MALD CAPSTONE

Solving Boston's Traffic Nightmare While Reducing Transportation Sector Emissions: The Case for Bus Rapid Transit and Congestion Pricing Along I-93's Southeast Expressway

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Spring 2018

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In full fulfillment of the MALD Capstone requirement

30 April 2018

Lane Widening Didn't Work Then and it Still Doesn't. It's Time for a New Solution to Traffic Congestion.
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Solving Boston's Traffic Nightmare While Reducing Transportation Sector Emissions: The Case for Bus Rapid Transit and Congestion Pricing Along I-93's Southeast Expressway

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1. Executive Summary

Massachusetts, and Boston, more specifically, faces a traffic congestion problem that has huge economic, public health, and environmental ramifications. A ten-mile span of the portion of Route 93 (I-93) to the south of the city, also known as the Southeast Expressway, has garnered national attention by claiming the dubious distinction as the 10th most congested road in the US. This paper makes the case for how congestion on Route 93 can be relieved via a combination of bus rapid transit (BRT) and congestion pricing. This solution is financially feasible because a portion of the road has the preexisting infrastructure needed for BRT in the form of movable barriers; and environmentally beneficial since improving traffic flow will help Massachusetts progress towards achieving its long-term emissions goals as laid out in the Global Warming Solutions Act (GWSA). We are at a crucial time for emissions reduction as the transportation sector continues to lag behind all other sectors. Concurrently, if BRT uses low emission buses and limits particulate matter and air pollution, it will also prove environmentally and socially equitable by improving the health of those who live near the highway.

This paper draws on the experience of Stockholm, Sweden, and Mexico City as examples that congestion pricing and BRT reduce traffic congestion, reduce transportation sector greenhouse gas (GHG) emissions, generate revenue, improve air quality, are popular with citizens, and correct the market failure that traffic represents. The conclusion of this paper is that a combined approach (BRT and congestion pricing) is both technologically and financially feasible, yet requires political willpower to invoke a shift in the popular, but incorrectly held notion that expanding lanes reduces traffic as well as counter the knee-jerk reaction associated with instituting road pricing. By using a combination of BRT and congestion pricing to solve the Route 93 traffic problem, Boston can then export this solution to its other feeder roads to stave off the issue of traffic inside the city by fighting it before it ever even gets there. The hope is that this two-pronged solution, once demonstrated successfully by a major US city, will be adopted by other cities to solve their own traffic congestion issues and begin to reduce transportation sector GHG emissions nationwide.

Recommendations

- Simultaneously implement congestion pricing in concert with BRT to reduce the number of cars by 5% in the short-term and keep it flowing in the long-term. The fear is that using only BRT may thin traffic enough that more people start using the highway once they see better flowing traffic. Congestion pricing guards against this and "locks in" the gains of BRT.
- Launch an immediate BRT pilot program. Move both sets of movable barriers on the Route 93 Southeast Expressway between exits 15 and 7 to open a dedicated BRT lane in each direction during peak times. Purchase new movable barriers for the portion of 93 north of Exit 15. Launch BRT buses from South Station. Ensure BRT is meeting at least the 5 essential elements of BRT. Strive for Gold Standard for permanent implementation with low emissions buses only.
- Use revenue to subsidize tolls for low-income residents, and fund BRT.
- Immediately halt any lane expansion projects along Massachusetts highways and reinvest that money into projects such as BRT and the expansion of light rail.

2. Introduction

2a. The Current Situation

For the first time in 40 years in the United States, the transportation sector is responsible for more carbon dioxide (CO2) emissions than any other sector, surpassing the incumbent leader, the electricity generation sector (Figure 1). [1] Per the US Department of Transportation, since 1965, the total number of vehicle miles travelled (VMT) has increased each year, with most projections calling for that trend to continue. [2] Concurrently with this increase in VMT, the US electricity generation sector has transitioned away from carbon intensive, inefficient forms of electricity production such as coal, and towards natural gas and renewables. As the power generating sector becomes more efficient and less carbon intensive, the transportation sector lags further and further behind. One of the main issues driving the increasing emissions is traffic congestion, which costs billions of dollars in lost time and lost work each year, while also harming both the physical and mental well-being of local citizens via GHG emissions. [3] This issue is not limited to the United States. In most nations their respective transportation sector remains either a laggard in GHG emissions reductions or their largest predicted sector of GHG emissions growth. In China for example, the transportation sector's share of GHG emissions in major cities has grown by about 5% each of the last several years. [4] Per a 2012 study conducted by the World Bank, "transportation produces more than 23% of global CO2 emissions from fuel

