally, the management tools (performance measures) that transit authorities use to rate the performance of the service and quality are presented. An analysis of the key bus routes towards quantifying congestion for buses is performed.

The chapters in this part are:

- Chapter 8 Policies and Actors for Public Transportation
- Chapter 9 Technology for Public Transportation
- Chapter 10 Management Tools

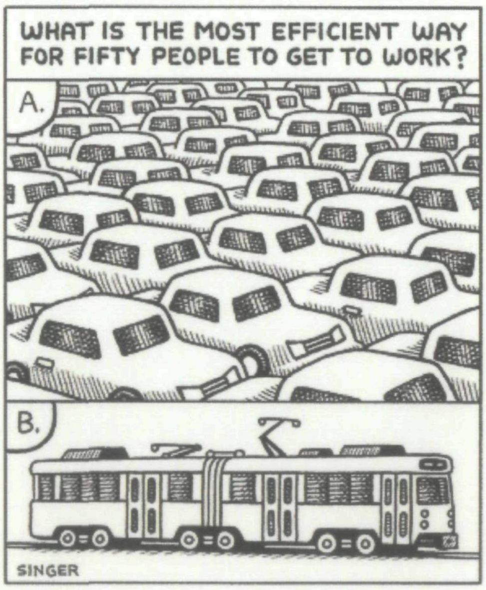

Figure 37: Investment paradox cartoon

Source; www43

Chapter 8 Policies and Actors for Public Transportation

8.1 Introduction

In the USA, since 1970, different studies, programs and policies have focused on signal priority and or bus lanes [13]. Two strategies converged since the late 1970s and early 1980s. First, development of federal programs aimed at reducing highway congestion through improved management. Second, the emphasis on encouraging consideration of a range of actions to meet mobility needs and enhance environmental quality as required through successive federal planning and environmental regulations [24]. The concept of priority was relatively new at the time, where development of plans and programs focus primarily towards vehicles. Known as the Interstate Era, it led to a slow development of plans and programs towards public transportation. In the early 1990's public transportation interest and development showed a gradual increase. Ever since, the Federal Transit Administration (FTA) has procured for the development and deployment of public transportation projects with priority controls, Transit Signal Priority (TSP) and or Bus Rapid Transit (BRT). Although study results and interest from stakeholders towards TSP and BRT projects have had an impact on the consideration over public transportation projects, this mode still struggles and competes for funding in relation to highway projects.

The chapter discusses the policies and actors identified at the site under evaluation. The jurisdiction conflict encountered when there are a numerous number of actors from the perspective of the MBTA is addressed. Through an actor analysis the policies and actors are analyzed. The policies and actors are further described in Appendix B and Appendix C respectively. A frame of reference is proposed to develop thresholds to evaluate the efficiency and performance of BRT and TSP projects.

The policies identified at the site regulating public transportation in the United States of America analyzed in this chapter are listed here below:

- Title 49 of the United States Code (US Code 49);
- Safe, Accountable, Flexible and Efficient Equity Transportation Act: a Legacy for Users (SAFETEA-LU);
- Clean Air Act (CAA);
- Congestion Mitigation and Air Quality Improvement Program (CMAQ);
- Traffic Operation;
- General Laws of Massachusetts and;
- City of Boston (Boston).

The actors identified at the site with decision-making power and enforcing the policies previously listed are listed here below:

- Department of Transportation (DOT);
- Federal Highway Administration (FHWA);
- Federal Transit Administration (FTA);
- Executive Office of Transportation and Public Works (EOT);
- State Department of Transportation – Massachusetts Highway Department (Mass Highway);
- Department of Recreation and Conservation (DRC);
- Metropolitan Planning Organization (MPO);
- Metropolitan Area Planning Council (MAPC);
- Boston Transportation Department (BTD) and;
- Massachusetts Bay Transportation Authority (MBTA).

City Groups and Organizations are considered as the citizens and users of the public transportation system and other stakeholders involved who have decision-making power over transportation projects.

8.2 Jurisdiction Conflict

The identified actors at the site play a role in terms of the infrastructure and policies surrounding the "Hot Spot". The actors' involvement translates to a jurisdiction barrier between infrastructure, policies and funding possibilities. Their involvement is necessary to consider when developing and deploying congestion protection strategies. As each actor has different interests and objectives at the site concerning infrastructure, where deployment of congestion protection strategies might come into conflict, perceived as the jurisdiction conflict. To further explain this effect, it is necessary to consider the following. At the "Hot Spot" the actors operate, maintain, own and have a decision-making power over the infrastructure. In Figure 38 each actor's jurisdiction is illustrated. Mass Highway (the State Department of Transportation) maintains and owns the Harvard Bridge. Mass Ave is labeled as Route 2A a Secondary Highway. Arguably, State routes are under Mass Highway jurisdiction, although not entirely clear if it is maintained by this agency or the city of Boston. The Department of Recreation and Conservation maintains and operates the intersection of Memorial Dr. as it is within the Charles River reservation (in Appendix C a figure of the Charles River reservation is provided). The MBTA operates the bus routes, while it is the city of Boston who determines the location of the bus stop not to interfere with parking spaces. The Boston Transportation Department owns and maintains some of the traffic signals operating at the site under evaluation and determines the traffic control program. This agency also owns and maintains some of the detectors.

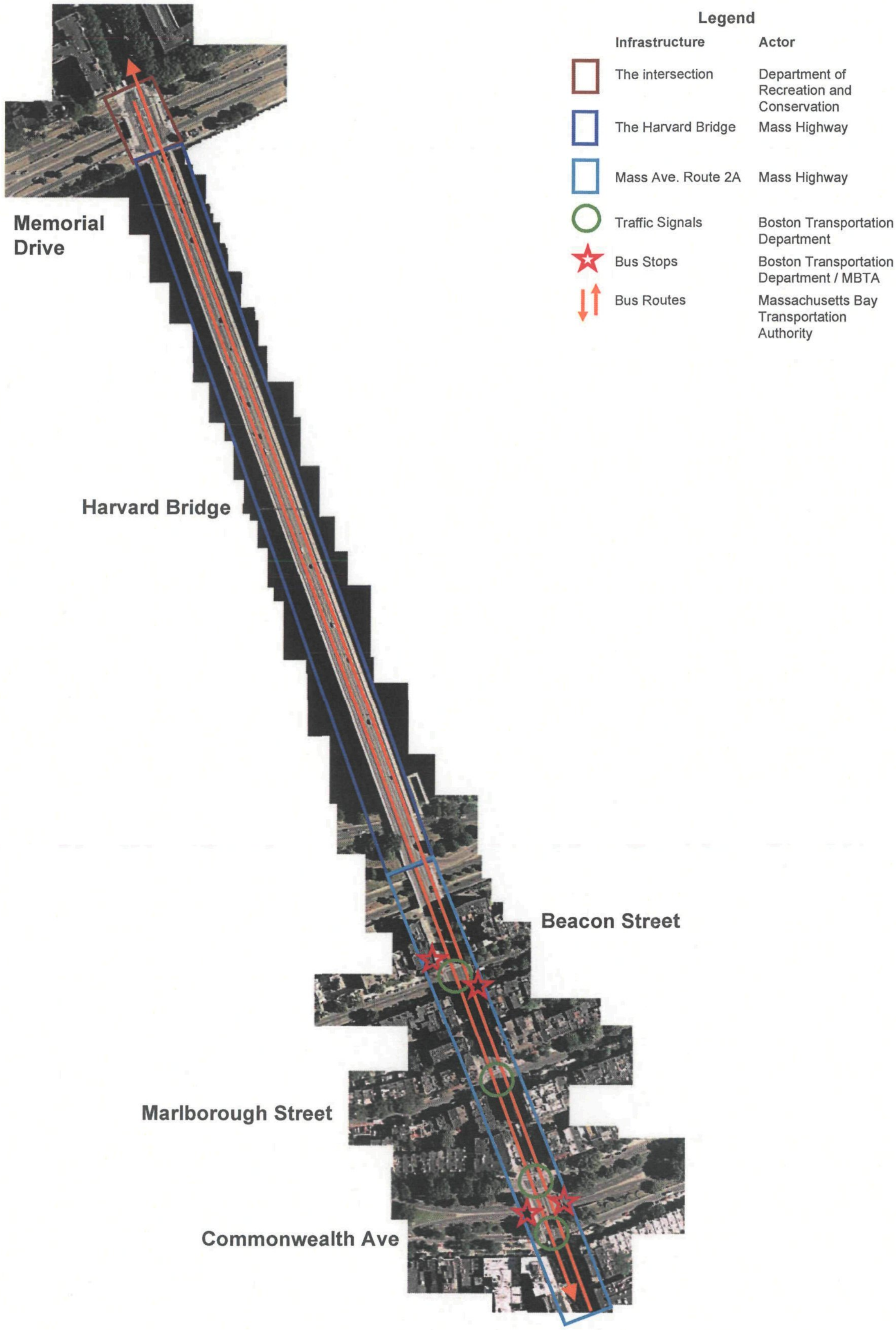

Figure 38: Jurisdiction Demarcation

The jurisdiction conflict represents one of the constraints that the Massachusetts Bay Transportation Authority needs to overcome in order to achieve any type of priority strategy. By means of an actor analysis the relation between actors and policies focusing on the MBTA will be visualized.

To get a better understanding about the policies and actors' jurisdiction, perspective and objectives, these need to be defined. An overview of the actors and policies is presented in the ensuing paragraphs to subsequently perform an actor analysis. Appendix B - and Appendix C - further information about their mission, objectives, characteristics and funding capabilities from the actors and policies.

8.3 Policies and Actors for Public Transportation

8.3.1 Policies

The policies through the development of programs specify the "carrots and sticks" for public transportation. The programs define the funds, the "carrots", to implement public transportation projects, while the "sticks", what are the penalties for incompliance, are not mentioned within the identified policies. Classified at different levels of government, the funds allocated come from different sources, primarily federal programs and agencies, e.g. the Highway Aid fund and or fuel tax. In Appendix B - the policies regarding their characteristics and funding capabilities are discussed. The table below depicts in a summarized manner the policies and their funding characteristics towards public transportation projects identifying the conflicts of each policy.

Table 14: Policy problem demarcation

Policy	Governance Role	Characteristics	Funding Projects	Conflicts
US Code Title 49 - Public Transit	Federal Government	With a countrywide focus it encourages the development of infrastructure favoring private vehicles and freight.	All programs and projects under the SAFETEA-LU	High correlation to title 23 Highways; policy and programs fund public transit projects
Safe, Accountable, Flexible & Efficient Transportation Equity Act; a Legacy for Users (SAFETEA-LU)	Federal Government	Encourages and assist in planning public transit in urbanized areas. Provides funds for Bus Rapid Transit projects. Recognizes the benefits of these projects that are in starting stages and deployed as demonstration projects.	Different programs fund capital projects for buses; Urbanized Formula Grants, the New Starts Program, CMAQ and, bus and bus related facilities	Funds for transit projects are only 18% of the total funds for surface transportation projects.
Clean Air Act (CAA)	Federal Government	The air quality legislation intended to reduce smog and air pollution. Sets the standards for air quality improving human health and longer life pans by environmental standards for tail pipe exhaust from buses as well as emissions control and use of fuels	Funds for the CMAQ programs as well as projects that demonstrate an improvement in the quality of the air or reduce emissions	See CMAQ conflicts

Policy	Governance Role	Characteristics	Funding Projects	Conflicts
Congestion Mitigation and Air Quality (CMAQ)	Federal Government	An amendment of the CAA and strongly related to the SAFETEA-LU, the program funds transportation projects that improve air quality and or reduce congestion. The program only applies to areas that do not meet the National Ambient Air Quality Standards (majority of urbanized cities)	Public Transit & Traffic Flow Improvements; Transportation Demand Management; Bicycle and Pedestrian; and Alternative Fuel Projects; Inspection and Maintenance Programs; Intermodal Freight Transportation; Public Education and Outreach; Idle Reduction Technology and; Intelligent Transportation Systems	Long list of projects that qualify for funds while the amounts apportioned to this program are small. The funds come from the Federal Highway Aid Fund
Massachusetts General Laws	State Government	The Massachusetts Bay Transportation Authority is regulated at a State level. Transit policies strongly related to Highway policies, hardly procure realization of public transportation projects	Different amendments provide funds for transportation projects; transit projects fund primarily subway and rail projects. States have to fund up to 50% of transit projects to receive federal funds, finding alternative means from bonds or lottery tax.	Highway projects receive more funds than public transit, strong relation to Highway policies and funds from local share
Boston	City Government	Boston Municipal Code describes policies for parking, use of vehicles, licenses, and violations among others	No funds for public transportation projects	Primary focus is parking policies and private cars

Note; the information provided in this table results from the analysis performed to the policies which are described in Appendix B -.

There are limitations on how public transportation can be funded. A discrepancy between rail and bus projects competing for funding arises. The latter still needs to overcome some constrains and difficulties to fulfill as a project. The primary conflict is the involvement of Bus Rapid Transit (BRT) or bus related projects to the definition of fixed guide way, referring primarily to rail. If BRT projects are to be introduced as strategies for developing public transportation projects a distinction is required between modes. Secondly, funding for public transportation projects is primarily done with Federal, State and or Local sources, with no (or hardly none) private involvement. As infrastructure and operating costs are part of the public sector costs the budgets of the transit authorities fall or are already in deficits [4, 20]. Public transportation projects to qualify for funding require a local share, in some instances of up to 50% depending on the funding program. In addition, funding from these programs may not be used for operating costs for example. Local share makes State or local agencies find means to fund their project through local taxes or bonds. State and local capital infrastructure or maintenance budgets can be an important source to fund projects [25]. States and local agencies go through long and difficult accounting processes to find funds for their projects. Even, in some cases, innovative ways have to be developed despite the procedure and local policy entanglements to make funding available. For example, the Silver Line in Boston was primarily funded by the DOT of the State (Mass Highway) as it runs and creates improvements to the roads under the jurisdiction of the agency [25, www1].

The actors identified at the site, being those agencies that enforce the programs and provide the funds for public transportation projects, are described in the ensuing paragraph.

8.3.2 Actors

As part of the analysis performed in this research, each of the identified actors at the site is individually assessed identifying their interest, objectives, characteristics and funding possibilities towards deploying priority strategies for public transportation. Table 16 provides a snapshot of information for each identified actor to carry out an actor analysis. In Appendix C - the mission, objectives, goals, characteristics and funding possibilities for each of the actors are individually described. Actors' perceptions, objectives and goals as well as policies allocating funds change continually, resulting in a strategic and institutional uncertainty. The actor analysis as a result is simply a snapshot of a moment in which the dynamic change has been halted.

The actors' interdependencies have been identified in a power versus interest grid table, as shown below. The power versus interest grids typically helps determine which players' interests and power bases must be taken into account in order to address the problem or issue at hand [26]. The interest and power grids are focused towards deploying congestion protection strategies and the power to achieve these.

Table 15: Interest versus Power Grid

INTEREST \ POWER	Low	High
High	Subjects MPO MAPC	Players FTA MBTA
Low	Crowd DRC City Groups & Organizations	Context Setters DOT FHWA Mass Highway EOT BTD

The classification of the actors in four categories; players (high interest and high power), context setters (low interest and high power), subjects (high interest and low power) and crowd (low power and low interest) illustrates how partnerships and collaboration between actors can be encouraged to shift interests and decision making power.

Table 16 presents the problem formulation towards congestion protection strategies from all of the identified actors.

Table 16: Actors problem formulation towards congestion protection strategies

Actors	Governance Role	Interest	Desire Situation / Objectives	Existing or Expected Situation	Causes	Possible Solutions
Massachusetts Bay Transportation Authority (MBTA)	Problem owner, State Government	Transit system built upon customer service excellence, accessibility, reliability, state-of-the-art technology, and a diverse work force reflected in the communities served	Public transportation Service, Infrastructure, Financial Condition, Employee Development, Communication	Reliability and image of the system. Funds allocated to preferred modes, limited deployment of priority strategies	Congestion, cities served, funding, policies and bureaucratic process for public transportation projects	Among others; Congestion protection strategies deployed and encouraged by policies and funding capabilities
Department of Transportation (DOT)	Federal Government	Develop transportation policies and programs to contribute to fast, efficient and convenient transportation	Safety, Mobility, Global connectivity, Environment and Security	Primary focus of policies and programs towards private car	Private car preferred mode of transportation in the USA public transportation image - less fortunate.	Shift in mode preference and image of public transportation through recognizing its benefits
Federal Highway Administration (FWHA)	Federal Government, Subdivision of the Department of Transportation	Same interests as the Department of Transportation	Focus to Highway infrastructure; safety, mobility and productivity, global connectivity, environment and national homeland security	Policies and programs for highway projects provide funds for public transportation projects	Policies encourage Highway projects and are the origin of funding resources	Separate the modes of transport through policies and fund resources focused individually

Actors	Governance Role	Interest	Desire Situation / Objectives	Existing or Expected Situation	Causes	Possible Solutions
Federal Transit Administration (FTA)	Federal Government, Subdivision of the Department of Transportation	Leadership, technical assistance, and financial resources for safe, technologically advanced public transportation that enhances mobility and accessibility, improves America's communities, preserves the natural environment, advances economic growth, and ensures that transit systems are prepared to function during and after criminal or terrorist attack	Affordable mobility, congestion management, support transit intensive neighborhoods, economic benefits of transit, transit system usage and characteristics and transit finance	High interdependency and relation from policies and programs which focus in Highway projects	Decrease dependency and interrelation through policies and funding sources allocated to this mode	Among others; policy and programs creating funding sources exclusive for public transportation, recognition of role and importance of mode
Executive Office of Transportation and Public Works (EOT)	State Government, Massachusetts State Transportation Department	To promote economic vitality and a better quality of life by safely and efficiently moving people and goods within and through the Commonwealth	Developing, coordinating, administering and managing transportation policies, planning and programs related to design, construction, maintenance, operations and financing. Assure the coordination and quality of roadway, transit, airport and port infrastructure and security.	Strong interrelation to Federal Transportation Department. Mode preference and similar situations as Federal agency	State laws derive from federal policies, transit authority State governance, public transportation perception, funding resources Federal and State	Minimize interrelation between modes at State level through changes of policies and programs from Federal government, recognize the benefits of public transportation for the Commonwealth

Actors	Governance Role	Interest	Desire Situation / Objectives	Existing or Expected Situation	Causes	Possible Solutions
Massachusetts Highway Department (Mass Highway)	State government, subdivision of FHWA, under State Transport Department.	The design, construction and maintenance of all State highways, bridges and signage of numbered routes	Similar to those of the Federal Highway Administration.	Funding for Highway and public transport projects provided from the Federal and State resources	Strong relation to Federal agency, primary focus to Highway projects	Policies and funding resources for each mode from Federal and State agencies
Department of Recreation and Conservation (DRC)	State Government, under State Department of Transportation	To protect, promote and enhance our common wealth of natural, cultural and recreational resources	Improving outdoor recreational opportunities and natural resource conservation; Expanding public involvement in carrying out DRC's mission; and Establishing first-rate management systems and practices	Memorial Drive is part of the Charles River reservation under protection and jurisdiction of this agency		Change agency jurisdiction for this intersection (minimize number of actors).

Actors	Governance Role	Interest	Desire Situation / Objectives	Existing or Expected Situation	Causes	Possible Solutions
Metropolitan Planning Organization (MPO);	Regional Government	Work together on the federally required transportation planning process; Establish a Joint Regional Transportation Committee to ensure citizen participation in regional transportation planning; Work together to ensure compliance with federally mandated planning documents and; Establish a joint technical staff to support decision making	System preservation; modernization and efficiency; mobility; Environment; Safety and security; Regional equality; Land use and economic development, public participation and finance	Through different State programs appoints funding for public transportation projects, defines the projects and recognizes the situation of the system	Focuses on rail and subway projects which still apply old common priority practices. Bus projects recognize the use of priority strategies without any project in the near future	Among others; Deploy priority strategies by benchmarking the benefits from other bus projects, procure funds for these projects and procure a shift in preferred mode
Metropolitan Area Planning Council (MAPC);	Regional Government, regional planning agency for the city of Boston	Provides the technical assistance to improve environmental, social and economic health through services that include transportation to the 101 cities and towns.	Need for mobility, impacts transportation has on environment, social and economic matters and the necessity to continue with careful allocation of funds to roads, bridges and public transportation	Coordinates and implements different programs, a combination of Federal and State programs providing funds for a wide variety of projects	Funds for transport projects only possible for those focusing on the environment and transportation enhancement program	Among others; development of a program finding alternatives to fund public transportation projects considering priority strategies

Actors	Governance Role	Interest	Desire Situation / Objectives	Existing or Expected Situation	Causes	Possible Solutions
Boston Transportation Department (BTD);	City Government	Promote public safety, manage the city's transportation network, and enhance the quality of life for residents of our city neighborhoods, ensured through the use of planning coordinated engineering, education and enforcement	Parking, use of vehicles, violations and licenses policies and programs. Street Guidelines for the streets within the city	Policies and programs only; focus on parking, use of vehicles, violations and licenses.	Member of the Board of the MBTA and MPO, key player in transportation planning with primary focus to private vehicles	Among others; shift preference of mode and minimize policies for private vehicles that hamper public transportation development
City groups and organizations	Non-governmental	Procure and enhance the transportation system within the city	Diverse objectives, depending on their advocacy		Public participation over public transportation projects with veto powers over the project	Among others; interest parties should consider the overall benefits of public transportation and coordinate their objectives with development of transit projects

Note; the table is adapted from lecture notes course EPA1121-Policy Analysis of Multi-Actor Systems [27] (columns) and the information provided is adapted from the information and resources consulted which are described in Appendix C -.

A complex situation arises for the MBTA in relation to priority strategies being developed and deployed for public transportation. The MBTA supports the development of BRT, acknowledges that priority is beneficial bringing higher performance as well as acceptability and image among other reasons to the entire system. Despite, this knowledge, it developed the Silver Line through the design of a tunnel, instead of a different strategy. Through this strategy the service was achieved and qualified for funding. Public transportation perception, jurisdiction, interests, decision making, existing policies and perhaps understanding from all actors involved in the decision-making process towards priority strategies might be the cause to choose and develop an old priority practice. In addition, the complexity of sources to fund capital projects plays an economic role. Investing in BRT, signals and other infrastructure is relatively cheaper than a tunnel. Not accounting for the inconvenience it brings to the people of the city as well as the hidden costs. Consequently, it seems easier to fund a small tunnel than traffic signals, equipment and other infrastructure needed for BRT and or TSP, which in turn results in improvements of the whole network and not a small area.

Agencies strongly require to cooperate but also to create well-built and inter-agency partnerships. The MBTA serves 175 cities and the MPO only 101 for example, creating a discrepancy and large number of decision-makers over public transportation projects that the MBTA needs to consider. For these reasons partnerships, not only public but also perhaps public-private-partnerships (PPP) should be considered. Public transportation in the USA is funded primarily through public agencies. Partnerships with private agencies further provide commercialization of transit and can increase reliability when tendering processes are effective driving transit authorities out of deficits. However, this type of partnership is not subject of study or reviewed in this research.

8.4 Actor Analysis

The actor analysis consists of a number of steps. First step is to identify the actors and describe their objectives, goals and characteristics. Secondly, identify the critical actors highlighting their relations to finally present the actors and their relations in a visualized manner. The goal is to find if any of the current policies promotes through funding public transportation projects with priority strategies (TSP or BRT) and or if a new policy should be proposed among the actors involved to accomplish the deployment of such projects. The latter, will support and encourage the development and deployment not only in the city in question but also perhaps from a country wide perspective. In Table 14 and Table 16 the necessary input to conduct the analysis has been depicted. In this paragraph an actor-policy diagram (actor network) is presented.

Table 17 summarizes the objectives and goals from each of the identified actors.

Table 17: Common Actor Objectives

	DOT	FHWA / Mass Highway	FTA	EOT	MPO	MAPC	BTD	MBTA
Safety	X	X		X	X		X	
Mobility	X	X	X	X	X	X		X
Global Connectivity	X	X						
Environment	X	X	X		X		X	
Security	X	X	X		X			
Productivity		X						X
Congestion Management		X	X					
Land use			X		X	X	X	
Economic Benefits / Development			X	X	X	X	X	
Transit Usage and Characteristics			X	X	X		X	
Finance			X		X	X		X
Public participation					X		X	X

The objectives presented highlight the perception from the actors towards public transportation projects. The policies to accomplish such projects render their involvement. To simplify this involvement, the funds apportioned to public transportation projects by the policies have been expressed in units. The units are High!, Med! and Low!. The units depend on apportions made by the actors through the programs and the mutual goals between the policies. Therefore the connectors will be represented in threefold. In order to include those actors that have no direct relation to the policies, they will be considered as indirect actors given their decision-making power and or influence.

The critical actors shown in Table 18 are; The Federal Highway Administration through the State Department of Transportation (Mass Highway), The Federal Transportation Authority and the Executive Office of Transportation and Public Works. All apportions and projects to be developed are intended to benefit the services provided by the MBTA and being the problem owner all relations are focused towards the transit authority. Distinguishing the transit authority separately provides the flexibility to include other transit authorities and or agencies into the scheme. All actors either provide funding opportunities or have decision-making power to achieve public transportation projects. Hence, all actors can be regarded as highly dependent. Table 18 presents the actor analysis distinguishing the policies and involvement, as well as critical actors.

Table 18: Actor Analysis

Actor	Policy	Funding / Programs	Involvement	Critical
MBTA	Massachusetts General Laws Quality Service Manual	Federal, State and Local	Problem Owner	
DOT	U.S. Code Title 23 and 49	Federal	High	
FHWA	U.S. Code 23 and SAFETEA-LU	Mass Transit Account of the Highway Trust Fund CMAQ	High	Yes
FTA	U.S. Code 49 and SAFETEA-LU	Funds primarily come from the FHWA	High	Yes
EOT	Massachusetts General Laws	Diverse federal and non-federal sources (State) CMAQ	State DOT High	Yes
Mass Highway	Massachusetts General Laws SAFETEA-LU	Design projects or construction contracts CMAQ	State FHWA High	Yes
MPO	Massachusetts General Laws	Planning of expenditures and funding resources	Med	
MAPC	Massachusetts General Laws	Federal funds: there are 7 different programs	Med	
BTD	Massachusetts General Laws Jurisdiction		Low	
DRC	Jurisdiction		Low	

Figure 39 shows the relations in the actor network around the MBTA. The actors (blocks) interact between each other linked through their involvement determined by funding possibilities (connectors) to achieve public transportation projects with the intention to deploy priority strategies.

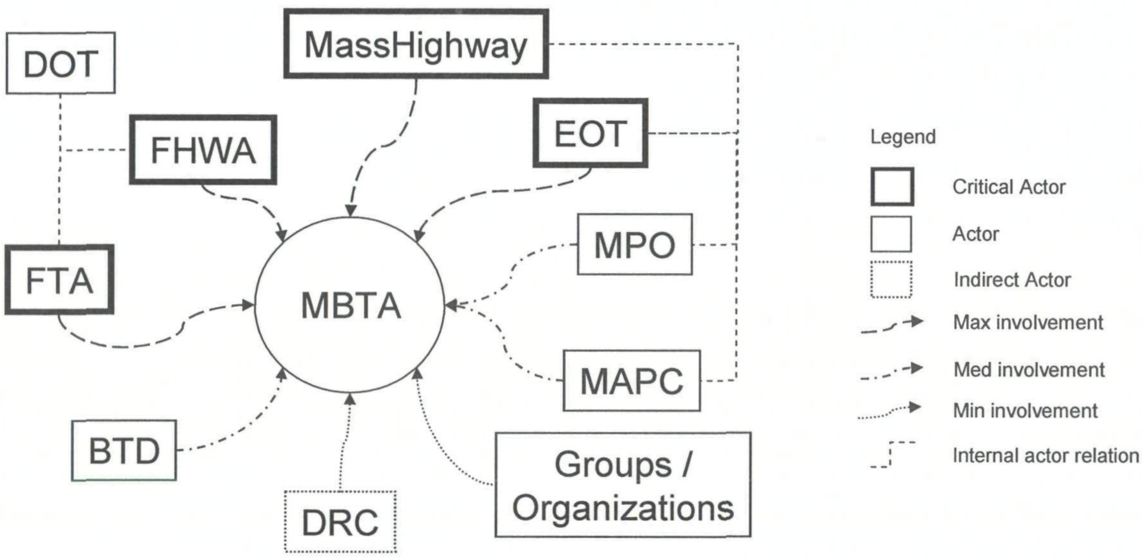

Figure 39: Actor Network

It is worth remembering that the Executive Office of Transportation (EOT) is the State Department of Transportation, while Mass Highway is the State representation of the Federal Highway Administration (FHWA). Through local offices subdivided in different regions the Federal Transit Administration (FTA) is represented. The Department of Recreation and Conservation is considered as an indirect actor given the jurisdiction conflict at the site. The Boston Transportation Department has a double function as it has jurisdiction over streets, signs and traffic signals as well as being a member of the board of the MBTA. For these reasons it is not considered as an indirect actor.

In order to overcome conflicts, which are difficult to identify, but in many cases exist between actor objectives and goals, a general objective is proposed. The goal of such objective shall identify and minimize the conflicts between actors. Therefore in this particular case, derived from the actor analysis the following statement is proposed serving as a common objective for all actors;

To ensure a public transportation system that provides mobility to all members of society, where planning and communication involves all agencies in a systematic manner to overcome communication and jurisdiction conflicts, intended to minimize congestion and improve bus running time by applying cost-efficient strategies and technology.

The statement addresses two key issues that need to be resolved between actors; communication and jurisdiction. Through cooperation and creating coordination programs these issues can be resolved. Although the benefits of priority strategies are known there is still further implementation needed.

8.4.1 Frame of Reference

The funds, "carrots" provided to implement transportation projects derive from the policies. However, the policies set a side the penalties for non-attainment or incompletion of the project, the "sticks". There is a lack from the policies as to state the consequences of non-attainment perhaps caused by the inexistence of thresholds to evaluate the project. These shall be described by the policies in order to quantify the benefits of the project. Thresholds allow evaluating the efficiency of the project and making necessary adjustments in order to reach the objectives of such project. Therefore, a Frame of Reference, following the methodology described in the user guide Sustainable Traffic Management [28] will be proposed. A frame of reference specifies criteria and thresholds resulting in a quantitative measurement to achieve a goal. The frame of reference is achieved by defining a theme, criterion and threshold. The goal is to reach a desirable situation.

The theme derives from the mission, objectives and goals of the actors as well as from the problem statement. The criterion, which is closely related to the theme, represents the means (the criteria) in which the theme will be fulfilled. The threshold is a quantitative representation of the criterion. The thresholds are roughly mentioned without specifying any measure for desirable situation. Specific measures of the desirable situation, such as to reduce by 2 minutes congestion are not the intention at this time. The intention is to propose a set of thresholds to evaluate and therefore develop "sticks" for projects deploying priority strategies for public transportation. The desirable situation; describe in a quantitative manner what the benefits are in relation to the set objectives. The frame of reference is presented in Table 10 following the problem statement, the integration of priority control strategies to public transportation, the objectives of the actors and policies.

Note that the frame of reference proposed does not consider the conflicts, objectives and agendas that arise from each of the actors and or policies.

Table 19: Frame of Reference

Theme	Criterion	Threshold
Transit Mobility and Benefit	Reliable public transportation Running Time Delay Speed	Variation of travel time and delay Minutes form point to point Minutes saved Miles per hour
Environment	Reduce Emissions and Air Quality	Assumed environmental impact
Planning and Design	Road Selection Communication process Jurisdiction Public Participation	Hot Spots Between stakeholders Limit and constrains Plans and Programs
Finance	Implementation costs Funding	In monetary terms Alternative funding programs
Congestion	Queue length Impact of congestion on buses	Reduction in meters (mile) Minutes / Minutes per $
Congestion Protection	Priority Strategy Technology	Different layouts and controls Implementation

The proposed frame of reference is just an initial step to establish penalties for projects that do not meet the objectives and or intended benefits. Further work is required to evaluate a minimum threshold value for public transportation projects and how "sticks" can be accomplished.

8.5 Conclusions

This chapter presented an analysis of the policies and actors involved at the "Hot Spot". Through an actor analysis the relations and interdependencies of the actors where visualized. A frame of reference was proposed as an initial step to establish threshold values in order to develop penalties for public transportation projects deploying priority strategies.

The analysis presented in this chapter can in practice be used to identify the conflicts between actors and understand what their goals and expectations are. The latter in order to determine to what extend their involvement and their interests as well as power play a role identifying the leader, critical and other actors that interact to develop and deploy a public transportation project.

A jurisdiction conflict arises with the number of actors, which determines their involvement given the infrastructure and policies regulating at the site under evaluation. In this case, the infrastructure is own, operated and or maintained by several actors. The result from the perspective of the Massachusetts Bay Transportation Authority is the limitations of the actors given their goals and or perspectives to deploy congestion protection strategies. There is a strong need for agencies not only to cooperate but also to create well built and inter-agencies partnerships. Through these agreements and cooperation, transit authorities will accomplish efficient and reliable public transportation projects. A common objective to address the issues of communication and jurisdiction should be adopted by all actors.

The need for mobility, increase in congestion, jurisdiction conflicts, satisfactory movement of people, the financial burdensome to maintain the system as well as the difficulties (existing) for development make the primary interest of the USA in terms of public transportation difficult to achieve. Within the policies for public transportation there is a sturdy correlation between highway and public transportation projects. The policies are interrelated. The majority of the federal funds for public transportation projects come from Highway Aid funds. The Federal Highway Administration manages a Mass Transit fund being the primary source of funds for public transportation. In addition, funding capabilities are possible within other programs. However, by federal mandate Sates are required to meet 50% of the funds for public transit projects. Innovative ways have to be found in order to qualify or even get the grants for the projects in question meeting the local share. A separation between modes by recognizing public transit through its benefits should happen in order to create a shift in the preferred mode, cars.

Policies for public transportation projects lack the "sticks", penalties when the projects, primarily Bus Rapid Transit (BRT) and or Transit Signal Priority (TSP), do not meet their objectives. Therefore, a frame of reference was proposed. The frame of reference is developed under consideration of the common objectives of the actors and through a set of criteria to evaluate the performance of the project. The performance is measured through thresholds that define the benefits of the project when completed. Through evaluating in a quantitative manner BRT and TSP projects could be the initial step towards a shift in mode preference and perception of public transportation. Recognizing such benefits from a global perspective might also help to eliminate the skepticism from different actors. Be that as it may, it is necessary to begin developing BRT and or TSP projects without the premise –for demonstration purposes.

The information in this chapter serves to discuss the findings of this thesis by answering the research question and sub-questions in order to find the reasons behind the limited deployment of congestion protection strategies to improve the running time of the bus in the city of Boston.

Chapter 9 Technology for Public Transportation

9.1 Introduction

The traffic signal since its invention has suffered several modifications. The communication with the controllers has brought changes due to the development of technology. Technology has develop different ways to detect a bus when approaching a traffic signal and communicating the bus route, bus number and location to provide a priority call dependent on the phase the traffic signal is in.

This chapter analyzes the traffic signal in the United States of America (USA) to apply priority calls given the existing products. Products and communication technologies between traffic signals and controllers are described in paragraph 9.4 and 9.5 respectively.

9.2 The Traffic Signal in the USA

The development of technology and products to deploy Transit Signal Priority (TSP) has focused on isolated intersections as well as network-wide. Considering isolated intersections (one intersection at the time without considering adjacent intersections) is the most common practice in the USA; an attractive manner to deploy TSP given the jurisdiction and actor conflicts that exists. From the technology point of view, to implement TSP systems encounters a few conflicts; as a result of the interaction between the traffic signal, TSP products, technologies, traffic controllers and communication between hardware. Several agencies and transit authorities have identified a diversity of conflicts. For example, an Federal Transit Administration (FTA) report identified that; "Most transit agencies have neither jurisdiction nor adequate field operation knowledge over traffic control devices, including signals and signs and pavement markings" [29].

To execute TSP it is essential to know and consider the capabilities of the existing traffic signal. The USA Department of Transportation (DOT) reports that congestion is reduced by optimizing signal times; There are more than 300,000 traffic signals in the United States of America, and, according to U.S. DOT estimates, as many as 75 percent could be made to operate more efficiently by adjusting their timing plans, coordinating adjacent signals or updating equipment [30]. Not only updates to the traffic signals are beneficial. In addition to updates, coordination of signals and adaptive signal systems (those that adjust to traffic conditions) also provide benefits; decrease in travel time, fuel consumption and emissions. According to the DOT, ITS Deployment Statistics in a 2006 Survey to different metropolitan areas published a National Summary covering several ITS subjects. For signalized intersections, it found, in the State of Massachusetts that out of the 2428 signalized intersections reported only 22 operate with transit signal priority, representing 1% [www12].

Funding for TSP represents a challenge as it competes with other agency programs e.g. police department or fire department, for traffic signal pre-emption or simply updates to the traffic control system. According to a report from the FTA, the capital cost of updating or retiming a signal per intersection is $3,500 USD, while the capital cost for TSP per cost element is; signal priority software costs $300 to $600 USD, signal control hardware $4000 - $10,000 USD, and vehicle $500 to $2,000 USD [30].

Throughout the USA intersections use a wide variety of traffic signal hardware. Some of the most common hardware used is National Electrical Manufactures Association (NEMA) controllers, type 170 and type 2070 controllers. Controller type 170 is designed to operate traffic applications from two/eight phase intersections to computerized network systems [www13]. Controller type 2070 is a modular, multipurpose controller used for traffic control operations. The functions they perform depend on their software.

The table below describes a relation between the controller type, the TSP strategy and typical implementation capabilities using the most common controller in the country. The table has been adapted from the ITS America report [31]. Further, in Figure 40 the dual ring concept for the NEMA controller is depicted.

Table 20: TSP Control and Implementations

TSP Strategy	Vehicle Detection Required	Controller Type	Traffic Control	Implementation Area / Type
Passive Priority	NO	NEMA, Type 170 and Type 2070	Fixed Time	Corridor, Network
Early Green / Red Truncation	YES	NEMA, Type 170 and Type 2070	Actuated	Intersection
Green Extension	YES	NEMA, Type 170 and Type 2070	Actuated	Intersection
Actuated Vehicle Phase	YES	NEMA, Type 170 and Type 2070	Actuated	Intersection
Phase Insertion	YES	NEMA, Type 170 and Type 2070	Actuated	Intersection
Phase Rotation	YES	Type 2070	Actuated	Intersection
Adaptive	YES	Type 2070	Adaptive	Intersection, Corridor, Network

The table shows how within the existing controllers TSP can be realized. In most intersections (if not all) the traffic control currently is fixed time. Deploying TSP in many cases involves changing the traffic controller to vehicle actuated, which might represent further challenges. By just changing the traffic controller might bring benefits i.e. improved traffic signal timings improving the situation overall without realizing TSP. Traffic signals are not a panacea for street congestion as they have several disadvantages, e.g. increase vehicle speeds at intersections are prone to accidents and fatalities with pedestrians and cyclists.

In the United States of America the conflicting phases that occur in an established manner are controlled differently than in Europe. A dual ring is employed when the traffic control is actuated. This traffic control is required to achieve a TSP strategy. The figure below shows the dual ring structure concept for a NEMA controller.

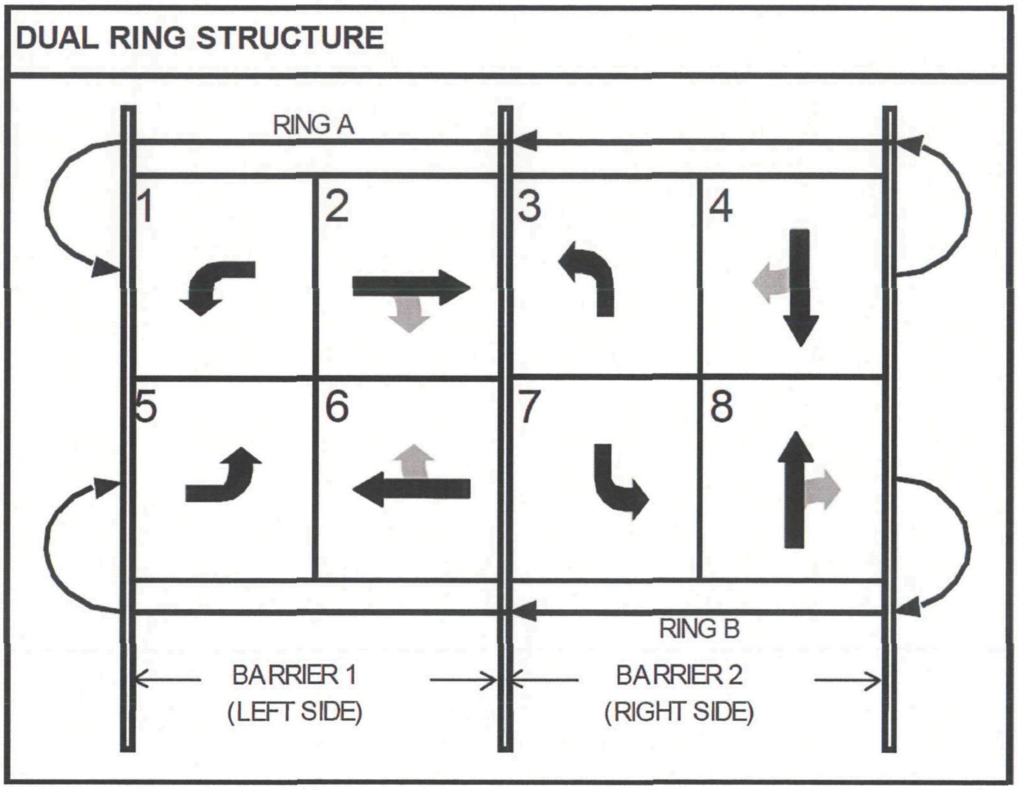

Figure 40: Dual ring NEMA controller concept

Source; www14

The two rings operate independently providing movement to 2 non-conflicting streams simultaneously (upper and lower ring). There are two legs - 8 phases (four on each ring) to accommodate traffic movements. Phases need to be terminated before the barrier is reached. Priority calls are introduced into any of the phases, where depending on the priority strategy the controller will provide the priority when requested. The phase might be extended or terminate the current phase and directly go to the phase requesting the call bypassing all others. To request a priority requires the controller to communicate with the detection system. Communication and detection technologies are discussed in the ensuing paragraphs.

From the technology perspective, it is necessary to consider the lack of coordination between actors. Agencies must cooperate and share traffic information, create agreements and develop methods of information and data sharing. At an intersection, for example, different agencies have jurisdiction over the road, infrastructure, components, etc. Agencies and traffic engineers have to go through extensive procedures to accomplish TSP. In some cases, innovative and smart solutions only applicable to a specific site have been developed to overcome complex situations. Therefore, having a limited impact in the development of technology as it is site specific.

9.3 Transit Signal Technology Considerations

The development of technology in the past decades has resulted in improved systems to manage, operated public transportation networks and vehicles. The technological advances have led to a diversity of products capable of providing a priority control at intersections for public transportation.

Considered as Intelligent Transportation Systems (ITS) for public transportation include among others; traffic signal priority, driver assistance, automation technology, passenger information, safety and security technology, advanced communication systems, automated dispatch and scheduling systems, video monitoring, real-time travel information and other supportive technologies. These technologies can be classified as follows;

- The vehicle; In-Vehicle communication with the wayside
- The traffic signals; Signal and cabinet controller
- Communications; Center-to-field and center-to-center and field-to-field.

Within this classification, there are two basic components to consider; the road and the vehicle. The road components refer to the traffic signals and the road infrastructure, while the vehicle refers to the equipment necessary to detect the vehicle. The communication equipment, e.g. detector loops, links the two components. These are further described in the subsequent paragraphs.

Taking into consideration the road, the vehicle and the communication equipment to implement TSP and or ITS systems in public transportation to grant a priority call, transit agencies are required to make use of standards. The National Transportation Communications for ITS Protocol (NTCIP), is a joint standardization project of AASHTO, ITE, and NEMA, with funding from the FHWA [www5]. As defined by the NTCIP guide; "is a family of communications standards for transmitting data and messages between microcomputer controls devices used in Intelligent Transportation Systems (ITS) [32].

According to the NTCIP1211 standard, the standard defines the functional entities involved to grant priority: the Priority Request Generator (PRG), the communication system (links the components with the system) and the Priority Request Server (PRS). The use of different technologies needs multiple standards working together to ensure interoperability. To work together it is necessary to understand how standards interface with another. Following the standard definition as a bus approaches the intersection (PRG), it is detected or sends a signal to a receiver antenna (depending on the system). The antenna transmits to a controller (or phase selector) to validate the priority call, depending on the phase (green extension or red truncation), sends the message to the traffic light, which in a smooth manner grants priority to the bus (PRS). The figure below depicts this in a simple manner. The use of different products and controllers under the implemented standards ensures the information and operability of the priority system. However, this leads to a conflict regarding the application of technologies, their products and communication. To grant a priority call, traffic signals, the bus, the detector equipment most be able to work together in order for a priority call to be accomplished. This conflict is further described and clarified in the ensuing paragraphs.

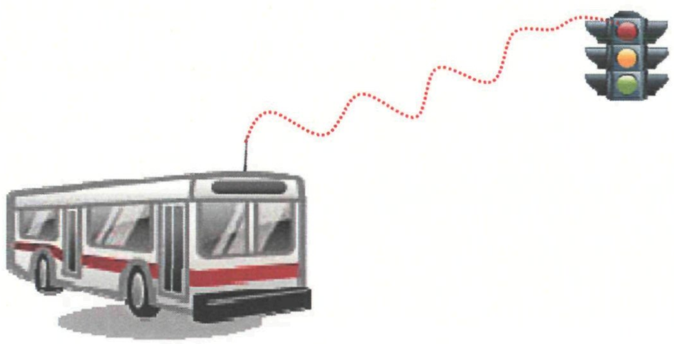

Figure 41: Simple form of TSP

9.4 Products

Priority for public transportation involves identifying the approaching vehicle, determining the priority dependent on the type of vehicle and or bus route and executing the priority call. Once the bus is detected and identified, an algorithm communicates the priority call to the hardware. Several companies manufacture hardware and the software for Transit Signal Priority systems. To accomplish TSP, the traffic signal control phase is interrupted or extended (depending on the phase it is). Therefore, the TSP product capability needs to be compatible and capable of working with the traffic signals and their controllers. A wide variety of computerized control sequences exist to control the traffic signal. The most common control sequences include; the basic controller (fixed time bases), vehicle actuated controllers (green time varies according to traffic flow), controllers with time variation (by day and time) and adaptive controllers (adjust timing or re-time) [7]. The two most applied are depicted in Figure 42. If traffic signal controllers cannot be integrated to the product capabilities and the software to accomplish TSP, priority will not be achieved.

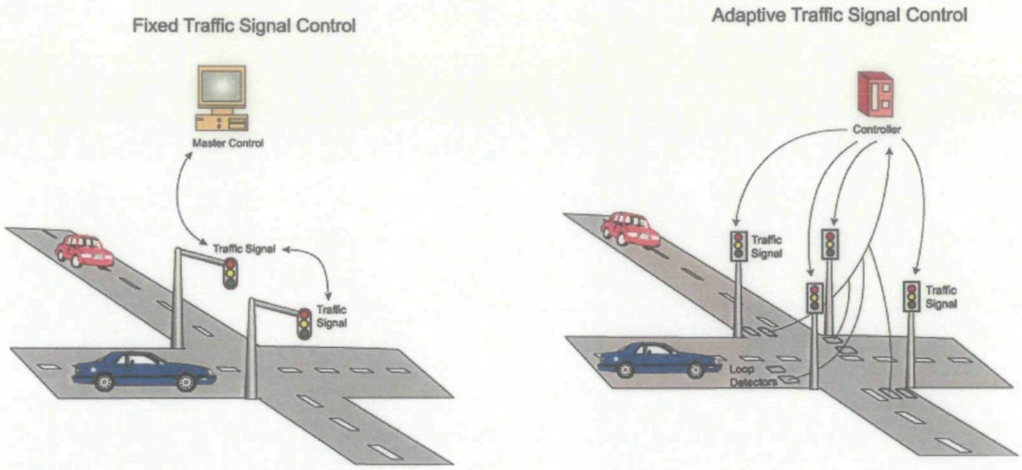

Figure 42: Fixed Traffic Signal Control and Adaptive Traffic Signal Control
Source; www15

Manufacturing companies offer a wide variety of products with diverse capabilities. However, product capabilities are constrained by the range of software variations. Product and software information has been regarded a very well kept secret making difficult to assess the product capabilities. Some product manufactures state that their products provide a wide range of capabilities without acknowledging if the software could be retrofitted to suit a different or specific situation. This is important as mentioned previously not all congestion situations and or intersections are identical. Therefore, transportation authorities, planners and managers face a conflict in order to assess the capabilities of deploying a TSP system.

Manufacturing companies include among others; Global Traffic Technologies Econolite, McCain, LoopComm or TOTE, and, Quixote Traffic Corporation. Many of the companies providing a range of products for traffic operation, for TSP a combination of their products are needed. Meaning that mix and matching within product capability is required. Many of the manufacturer products provide as default a conditional priority. The software and algorithms can be modified to perform other strategies, however, limited by the hardware capabilities. The result might constrain the requirements and or capabilities of the intersection and products

Diverse agencies and traffic engineers state that the reliability of products is still unproven [29]. In some cases, even, different products have limited deployment. While all of the traffic signal traffic controllers available on the market today have internal preemption capability, not all of them have the specific capability to support a bus priority system [16].