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[1] Randall, Tom. 2017. "Transport Sector Now Largest Source of GHG Pollution in US" Transport News. http://www.ttnews.com/articles/transport-sector-now-largest-source-greenhouse-gas-pollution-us. Accessed Jan 2018.
[2] US Dept. of Transportation: Bureau of Transportation Statistics. 2015. https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_35.html. Accessed Jan 2018.
[3] Kylstra, Carolyn. 2014. 10 Things Your Commute Does to Your Body. Time Magazine. http://time.com/9912/10-things-your-commute-does-to-your-body/. Accessed March 2018.
[4] The World Bank. 2012.

combustion and is the fastest growing source of CO2 emissions." [5] Transportation's share of global emissions has only increased since then.

Fortunately, there are also widely agreed upon solutions. The World Bank, and other leading agencies advise that a reduction in GHG emissions from transportation can be accomplished via a three-pronged approach of reducing demand for personal vehicle use via well designed urban transport; promotion of low-emission modes of transport; and using the most fuel-efficient vehicle technology for all trips. This paper calls for the implementation of well-designed, low-emissions public transit on one of Boston's most congested highways and demand-side policy in the form of congestion pricing to reduce traffic around and inside the city.

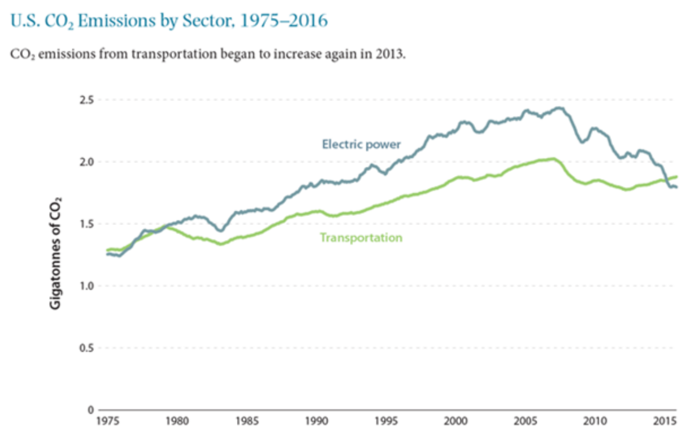

Figure 1: US CO2 Emissions By Sector 1975-2016
Source: DOE, EIA, May 2016 Monthly Energy Review

However, before diving into the issue of traffic congestion (and its resultant GHG emissions) and how to best address it on Boston's Route 93 Southeast Expressway, it will first be helpful to give an overview of the historical regulatory environment globally, as well as in the US at both the state and national levels.

[5] The World Bank. 2012. Urban transport and climate change. http://www.worldbank.org/en/news/feature/2012/08/14/urban-transport-and-climate-change. Accessed 2018.

2b. The History of Emissions Regulations at the Global and National Level

In the United States, the federal government initially led the charge in environmental regulation, which can be traced back to the late 1960's and early 1970's. Under Richard Nixon, a Republican President, the US passed the National Environmental Policy Act (1969) and created the Environmental Protection Agency (EPA) (1970). The EPA was authorized by Congress to set national air quality, auto emission, and anti-pollution standards which took the form of the Clean Air Act (1970). [6] Over the years air quality improved and localized pollution was cleaned up, however, a growing body of climate research made it clear that an invisible GHG, CO2, was causing changes in the earth's atmospheric and oceanic temperatures. This problem of non-localized, largely invisible pollution proved much harder to regulate than the more obvious localized pollution. Thus, in Rio De Janeiro in 1992, the United Nations held its first annual climate meeting with the objective of working towards the "stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." This meeting resulted in a treaty called the United Nations Framework Convention on Climate Change (UNFCCC), signed and ratified by 197 countries, who then became known as "Parties to the Convention." [7] Each year since, these parties have met at a Conference of Parties (COP) to discuss methods to reduce GHG emissions, mitigate and adapt to the effects of climate change, and how to best transition to a low carbon world. Each COP has had varying degrees of success, with the most substantial being the 2015 Paris Agreement.