9.5 Detection Technologies

Technology evolved the way of communication between the two basic components; road and vehicle. Efficient technologies have resulted to detect the vehicle and communicate the information detected. There are several ways to detect and communicate the information. Examples of different detection technologies are illustrated in the following table.

It is quite robust to implement the communication link between the vehicle and the traffic. Operations with signal priority require constant updates and different types of data. Updates and extensive data need a high bandwidth and speed to perform their tasks. This may cause the communication system to fail.

The communication technologies existing today when combined with the traffic signal and controllers provide a rather limited amount of information. The lack of development, limited algorithms, software, product capabilities, the design and existing road infrastructure among others are the reason behind the further constrains to deploy TSP. As to radio based systems, the City of Portland in part asserts; “Many systems such as Opticom, Tote, LoopComm are available of which all are third party systems. In addition, there are other, radio based systems which have not been extensively tested in this country” [8].

Table 21: Examples of Detection Technologies

Inductive loop-based detection

A detector placed 250 meters downstream (generally a wired carved in the pavement) is reliable and does not require line-of-sight. An exit detector is generally used to call off the priority. A wire connects the detector to the traffic signal.

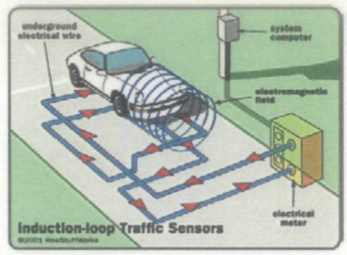

Figure 43: Inductive loop-based detection

Source; www16

Infrared detection

It is a well-tested technology, used in the USA primarily for emergency vehicle pre-emption. Mounting to a post is needed with accessibility to a power outlet. This system requires a line-of-sight between emitter and detector, missing the emitter is common if installation is improper.

Figure 44: Infrared detection

Source; www9

Radio based detection

Through radio frequencies emitter and detector communicate, no line-of-sight needed. RF tags are required for the bus and upstream of the intersection.

Figure 45: Radio Based detection

Source; www17

Video Surveillance detection

Video cameras mounted on a post connected to a central controller room that provides a priority call when a vehicle is approaching.

Figure 46: Video Surveillance Detection

Source; www18

Real-time can be recognized as another form of communication, although some recognize real-time as a control strategy. Real-time vehicle information to provide priority is not widely spread. Bus Information and Priority System (BIPS) is active real-time systems that can utilize different methods of detection [33]. The system considers the entire network where buses and signals interact. More and more buses are being equipped with systems like AVL and or other communication technology. To communicate with a traffic signal in real-time, however, the signal must incorporate the capabilities of this technology. Within the growing interest for improvements, different technologies have been adopted. These differ in sophistication but rely on the use of microprocessors. Different systems have been developed such as SCOOT, SCATS and UTOPIA [7]. These systems perform their control tactics in different manners (communicate in real-time) and are generally applied to a central corridor or whole networks. In addition, these systems provide an improvement in time delay reductions but have different disadvantages, such as limitations of traffic variable estimation or the effects in private vehicles. There is, despite the advances in technology, a lack of accurate models to predict traffic demand as well as proper algorithms to allow traffic to flow within these systems. This research does not look into systems such as SCOOT for example; therefore they are not furthered addressed.

9.6 Conclusions

This chapter discussed the technology to implement Transit Signal Priority (TSP). The traffic signal, being the basic element to deploy TSP, was described as well as products and communication systems.

Through the use of technology, transportation agencies have seen remarkable results in the performance and reliability of their public transportation network. Notwithstanding the jurisdictional and policy conflicts, technology further limits the deployment of TSP. The traffic signal, TSP technology and products as well as the communications systems required between detector and traffic signals need to work in a compatible manner. Hardware and software capabilities are not fully described by manufactures and their information is a very well kept secret. Products in some instances need to be used in combination in order to implement TSP systems. Software algorithms and intersection characteristics limit the capabilities of the products. Transportation agencies in many cases have a misunderstanding of the capabilities of their traffic signals. The result is a complex range of conflicts that agencies are left with if they are to deploy priority strategies.

The development of technology is far from over. Technology develops while software algorithms, product capabilities, lack of cases to learn from, coordination between agencies amongst others limit how the technology can be used to implement Transit Signal Priority for example. Nevertheless, TSP has been realized. Different cases overcame the technological issues deploying successful and efficient priority strategies.

While the benefits and successful results of systems such as BRT and other priority strategies help to increase the interest of the transportation agencies to implement these strategies, technology is still far away from being the primary initiator of priority for public transportation.

The information in this chapter serves to discuss the findings of this thesis by answering the research question and sub-questions in order to find the reasons behind the limited deployment of congestion protection strategies to improve the running time of the bus in the city of Boston.

Chapter 10 Management Tools for Public Transportation

10.1 Introduction

Performance measures are used as a management tool to fine-tune the public transportation system. Performance measures provide the necessary information to the transportation agency to improve the service and its reliability. In this case, the transit authority, the Massachusetts Bay Transportation Authority (MBTA) applies a wide range of performance measures to the different modes it operates. In this chapter, performance measures for public transportation services are briefly discussed. The performance measures the MBTA applies to the bus are described. An analysis of the bus key routes, as defined by the MBTA, is made in order to assess the impact of congestion over these bus routes.

10.2 Performance Measures

Performance measures derive from the individual characteristics of each transportation mode used to determine the successful operation and service quality of the public transportation system. Basically, performance measures capture the necessary information and data to process in order to make changes or improvements in the system. The measures help illustrate how well the goal of the transit authority is achieved throughout the system. The National Governors Association states that performance measures to gauge the overall effectiveness of activities and to serve as barometers for changing transportation needs should be a priority for every coordinating body [34]. The performance measures represented and classified by the National Governors Association are listed and further described here below [34];

- Cost efficiency;
- Cost effectiveness;
- Service effectiveness;
- Service quality.

Cost efficiency

Cost efficiency as a performance measure refers to the relationship between resource inputs and service outputs. Cost efficiency provides information to measure, among others:

- Total vehicle operating cost per hour;
- Vehicle operating costs per mile;
- Costs per driver per hour;
- Operating hour to driver hour ratio;
- Vehicle maintenance costs;
- Administration costs per hour/vehicle;
- Average service vehicle costs and;
- Labor costs per vehicle hour.

Cost effectiveness

The service becomes more cost effective the greater the consumption of services per dollar spent. Therefore, costs effectiveness refers to that relation between the consumption of public transportation services and the resources expended. The performance measures, among others, are:

- Total operating costs per passenger;
- Passenger revenue as a function of the total operating costs and;
- Passengers per dollar spend.

Service effectiveness

This performance measure refers to the relation of consumption service versus service availability. Service effectiveness measures the capacity of the system, its reliability and overall performance. Service effectiveness is measured through:

- Passenger per vehicles per hour;
- Passengers per mile;
- Passenger revenue per mile;
- Average month passenger trips;
- Average passenger per hour of operation.

Service quality

Service quality is measured through ridership surveys to passengers inquiring about:

- On-time service;
- Safety;
- Driver appearance;
- Schedule adherence.

This performance measure is much harder to measure than the previously mentioned performance measures given that it is quantified by (user) opinions and not in a mathematical way.

10.3 Performance of the Transit Authority

The National Transit Database report published in 2007 the transit profile for the MBTA [5], depicted in Appendix A. The performance measures for service efficiency, cost effectiveness and service effectiveness are depicted here below. The graphs represent the performance measures for the last 10 years for bus and heavy rail. For the bus, in the last 5 years, operating expenses have almost doubled while unlinked passenger trips per vehicle revenue mile where steady for the years 2003, 2004, and 2005 suffering a decrease for 2006. The decrease of 2006 can be attributed to several factors influencing the decisions that the MBTA is to take in the coming years.

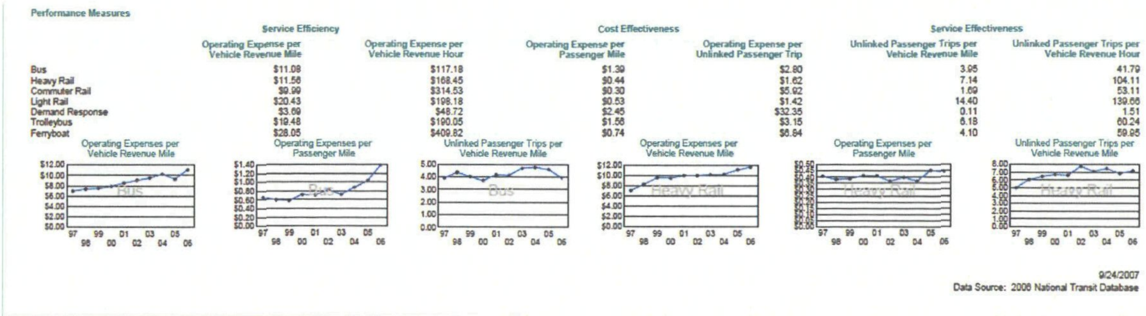

Figure 47: Performance Measures from the transit profile of the MBTA

Source: [5]

A comparison between transit agencies in the United States of America renders how well the transit authority performs. In Table 22 the comparison is made in terms of their service area, population, speed, productivity and, cost efficiency and effectiveness.

Table 22: Comparing Transit Authorities in the USA

	Boston MBTA	San Francisco SFMTA	New York City NYCT	Chicago CTA	Los Angeles LACMTA	Washington D.C. WMATA
Service Area (square miles)	3,244	49	320	360	1,220	690
Population (millions)	4.5	0.8	8	3.7	8.5	1.3
Speed (mph)	16.9	8.1	14	12.8	13.3	16.8
Productivity (unlinked pax trips per veh revenue hour)	88	66	84	46	55	69
Cost Efficiency (operating costs per veh revenue hour)	$183	$132	$133	$105	$124	$160
Cost Effectiveness (Operating cost per passenger trip)	$2.08	$2.00	$1.59	$2.26	$2.27	$2.32
Cost Effectiveness (Operating cost per pax mile -bus only)	$1.39	$0.96	$1.02	$1.11	$0.57	$1.11

Source: [5]

The MBTA performs relatively well compared with other transit agencies in the USA making it a productive and cost effective transit authority in relation to the service area and passengers it serves. However, its cost efficiency is one of the highest in the country driving the budget of the authority to a deficit. Operating cost per passenger mile for the bus is relatively high, however, compared with the service area and population the cost could be lowered or improved by applying priority strategies to attract ridership.

10.3.1 Performance measures for the Bus

The performance measures that the MBTA applies to all of the modes it operates in relation to the service effectiveness and quality are specified in the MBTA "Service Delivery Policy". The MBTA "Service Delivery Policy" update of 2006, sole purpose is to ensure that the transit authority provides quality transit services that meet the needs of the ridding public and are consistent with the MBTA's enabling legislation and other external mandates by [35]:

- Establishing Service Objectives that define the key performance characteristics of quality transit services;
- Identifying quantifiable Service Standards that are used to measure whether or not the MBTA's transit services achieve the Service Objectives and to evaluate whether MBTA services are provided in an equitable manner (as defined by Title VI);
- Outlining a Service Planning Process that applies the Service Standards in an objective, uniform, and accountable manner; and
- Involving the public in the Service Planning Process in a consistent, fair and thorough manner.

The MBTA measures the performance of its service throughout different service standards [35]:

- Accessibility;
- Reliability;
- Safety;
- Comfort;
- Cost effectiveness.

The reliability of the bus route and bus service is measured via schedule adherence standards. Two thresholds are specified in the bus schedule adherence standard: bus trip test (individual trips on time) bus route test (entire route on time). However, schedule adherence specifies a percentage of how late a bus/bus route departed or arrived. A quantifiable measure related towards how much the bus suffers from congestion lacks from the MBTA performance measures. To grasp how much buses suffer from congestion and how priority is beneficial, an analysis trying to achieve how much a bus suffers from congestion is performed.

10.4 Performance Measure; Impact of Congestion

Within the Massachusetts Bay Transportation Authority performance measures congestion encountered by a bus or the impacts over a public transportation vehicle are not assessed. Therefore, an analysis is made in order to assess the impact of congestion over the bus. Defined in the "Service Delivery Policy" [35] different bus services are rendered by the MBTA: local key bus routes, key bus routes, commuter bus routes, express bus routes and community bus routes. Considering key bus routes due to their characteristics, e.g. they serve high-demand corridors with high frequencies; will provide insight into what is the impact of congestion over a bus route travel time. The bus routes considered as key bus routes are:

- 1 - Harvard/Holyoke Gate - Dudley Station via Mass. Ave.
- 15 - Kane Sq. or Fields Corner Sta. - Ruggles Sta. via Uphams Corner
- 22 - Ashmont Sta. - Ruggles Sta. via Talbot Ave. & Jackson Sq.
- 23 - Ashmont Sta. - Ruggles Sta. via Washington St.
- 28 - Mattapan Sta. - Ruggles Sta. via Dudley Sta.
- 32 - Wolcott Sq. or Cleary Sq. - Forest Hills Sta. via Hyde Park Ave.
- 39 - Forest Hills Sta. - Back Bay Sta. via Huntington Ave.
- 57 - Watertown Yard - Kenmore Sta. via Newton Corner & Brighton Center
- 66 - Harvard Square - Dudley Station via Allston & Brookline Village
- 71 - Watertown Square - Harvard Station via Mt. Auburn St.
- 73 - Waverley Sq. - Harvard Station via Trapelo Road
- 77 - Arlington Heights - Harvard Station via Massachusetts Ave.
- 111 - Woodlawn or Broadway & Park Ave. - Haymarket Station via Mystic River
- 116 - Wonderland Station - Maverick Station via Revere Street
- 117 - Wonderland Station - Maverick Station via Beach St.

It is worth noting bus route CT1 is considered an express bus route, therefore, not included in the analysis. Express bus routes, CT1, CT2 and CT3 provide service as commuter bus routes characterized by high-speed, non-stop operation and a limited number of stops with some restrictions.

The analysis is performed as follows based on the key bus routes schedule for weekday and weekend, inbound and outbound service (schedule effective 03/22/08) taken from the MBTA webpage [www1]. The schedule considers the route running time, dwell time at stops and a certain degree of congestion. However, the extra time considered for congestion from the free flow running time is unknown. The schedule for weekend (Sunday being different from Saturday) has a shorter running time compared with peak hour weekday schedule as there is less congestion in the weekend. Therefore, the weekend schedule is considered as the base running time for each key bus route. Ridership is also higher in the weekday. To account for increase in ridership (longer dwell times) and or any other affecting factors besides congestion an extra time variable is added to the weekend schedule. The extra time variable, called extra dwell time is calculated in terms of the frequency, ridership numbers (provided by the MBTA) and a dummy variable. The load passenger per bus was calculated given the frequency and passenger ridership. A dummy variable was added to account for a certain loss time. Loss time refers to the time lost by the number of stops and the starting and stopping of the bus for example besides the dwelling time at the bus stop. The dummy variable (called extra dwell time) and the sum of the load passenger per bus is added to the running time per bus for the weekend service inbound and outbound. The latter is a minimum running time for the bus route. This can be considered as the running time without congestion. When compared with the weekday running time results in a difference. Such difference is considered as the congestion encountered in minutes by the bus for inbound and outbound. Figure 48 only depicts the resulting difference between weekend running time and weekday for inbound and outbound. Further below the running time in the weekend, the weekday and the calculated running time with extra dwell time for inbound and outbound is depicted highlighting the difference between the calculated running time and the weekday schedule.

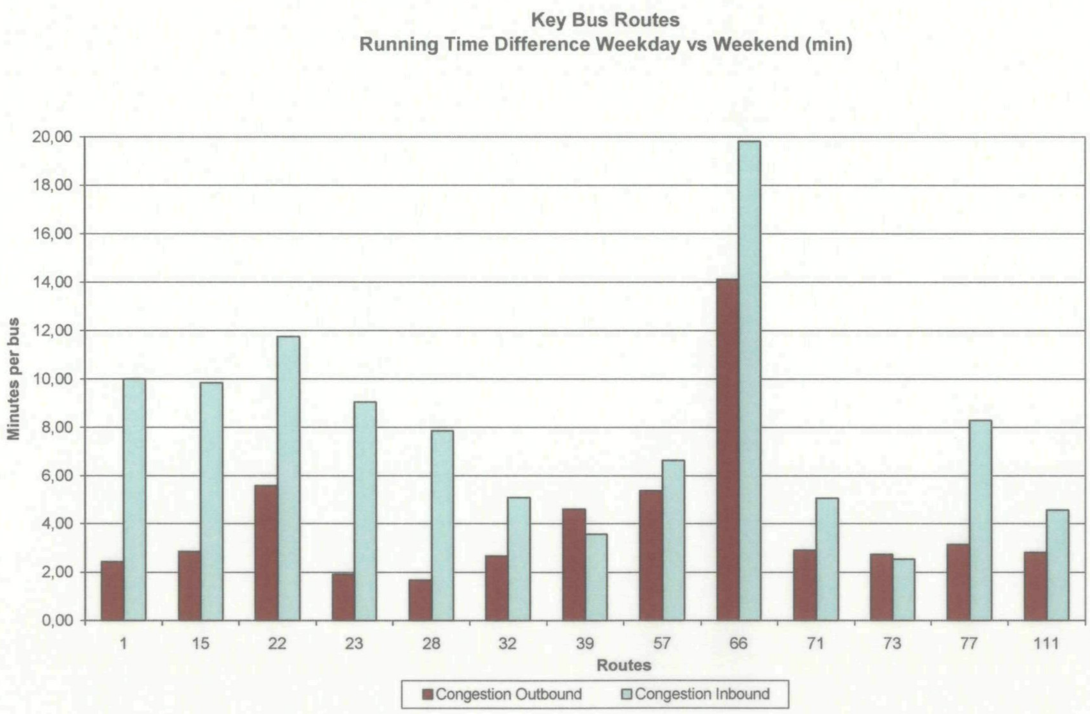

Figure 48: Key Bus Routes Weekday vs. Weekend Running Time for Inbound and Outbound

The results provided in the graph above can be considered as the extra congestion the bus suffers in any weekday. Bus route 66 is one of the bus routes that most suffers from congestion. In general, the running time of the bus is affected by congestion, primarily on outbound routes.

Key bus route 116 and 117 are not shown as congestion inbound values were negative. This can be explained by the following; the schedule between weekday and weekend is similar (1 minute difference) for inbound route 117 while for outbound the running time difference is 14 minutes. The calculated dwell time when added to the running time results in a negative value for the minimum running time with the extra dwell time. An explanation for the schedule being similar between weekday and weekend can be that the bus encounters several conflicts throughout its route (rail crossings, higher number of stops among others, which the MBTA has incorporated in the schedule.

Figure 49 and Figure 50 depict a comparison between weekend running time (RT WKND), weekday running time (RT WK) and the minimum running time with the extra dwell time (Min RT w Extra DW) for inbound and outbound respectively.

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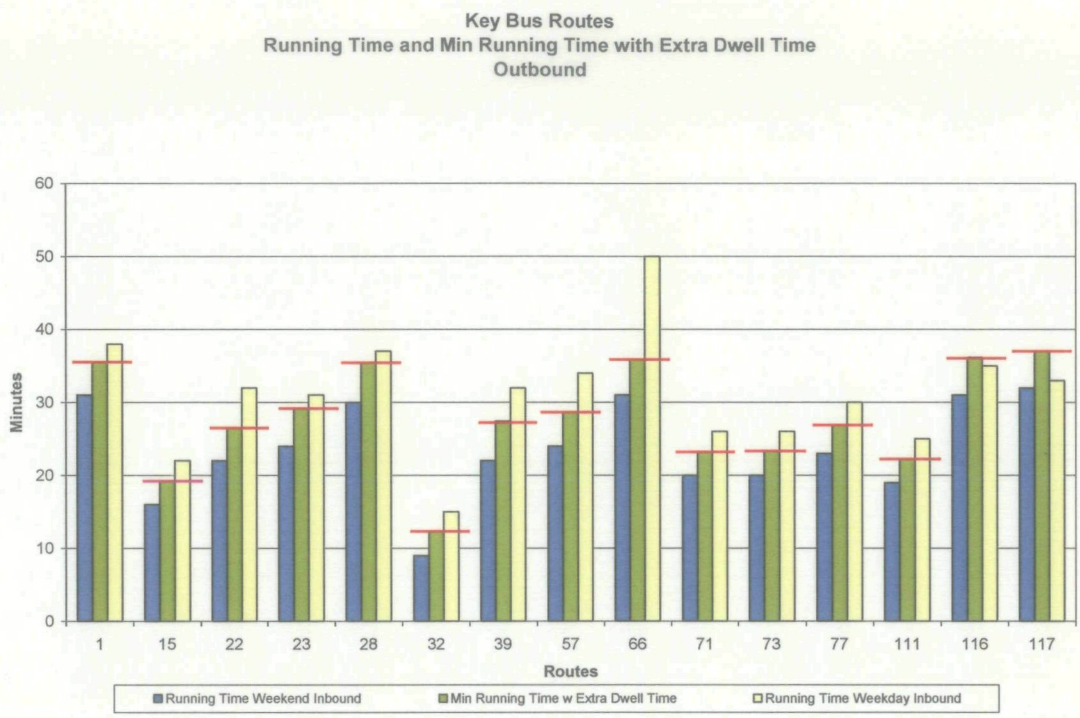

Figure 49: Key Bus Routes Running Time Weekday, Weekend and Minimum Running Time Outbound

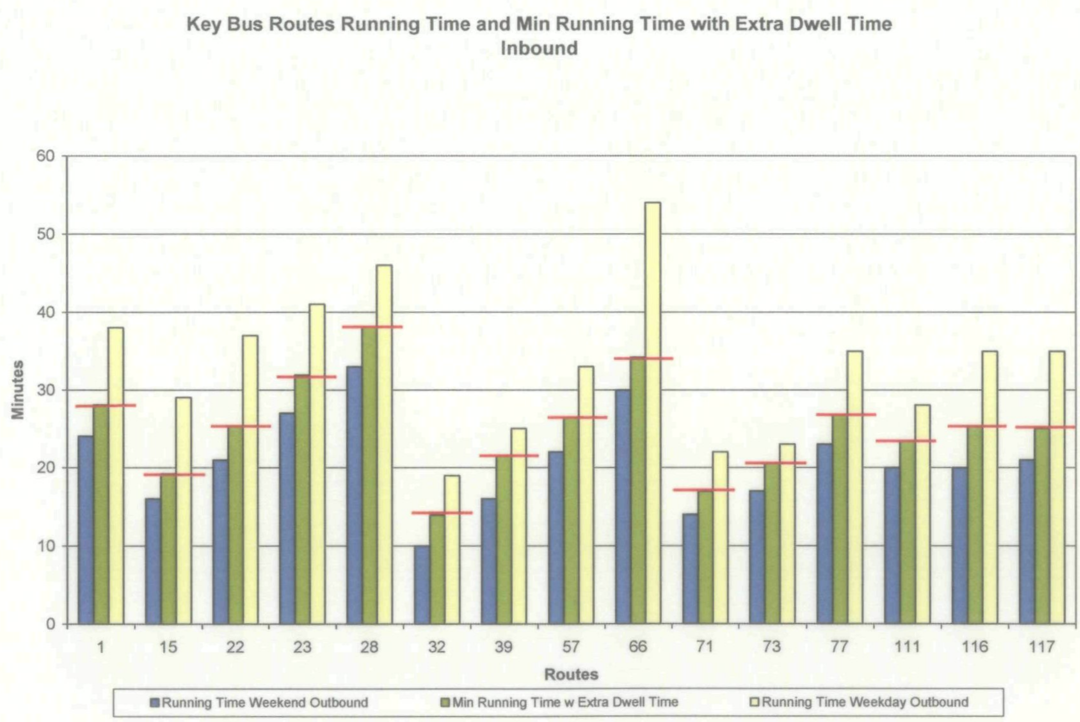

Figure 50: Key Bus Routes Running Time Weekday, Weekend and Minimum Running Time Inbound

In the previous graphs, the red line placed at the maximum value of the calculated minimum running time with extra dwell time (green colored column) distinguishes what can be considered as congestion. The congestion suffered is the value above the red line for the column running time weekday outbound (light colored column). The blue column is the running time in the weekend.

In both graphs all key bus routes suffer from congestion (an average above 5 minutes), where bus route 66 is the most affected. To corroborate this effect, trips were made on bus route 66 as well as in other bus routes at different times and days. The effect congestion had over the bus routes caused by numerous factors is considerable resulting in a delay. Congestion, therefore, is the primary cause that jeopardizes the reliability of the bus.

In 2004 the CTPS published a report titled "2004 Congestion Management System report" [36] evaluating the quality of transit by applying two performance measures: schedule adherence (on-time performance) and passenger crowding. The on-time performance is measured by the MBTA for bus service with headways of 10 minutes or greater -75% of all trips departing and arriving within 5 minutes late- for bus service with headways of less than 10 minutes -85% of all trips having actual headways within 150 percent of schedule headways [36]. The analysis from the CTPS performance measure for buses differs from that of the MBTA. The performance measure used in the analysis only accounts for arrivals and not departing buses and links poor bus on-time performance to congestion situations during peak periods. The threshold is -60% of peak period trips arriving within 2 minutes early and 5 minutes late. From the bus routes considered (all bus routes operated by the MBTA) in the report approximately on peak morning period 36% of trips arrive more than 5 minutes late and in the evening period 39%. For the bus routes considered as express service (CT1, CT2 and CT3) by the MBTA, the on-time performance percentage of inbound trips in the evening for CT1 and CT3 is considerable, 38% and 17% respectively and 50% for CT3 outbound [34]. Express routes have fewer bus stops suffering as well from congestion. The Congestion Management system report from the MPO admits and recognizes the congestion situation in the city of Boston and that the bus performance is impaired by this. There is a need for policies and management tools to address mobility and congestion.

If a cost were allocated to the congestion found in the analysis or the results provided by the CTPS, the outcome would be considerably high as the running time difference is greater too. Unfortunately, some of the bus routes in Boston run with a delay suffering from congestion and the impact over the transportation system is considerable. To minimize the effect of congestion and improve the operational speed congestion protection strategies at congested zones might be the solution.

10.5 Conclusions

This chapter presented performance measures as a management tool. An analysis of the performance measures and the impact of congestion over the bus routes in the city of Boston were performed.

Transit agencies develop performance measures in order to make changes or improvements to the public transportation system. Performance measures supply the necessary information to fine-tune the system. Furthermore, they assist transportation agencies in determining the successful operation and service quality of the public transportation system. Performance measures can be classified in cost efficiency, cost effectiveness, service effectiveness and service quality.

The Massachusetts Bay Transportation Authority (MBTA) uses service quality as a performance measure. The service delivery policy of the MBTA defines the quality standards for the bus service. It measures the performance of the service through accessibility, reliability, safety, comfort, and cost effectiveness. The performance of this transit authority is compared with other transit authorities in the USA where the authority performs relatively well given the service area size and the population it serves.

However, the MBTA lacks a performance measure to quantify the impact of congestion over its bus route. Therefore, analysis was made of the key bus routes (as defined by the MBTA) given their characteristics; serving high demand areas and with high frequency. The analysis found that all of the bus routes considered suffered a considerable delay caused from congestion. Bus route number 66 was the most affected bus route. It is clear that buses suffer from congestion; however, the effects of congestion over the running time of a bus are considerably high. If this effect were to be quantified in, e.g. dollars per minute, the cost of such delay would be significant. The development and deployment of congestion protection might provide benefits to reduce the delay encountered. In the ensuing paragraphs a site evaluation would be performed to assess how much the delay is reduced by applying congestion protection strategies at the intersection of Mass. Ave and Beacon St., Chapter 6.

The information in this chapter serves to discuss the findings of this thesis by answering the research question and sub-questions in order to find the reasons behind the limited deployment of congestion protection strategies to improve the running time of the bus in the city of Boston.

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Part IV. The End

Part II with Part III are discussed in combination through a synthesis focusing on deployment of congestion protection strategies at the site evaluated given the analysis of the actors, technology and management tools. The main conclusions reached by the subjects dealt are presented hereafter. In addition, recommendations for further research are discussed. The report is brought to an end with a reflection.

The chapters in this Part are:

- Chapter 11 Synthesis, Main Conclusions and Reflection

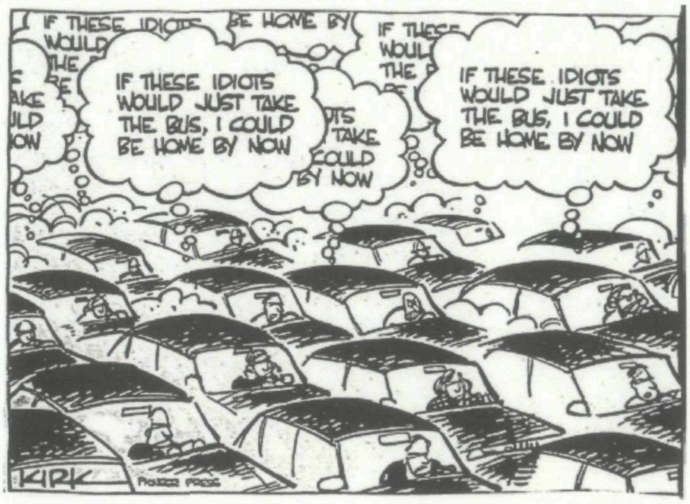

Figure 51: Congestion situation cartoon

Source;www45

Chapter 11 Synthesis, Main Conclusions and Reflection

11.1 Introduction

The research carried out as part of this thesis has covered a range of subjects evolving from the importance of public transportation to the modeling of a specific site and analysis of the policies, actors, technology and management tools. All of this leading towards the evaluation of different congestion protection strategies. The goal of the research: to improve the running times of public transportation specifically the bus. The problem owner, the Massachusetts Bay Transportation Authority operates two bus routes that run over a major arterial in Boston which were subject of the evaluation. The intersection of Massachusetts Avenue and Beacon St., just before crossing the Harvard Bridge, is identified as a "Hot Spot", where congestion affects the running time of the previously mentioned bus routes.

The research performed the analysis of different proposed congestion protection strategies and the actors, technology and management tools in order to evaluate and identify the reasons behind the limited deployment of congestion protection strategies in the USA and the city of Boston. The former analysis, conducted in Part II and Part III, through a synthesis discusses the capabilities towards deployment of the proposed strategies at the intersection of Mass Ave and Beacon St.

To achieve the goal of the investigation, the problem statement led to the formulation of a research question and several sub-questions. The research questions and sub-questions are centered among four main subjects in order to find a (or several) solution(s). Therefore, this chapter presents the main findings and conclusions based on the research objective and answering the main research question. The conclusions are given in an orderly manner following each of the subjects addressed in this research. In addition, recommendations for future research are discussed. The report is brought to an end with a reflection form the author.

11.2 Synthesis

Deployment of congestion protection strategies to improve the running time of public transportation can be achieved by the combination of several factors working together with and at the site. This combination is initiated by identifying the congested area and its characteristics. Essential in the "Hot Spot" is to determine the involvement of the unveiled actors and the policies to fund projects, which consider public transportation and or priority strategies. In addition, technology capabilities within the proposed congestion protection strategies are necessary in order to comprehend to what extend the strategy can be accomplished. As well, performance measures are required to quantify the benefits and make any necessary adjustments.

In the case of the “Hot Spot” at Mass Ave and Beacon St. the proposed congestion protection strategies can be realized through the combination of actors, policies, technology, and management tools. For example, to implement a change in traffic control from fixed time to vehicle actuated requires among others the following commitments. From the actors perspective; Mass Highway allowing installation and operation of detectors, BTD to accept a change in traffic control. If Memorial Dr. is to be considered a shift in jurisdiction from DRC to Mass Highway or the city of Cambridge should take place. From the technology perspective it is necessary to determine the detection and communication between vehicles and traffic signals among the actors. The expected benefits from this change in terms of travel time or delay should be defined from the performance measure perspective.

To accomplish all other scenarios, besides the previously mentioned, requires the following commitments explained individually hereafter. If a priority call is to be introduced to the traffic control phase from the actor perspective it is necessary for all actors to change their perspective towards public transportation as a priority call benefits this mode. The change in perception will also allow the actors to select an active priority strategy instead of only conditional priority. Given the characteristics of the intersection, the detection and communication of the bus needs to be defined according to the capabilities of the hardware and software for the existing traffic signals. Performance measures should be identified to quantify the benefits primarily of the bus. The impact over other traffic and over side streets should be also considered. In this scenario, changing the location of the bus stop to far side would be highly beneficial. However, it involves a shift in perception and parking policies from the Boston Transportation Department. Furthermore, the shift from the Boston Transportation Department is required if the three lane scenario and vehicle actuated left turn scenario are to be one of the preferred solutions. Here, the technology should consider one more lane and the software for the integration of a phase within the traffic control. Performance measures should be determined in relation to the reduction of travel time for through traffic and the bus on both directions. Redirecting traffic to turn right at the previous intersection to subsequently reach Beacon St., eliminating left turns, might be beneficial in these (as well as all other scenarios).

Bus lane scenario might be one of the straightforward scenarios to accomplish as Mass Highway has jurisdiction over the Harvard Bridge. A traffic signal closing the lane when a bus approaches and the detection of the bus are required. Mass Highway can decide the technology and location of the traffic signal as well as the detection and communication. Coordination between the technology and the bus (therefore the MBTA) is necessary. The scenario does not reduce capacity over the bridge. The commitments in order to insert a priority call in coordination with a bus lane over the Harvard Bridge are similar to those described for bus lane and vehicle actuated with priority.

Given the large number of actors and their perceptions partnerships need to be created as well as determine the communication channels or tools between all actors involved, regardless of the previously mentioned commitments. The preferred or deployed congestion protection strategies have to achieve a common objective. Regarding this as the initial step can assist towards determining partnerships and communication channels. However, willingness and skepticism not only from the actors but all of the stakeholders plays an important role. Deployment of congestion protection strategies is constrained by the limited recognition of the benefits of public transportation and the preference of the car. Decision makers, agencies and transportation authorities are to overcome old practices and preference -cars to public transportation- in order to implement congestion protection strategies at the relevant intersection.

The proposed congestion protection strategies can be deployed if all actors, through the leadership of the CTPS and or the MBTA participate with the same objectives and enthusiasm.

11.3 Main Conclusions

In relation with the objective of this investigation (Part I – paragraph 1.4) and answering the main research question (Part I – paragraph 1.4) through the analysis presented in the previous parts, the following main conclusion of this research is achieved.

1) A policy focusing towards public transportation priority at a State level should fund transit projects while transit authorities over come their jurisdiction conflicts through cooperative programs and or partnerships. The policy should specify the "carrots and sticks" to accomplish such projects.

2) Technology manufacturers should provide more and specific information about their software and hardware.

3) Transit authorities should apply performance measures quantifying the impacts of congestion towards public transportation in order to provide information which can be used to generate the necessary pressure to deploy and fine-tune congestion protection strategies.

Following the objective of this research, as described in Part I – paragraph 1.4, two main limitations towards deployment of congestion protection strategies have been identified: a) *Public transportation perception* and b) t*he reliance of old common practices of priority (underground).* Other limitations include jurisdiction, willingness, funding possibilities (public transit receives fewer funds than highway projects), the inter-relation between traffic signal software and hardware (technology) and skepticism to develop performance measures, among others.

The above named limitations involve a countrywide perception over transportation. Although other cities have overcome these, it is possible, therefore, to consider them as country wide and not specific to the city of Boston. However, the achieved conclusion of this research might only be specific to the city of Boston and even the "Hot Spot" due to its characteristics.

The research sub-questions are answered in the ensuing, following the subjects the research has focused on.

1. **Policy**

   a. Which are the transportation policies for public transportation in the United States of America? Do any acknowledge or promote the use of congestion protection strategies for public transportation projects? What are the funding possibilities derived from the transportation policies for public transportation projects?

There is a wide range of policies focusing on public transportation projects. However, none deal with priority directly but through different programs and innovative ways to fund these projects they have been realized. Furthermore, the majority of projects deployed (Transit Signal Priority or Bus Rapid Transit) have done it under the premise of –for demonstration-purposes only or with limited potential.

   b. Who are the actors involved?

Considering the actors involved at the "Hot Spot", agencies at all levels of government are involved in diverse manners. This creates a jurisdiction conflict necessary to be overcome through cooperative sources and partnerships in order to have priority policies, funds and deploy projects focusing on transit priority.

   c. What are their expectations / goals towards public transportation and priority strategies?

The actors identified acknowledge a need to improve public transportation, increase mobility and improve reliability of the transportation system. However, underground priority strategies as a mean to provide priority are highly preferred. Projects tend to focus on vehicles and modes such as rail and subway. The use of technology within the projects is recognized but not for priority strategies.

   d. Is there a need for new or improved policies relating to public transport focusing on priority strategies?

A policy that would focus on promoting funds for projects that encourage the use of congestion protection strategies would be highly beneficial. However, the skepticism, the reliance of old common practices and the vehicle as preferred mode should be overcome to have such a policy at a State level.

2. **Technology**

    a. What technology applications and products does the market offer to deploy congestion protection strategies?

The market offers a wide range of products, technology and communication controllers. However the information provided by manufacturers is limited. This in turn affects the parties interested (e.g. transit authorities), as the capabilities between software and hardware are not entirely known.

    b. What developments of technology are needed to have solutions at a local level?

Congestion situations are in many cases site specific; therefore, manufactures should provide easier access and product capabilities to achieve solutions at a local level without the use of numerous equipment quantities. Large number of equipment increases the investment costs and further limits the capabilities of the software and hardware of each product.

    c. What is the current state-of-the-art in congestion protection strategies deployed in the city of Boston, the United States of America and other countries?

Different congestion protection strategies with high results have been deployed in the USA. Through Transit Signal Priority and or Bus Rapid Transit transportation authorities have been able to improve the running time of one or several bus corridors. The Silver Line in Boston, through tunnels and conditional priority over Washington Street has been highly beneficial to its users. Other strategies, primarily used in other countries, have also proven highly beneficial.

3. **Management Tools**

    a. Which performance measures exist to evaluate the performance of the transit modes?

Transit authorities in the United States of America gather information to evaluate the operation and service quality of their modes through measures such as cost efficiency, cost effectiveness, service effectiveness and service quality. There is a lack in performance measures to evaluate the benefits and fine-tune projects that have deployed congestion protection strategies.

    b. What performance measures does the relevant transit authority use? Do any consider the impact of congestion?

The Massachusetts Bay Transportation Authority assures the modes it operates, such as the bus meet the service quality standards as stated in the Service Delivery Policy. The service is measured through accessibility, reliability, safety, comfort and cost effectiveness. Neither the transit authority nor any of the agencies identified apply performance measures to quantify the impact of congestion over public transportation. Implementing such a performance *measure might bring other issues derived primarily from the jurisdiction conflict between actors and the perception towards vehicles.*

c. Can we predict the cost – benefit efficiency over the congestion impact?

An analysis of the key bus routes operated by the Massachusetts Bay Transportation Authority revealed that the congestion suffered by some of the bus routes is considerably high. The benefit ratio of quantify this impact would be considerably high. However, knowing the impact is high and given the benefits resulted from other cases, it is possible to predict the cost benefit ratio of a bus route when priority strategies are deployed.

4. **Boston**

a. Which strategies of congestion protection can be deployed at the site being evaluated?

Given the characteristics of the "Hot Spot" only those that do not alter the road geometry, such as Transit Signal Priority and a Bus Lane over the Harvard Bridge. Several scenarios proved beneficial, where the simple change in traffic control to vehicle actuated resulted in an improvement of travel time.

b. Are these strategies particular to a conflict area? Should they focus to other conflict areas?

There are diverse congestion protection strategies given that the majority of congestion situations and road layout are different. The strategies therefore focus on a general basis where slight modifications are needed to suit the area in question. Through several scenarios, adapting congestion protection strategies to the site characteristics allowed to model and evaluates them. Congestion situations make the use of congestion protection strategies (mix and match) to reduce the impact of congestion.

c. Which priority strategy would benefit the bus and other vehicle classes at the intersection under evaluation?

Following the results from the site evaluation, where seven scenarios were proposed using the performance indicators delay and travel time the priority had an array of mixed results. However, a simple change to vehicle actuated from fixed time control already provides benefits.

The most suited congestion protection strategies for the "Hot Spot" are either traffic signal priority or a bus lane over the Harvard Bridge. The change in traffic control from fixed time to vehicle actuated proved beneficial towards a reduction in travel time for the bus. The latter is the preferred approach when congestion protection strategies are to be disregarded in order to increase the travel time of the bus. The elimination of protected left turn is the primary reason behind the mixed results. The geometry of the intersection, protected left turns and the location of the bus stops make it difficult to deploy a congestion protection strategy at this "Hot Spot" in order to reduce the travel time and delay of the bus with minimum effect over other vehicle classes.

11.4 Recommendations

The following recommendations could be considered for (in) future research. It is recommended to carry further research in the field of analyzing the possibilities to differentiate and separate public transit from cars in relation to the policies of transportation. Furthermore, considering the inter-relation that exists between the Federal Highway Administration (FHWA) and the Federal Transit Authority towards allocating funds that fund projects without depending on funds from the FHWA. Conduct research to create a framework towards cooperation and communication between agencies to accomplish public transportation projects focusing on priority. The proposed frame of reference should be further analyzed with the focus to develop thresholds to develop penalties for none-attainment of public transportation projects. Additionally, propose performance measures that will evaluate quantitatively the benefits of Bus Rapid Transit and Transit Signal Priority. Research should continue in the field of communication and detection technology and the capabilities of software and hardware to meet specific congestion situations. Further research should be carried out in order to evaluate the possibilities of Public-Private-Partnerships and tendering process towards the introduction of private companies rendering public transportation services in the city of Boston.

The site characteristics such as the importance of the infrastructure surrounding the intersection and the geometry of the roads limited the possibilities to develop congestion protection strategies. Notwithstanding this limitation, it is recommended to further assess the congestion protection strategies considering side streets and a longer intersection corridor. Bus effects such as bus bunching and crossings at rail or tram intersections should be included too. Additionally, other "Hot Spots" throughout the city should also be evaluated.

The simulation program in future versions should allow the user to change the geometry of the road without changing the parameters previously determined. This will facilitate the integration of congestion protection strategies, primarily those that consider changes in the road geometry. Driving behavior in the United States of America is different than that from European cities. The simulation program should allow making changes in the behavior in an easier manner as the program is developed considering the European behavior.

As a final recommendation, the Massachusetts Bay Transportation Authority should perform studies in the field of deployment and implementation of congestion protection strategies at different congested areas. The intention is to create the necessary information and pressure to achieve a shift in perception and preferred mode focusing on public transit.

11.5 Reflection

This paragraph presents a reflection of the research conducted in this master-thesis.

The research presented the problem from a perspective of the Massachusetts Bay Transportation Authority. The author is of the opinion that the transportation authority has the relevant power to and would be the primary beneficiary from the implementation of congestion protection strategies as they would increase ridership and improve the reliability of the bus.

A wide diversity of subjects where addressed. The author is of the opinion that the several overviews presented, supply the necessary information to highlight the difficulties behind deployment of congestion protection strategies. Although, the subjects could have been addressed in full depth it would have been to complex to present in a thesis. The way the problem solving process was followed through the evaluation of different strategies and the analysis of actors and policies, technology and management tools helps to unveil the constrains for deployment. Furthermore, it also helped to identify what are the initial steps towards implementing a congestion protection strategy. The policies and actors subjects were perhaps the most complex as well as the different congestion protection strategies that could be deployed at the site. First, the policies, it is in the opinion of the author that a shift in perception and allocating more funds for mass transit is eminent. Further research will allow evaluating and analyzing how this could be a reality. Moreover, it should also be considered the relation and dependency of oil, highway construction and cars. It is concluded that in the United States of America a shift in the preference of the car and perception of public transportation are to happen if public transit is to become the transportation alternative for urbanized areas. However, the authors' opinion is that such shift might never be possible but perhaps a balance could be achieved as it all depends on the actors and their perception.

Secondly, congestion protection strategies could easily be deployed and they present an optimal solution for public transportation. Deployment, unfortunately, depends on several factors besides policies and actors. Different solutions can be implemented together to boost performance of the system. In this case, the transit authority needs to overcome a large number of actors, the bureaucratic hurdle and many other aspects in order to develop and deploy such strategies. It is in the author opinion that for the transit authority given the large number of actors and the perception of public transit to "sell" the idea of such strategies is quite difficult.

In the opinion of the author, to overcome the complexity and "sell" such solutions starts by acknowledging the benefits and minimizing the skepticism from the actors. However, to quantify the benefits and create the necessary (essential) input begins by the policies and funds towards public transportation projects focusing on congestion protection strategies. Therefore, it is a cycle that needs fine-tuning as cases and experiences are developed.

The author concludes that it is indispensable to procure and maintain the flow of information through research, experiences and demonstration projects from transit authorities, public transit companies, activists, organizations and anyone interested in public transportation. When more highways are built, more vehicles will get to them generating traffic and inefficient suburban sprawl. If more public transportation systems are deployed efficient suburban development and fewer cars create less pollution (air and noise), better public health and, ultimately, people living without cars in better and friendlier communities.

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WWW1	http://www.mbta.com/
WWW2	http://en.wikipedia.org
WWW3	http://www.jornada.unam.mx
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WWW5	http://dcmud.blogspot.com
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WWW7	http://www.smarttransport.org.nz
WWW8	http://www.cflhd.gov

WWW9	www.ops.fhwa.dot.gov
WWW10	http://www.earth.google.com
WWW11	http://maps.live.com/
WWW12	http://www.itsdeployment.its.dot.gov
WWW13	http://www.mccain-inc.com/products/bus.html
WWW14	http://www.dot.state.mn.us
WWW15	http://www.calccit.org
WWW16	http://www.mistergates.net
WWW17	http://www.hel2.fi
WWW18	http://www.lumenera.com
WWW19	http://www.cms.ukintpress.com
WWW20	http://www.gobrt.org/db/index.php?s1=Y
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WWW35	http://www.bostonmpo.org
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[INT 1] Interview with Melissa Duella, student at Northeastern University and staff at the Massachusetts Bay Transportation Authority.

Abbreviations and Acronyms

3C	Transportation Planning Process of the MPO
AASHTO	American Association of State Highway and Transportation Officials
AVL	Automatic Vehicle Locator
BIPS	Bus Information and Priority Systems
BRT	Bus Rapid Transit
BTD	Boston Transportation Department
Bus	Rubber-tired vehicles operating on fixed routes and schedules on roadways.
CAA	Clean Air Act
CIP	Capital Investment Plan
CMAQ	Congestion Mitigation and Air Quality Improvement Program
Commonwealth of Massachusetts	Massachusetts is officially named "The Commonwealth of Massachusetts" by its constitution. This designation, which has no constitutional impact, emphasizes that they have a "government based on the common consent of the people." Also named "State of Massachusetts Bay"
Congress	The United States Congress, House of Representatives
DOT	Department of Transportation
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
FY	Fiscal Year
HCM	Highway Capacity Manual
HOV	High Occupancy Vehicle
IBL	Intermittent Bus Lane
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
LRT	Light Rail Transit
M.G.L.	Massachusetts General Laws
Mass Gov	Massachusetts Government, Office of the Governor
Mass Transit	See Public Transportation
MBTA	Massachusetts Bay Transportation Authority
MPO	Metropolitan Planning Organization
MUTCD	Manual for Uniform Traffic Control Devices for Streets and Highways
NEMA	National Electrical Manufacturers Association
NTCIP	National Transportation Communications for ITS Protocol
PMT	Program for Mass Transportation
PPP	Public Private Partnership
PRG	Priority Request Generator
PRS	Priority Request Server
Public Transportation, Public Transit, and or	Transportation by a conveyance that provides regular and continuing general or special transportation to the public, but does not include school bus, charter, or

Mass Transit	intercity bus transportation or intercity passenger rail transportation.
RITA	Research and Innovative Technology Administration
r-o-w	Rights-of-way
RTP	Transportation Plan (Region)
SAFETEA-LU	Safe, Accountable, Flexible Transportation Equity Act; a Legacy for Users
SCATS	Sydney Coordinated Adaptive Traffic System
SCOOT	Split Cycle Offset Optimization Technique
SIP	State Implementation Plan
State	Used indistinctively between The State of Massachusetts and or any of the fifty sub national entities of the United States, the District of Columbia and Puerto Rico
STIP	State Transportation Improvement Program, is a compilation of the Regional Transportation Improvement Programs prepared annually by the state's Metropolitan Planning Organizations.
Surface Transportation	See Public Transportation
TCM	Transportation Control Measures
TE	Transit Enhancement
TIP	Transportation Improvement Plan
Transit	Mass Transportation
Transit Enhancement	With respect to any project or an area to be served by a project, projects that are designed to enhance mass transportation service or use and that are physically or functionally related to transit facilities
TRB	Transportation Research Board
TSP	Transit Signal Priority
USA	United States of America
U.S.C.	United States Code
USD	American Dollars
UTOPIA	Urban Traffic Optimization by Integrated Automation

Appendices

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Appendix A - Transit Authority – Massachusetts Bay Transportation Authority Profile

ID Number: 1003
www.mbta.com
10 Park Plaza
Boston, MA 02116-3974

Massachusetts Bay Transportation Authority (MBTA)

General Manager: Mr. Daniel Grabauskas
(617) 222-5176

General Information

Urbanized Area (UZA) Statistics - 2000 Census	
Boston, MA-NH-RI	
Square Miles	1,736
Population	4,032,484
Population Ranking out of 465 UZAs	7
Other UZAs Served	34, 74, 234
Service Area Statistics	
Square Miles	3,244
Population	4,510,400

Service Consumption	
Annual Passenger Miles	1,767,608,772
Annual Unlinked Trips	380,260,730
Average Weekday Unlinked Trips	1,252,312
Average Saturday Unlinked Trips	671,305
Average Sunday Unlinked Trips	476,700
Service Supplied	
Annual Vehicle Revenue Miles	89,316,780
Annual Vehicle Revenue Hours	6,294,738
Vehicles Operated in Maximum Service	2,137
Vehicles Available for Maximum Service	2,704
Base Period Requirement	484

Financial Information

Fare Revenues Earned		$341,868,507
Sources of Operating Funds Expended		
Fare Revenues	(29%)	$341,868,507
Local Funds	(11%)	129,643,171
State Funds	(53%)	623,279,908
Federal Assistance	(1%)	10,884,750
Other Funds	(6%)	65,531,612
Total Operating Funds Expended		$1,171,207,948
Sources of Capital Funds Expended		
Local funds	(68%)	$342,386,099
State Funds	(2%)	11,400,233
Federal Assistance	(29%)	147,171,947
Other Funds	(1%)	2,839,882
Total Capital Funds Expended		$503,798,161

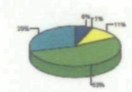
Summary of Operating Expenses

Salary, Wages and Benefits	$666,622,597
Materials and Supplies	97,913,956
Purchased Transportation	59,587,792
Other Operating Expenses	120,001,987
Total Operating Expenses	$944,126,332
Reconciling Cash Expenditures	$227,081,816

Vehicles Operated in Maximum Service and Uses of Capital Funds

	Directly Operated	Purchased Transportation[1]	Revenue Vehicles	Systems and Guideways	Facilities and Stations	Other	Total
Bus	758	58	$32,376,026	$3,027,458	$10,302,546	$26,205	$45,732,235
Heavy Rail	320	0	$4,940,357	$129,462,359	$50,295,209	$0	$184,697,925
Commuter Rail	389	0	$24,880,930	$121,648,736	$7,187,130	$0	$153,716,796
Demand Response	0	439	$29,317	$17,888	$0	$0	$47,205
Ferryboat	0	9	$798,573	$0	$204,523	$0	$1,003,096
Light Rail	142	0	$28,481,519	$49,999,101	$17,546,920	$0	$96,027,540
Trolleybus	22	0	$4,202,116	$3,775,982	$14,595,266	$0	$22,573,364
Total	1,631	506	$95,709,838	$307,931,524	$100,131,594	$26,205	$503,798,161

Sources of Operating Funds Expended



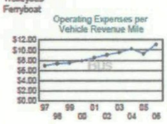
Sources of Capital Funds Expended

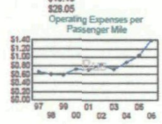
Modal Characteristics

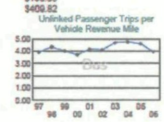
	Operating Expenses[1]	Fare Revenues[1]	Uses of Capital Funds	Annual Passenger Miles	Annual Vehicle Revenue Miles	Annual Unlinked Trips	Annual Vehicle Revenue Hours	Fixed Guideway Directional Route Miles	Vehicles Available for Maximum Service	Average Fleet Age in Years	Vehicles Operated in Maximum Service	Peak to Base Ratio	Percent Spares
Bus	$292,758,990	$62,460,479	$45,732,235	210,597,663	26,412,207	104,399,208	2,498,439	18.1	1,048	6.2	816	2.24	28%
Heavy Rail	$243,852,816	$109,922,405	$184,697,925	551,634,497	21,101,990	150,705,803	1,447,617	76.3	408	23.9	320	2.11	28%
Commuter Rail	$223,835,440	$104,286,465	$153,716,796	749,518,088	22,407,014	37,797,601	711,654	702.1	488	17.1	389	2.01	25%
Light Rail	$113,912,100	$55,719,465	$96,027,540	215,711,014	5,575,777	80,278,013	574,794	51.0	204	17.4	142	1.67	44%
Demand Response	$47,199,820	$1,661,648	$47,205	19,277,514	12,802,174	1,458,824	968,814	N/A	505	2.8	439	N/A	15%
Trolleybus	$13,592,941	$1,792,105	$22,573,364	8,724,975	697,672	4,308,558	71,522	21.0	39	12.2	22	2.44	77%
Ferryboat	$8,974,225	$6,025,740	$1,003,096	12,142,001	319,946	1,312,723	21,898	38.4	12	13.9	9	2.25	33%

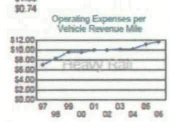
Performance Measures

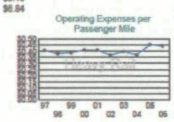
	Service Efficiency		Cost Effectiveness		Service Effectiveness	
	Operating Expense per Vehicle Revenue Mile	Operating Expense per Vehicle Revenue Hour	Operating Expense per Passenger Mile	Operating Expense per Unlinked Passenger Trip	Unlinked Passenger Trips per Vehicle Revenue Mile	Unlinked Passenger Trips per Vehicle Revenue Hour
Bus	$11.08	$117.18	$1.39	$2.80	3.95	41.79
Heavy Rail	$11.56	$168.45	$0.44	$1.62	7.14	104.11
Commuter Rail	$9.99	$314.53	$0.30	$5.92	1.69	53.11
Light Rail	$20.43	$198.18	$0.53	$1.42	14.40	139.66
Demand Response	$3.69	$48.72	$2.45	$32.35	0.11	1.51
Trolleybus	$19.48	$190.05	$1.56	$3.15	6.18	60.24
Ferryboat	$28.05	$409.82	$0.74	$6.84	4.10	59.95

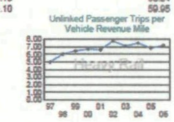












1 Excludes data for purchased transportation reported separately

9/24/2007
Data Source: 2006 National Transit Database

Appendix Figure I: Massachusetts Bay Transportation Authority Transit Profile

Source: [5]

Appendix B - Policies for Public Transportation

In this appendix an overview of the policies involved in public transportation and their funding possibilities in the United States of America, the State of Massachusetts and the city of Boston are discussed.

Federal Level

The policies classified at a Federal level regulating and providing funds for public transportation projects are:

- Title 49 of the United States Code (US Code 49);
- Safe, Accountable, Flexible and Efficient Equity Transportation Act: a Legacy for Users (SAFETEA-LU);
- Clean Air Act (CAA);
- Congestion Mitigation and Air Quality Improvement Program (CMAQ).

Title 49 of the United States Code

The United States Code is the codification by subject matter of the general and permanent laws of the United States of America [www21]. Title 49 Chapter 53 Mass Transportation [www21] lays down the main policy standards for transportation, being the foundation for public transportation policies.

From the title in question the following policy standards can be summarized;

- It is the policy of the United States of America to promote the construction and commercialization of high-speed ground transportation systems by;
- Conducting economic and technological research;
- Demonstrating advancements in high-speed ground transportation technologies;
- Establishing a comprehensive policy for the development of such systems and the effective integration of the various high-speed ground transportation technologies; and
- Minimizing the long-term risks of investors
- It is the policy of the United States of America to establish in the shortest time practicable a United States of America designed and constructed magnetic levitation transportation technology capable of operating along Federal-aid highway rights-of-way, as part of a national transportation system of the United States of America.
- Intermodal Transportation; It is the policy of the United States of America Government to encourage and promote development of a national intermodal transportation system in the United States of America to move people and goods in an energy-efficient manner, provide the foundation for improved productivity

growth, strengthen the Nation's ability to compete in the global economy, and obtain the optimum yield from the Nation's transportation resources.

With a countrywide focus, referring to all modes of transportation, it primarily encourages infrastructure for cars and freight in order to achieve its goals. The achievement of an intermodal transportation system, as it links other modes, results in improvement of the entire transportation system. The benefits of public transportation as part of the intermodal transportation system have shown that bus priority is energy-efficient, as it creates a modal shift and reduces emissions and congestion [11].

Title 23 of the U.S. Code sets the policy standards for Highways. A strong co-relation exists between this title and Title 49. Several policies and programs for transportation are directly sourced through the highway policies and programs. This creates an un-clear distinction between title 23 and 49. The existing co-relation still demonstrates how in terms of transportation the vehicle is still regarded as the preferred mode.

An analysis of the U.S. Code Title 23 and 49 provided the following results towards acknowledging priority strategies for transportation, in particular public transportation. Through both titles several sections lay down the provisions for signal control for emergency vehicles (preemption control), at railroad crossings and HOV lanes at highways. The U.S. Code does not provide policies for priority strategies focused towards public transit. However, it lays the foundations for amendments that could procure the development and deployment of these strategies for public transport.

To face the future challenges of transportation in accordance to the era, since 1991 the Federal Transit Administration began creating amendments to this title. The amendments resulted in a series of transportation acts, such as the Federal Public Transportation Act of 2005 an amendment made from the Safe, Accountable, Flexible and Efficient Transportation Equity Act; a Legacy for Users [37].

Safe, Accountable, Flexible and Efficient Transportation Equity Act; a Legacy for Users

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) was the first USA Federal legislation on the subject in the post-Interstate Highway System era. It presented an overall intermodal approach to highway and transit funding with collaborative planning requirements, giving significant additional powers to metropolitan planning organizations. Preceded by the Surface Transportation and Uniform Relocation Assistance Act of 1987 and followed by the Transportation Equity Act for the 21st Century (TEA-21) and most recently since 2005, the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) [www22].

The Federal Highway Administration defines the SAFETEA-LU as; "Broad in scope, SAFETEA-LU addresses the many challenges facing today's transportation system, such as improving safety, reducing traffic congestion, improving efficiency in freight movement, increasing intermodal connectivity, and protecting the environment. The SAFETEA-LU also lays the groundwork for addressing future challenges" [www22].

The SAFETEA-LU assists and encourages the planning of public transportation, in urban areas. More and more agencies are planning or proposing the development of Bus Rapid Transit (BRT) projects for their cities as they have seen the benefits benchmarking from other agencies and cities. Several Bus Rapid Transit projects are being funded by the SAFETEA-LU. The SAFETEA-LU through BRT projects recognizes the benefits that arise from deployment although these projects are in starting stages and developed as demonstration projects.

Funding Characteristics

The SAFETEA-LU provides $286.4 billion USD in guarantee funding for federal surface transportation programs over five years, through FY 2009. From this funding, $52.6 billion USD is allocated for federal transit programs, representing a 46% increase over transit funding guaranteed in TEA-21 [www22].

Title III of the SAFETEA-LU can be sited as the Federal Public Transportation Act of 2005. A review of the title drew the following result: Funding is provided for Fixed Guideway Capital Projects, if the project represents a substantial investment in "demonstrated by features such as ... traffic signal priority [37]. There are different programs that provide funds for capital projects related to buses. These will be briefly described.

First, Urbanized Formula Grants include eligible projects for, among others; "Transit enhancements, Operating costs of equipment and facilities for use in public transportation in a portion or portions of an urbanized area with a population of at least 200,000, but not more than 225,000" [37]. Funding is limited to the area for which the project could be applied too. If the area is above the population of 250,000 the funds can only be used for capital investment.

Secondly, Capital Investment Grants Less than $75,000,000 USD, the "New Starts" program, funds major new public transportation capital investments. One of the most important funding programs for public transportation projects includes eligible projects if: "a corridor-based bus capital project if it represents a substantial investment in a defined corridor as demonstrated by features such as park-and-ride lots, transit stations, bus arrival and departure signage, intelligent transportation systems technology, traffic signal priority, off-board fare collection, advanced bus technology, and other features that support the long-term corridor investment" [37].

Third, Congestion Mitigation and Air Quality (CMAQ) programs, funded by the Highway Federal aid, funds projects that improve air quality and reduce emissions in areas classified as non-attainment or maintenance. Boston, in this case is a non-attainment area. An advantage is the full funding possibilities for all phases of the project and the small percentage to meet in local share. However, payment is not made until completion of the project, a disadvantage of this fund.

Forth, bus and bus related facilities program, where there are 665 total projects, large or small. The program only funds bus related facilities where ITS technologies are applied, e.g. passenger information systems and AVL.

In general, funding and programs are available for bus and or public transportation projects through the SAFETEA-LU. The policy does not set the necessary criteria (e.g. of criteria, speed or signal control system) in order for a project to be considered a BRT project. Additionally, limitations exist towards how these projects can be funded. A discrepancy between rail and bus project funding arises, where the latter still needs to overcome some constrains and difficulties to fulfill as a project. The primary conflict is the involvement of BRT or bus related projects to the definition of fixed guide way, referring primarily to rail. If BRT projects are to be introduced as strategies for developing public transportation projects a distinction is required between modes. Secondly, funding for public transportation projects is primarily done with Federal, State and or Local sources, with no (or hardly none) private involvement. As infrastructure and operating costs are part of the public sector costs the budgets of the transit authorities fall or are already in deficits [4, 20]. Public transportation projects to qualify for funding require a local share, in some instances of up to 50% depending on the fund program. In addition, funding from these programs may not be used for operating costs for example. Local share makes State or local agencies find means to fund their project through local taxes or bonds. State and local capital infrastructure or maintenance budgets can be an important source to fund projects [21]. States and local agencies go through long and difficult accounting processes for funding of their projects. Even, in some cases go through innovative ways. Despite the procedure and local policy entanglements funding is made available. For example, the Silver Line in Boston was primarily funded by the DOT of the State (MassHighway) as it runs and creates improvements to the road within the agency's jurisdiction (The MBTA) [21, www1].

The National Surface Transportation Policy and Revenue Study Commission [www23], released on March 26, 2008 "Transportation for Tomorrow" [38] a report to the USA Congress concerning the current and future state of transportation in the country. This report concedes with the increase in population growth in the USA calling for a higher need of mobility and efficient transportation, resulting in an emphasis to improve public transportation. Furthermore, it considers the changes in travel behavior, travel patterns and travel demand having an impact on the mobility and efficiency of transportation. Recognizing that overall the culture of the country needs to change, the perception on how they commute, public transportation is perceived as eminent. However, it still makes a strong emphasis on highway transportation. Finally, it points out the necessity of a policy or restructuration of the policies towards Federal programs and those for public transportation as they deal with mobility but not in a comprehensive way.

Clean Air Act

The Clean Air Act (ACC) [www24] is the air quality legislation at a federal level intended to reduce smog and air pollution. In addition, sets the standards for air quality improving human health and longer life pans. By setting the standards for air quality in general, the policy, in this case sets the environmental standards for tail pipe exhaust from buses as well as emissions control and use of fuels.

The Clean Air Act provides funds for projects that reduce emissions through the application of diverse strategies and solutions. An amendment to the CAA resulted in the Congestion Mitigation and Air Quality Improvement program. The Clean Air Act provisions towards public transportation are given through this program.

Congestion Mitigation and Air Quality

The Congestion Mitigation and Air Quality (CMAQ) Improvement program as mentioned previously was authorized by an amendment to the Clean Air Act. With a direct relation towards the SAFETEA-LU as discussed previously, the improvement program, Congestion Mitigation and Air Quality provides funding for surface transportation and other related projects that contribute to air quality improvements and reduce congestion. For these reasons and the advantages it provides in terms of granting funds to projects that focus on improving the air quality this program is considered.

Jointly administered by the Federal Highway Administration and the Federal Transit Administration, reauthorized by the SAFETEA-LU provides over $8.6 billion USD (FY 2008 $1,749,098,821USD) [39] in funds to State Department of Transportations, Metropolitan Planning Organizations, and transit agencies to invest in projects that reduce air pollutants related to transportation sources. This fund only applies to areas that do not meet the National Ambient Air Quality Standards (non-attainment areas) as well as former non-attainment areas that are now in compliance (maintenance areas) [www22]. The city of Boston as well as other major urban areas has been labeled as a non-attainment area.
The program provides funds through a priority structure to distribute funds for projects that provide air quality benefits, congestion mitigation and others from State and Metropolitan Planning Organizations.

The projects that qualify for CMAQ funds are;

- Public Transportation Improvements;
- Traffic Flow Improvements;
- Transportation Demand Management;
- Bicycle and Pedestrian Projects;
- Alternative Fuel Projects;
- Inspection and Maintenance Programs;
- Intermodal Freight Transportation;
- Public Education and Outreach;
- Idle Reduction Technology and;
- Intelligent Transportation Systems.

CMAQ funds may be used to support the use of public transportation. All projects should be mentioned on the State Transportation Plan and Transportation Improvement Plan (TIP). These plans are further described in paragraph 0.

There are three broad categories of transit projects eligible for funding: provision of new transit service, service or system expansion, and financial incentives to use existing transit services [www22]. CMAQ funds for the projects qualifying are provided by the Federal Highway aid. This program extends funds for transit improvements, travel demand management strategies, traffic flow improvements, and public fleet conversions to cleaner fuels, among others. However, not all transit improvements are eligible under the CMAQ program. The general guideline for determining eligibility is a reasonably expected increase in transit riders resulting from the project. The criteria as to what the number of increase in ridership necessary for eligibility is unclear. Projects with priority strategies do attract an increase in ridership, allowing for these projects to qualify for CMAQ funds. All CMAQ-funded projects must be supported by a quantified estimate of the emissions reductions resulting from the project. The share of funds is 80% Federal and Local share 20% [37, 39]. The State is the responsible distributor of CMAQ funds. Funding is available for all phases of the project (other programs only fund certain phases) if project approval and operates on a reimbursable basis, so funds are not provided until work is completed.

In addition, CMAQ provides funds for Transportation Control Measures (TCMs) [www22]. TCMs are specifically identified and committed too in State Implementation Plans (SIPs). Excluding measures that reduce emissions by improving vehicle technologies, fuels, or maintenance practices are not TCMs.

The Clean Air Act defines the TCM projects to qualify for CMAQ funds, which include [www8];

- Improved public transit;
- Traffic flow improvements and high-occupancy vehicle lanes;

- Shared-ride services;
- Bicycle/pedestrian facilities and;
- Flexible work schedules.

Transportation Control Measures receive the highest priority for funding under the Congestion Mitigation and Air Quality Improvement Program. Many other measures, similar to the TCMs listed in the CAA, are being used throughout the USA to manage traffic congestion on streets and highways and to reduce vehicle emissions. Increasingly TCM's are being recognized for their benefits toward improving an area's livability.

The CMAQ program has a high rate of success for public transportation projects. Some of the projects procuring priority strategies, such as BRT have found funding through it, demonstrating the benefits of deploying projects with priority strategies. The program allows including priority strategies within the policies that combine the benefits of mobility and emissions reduction for public transportation.

Traffic Operation Policies

Traffic Operation policies are considered in order to comprehend the characteristics of the signal control devices and traffic control signals in the USA More specific, these policies will provide the necessary insight into the capabilities and possibilities to integrate priority strategies with the exiting technology and the traffic signals in use at intersections throughout the country. The traffic signal and the U.S and technology for congestion protection strategies, Transit Signal Priority, are discussed in Chapter 9.

From title 23 of the U.S. Code Traffic the Manual for Uniform Traffic Control Devices (MUTCD) derives. As well from this title the Highway Capacity Manual is of relevance as it sets the concepts and guidelines for signalized intersections

The Federal Highway Administration through the Manual Uniform Traffic Control Devices (MUTCD) specifies standards for traffic signs, road markings and signal design, installation and use. This manual is used by state, local agencies and private organizations to ensure conformity with national standards. Road managers nationwide use the manual to install and maintain traffic control devices on all streets and highways. Furthermore, the manual ensue the guidelines and standards towards priority control at traffic signals for signalized intersections [www25]. Recognizing the use of priority control strategies for certain vehicle classes the manual does not specify the complexity of the traffic signal and technology to be used. The vehicle classes are classified focusing on the importance and or difficulty in stopping of the vehicle class. Buses and vehicles are classified together. A conflict to make an individual distinction for these two vehicles might arise when developing priority strategies at signalized intersections.

The Transportation Research Board (TRB), in an effort of over 50 years, publishes concepts, guidelines and computational procedures to compute the capacity and quality of service of highways, intersections (signalized and un-signalized) as well as the effects of public transportation, pedestrians and bicycles on the performance of these systems, which are contained in the Highway Capacity Manual (HCM) [35]. The capacity calculations for the "Hot Spot" are done following the guidelines stated in the HCM (refer to paragraph 5.2).

State Level

The SAFETEA-LU requires that each State develop its own plans and programs focused towards statewide transportation improvement. These shall provide development and integration of management and operation of transportation systems and facilities functioning as an intermodal transportation system for the State and an integral part for the country. Development of the plans and programs in cooperation with other agencies allows the actors involved to participate in a coordinated way. The policies classified under this level are: the General Laws of Massachusetts.

General Laws of Massachusetts

The transportation policies for the State of Massachusetts regulated by the Massachusetts Government (Mass Gov) are provided in the General Laws of Massachusetts, under diverse chapters and sections [www26]. For public transportation policies, as the Massachusetts Bay Transportation Authority (MBTA) is in charge and provides all of the transportation modes serving the region of Boston, the agency at a State level is regulated under the Massachusetts General Laws. The General Laws of Massachusetts specify the "carrots and sticks" in terms of transportation for the State. Comparing these policies with those described at a federal level, the latter do not set penalties for non-accordance where the former does describe the penalties for non-accordance.

In 1970, Governor Francis W. Sargent acknowledged critical issues in transportation planning, calling for a better planning process, setting an emphasis that included Transit. In 1972, a report from the Boston Transportation Planning Review resulted in "Policy Statement on Transportation in the Boston Region," setting new policies for: highway construction, parking policies and freezes, and transit policy and funding [www26]. The first policy to help decision makers make oriented decisions. However, the statement towards transportation focused largely on highway projects, assisting the Central Artery project to be realized. In addition, public transportation investments expanded due to the parking freezes. The result provided public transportation with funds from the Interstate fund, "basically rebuilding the public transportation infrastructure of the city," as stated by Frederick Salvucci7 [40]. In addition, Salvucci recognizes that laws need to be changed in order for the policy to have an effect and procure realization of public transportation projects. In Massachusetts it led to amendments (called session laws), which resulted in the creation of the long-range transportation plans for the State with the involvement of all State agencies. The plans assist decision-makers by providing the necessary planning, design and funding information in order to develop and deploy transportation projects in the State.

A review of the General Law of Massachusetts and the Session Laws provided the following results regarding public transportation policies, projects and funding opportunities. From the Acts of 2008, Chapter 86 [www26] is the only act concerning transportation for the Commonwealth of Massachusetts, the Region, City and MBTA. Being an act for financing improvements to the State's transportation system it provides the sums to accomplish different projects. In comparison between highway and public transportation projects, the amounts provided for the former are considerably higher than for the latter.

States are required for certain programs to qualify for funds to meet a local share. Through State funds, non-federal, public transportation projects are realized. State funds are; Non federal aid, State bonds, revenues collected from the Massachusetts Turnpike Authority, Transportation Infrastructure Fund, some of the local tax revenues and lottery revenues provide the monetary resources to meet the local share.

From the Acts of 2006 [www26] chapter 123 describes funding limits and authorizations for several transportation projects. Among other projects, those for public transportation improve transit and traffic controls in and around the city of Boston. In addition, the congestion situation in the city of Boston is addressed by funding projects that study diverse strategies to improve traffic flow. From the Massachusetts Community Investment Capital Program funds are provided, not less then $2,545,000 USD, for the feasibility study of a tunnel for the Silver Line under the city of Boston [www26]. A feasibility study of a tunnel is seen as an improvement to traffic flow, however, as previously discussed it follows to distinguished trends towards improvement of traffic flow: underground practices and solutions vehicle oriented. The funds allocated for the feasibility study have funded in other cities corridors where priority control strategies were deployed. Other Session laws, such as Chapter 291 of the acts of 2004, an act modernizing the transportation system in the Commonwealth [www26], provide funds towards transit improvements for the State without considering BRT or any other priority strategy projects for public transportation.

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[7] Frederick Salvucci, former State Secretary of Transportation, developed and pioneer of the Central Artery project, also known as "The Big Dig"

In the Five-Year Capital Investment Plan for the Commonwealth of Massachusetts, FY2008-FY2012 [41] specifies spending allocated to transportation. Substantial gaps in funding to achieve projects for transportation exist according to the investment plan. As well acknowledges the need for improvements within public transportation. In addition, notes that the MBTA deficits would be difficult to be addressed by this agency alone. The list of project addressing mobility includes projects such as bridge improvement, highway maintenance and enhancement, and improvements or extensions to rail or subway modes. The improvements for rail and subway, generally incur in high investment costs. This might not be the answer to improve public transportation when budgets are in deficit and only if these two modes are addressed.

City policies

The policies for transportation are contained within the City of Boston Municipal Code [www27]. The municipal code derives from the General Laws of Massachusetts. The code sets the "carrots and sticks" regarding transportation for the city of Boston addressing issues, such as parking, use of vehicles, violations and licenses among others. As a result, the Municipal Code does not describe any related policies towards public transportation as these are contained in the General Laws of Massachusetts.

Appendix C - Actors involved at the "Hot Spot"

In this appendix each of the actors identified at the "Hot Spot" and by the policies, having a decision-making power over projects that procure, develop and deploy priority controls for public transportation in the city of Boston is discussed. In the subsequent paragraphs each of the actors' mission, objectives and goals are briefly described as well as their funding characteristics.

Department of Transportation

The United States Department of Transportation (DOT) is the highest-ranking authority regulating mass transportation, setting the Federal transportation policies, working with State, Local and the private sector.

Mission, Objectives and Goals

The mission of this stakeholder is;

"The National objectives of general welfare, economic growth and stability, and the security of the United States require the development of transportation policies and programs that contribute to providing fast, efficient, and convenient transportation at the lowest cost consistent with those and other National objectives, including the efficient use and conservation of the resources of the United States" [www28].

The DOT recognizes the necessity for a transportation system that would be accessible to all members of society. Form this perspective and the reliance into creating a transportation system to serve all members of society the focus over the last decades has been primarily on highways and car transportation. It has encouraged and developed plans, policies and programs towards other modes. The encouragement towards other modes includes a magnetic levitation system as mentioned in the SAFETEA-LU in order to achieve its objectives.

As described by the DOT its goals are [www28];

- Safety; Enhance public health and safety by working toward the elimination of transportation-related deaths and injuries
- Mobility; Advance accessible, efficient, intermodal transportation for the movement of people and goods
- Global connectivity; Facilitate a more efficient domestic and global transportation system that enables economic growth and development, concerns the efficiency of transportation, an important part of our competitive edge in global trade
- Environment; Promote transportation solutions that enhance communities and protect the natural and built environment

- Security; Balance homeland and national security transportation requirements with the mobility needs of the Nation for personal travel and commerce

These goals inline with its mission and in order to achieve them have resulted in a number of programs, of interest, that procure and provide a source of funding to public transportation projects. Some of these programs are described hereafter.

Characteristics

The Federal Intelligent Transportation Systems Program is a DOT program, based on vehicles and infrastructure intelligent principle to create an intelligent transportation system. As stated by the program the investments will be directed at targets of opportunity - major initiatives - that have the potential for significant payoff in improving safety, mobility and productivity.[www28] In relation to the goals of the DOT this program falls into a preferred mode in terms of the preferred strategies for Intelligent Transportation Systems (ITS). The majority of ITS systems in effect in the USA can be seen in major highways and interstates and other transport modes (e.g. trains), with little application on public transport. ITS Deployment Statistics in a 2006 Survey to different Metropolitan Areas published a National Summary covering several ITS subjects. It reported that at a country level only 2% of surveyed intersections operate with TSP

Research and Innovative Technology Administration (RITA) [www29], coordinates the USA Department of Transportation's (DOT) research programs and is charged with advancing the deployment of cross-cutting technologies to improve the transportation system, also provides strategic direction and oversight of DOT's Intelligent Transportation Systems Program. This agency recognizes the use of ITS and Transit Signal Priority (TSP) and BRT, under arterial management systems, which include other technologies as well. There is a recognition, intention, interest and knowledge towards the use and application of this technology. Throughout different publications, integrating different sources of information, the knowledge is made available. However, it is not clear how this administrative agency procures this knowledge towards decision-makers. The information available shows and references several practices and their results. Such cases and practices are; the benefit with a low cost margin (compared to other strategies) in USA cities as well as other countries in cities like Eindhoven in the Netherlands [www30] providing the work of Furth and Muller for example.

Federal Highway Administration

The Federal Highway Administration (FHWA) is a division under jurisdiction of the Department of Transportation (DOT) specializing in highway transportation. This agency performs research in the areas of vehicle safety, congestion, highway materials and construction methods. It functions throughout the USA with a representative office in each state, State DOT's. In Massachusetts the state DOT is Massachusetts Highway Department described in paragraph 0.

Mission, Objectives and Goals

The FHWA follows the same mission of the DOT as it is a subdivision of the DOT. However, the goals are defined focusing on highways as described here below [www22];

- Safety; continually improve highway safety.
- Mobility and Productivity; preserve, improve, and expand the Nation's highway transportation system while, at the same time, enhancing the operation of the existing highway system and intermodal connectors.
- Global Connectivity; promote and facilitate a more efficient domestic and global transportation system that enables economic growth.
- Environment - Protect and enhance the natural environment and communities affected by highway transportation.
- National Homeland Security - Improve highway security and support national defense mobility.

Characteristics

The FHWA has a direct relation to public transportation. As the vehicle is the preferred mode of transportation in the USA this agency has a strong influence over public transportation. Several sources of funding, programs and publications that lead to public transportation are administered through the FHWA. A conflict is encountered here, as the agency would procure its goals (towards highway development) with a hindrance over public transportation towards creating a modal shift. It is not possible to quantify and know the limitations this has over public transportation.

One of the priorities of this agency is congestion mitigation. In order to achieve congestion mitigation, the agency should procure priority control strategies as they reduce travel costs for public transportation, reducing also private vehicle costs, as there is less congestion as shown by Mordridge (1997) [7]. Increasing the reliability creates a modal shift and accessibility of the public transportation system in urban areas as described in previous chapters.

Within the information available by the FHWA, the agency published in 2005, an updated version of the "Traffic Control Systems Handbook" [42], which provides an extensive description of traffic control system technology, street traffic management, and traffic control systems. This publication is highly intended for vehicles and intersections, acknowledging the use of priority strategies (TSP and BRT) for public transportation.

Funding Characteristics

A primary source of funding for this agency comes from gasoline tax. As the cost of fuel tends to increase, a modal shift might occur. However, the modal shift might also hindrance development of public transportation as the FHWA funds projects where the funds provided come from fuel tax. A recurrent conflict for pubic transportation projects, aside from other reasons that jeopardize funding from this agency towards public transportation projects. The majority of funds for public transportation projects come from the Mass Transit Account of the Highway Trust Fund.

Federal Transit Administration

The Federal Transit Administration (FTA) provides leadership, technical assistance, and financial resources for safe, technologically advanced public transportation that enhances mobility and accessibility, improves America's communities, preserves the natural environment, advances economic growth, and ensures that transit systems are prepared to function during and after criminal or terrorist attack [www31]. The FTA is under jurisdiction of the Department of Transportation (DOT), functioning with a headquarter office and 10 regional offices throughout the country; region 1 includes the State of Massachusetts.

Mission, Objectives and Goals

The FTA follows the mission of the DOT as it an agency within the DOT jurisdiction. When it comes to the public purposes of public transportation the FTA states the following [www31];

"Transit serves many public purposes among the most important ones are: affordable mobility, congestion management, and supporting neighborhoods served by intensive transit services.

These objectives are not mutually exclusive and frequently overlap" [www31];

- Affordable Mobility; affordable mobility for all
- Congestion Management; Transit services that can compete effectively
- Supporting Transit Intensive Neighborhoods; Transit trips that help support household locations
- Economic Benefits of Transit; by economic yardsticks
- Transit System Usage and Characteristics; Five hundred fifty-six (556) local public transit operators provided transit services in 408 urbanized areas of over 50,000 population. An additional 1,215 organizations provided transit services in non-urbanized (rural) areas and 3,673 organizations provided specialized services to the elderly and to people with disabilities. Over 9 billion trips representing 46 billion passenger miles of transit services were provided in 2001.
- Transit Finance; Almost all-public transit systems need financial assistance.

These purposes recognize the need, advantages and importance of public transportation. Nevertheless, in terms of mobility the FTA regards the use of transit to people how cannot or do not want to drive and to people of low income as well as others. Among other misconceptions towards public transportation discussed previously, this perception is common in the USA

Characteristics

The FTA is legislated by the Federal Transit laws codified in the U.S. Code title 49: Transportation, chapter 53 [www31] and by the SAFETEA-LU which amends the Federal Transit laws.

Since the late 1970s through different programs and studies, the FTA has reported the benefits, advantages and the need of priority strategies for public transportation. For the FTA, the bus and rail vehicles are regarded as the most common mode of public transportation. For this agency congestion mitigation thru increased reliability is regarded as an advantage and a necessity for this mode to develop efficient services to compete with the vehicle. It recognizes the environmental, air quality and emissions reduction, benefits that result from public transportation systems.

Funded by the DOT, in May 2005 the handbook; "Transit Signal Priority: A Planning and Implementation Handbook," was published [12]. A quite complete handbook acknowledging the objectives of Transit Signal Priority and its benefits as well as design, implementation, maintenance and technical approach describes the steps to follow in order to implement a successful TSP. The handbook provides transportation authorities and decision makers the approach towards implementation of a priority control for public transportation projects. This could be regarded as "the beginning" towards a push for transit priority by the federal government. Other programs, plans and publications are being developed towards providing the guidance and information to develop and deploy priority strategies for public transportation.

Funding Characteristics

The DOT through this agency provides the funding to develop new transit systems, maintain and operate existing systems. The FTA through its regional offices to State and local public transportation providers grants funds. They are responsible for managing their programs in accordance with Federal requirements. To fulfill all of the funding opportunities one of the areas that need attention to increase reliability and provide a better service is the fare box collection. This is a problem not only in this country but in others as well. There is a persistent need for funding from several levels and instances to afford this mode.

Executive Office of Transportation

This stakeholder, Executive Office of Transportation (EOT), is considered as the Massachusetts State Department of Transportation (State Secretary of Transportation). It is the highest-ranking actor in the State of Massachusetts and the Massachusetts Office for Commonwealth in charge of managing the development of the majority of transportation. The agency sets the policies and coordinates the transportation work of the various State departments, commissions and authorities. It is an umbrella for all actors involved with transportation for the State of Massachusetts. The agencies part of the Massachusetts State government agencies under the EOT are; Massachusetts Highway Department (Mass Highway), the Massachusetts Bay Transportation Authority, Massachusetts Aeronautical Commission, the Registry of Motor Vehicles, Massachusetts Turnpike Authority (MassPike), and other regional transportation authorities. The Department of Recreation and Conservation, and Massachusetts Port Authority are not within the EOT.

Mission, Objectives and Goals

The mission and purpose of the EOT is to;

"To promote economic vitality and a better quality of life by safely and efficiently moving people and goods within and through the Commonwealth" [www32]

Its goals are [www32];

- Developing, coordinating, administering and managing transportation policies, planning and programs related to design, construction, maintenance, operations and financing;
- Supervising and managing the organization and conduct of the business affairs of the departments, agencies, commissions, offices, boards, divisions, and other entities within the executive office to improve administrative efficiency and program effectiveness and to preserve fiscal resources;
- Developing and implementing effective policies and programs to assure the coordination and quality of roadway, transit, airport and port infrastructure and security provided by the secretary and all of the departments, agencies, commissions, offices, boards, divisions, authorities and other entities within the executive office.

Characteristics

The Transit Unit Staff, an internal office within the EOT, oversees the 15 regional Transit Authorities in the State of Massachusetts. This staff unit receives capital funds from the FTA as well as other State sources. Assisting the State Secretary of Transportation in the development of policies, programs and projects intended to improve transit operations and services and to provide an environment that encourages economic growth and alleviates congestion, minimizing the impacts of construction projects on traffic patterns [www32].

As priority control and traffic signal priority are considered Intelligent Transportation Systems (ITS) solutions to include the priority strategy into projects of transportation most comply with the Boston Metropolitan ITS architecture [www32]. The EOT has published an ITS final report for the area of Boston [43] acknowledging priority strategies for public transportation. The report considers the existing priority control at the Silver Line as well as it describes a more general perspective towards transit priority for buses throughout the Commonwealth and the Boston area. One of the strongest recommendations is; "near-term" multi-agency initiatives are for traffic signal priority on MBTA buses, pushed by extending the existing priority control to other routes [43]. Recognizes the conflicts generated by different agencies involved and the definitions of different packages interfering with issues such as priority for buses. Coordination between agencies is necessary and a cooperative agreement must exist as different stakeholders manage and administer the information, roads, equipment and others.

Towards priority strategies and their deployment in the State of Massachusetts, the report might be an advantage and the tool to the initiate further priority strategies for public transportation. However, this report as well as other information (as previously discussed) needs to reach the decision-making actors in order to have an effect towards transit projects.

Funding Characteristics

According to the State's State Transportation Improvement Plan (STIP), from different funding sources, for the year 2008 throughout the State, for public transportation over $45 million USD are provided. Over $28 million are non-federal funds will be spent in different projects, must for bus capital and enhancements. In comparison with projects for roadway, bridge and intermodal projects, funds reach almost one billion ($992,884,287) [44] shows an enormous discrepancy and preference between modes.

Massachusetts Highway Department

Under the jurisdiction of the Executive Office of Transportation, as discussed previously, the Massachusetts Highway Department (Mass Highway) is the Department of Transportation (DOT) for the State of Massachusetts. This agency is responsible for the design, construction and maintenance of all State highways, bridges and signage of numbered routes. Organized in five District offices, each district office supervises all construction within its jurisdiction; performs on-site engineering; implements maintenance and preventive maintenance programs; generates proposals for maintenance and construction work; and provides engineering support to cities and towns [www33].

Mission, Objectives and Goals

As this stakeholder is the Federal entity at State level of the FHWA, the objectives are assumed the same, as there is no available information of objectives and mission of Mass Highway. As discussed previously, this agency has a direct relation to public transportation projects as they are realized by funds provided by this agency.

Characteristics

In the State of Massachusetts, Mass Highway, owns and administers the bridges and some of the routes (aside from highways, municipal roadways and or rural roadways) throughout the State and in particular the city of Boston. Mass Highway focuses on highway maintenance, congestion impact and mitigation, bridges and safety through different Federal and State programs and plans. In addition, the agency publishes different manuals related to highways and bridges in design and maintenance. The bridges are considered as one of the most important assets of the agency. For this reason, it is important to consider the guidelines specifying the design, re-designing, markings and traffic signals over the bridge or at roadways, in particular for the Harvard Bridge, following the Bridge Manual, the Massachusetts Highway Department Project Development and Design Guide and the Manual for Uniform Traffic Control Devices, Federal and amended for the State [www33]. In regard to the manuals and relation to the installation and operation of traffic signals (those owned by) the agency has developed several forms and permits. The development and design guidelines of the agency include the integration of public transportation when planning and designing efficient transportation systems. The procedure is closely followed by the agency, creating an impact over the capabilities to deploy TSP at traffic signals under the agencies jurisdiction.

Funding Characteristics

The programs under Mass Highway indirectly involve public transportation projects as funds might be provided by jurisdiction and or through innovative means. Funding for projects must qualify for one of the two organizational structures from Mass Highway either by managing design projects or construction contracts. Design projects originate from those projects classified as priorities by the Metropolitan Planning Organization, bridge or highway maintenance, other federal funding programs such as CMAQ and district requests. An example of this is the Silver Line, as previously discussed qualified for Mass Highway funds as a design status project.

Department of Recreation and Conservation

The Department of Recreation and Conservation (DRC) is under the Massachusetts Government, outside the Executive Office of Transportation (EOT) jurisdiction, being a steward of one of the largest state parks in the USA It is considered given the relationship with the “Hot Spot”.

Mission, Objectives and Goals;

The agency’s mission as stated is; *“To protect, promote and enhance our common wealth of natural, cultural and recreational resources”* [www34].

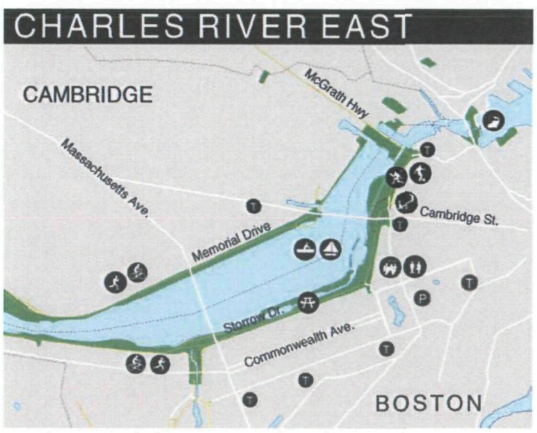
To fulfill its mission the agency focuses on the following;

- Improving outdoor recreational opportunities and natural resource conservation;
- Restoring and improving our facilities;
- Expanding public involvement in carrying out DRC's mission; and
- Establishing first-rate management systems and practices.

Characteristics

The organizational structure of the agency is conformed by four divisions. The planning and engineering division is in charge of planning, engineering, design and construction management services. This division pays close attention to intersections and traffic control signals within its jurisdiction.

The Harvard Bridge provides a crossing within the Charles River reservation, a park reservation between the cities of Boston and Cambridge under the jurisdiction of this agency. The intersection of Memorial Drive and Mass Ave is under the jurisdiction of the DRC. For this reason this agency is considered within the actor analysis.



Appendix Figure II: Charles River Reservation
Source: www34

Metropolitan Planning Organization

The Metropolitan Planning Organization (MPO) is a regional agency established to carryout federal funded transportation plans and programs throughout its regions. Subdivided in 13 regions, the region for the city of Boston includes 101 cities and towns being home to over three million people [www35]. Appendix Figure III shows a map of the 101 cities and towns subdivided in this region. The MPO collectively carries out the continuing, comprehensive and cooperative transportation planning process for the region. The city of Boston, the Federal Transit Administration (FTA) and Federal Highway Administration (FHWA), the Executive Office of Transportation (EOT), the Massachusetts Bay Transportation Authority (MBTA), Massachusetts Highway Department and among others like the city of Salem, Everett, Newton, and other agencies and towns are its primary stakeholders.

Appendix Figure III: MPO map city jurisdiction

Source: www36

Mission, Objectives and Goals;

As a mission for this agency given through a framework for regional transportation planning in the Boston area establishing the following [www36];

- Work together on the federally required transportation planning process;
- Establish a Joint Regional Transportation Committee (now known as the Regional Transportation Advisory Council) to ensure citizen participation in regional transportation planning;
- Work together to ensure compliance with federally mandated planning documents and;
- Establish a joint technical staff to support decision-making.

Described in the Regional Transportation Plan, the objectives and policies of the MPO are the basis to accomplish the MPO's vision of the region. The policies and objectives are [www20];

- System preservation;
- Modernization and efficiency;
- Mobility;
- Environment;
- Safety and security;

- Regional equity;
- Land use and;
- Economic development, public participation and finance.

The Boston Region Metropolitan Planning Organization is responsible for programming the spending of transportation funds and for conducting the regional transportation planning process through which it identifies and prioritizes the current and future transportation needs. In addition, it is responsible for conducting its work and decision-making as to equitably distribute the benefits and burdens of the transportation system, and utilize and conserve the available financial, infrastructure, natural and cultural resources in the most effective way possible [www36].

Characteristics

The Central Transportation Planning Staff (CTPS) carries out the unified work program of the MPO. It conducts comprehensive multimodal transportation planning and analysis for the MPO. The CTPS "provides the technical and policy-analysis support perceived as a mean to promote cooperation between agencies and consistency among planning efforts" [www36].

The CTPS performs work under four major categories;

- Travel modeling and forecasting;
- Transportation planning and analysis;
- Certification activities; and
- Data, maps, and graphics.

Following the vision of the MPO and the work of the CTPS, the 3C transportation planning process; a Continuing, Comprehensive transportation planning process carried out Cooperatively by states and local communities, [www36], is required to developed documents and programs in the State of Massachusetts. The documents and programs are of interest as they appoint the funding for public transportation projects. The programs are;

- The Regional Transportation Plan (RTP) [45],
- The Transportation Improvement Plan (TIP) and;
- The Unified Planning Work Program (describes transportation planning studies for a Federal FY).
- Other documents considered include the MBTA Program for Mass Transportation (PMT).

The Regional Transportation Plan (RTP) gathers information from other sources, which are developments of the agency such as; The Mobility Management System (monitors mobility in the region). Developed by the MPO, adopted in June 2007, the Regional Transportation Plan titled "Journey to 2030" [45] outlines the MPO's vision for the future in transportation in the region. The plan, developed by the CTPS every four years is the long-range, comprehensive transportation-planning document of the MPO. The program establishes policies and principles leading to achieve the MPO's vision and allocates project revenues to reflect the policies and principles. The plan and policies follow the principles stated in the SAFETEA-LU.

The RTP proposes a mobility requiring safe, reliable and convenient travel options where allocations of funds are focused towards improvements that can increase the system's mobility. This mobility should also reach those communities of low-income or without accessibility among other reasons to have an equitable transportation throughout the region. The environment, use of alternative fuels, reduce energy consumption, single vehicle occupancy and natural resource protection are highly recognized and addressed. The plan identifies the needs for improvements, accessibility and reliability of public transportation through the use of ITS, traffic signal coordination and traffic signal priority. The plan recognizes the use of traffic signal priority under mobility, as a beneficial strategy for public transportation projects. "Traffic signal prioritization for transit vehicles has the potential to improve the speed and reliability of the MBTA bus system while maximizing the number of people passing through an intersection." [45] The MPO describes projects for intersection and signal improvements, including: signal upgrades and realignments. It recognizes the benefits that result from coordinated traffic signals and relatively low cost investment to increase mobility and efficiency of the system but also help to preserve the transportation system. The results are the continuing funding resources that the MPO allocates to projects improving intersections and traffic signals The agency is currently studying the application of traffic signal priority for a bus route (bus route 39) in order to asses the benefits of such priority strategy. Traffic signal priority, as conditional strategy exists in the city of Boston throughout the Silver Line.

The system preservation, modernization and efficiency policy as stated in objective D, encourages and supports the planning and programming of projects that improve transportation primarily through the use of ITS, new technologies and or transportation system management. By modernizing transportation system elements with ITS, the MPO can improve operating efficiency without the physical expansion of facilities [www36]. In addition, it also refers to the U.S. DOT reported national benefits on ITS in regard to advanced traffic surveillance and signal control systems which results in decrease of travel time [45].

Despite the stated objective, still the use of technology is limited to; real-time travel information for passengers, system monitoring provided incident response (regarded as one of the most important uses of ITS) and electronic use of payment at tolls and fare box collection for public transportation. The MPO objectives focused towards mobility, modernization and efficiency, safety and security and the environment and recognizing the use of technology for public transportation projects make it a key actor for a push in priority at a State and Regional level. This can also be accomplished through the Central Transportation Planning Staff.

Produced annually by federal mandate by the MPO the Transportation Improvement Program (TIP) [46] serves as a tool to monitor the Regional Transportation Plan (RTP). The TIP describes the projects expected for implementation for the next four years. The TIP contains a financial plan, current or proposed, for each project programmed to receive federal funding (for highway and transit projects) and state funding (for highways) over the four-year period [www36]. The TIP for FY 2008, states several projects for highway and transit, where transit projects are apportioned a small amount compared to highway projects. From the list of transit projects for FY 2008 none deal with priority strategies, TSP and or BRT.

The CTPS produces the MBTA Program for Mass Transportation (PMT) a long-range 25-year capital planning document defining the authority's vision for public transportation in Massachusetts. Its objective is to identify and prioritize projects that will result in a cost-effective public transportation system.

Metropolitan Area Planning Council

The regional planning agency that represents the 101 cities and towns in the metropolitan Boston area is the Metropolitan Area Planning Council (MAPC) [www35]. It serves as an independent public agency of the Commonwealth. State and local officials address issues of the region. A member of the MPO with oversight responsibility for the Region it is federally funded.

This agency is quite relevant to consider as it involves land use and other aspects of planning to the transportation needs of the area. As it encompasses different issues that surround transportation, the former might orient its planning and design of transportation projects with a focus not towards mobility and transportation needs but towards suitable and reliable possibilities.

Mission, Objectives and Goals

Throughout its council membership, provides the technical assistance to improve environmental, social and economic health through services that include transportation to the 101 cities and towns.

When dealing with transportation projects, the agency recognizes the need for mobility, the impacts transportation has on environment, social and economic matters and the necessity to continue with careful allocation of funds to roads, bridges and public transportation. The latter is critical to the long-term success of the Region. The support to transportation planning is done for the following services; air quality and transportation, transportation funding needs, transportation alternatives, funding opportunities, and planning support to the MPO.

Characteristics

The organizational structure of the MAPC provides transportation alternatives services. These refer to the work the agency provides in conjunction with the CTPS. The work the two agencies perform is towards technical and research support for different Transportation Demand Management (TDM) services and for transit in under-served areas. The transportation alternatives have a strong focus towards pedestrian and bicycle transportation modes.

The MAPC develops the Regional Plan for Metropolitan Boston area, where in 2002 the agency published an update of the previous plan titled: "MetroFuture: Making a Greater Boston Region" [47]. This plan is an approach to address the challenges and opportunities for the future. Regarding the future of transportation, it identifies an increase for the need of public transportation is to happen and alternatives should be provided. The plan outlines the following goals [47];

- Increase the percentage of trips made by public transportation;
- Use of funds other than for highway expansions;
- Eliminate deficit and add new revenues to pay for the transportation system and;
- A revenue stream for transportation that is reliable.

The goal increase on trips made by public transportation does not specify how this will be met nor does it specify which modes will be the preferred towards development. It is assumed from the different projects mentioned that heavy rail might be the preferred mode as it forecasts a future growth in suburban areas, where buses (local and feeders) would have to serve commuter rail stations. This also brings a development of bus routes not only in the inner core (Boston city area) but also in other areas where growth is forecasted. The need for new transit services and the need for alternatives to cars-based trips provide a future vision of public transportation development. BRT and TSP or any other priority strategy could see an opportunity for development. However, the plan does not discuss how these or if any other priority strategies might be developed.

The agency is involved towards planning transportation matters in the region with a primary focus on economic, environmental and social issues, if the MAPC is seen as a stand alone agency. However it works in conjunction with the CTPS and the MPO, where all together provide the necessary scope to address the transportation issues of the State, Region and Boston area.

For transit in under-served areas the MAPC Creating Transit Friendly Communities, Draft, [48] provides a checklist of criteria to analyze the accessibility of transit in a community or area. Recognizes that an area served by transit is more livable and the need for transit within an area for its development.

Funding Characteristics

As to transportation funding needs, a report titled "Work Undone Report" [49] in partnership with the Massachusetts Association of Regional Governments describes the unfunded or under-funded projects for mobility, economic needs, connectivity and promotion of the public policy goals that would maintain, improve and expand the transportation infrastructure. The report only describes one project that includes BRT as a priority strategy. All others projects are focused on cars or railroad modes.

The MAPC funding opportunities service coordinates and implements different funding programs. There are seven different programs;

- Enhancements Program; Federal funding for TE only those eligible according to criteria. Priority and TSP are not eligible.
- Transportation Demand Management; programs that provide incentives for alternative ways of commuting primarily for businesses
- Suburban Mobility Program; funds used under CMAQ program
- Transportation Improvement Program (TIP); managed by the MPO, lists the transportation projects that will receive Federal funds and highway federal funds as well as State funds
- Massachusetts State Trail and Greenway Programs; DCR recreational trails program and greenway corridors and grants
- Scenic Byways; provides funds from the Federal Highway Administration program for communities to preserve and enhance corridor of roads having unique and regional qualities
- Safe Routes to School Program; healthier alternatives to go to school

The suburban mobility program provides funding resources for bus projects through the CMAQ program. This program has been previously discussed.

City of Boston

This actor is represented by the Boston Transportation Department (BTD) managing transportation within city limits. The city BTD jurisdiction of street elements, services and responsibilities extends to traffic signals and pedestrian signals, signs (regulatory and directional), roadway lane markings, parking meters and crosswalks.

The jurisdictional and ownership conflict arises for this actor as the agency manages the transportation in the city and owns some of the streets; traffic signals, parking lanes and spaces as well as determining the possible locations for bus stops (not interfere or reduce parking spaces).

Only the city of Boston is regarded although the "Hot Spot" consider a intersection in Cambridge. This city is not considered as the intersection mentioned previously is under jurisdiction of the DRC. However, it is worth mentioning that the city of Cambridge has undertaken different strategies to improve mobility in this city (not addressed in this research).

Mission, Objectives and Goals

The BTD is a department within the Streets, Transportation and Sanitation cabinet of the city. Its mission is to;

"*Promote public safety, manage the city's transportation network, and enhance the quality of life for residents of our city neighborhoods. Accomplishment of our mission is ensured through the use of planning coordinated engineering, education and enforcement*" [www27].

Characteristics

The policies for transportation within the city of Boston are contained in the city of Boston Municipal Code [www37]. This code primarily derives from the General Laws of Massachusetts as well as it refers to some of the policy provisions of these laws. This code sets the "carrots and sticks" regarding transportation issues, such as parking, use of vehicles, violations and licenses among others. As a result, the Municipal Code does not describe any related policies to this investigation. However, the BTD has developed several guidelines and a plan for the city.

Access Boston 2000 – 2010 is Boston's Citywide Transportation Plan [www37], developed by the BTD. Through a one-year long workshop series throughout dialogue with the public, issues were identified to develop this plan. It deals with the various modes of transportation in the city. The initiative "doing while planning" provides the approach on implementation during the process. The report resulted in a multi-report effort, prioritizes programs and projects for the short term and develops strategies for the coming decade. However, there is no former report available and the series of available reports (results from the workshops) do not deal with projects or intentions for public transportation including priority strategies.

The BTD plays a key role in the transportation planning of the city and the Region, as it is a permanent member of the Board of the MPO and the MBTA. There is a certain degree of complexity within this stakeholder and the investigation. Meaning the following; it does own the roads (not limited to all of them) and traffic signals as well as bus stops, participates in the creation of public transportation Plans and Programs having an important role over the decision making process.

The guidelines towards traffic rules and regulations and, traffic signals (different sections) are of interest. The city of Boston provides a Traffic Signal Standard Plan and Specifications where it deals with the current standards. None of them mention or state priority strategies for traffic signals. These standards are guidance towards installation, construction and maintenance of traffic signs in the city and owned by the BTD. The Traffic Rules and Regulations for the City of Boston, in Article III describe traffic signs, signals, markings, and devices. This policy only sets the limits towards display, interference, obedience, and time of traffic signs and exemptions of signs, signals, markings and devices.

The BTD, published the Streetscape Guidelines for Boston's Major Roads [36] in July 1999, second edition (latest edition). Containing the guidelines for construction and or reconstruction of the major roads the plan's purpose is to create a co-existence of the different modes and provide an equitable share of the public right-of-way to develop balanced and efficient transportation systems. Roadway design deals with designing the road for vehicles, bikes and transit with goals such as; optimize roadway width to justly accommodate all users, where possible separate the modes of travel by dedicated lanes. The guidelines recommend the use of bus lanes in the road design, limited by "where space is available, and should be considered on high-frequency routes" [36], acknowledging that this benefits public transportation. The guidelines specify different design patterns that throughout the city are limited. Even in some cases, the design guidelines come into conflict between modes, e.g. parking and bus stops. The city, known as a walking city has made efforts to design sidewalks and pedestrian needs. The guidelines pay close attention to this, as it is a city policy to maintain the "walking city" designation. Chapter IV of the streetscape guidelines for traffic signals states that the traffic signals design should be for a "LOS (Level of Service) "D" or higher for motor- vehicles during peak hours and a V/C (volume over capacity) ratio not to exceed 0.85 for each approach" [36]. For bicycles, if an exclusive lane exists, separated signals and phasing should be considered. Throughout the city, there are a few dedicated bike lanes, but a separate bike signal has not been seen (until date) providing cyclist with their own signal phase. Although the guidelines specify equitability of modes through the public right-of-way, the car is the preferred mode. The guidelines require a review in order to accomplish the goals and mission of the department. A tendering to update to streetscape guidelines was issued by the city to develop new street guidelines accommodating equally all modes of travel including the integration of "green" technologies.

Nevertheless, the guidelines set the policies for the city roads and these will be followed to develop scenarios to simulate different priority strategies at the "Hot Spot", paragraph 6.2.

City Groups and Organizations

In Boston and other cities within the Region, different city groups and organizations have a stake in relation with transportation matters in the city. They represent different communities with diverse ideals and opinions from the people and to the people. By Federal mandate, these and any other citizen is able to participate in decisions, planning, design and development of projects. Every time a project is for review, the interested stakeholder organizes meetings, workshops and or other kind of reunions to inform the public about the project. These become information sessions to discuss matters related with the project. The interests of these organizations lay on intending their mission and goals as well as the overall well being of the citizens they represent. In addition, they review that the government agencies involved adhere to the standards of the project and intended results.

As these organizations participate in the decision-making for a project, as well as to a policy or other issues regarding transportation their input and influence is quite valuable. As an example, of a city group or organization, the organization walk Boston is considered. This organization is a non-profit organization dedicated to improve the walking conditions of the cities and towns of the State. Their goal is "to make walking and pedestrian needs a basic part of the transportation discussion" [www38]. Considering of such organization towards public transportation projects like TSP might have a double effect. These organizations can help to achieve a priority as long as there the project follows their views and improvements would assist the organization to meet their goal, a positive effect. On the other side, a negative effect, a veto from this organization could not make the project realizable. It is due to their influence in the process of decision-making that they have to be included as part of the stakeholders.

Massachusetts Bay Transportation Authority

The Massachusetts Bay Transportation Authority, MBTA [www1], is the principal actor as it is the agency responsible for public transportation in the Boston region and the problem owner. It is a regional transit agency, owned and controlled at the State level.

Mission, Objectives and Goals

The MBTA is under the leadership of a General Manager and governed by the Board of Directors chaired by the Secretary of the Executive Office of Transportation (EOT).

The MBTA mission is;

"*The MBTA is a dedicated "world class" transit system built upon customer service excellence, accessibility, reliability, state-of-the-art technology, and a diverse workforce that reflects our commitment to the communities we serve*" [33]

The goals of the MBTA, as described are [33];

- MBTA Service: To provide clean, safe, and reliable public transportation, accessible to everyone, and a clean and safe environment for employees
- MBTA Infrastructure: To modernize the system through an aggressive State of Good Repair program while investing in cost-effective expansion projects to increase our customer base
- MBTA Financial Condition: To provide affordable transit for the public toward reducing the burden to taxpayers through efficient operations, innovative fare policies, and the generation of non-fare revenues, while simultaneously supporting a balanced capital program of modernization and expansion through strong project and grant management
- MBTA Employee Development: To recruit, train, and retain a highly professional, diverse, and committed workforce capable of improving the system in an efficient and cost-effective manner
- MBTA Communication: To develop direct, effective communication techniques that inform our customers, obtain valuable feedback, and develop goodwill for the organization

Characteristics

The MBTA legislative mandate is specified in the Massachusetts General Laws (M.G.L.) under Chapter 161A [www26] and its sections setting the legislative powers, jurisdictions, purposes and limitations of activities and provisions of public transportation services to meet the Region's transportation needs.

Within the MBTA policies, the Service Delivery Policy, the Environmental Management Policy and the Fare Policy are among the most important policies in order to accomplish the mission and goals of the authority. The Capital Investment Program and the Program for Mass Transportation describe the investments and funding needed for current and future projects as well as the current and future trends in public transportation.

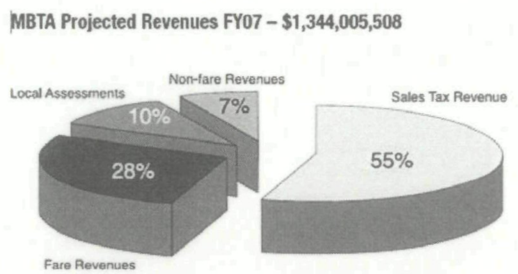
The Service Delivery Policy [33] and Chapter 161A of the M.G.L define the service quality standards and objectives to establish the effectiveness and quality of all modes of public transportation service based on measurements of; (a) comfort, (b) communication, (c) convenience, (d) rider satisfaction, (e) reliability, (f) security, and (g) environmental benefit [www26]. Within its services, the policy addresses fixed guide way services, the bus, describing key bus routes (some operate in dedicated r-o-w as BRT). However, these only operate for longer hours and in areas of high demand providing higher frequencies for corridors of high-density. Incorporating BRT acknowledges the benefits complying with the policy objectives setting the initial steps towards servicing other corridors with this strategy. Bus route number one is described as a key bus route (does not operate in its own r-o-w) among others in the system that fit the criteria for such a distinction. Neither this criteria nor the policy recognize the need for priority of this key route or the others. A criterion is to operate as BRT along a corridor. Defining or describing the characteristics of operation as BRT is for segments operated in dedicated r-o-w, not specifying any other priority or distinguished measure of BRT. The use of rapid transit and BRT from the MBTA is towards the subway lines (the former term) and the silver line, which falls under both terms, rapid transit for the schedules and BRT for the Service Delivery Policy.

The Environmental Management Policy strives, different guidelines, for public transportation of "world-class" as environmentally friendly as possible. Emissions control and use of strategies for improvements are included. The policy does not include or discuss any further the strategies to follow as guidelines.

Funding characteristics

The MBTA collects its own funds for its budget, which is a State legislation mandate. The MBTA is a self-sustained independent Authority responsible for balancing its budget. This mandate, in act since 2000, called "forward funding." There are four main sources; 20% of State's sales tax receipts, defined assessments on localities served by the MBTA, fare box collection and non-fare revenue (advertising for example) [www1].

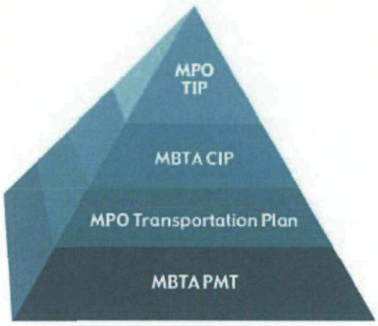
The picture below shows the percentage of funding from these sources for FY 2007.



Appendix Figure IV: Funding sources for the MBTA, projected Revenues
Source: www1

For project funding the MBTA, sources are; the Federal level FTA and the State EOT. Other sources might provide funding for projects but this is dependent on the project characteristics and criteria to provide funds from different agencies. As discussed previously projects that qualify as design status, toward improving mobility or environmentally friendly qualify for different sources of funding, provided by actors such as Mass Highway or CMAQ programs. The FY2008 revenue from all sources projects an increase of 5.1% to $1.413 billion USD [48]. This revenue is supplied from the major sources, which are; operating revenue, non-operating revenue and revenue from dedicated sources. Although there is an increase in revenue, this does not put aside the deficit and financial struggle of the MBTA. The fare increase of 2006, restructuration of fares, programs and the four main sources of funding have helped to narrow that gap. However, the MBTA has a debt service of nearly $5.2 billion USD [www1].

The Program for Mass Transportation (PMT) is the MBTA's long-range capital planning defining the vision for the next 25-years for public transportation in the Region [3]. By legislative mandate, this program is updated every five years and the policies and priorities outlined are implemented through the CIP. This program (report), defines the universe of projects to be included in the MPO's RTP and TIP. These projects receive if eligible federal funding. A diagram providing the relationship of the PMT to other plans is given below.



Appendix Figure V: Relationship between public transportation programs.
Source; www36

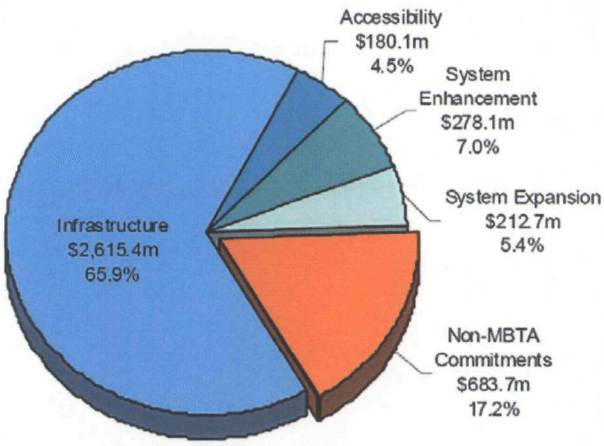
The PMT primarily focuses on potential public transportation expansion projects, prioritizing infrastructure investments. Due to several factors, primarily the Central Artery project and the MBTA budget deficit, the PMT of 2008 focus is on system preservation projects. The PMT 2008 has defined two goals to meet the 25-year vision of public transportation; 1) those that deal with the planning process, and 2) those that state the outcomes that are necessary to fulfill the vision. The objectives identify actions that must be taken to achieve the goals [www35]. Projects regarded, as high priorities for rapid transit are the Silver Line phase III and the Urban Ring phase 2 and 3. Other projects are given a priority ranking, none of them BRT or focus on priority. The PMT includes a financial unconstrained analysis of the projects, which includes more projects than what the MBTA or the State can fund. This calls for innovative ways of sources for funding, given by the complexity of legislative procedures and the financial situation of the area after the Central Artery project.

The PMT considers technology and ITS applications important for the provision of public transportation. The integration that the MBTA has made towards these applications is done in several ways, e.g. fare collection box and AVL. However, none of the applications deals with priority strategies for public transportation. Although recognition of technology and or ITS applications there is a strong focus towards the use of this technology for passenger travel information, adherence to schedule and information provision. The plan specifies different signal improvements; some regarded as high-priority projects, but only for the subway lines.

The Capital Investment Plan (CIP) revised yearly, is a guide to the five-year capital budget. It authorizes funds for projects that will meet the MBTA's operational objectives within its financial capabilities. This plan is financially constrained, unlike the PMT and others, including only capital projects affordable by the MBTA. The CIP FY 2008 – 2013 authorizes approximately $3.9 billion in capital [6] for capital projects reinvesting in transportation infrastructure and expansion projects. The capital program is funded by Federal grants, Non-Federal (revenue bonds, pay-as-you-go capital and State funds) and alternative financing (project financing grant anticipation notes). Funds from the Federal level, SAFETEA-LU, are a major contributor and component for the capital improvement program to implement transportation projects. Reinvestment in the existing infrastructure, accessibility improvements, enhancement to existing services and system expansion efforts are the four major programmatic areas of the CIP. The chart Appendix Figure VI provides the amount and percentage considered for these areas form the $3.9 billion USD authorized.

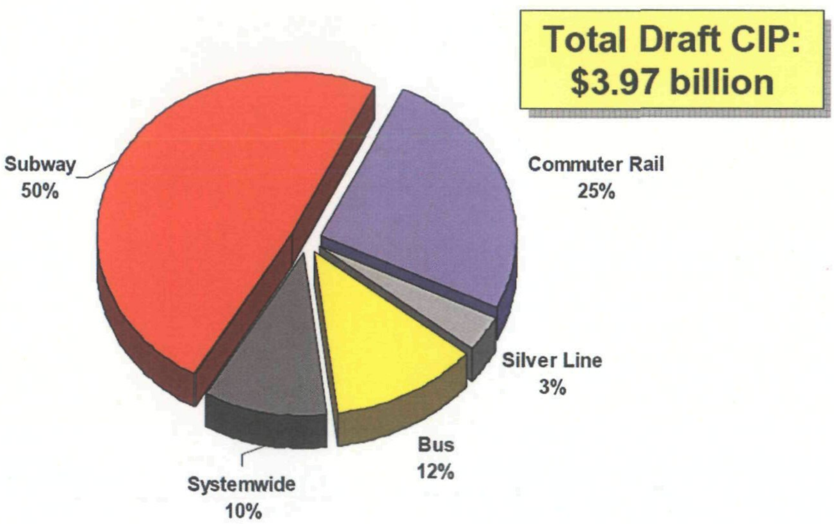
Infrastructure has the highest percentage of authorized funds, a major conflict for the authority due to extend infrastructure resulting in major capital needs. The chart Appendix Figure VII shows the investments for FY2008 per mode.

Besides phase III of the Silver Line, projects authorized for the next five years do not include any other strategy of BRT or priority for public transportation. However, under the system enhancement – bus – funded projects, "this effort supports the conceptual development of bus rapid transit system wide" [6].



Appendix Figure VI: Amounts and percentages authorized for the Capital Improvement Plan

Source: www1



Appendix Figure VII: Investment for FY2008 per mode

Source: www1

Appendix D - State-of-the-art cases in Europe, Asia and The Americas

An overview of state-of-the-art cases in the United States of America has been provided in paragraph 3.2. In this appendix cases from Europe, Asia and the Americas are depicted. Each of the cases, where information was available, presents the characteristics, priority control, benefits, future plans and conflicts encountered to achieve the project. The information provided has been adapted from several sources: The Transit Signal Priority (TSP): A Planning and Implementation Handbook [12], report published by the TCRP in 2003 BRT Case Studies [11], The Bus Rapid Transport Policy Center Database [www20] and literature review from different journals with information ranging from 2001 to 2007.

	Amsterdam, The Netherlands
Number of Corridors	One - Zuidtangent
Length (miles)	15.5
Total Costs (EUR)	€270 million Euros
Funding	
Number of Stations	23
Year First Opened	Construction 1994, service opened 2002
Congestion Protection Strategy	Mixed Traffic and Dedicated Bus Lanes
ITS	Yes
AVL	
Passenger Information announcements	Yes
Real-Time Info at Stations	No, plans delayed
Traffic Signal Priority	Absolute r-o-w at traffic lights
Bus Type	Articulated
Bus Propulsion	Diesel
Level Boarding	Yes
Number of Doors	3
Fare Collection (Pre-Payment)	Yes
Estimated Ridership (weekday bus riders)	27,500
Reported Travel Time Savings (min)	
Capacity Comparison / Increase % / Modal Shift	In 2002 there were 4-5 million passengers/year. 7-8 million passengers/year are expected by 2007.
Headway Peak hour	7 minutes
Future Plans	Southern branch will be operational by 2006. Construction of the East and West side extensions will be completed in 2008. ITS features, which have been delayed, will also be implemented.

	Eindhoven, The Netherlands
Number of Corridors	- Phileas
Length (miles)	9.3
Total Costs (USD)	
Funding	Federal, The Ministry of Transport and Public Works, The Ministry of Economic Affairs, The Ministry of Housing, Regional Development and the Environment. State, Province of North-Brabant. Local, Municipality of Eindhoven and Veldhoven. Other, Hermesgroep NV, APTS, Stimulus (EG), FOCUS (EG), SRE.
Number of Stations	Several
Year First Opened	
Congestion Protection Strategy	Dedicated bus lanes, electronic guidance
ITS use?	Yes
AVL	Yes
Pax Information announcements	Yes
Real-Time Info at Stations	Yes
Traffic Signal Priority	Guidance system allows to adhere to schedule
Bus Type	Articulated, Bi-articulated
Bus Propulsion	Hybrid Electric Diesel
Level Boarding	No
Number of Doors	3
Fare Collection (Pre-Payment)	Yes
Estimated Ridership (weekday bus riders)	
Reported Travel Time Savings (min)	
Capacity Comparison / Increase % / Modal Shift	
Headway Peak hour	10 minutes
Future Plans	

	Vancouver, BC, Canada
Number of Corridors	Two - Broadway and Richmond "B" Lines
Length (miles)	24 miles three different B lines
Total Costs (CAD)	51.8 millions
Funding	Services are funded by fares and a number of dedicated taxes including an 11.5 cents/liter tax on gasoline that rises more than CAD$240 million per year for regional transportation services. Transit services on average recover 54% of operating costs.
Number of Stations	40 in total
Year First Opened	1996
Congestion Protection Strategy	Bus Lanes, Mixed Traffic
ITS	Yes
AVL	Yes
Passenger Information announcements	Yes
Real-Time Info at Stations	Yes
Traffic Signal Priority	Yes, only one line and TSP account for 0.5 to 1.5 minutes travel time savings
Bus Type	Articulated
Bus Propulsion	Diesel
Level Boarding	Yes
Number of Doors	3
Fare Collection (Pre-Payment)	No
Estimated Ridership (weekday bus riders)	60,000 in all three lines
Reported Travel Time Savings (min)	10
Capacity Comparison / Increase % / Modal Shift	8000 new riders when bus started, 20% previously motorists, 5% new trips and 75% diverted from other bus line
Headway Peak hour	4 to 6 minutes
Future Plans	All three routes are slated to be replaced with Skytrain, LRT, or dedicated bus ways. The agency is evaluating other corridors for B lines due to their success

Ottawa, Canada

Number of Corridors	- Transitway System
Length (miles)	37 miles
Total Costs (CAD)	435 millions
Funding	State, 75% of construction was funded by the Province of Ontario. Local, 25% of construction was funded by Region of Ottawa-Carleton.
Number of Stations	28
Year First Opened	Build in stages, 1978 to 1996, initial segment opened in 1983
Congestion Protection Strategy	Busway, Bus Lanes
ITS	Yes
Passenger Information announcements	Yes
Real-Time Info at Stations	Yes, selected stations
Traffic Signal Priority	
Bus Type	Articulated / Standard
Bus Propulsion	Diesel
Level Boarding	Yes
Number of Doors	2
Fare Collection (Pre-Payment)	Mixed
Estimated Ridership (weekday bus riders)	200,000
Reported Travel Time Savings (min)	-
Capacity Comparison / Increase % / Modal Shift	Ridership increase 25% over the past six years, Transit way ridership accounts for 12% of all daily trips and 16% of peak period trips.
Headway Peak hour	4 to 8 minutes
Future Plans	"Smart card" technology planned in the future. The Ottawa 2020 Transportation Master Plan includes plans for expansion of the transit route network to serve increasing numbers of passengers; increasing services on routes with growing ridership; attracting new transit users, improving cost-efficiency by acquiring high-capacity articulated buses; reallocating operating resources away from services that do not meet minimum ridership targets; improving the reliability of transit service through new technologies such as vehicle location; making use of advanced technologies to provide transit information; and developing quality of service indicators and targets that can be used to assess transit operating conditions and to evaluate possible changes.

Bogota, Colombia

Number of Corridors	TransMilenio Median Busway
Length (miles)	25.4
Total Costs (USD)	$213 millions
Funding	Federal, federal grants 20%, Local, a fuel charge a 25% tax which 15% goes to TransMilenio provided 46% of funds, local revenues 28%, other, World Bank loan 6%
Number of Stations	59
Year First Opened	Different phases, first phase 2000 completed in 28 months
Congestion Protection Strategy	4 lanes Arterial Median Busways, high platform stations
ITS	Yes
AVL	Yes
Passenger Information announcements	
Real-Time Info at Stations	
Traffic Signal Priority	Yes
Bus Type	Articulated
Bus Propulsion	Diesel
Level Boarding	Yes, High level Platform
Number of Doors	3
Fare Collection (Pre-Payment)	Yes
Estimated Ridership (weekday bus riders)	800,000 with planned extension. In 2002, 207 million passengers. Each bus moves an average of 1,596 passengers per day. Eleven percent of riders own cars.
Reported Travel Time Savings (min)	32% reduction in travel time
Capacity Comparison / Increase % / Modal Shift	Since TransMilenio service began there have been 89% fewer traffic accident fatalities and 83% fewer injuries. There has been a 40% drop in air pollutants (SO2 dropped 43%, NO2 18% and particulates 18%), noise pollution has been reduced by 30% and violent crime has dropped 50% citywide.
Headway Peak hour	
Future Plans	Additional 40 kilometers and 60 stations include three terminals and four integration stations (2 trunk line-trunk line and 2 feeder-trunk line) to be completed by the first quarter of 2005. The overall expansion will continue until 2016, when the system will be 388 km in length. When complete, more than 80% of Bogota's citizens will live less than 500 meters from a TransMilenio line.

	Curitiba, Brazil
Number of Corridors	- Median Busway System
Length (miles)	37.2
Total Costs (USD)	$200,000 per mile
Funding	Funded from bus fares without any public subsidies
Number of Stations	139
Year First Opened	1973
Congestion Protection Strategy	Arterial Median Busways, high platform stations
ITS use?	Yes
AVL	
Pax Information announcements	Yes
Real-Time Info at Stations	
Traffic Signal Priority	Yes
Bus Type	Bi-Articulated
Bus Propulsion	Diesel
Level Boarding	Yes, High level Platform
Number of Doors	5
Fare Collection (Pre-Payment)	Yes
Estimated Ridership (weekday bus riders)	340,000
Reported Travel Time Savings (min)	
Capacity Comparison / Increase % / Modal Shift	Ridership growth with system expansion and the city as well. From 400,000 daily trips in 1982 to 1.9 million in 2001. 27 million fewer automobile trips annually
Headway Peak hour	90 seconds
Future Plans	Expand the network reducing the need for conventional bus services

	Leeds, United Kingdom
Number of Corridors	- Superbus Guided Bus System
Length (miles)	4.4
Total Costs (USD)	1.35 billions
Funding	
Number of Stations	3
Year First Opened	1995
Congestion Protection Strategy	Mixed Traffic, guided bus tracks with queue bypass
ITS	Yes
AVL	Yes
Passenger Information announcements	
Real-Time Info at Stations	
Traffic Signal Priority	Yes
Bus Type	Standard
Bus Propulsion	Diesel
Level Boarding	Yes
Number of Doors	1
Fare Collection (Pre-Payment)	No
Estimated Ridership (weekday bus riders)	Two different surveys, one reported 40% increase in 1999, 10 to 20% being former drivers. The other survey of 1999 reported only 6%
Reported Travel Time Savings (min)	10 minutes
Capacity Comparison / Increase % / Modal Shift	50% ridership growth in the first 2.5 years
Headway Peak hour	
Future Plans	

	Brisbane, Australia
Corridor	South East Busway
Length (miles)	10.5
Total Costs (AUD)	485 millions
Funding	
Number of Stations	10
Year First Opened	Construction 1999, Phase II completed Feb 2004
Congestion Protection Strategy	Bus Tunnel, Busway (separate r-o-w)
ITS	Yes
AVL	Yes
Passenger Information announcements	Yes
Real-Time Info at Stations	Yes
Traffic Signal Priority	Real Time Advanced Priority and Information Delivery is used
Bus Type	Standard, Articulated
Bus Propulsion	CNG / Diesel
Level Boarding	Yes
Number of Doors	2
Fare Collection (Pre-Payment)	Yes, ticket-machine and local shops
Estimated Ridership (weekday bus riders)	30,873 per week in 2004, over 45 million per year
Reported Travel Time Savings (min)	2 minutes per mile
Capacity Comparison / Increase % / Modal Shift	42% increase in May-October 2001, 375,000 fewer annual private vehicle trips
Headway Peak hour	2 to 10 minutes
Future Plans	The agency plans a fully integrated public transportation system to be running by 2025, "Smartcard" is also planned

	Seoul, Korea
Number of Corridors	- Bus Rapid Transit and Bus Lanes
Length (miles)	Curbside lanes 182.5, Median bus lanes 118.8 miles total by 2008 in 16 corridors
Total Costs (USD)	5 to 15 billion won/km, Costs for the first BRT anticipated at $71 million which is 5 billion won/km
Funding	Federal, 40% covered by the Ministry of Planning and Budget, for the first BRT corridor, the city of Hanam will cover the remaining balance
Number of Stations	11 stations with BRT
Year First Opened	2004
Congestion Protection Strategy	Median and Bus Lanes
ITS use	Yes
AVL	GPS
Passenger Information announcements	
Real-Time Info at Stations	Yes
Traffic Signal Priority	Yes for the first BRT corridor
Bus Type	Standard Articulated
Bus Propulsion	CNG
Level Boarding	No
Number of Doors	
Fare Collection (Pre-Payment)	No
Estimated Ridership (weekday bus riders)	The 2004 bus reforms have resulted in an 11.2% increase in total bus ridership and a 7.1% increase in total public transit trips. Bus-related accidents have decreased by 23%. It is anticipated that 18 BRT corridors will have a capacity of 30,000 passengers/hour and four BRT corridors will have a capacity of 20,000 passengers / hour.
Reported Travel Time Savings (min)	
Capacity Comparison / Increase % / Modal Shift	Median busway capacity is limited by officials to a maximum of 250 buses/hour/direction (more than 10,000 passengers/hour/direction).
Headway Peak hour	
Future Plans	A full feature BRT planned for 2009

Appendix E - Simulation programs, parameters and input data

This appendix discusses the software programs, input and parameters required to model the "Hot Spot" following the layout of the intersections of Memorial Dr., Beacon St., Marlborough St. and Commonwealth Ave. A screen shot of the "Hot Spot" is depicted in Figure 22.

Simulation programs

Modeling of the "Hot Spot" to assess different priority strategies is made possible by using the simulation program VISSIM 5.0. VISSIM 5.0 is a microscopic, timestamp and behavior based simulation model developed to model urban traffic and public transportation operations [VISSIM 5.0].

VRIgen and Trafcod a development of the TU Delft are used in coordination with the simulation program to as they assist in the traffic control scheme. Trafcod is a signal control program, which stems the control sequences from VRIGen. The control sequences are generated in VRIgen. The control sequences are linked to VISSIM via Trafcod. The streams, conflict matrix and traffic counts are used as input data to generate the control sequences.

Simulation Assumptions and Observations

Based on observations at the "Hot Spot" and due to the capability and requirements of the simulation program, to model the "Hot Spot" as close to reality as possible, assumptions have to be taken into account. Differentiating between the "real world" and the simulation the assumptions are described hereafter.

At the intersection of Beacon St., the curb locates the bus stop. Outbound, Commonwealth Ave to Memorial Dr in some observed cases, the bus operator did not hit the curb to load or dwell passengers given the merging possibilities after crossing the intersection (as the layout changes from 3 to 2 lanes). For inbound the same occurs, however, the lane is wide enough to be divided in two lanes. The use of this lane into one or two depends on driving behavior. All buses dwell by the curb in the simulation program despite the observed situations.

Between Commonwealth Ave East and West, Mass Ave becomes a three-lane avenue, returning to a 2-lane avenue after these intersections. The bus always dwells by the curb (right lane) due to passenger facilities at the bus stop of Commonwealth Ave on both directions. The right lane is hardly used by cars given the location of the bus stop and the required merging after crossing the intersection. Therefore in the simulation cars do not use this lane. Given the capabilities of the simulation program the driving behavior allows the bus to merge with ease. If congestion is to build-up the bus will have priority to merge, which is not always the case at the "Hot Spot".

Parking lanes and therefore parking vehicles are not accounted for. Pedestrians crossing are assumed to do when not conflicting with a stream. Vehicles yield to pedestrians. At the "Hot Spot" markings for a bike lane are only present at the Harvard Bridge.

Traffic Counts

Traffic counts were obtained by counting traffic during three periods of five minutes and compared with traffic counts provided by Mass Highway. Hourly counts for a week (in some cases just a few days) either in 2005 or 2006 could not provide a real insight of the vehicle count due to the lack of differentiation between cars and trucks. Traffic counts were conducted in two different days[8] between the months of April and May of 2008, at morning and afternoon hours to account for morning and afternoon peaks. According to the calculations the highest volume of vehicles encountered was in the afternoon. The results of the traffic counts are provided in Appendix Table I distinguishing turning ratios.

Pedestrian and bicycle counts are taken from counts made at the intersection of Beacon St. and Mass Ave. They do not have a significant impact over traffic or bus travel time at the "Hot Spot". Given that the counts were significantly low and for aesthetic reasons in the simulation the traffic counts for bikes are increased. For pedestrians a value of 15 ped/hr is adopted, which is increased to 85 ped/hr between the intersections of Memorial Dr. and Beacon St. (pedestrians over the Harvard Bridge) as there is a high flow of pedestrians over the bridge accessing the Charles River park areas.

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[8] A game at Fenway Park took place in the afternoon of one of the days traffic was counted.

Appendix Table I: Traffic Counts

TRAFFIC COUNTS "HOT SPOT"

Memorial Drive

Stream	Name and Direction	Movement	Count	Percentage
5	Mass Ave South - East	Right turn	294	30%
5	Mass Ave South - North	Through	691	70%
65	Mass Ave South - North	Through	558	81%
66	Mass Ave South - West	Left turn	133	19%
11	Mass Ave North - West	Right turn	69	8%
11	Mass Ave North - South	Through	793	92%
71	Mass Ave North - South	Through	793	100%
7	Memorial Drive West - South	Right turn	398	100%
1	Memorial Drive East - North	Right turn	148	100%

Beacon St.

Stream	Name and Direction	Movement	Count	Percentage
2	Beacon St East - North	Right turn	140	19%
2	Beacon St East - West	Through	480	66%
2	Beacon St East - South	Left Turn	112	15%
5	Mass Ave South - North	Through	754	79%
5	Mass Ave South - West	Left Turn	198	21%
11	Mass Ave North - West	Right turn	308	26%
11	Mass ave North- South	Through	866	74%

Marlborough St

Stream	Name and Direction	Movement	Count	Percentage
5	Mass Ave South - East	Right turn	21	2%
5	Mass Ave South - North	Through	923	98%
8	Marlborough St West - North	Left Turn	42	54%
8	Marlborough St West - East	Through	13	17%
8	Marlborough St West - South	Right turn	23	29%
11	Mass Ave North - East	Left Turn	47	6%
11	Mass Ave North - South	Through	751	94%

Commonwealth Ave

Stream	Name and Direction	Movement	Count	Percentage
2	Commonwealth Ave East - North	Right turn	96	48%
2	Commonwealth Ave East - West	Through	34	17%
2	Commonwealth Ave East - South	Left turn	68	34%
5	Mass Ave South - East	Right turn	30	4%
5	Mass Ave South - North	Through	765	96%
8	Commonwealth Ave West - North	Left turn	251	60%
8	Commonwealth Ave West - East	Through	48	11%
8	Commonwealth Ave East - South	Right turn	119	28%
11	Mass Ave North - West	Right turn	35	4%
11	Mass Ave North - South	Through	798	96%
65	Mass Ave South - North	Through	947	100%
71	Mass Ave North - East	Right turn	59	7%
71	Mass Ave North - South	Through	754	93%

Traffic Control Program

The traffic control program at each of the intersections' streams is fixed time. Fixed time also called pre-timed control refers to the sequence in the number of stages, cycle time, predetermined and with a fixed time. In order to analyze the control program of the "Hot Spot", the cycle time and time phase of each stream where provided by the Boston Transportation Department. A study performed at MIT regarding the intersection of Memorial Drive and Mass

Ave provided the phase times per stream for this intersection[9]. Observations at each traffic signal were performed to verify the obtained data. No variations were identified. Depending on the day of the week and time the cycle time and sequences for the intersections change. Given that in the afternoon of weekdays has a higher volume flow (as shown by the traffic counts) the phase times for weekday afternoon were selected. The phase time per sequence of each intersection is shown in Appendix Table II to Appendix Table V.

Appendix Table II: Memorial Drive traffic signal timings

Memorial Dr.			
Stream	**Start Green**	**Start Yellow**	**Start Red**
1	0	18	22
5	23	70	74
7	0	34	38
11	41	70	74
65	23	76	80
66	23	36	40
71	41	76	80
31	81	89	100
32	81	89	5
34	81	89	100
35	39	89	100
36	81	100	13
38	81	89	100

Appendix Table III: Beacon Street traffic signal timings

Beacon St			
Stream	**Start Green**	**Start Yellow**	**Start Red**
2	69	107	110
5	0	65	68
11	23	65	68
32	23	38	46
34	69	77	92
36	23	38	46
38	69	77	92

Appendix Table IV: Marlborough Street traffic signal timings

Marlborough St			
Stream	**Start Green**	**Start Yellow**	**Start Red**
5	12	78	81
8	82	107	110
11	0	78	81
32	13	23	33
34	82	98	108
36	13	23	33
38	82	98	108

[9] Information was not provided by BTD as the intersection is under the jurisdiction of the Department of Recreation and Conservation.

Appendix Table V: Commonwealth Avenue traffic signal timings

	Commonwealth Ave		
Stream	**Start Green**	**Start Yellow**	**Start Red**
2	88	18	21
5	22	77	80
8	88	18	21
11	22	77	80
65	22	84	87
71	22	84	87
30	88	98	4
31	22	68	78
32	22	68	78
34	81	91	101
35	22	68	78
36	22	68	78
38	88	98	4

The cycle time for the intersections is 110 seconds with the exception of Memorial Drive, which is 100 seconds. For Memorial Drive an all-pedestrian phase allows pedestrians to cross diagonally the intersection. With the cycle time known and the traffic volumes it is possible to calculate the volume capacity and Level of Service of each of the intersections.

Conflict Matrix

Between streams there are two types of conflicts: protected and permitted. Protected conflict refers to the prohibition of two streams having green and/or amber at the same time, while permitted allows combined movements of streams that would not conflict. Permitted conflicts are pedestrian streams and right turns where cars must yield to pedestrians.

The conflict matrix shows the conflicting and non-conflicting pairs of streams at an intersection. Representing the conflicting streams with the clearance time to clear the intersection the conflict matrix represents mathematically the layout of the intersection.

The computation of the conflict matrix consists of two steps. First, the clearance times are determined for each intersection. Second, the all-red times are calculated. The clearance times and all-red times calculated followed the approach described in the lecture notes of CT4822 [7]. The conflict matrix for each of the intersections is given in Appendix Figure VIII: to Appendix Figure X:.

ALL RED MATRIX / CONFLICT MATRIX
Memorial Dr.

From \ To	1	5	7	11	31	32	34	35	36	38	65	66	71
1					3.7					2.8	3.5		
5							4.2						
7							4.2	3.7					3.2
11										3.7		3.8	
31	4.9												
32													
34		6.4	8.7										7.6
35			5.6										
36												6.0	
38	7.0			6.9							7.0		
65	3.8									2.8			
66				3.4					3.4				
71			3.5				3.5						

Appendix Figure VIII: Memorial Drive Conflict Matrix (seconds)

ALL RED MATRIX / CONFLICT MATRIX
Beacon St.

From \ To	2	5	11	32	34	36	38
2		4.7	3.8	4.2		2.6	
5	4.3				4.0		2.7
11	3.2				2.5		4.0
32	13.0						
34		7.6	7.4				
36	12.8						
38		6.2	8.3				

ALL RED MATRIX / CONFLICT MATRIX
Marlborough St.

From \ To	5	8	11	32	34	36	38
5		3.4			4.0		2.5
8	4.3		4.5	2.8		3.9	
11		3.7			2.5		4.2
32		9.6					
34	8.0		7.3				
36		8.9					
38	7.5		7.8				

Appendix Figure IX: Beacon Street Conflict Matrix and Marlborough Street Conflict Matrix (seconds)

ALL RED MATRIX / CONFLICT MATRIX
Commonwealth Ave.

From \ To	2	5	8	11	30	31	32	33	34	35	36	37	38	65	71
2				4.0		3.7					2.5			3.6	
5			3.9					4.0							
8		3.9					2.5			3.7					3.6
11	3.5				2.5							4.2			
30				7.4										8.1	
31	7.8														
32			8.3												
33		7.6													
34															7.6
35			7.9												
36	7.9														
37				8.3											
38														7.8	
65	3.5				4.2								2.8		
71			3.9						2.5						

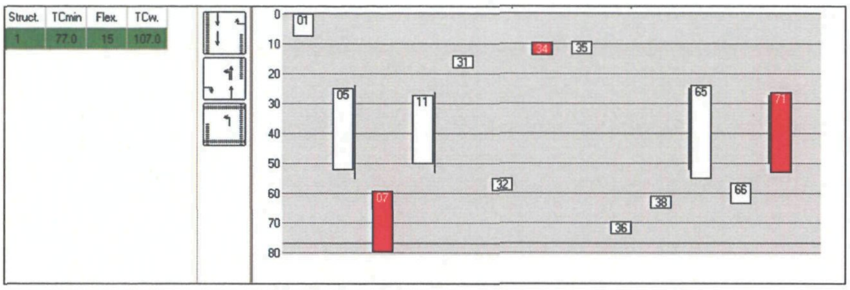
Appendix Figure X: Memorial Drive Conflict Matrix (seconds)

The values have been used as input data for each of the conflict matrices in VRIgen files for the simulation. The layout of the intersections, the conflict area, remains the same for all scenarios allow the conflict matrix for each intersection to be the same in all scenarios.

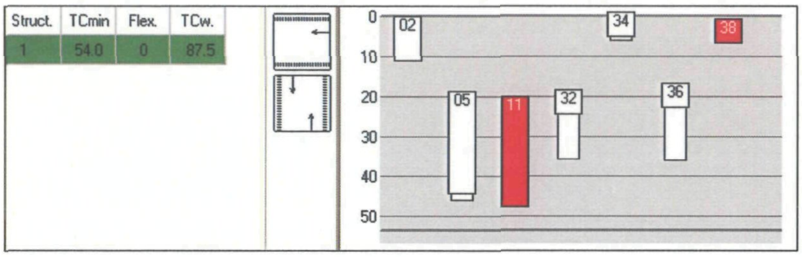
Control Sequence

With the conflict matrix and traffic counts known the control sequences are generated for each of the intersections. This is done with the aid of the computer program VRIgen. The conflict matrix, the flows and turning fractions per stream are used to calculate the control sequences. The software calculates the control sequences given the input data. Appendix

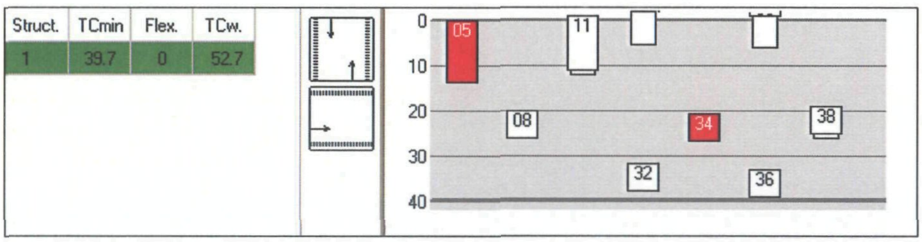
Figure XI to Appendix Figure XIV provides screen shots of the control sequence of each intersection. The streams colored in red indicate the conflict streams (conflict group).



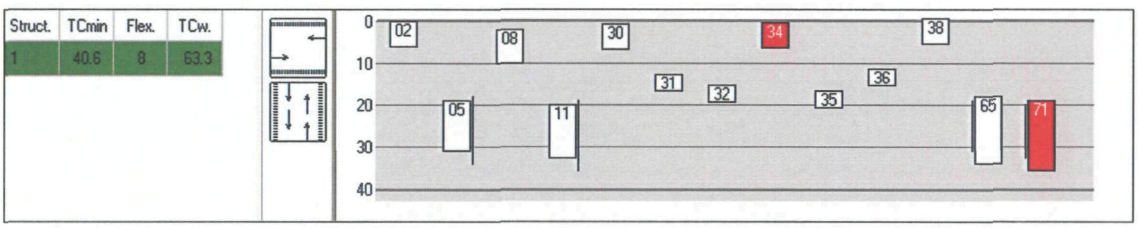
Appendix Figure XI: Memorial Drive Control Sequence



Appendix Figure XII: Beacon Street Control Sequence



Appendix Figure XIII: Marlborough Street Control Sequence



Appendix Figure XIV: Commonwealth Avenue Control Sequence

The control sequences are similar for all scenarios in the case of Memorial Dr., Marlborough St. and Commonwealth Ave. Depending on the scenario characteristics the control sequence for Beacon St. has to be re-calculated.

Validation and Calibration

Simulations are site specific given a range of factors. Therefore, it is necessary to calibrate the simulation and fine tune with the default parameters to simulate as close as possible real situations. The simulation was calibrated by compiling field data such as: travel time, discharge rate and queue length. Trial simulation runs were compared with the field data. No significant deviations were found.

Validation is made to test the calibrated parameters. The simulation was visually validated (after several runs) and verified; no collisions due to too short clearance times, missing priority rules, incorrect detector placement, priority strategy active and/or any other parameter was detected. In addition, the input and output flows are compared. The result of the trial simulation runs were compared with the data collected. When discrepancies were found the parameters were re-calibrated. Finally, when there were no discrepancies and significant deviations the different scenarios were generated.

Performance Indicators

The simulation program can provide data for several performance indicators in order to evaluate the outcome of the simulation. As the MBTA is the problem owner and the objective of the investigation is to reduce travel time by applying congestion protection strategies and their effect over the bus and all other vehicle classes, the performance indicators evaluated are based on the effects congestion and the priority strategies have over the travel time.

The performance indicators evaluated four different travel sections for all vehicle classes and two travel sections for bus route 1 and CT1. The travel sections are: 1) Massachusetts Avenue outbound (called Mass Ave to MIT with a total length of 1216 meters), 2) Massachusetts Avenue inbound (called Mass Ave from MIT with a total length of 1215 meters), 3) Mass Ave between Beacon St and Memorial Drive outbound (called Beacon & Memorial with a length of 845 meters), 4) Mass Ave between Beacon St and Memorial Drive inbound (called Memorial & Beacon with a length of 845 meters) for all vehicle classes. For bus route 1 and CT1 along Massachusetts Avenue the travel sections are: 5) outbound (called Mass Ave to MIT with a length of 1214 meters) and 6) inbound (called Mass Ave from MIT with a length of 1213 meters). The distance between travel times 1 and 2 and 5 and 6 is not the same given that the travel links are drawn slightly longer. However, the difference can be negligible. For travel links 1 and 5 and 2 and 6, the distance is dependant on the location of the bus stop. Therefore not been equal but as stated before this has no impact over the results. In addition, links 3 and 4 evaluate the causes of congestion over the Harvard Bridge.

The main performance indicators used to evaluate the priority strategies over the travel sections are: Delay and Travel Time. From the simulation runs the data for the performance indicators is provided. Delay as a performance indicator is calculated averaging the delay in each travel section, the units being seconds. Travel time is calculated by averaging the travel time of each travel section, the units being seconds. The results have been discussed in Chapter 7.