The Paris Agreement was signed by 197 nations (ratified by 175 as of April 2018) to "strengthen the global response to the threat of climate change by keeping global temperature

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[6] EPA. 2018. EPA History Timeline. https://www.epa.gov/history. Accessed April 2018.
[7] United Nations Framework Convention on Climate Change. 2018. History of UNFCC> http://unfccc.int/essential_background/convention/items/6036.php. Accessed April 2018.

rise this century well below 2 degrees Celsius above pre-industrial levels." [8] It represented a momentous achievement because it was the first time nearly the entire world had agreed to an actionable and well-financed plan to combat climate change. It also was the first time the COP attempted a bottom-up approach to regulating GHG emissions versus more top-heavy approaches such as the Kyoto Protocol (1997). [9] This bottom-up approach is best exemplified in the Paris Agreement via "Internally Determined National Contributions" (INDCs) in which nations make voluntary and non-binding pledges to reduce their GHG emissions by 2025 to a certain level using 2005 as a baseline. The United States under President Obama's leadership pledged to cut GHG emissions by 26-28% by 2020 and by 80% by 2050 (Figure 2). [10]

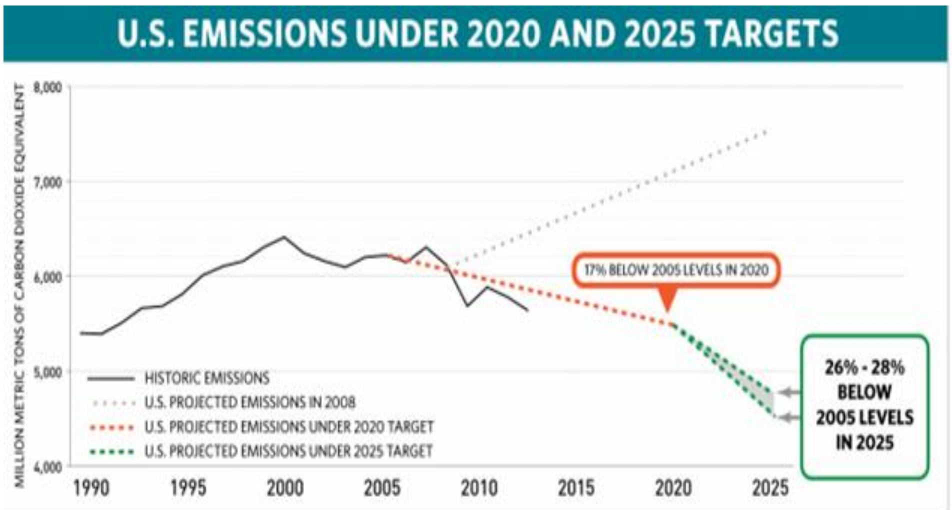

Figure 2: Voluntary US Emissions Targets Per Paris Agreement INDC
Source: UNFCC 2015

In January 2017 a new administration took the helm at the White House and in June 2017 among much advice to the contrary, President Trump withdrew the US from the Paris Agreement. Although this was largely a symbolic gesture to his political base (the withdrawal

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[8] United Nations Climate Change. 2018. The Paris Agreement. http://unfccc.int/paris_agreement/items/9485.php. Accessed April 2018.
[9] UNFCC. Kyoto Protocol. 2018. https://unfccc.int/process/the-kyoto-protocol. Accessed April 2018.
[10] United Nations Climate Change. 2016. NDC Registry. http://www4.unfccc.int/ndcregistry/PublishedDocuments/United%20States%20of%20America%20First/U.S.A.%20First%20NDC%20Submission.pdf. Accessed April 2018.

process will take the entire length of Trump's first term) the message that the US federal government is not interested in climate action was heard loud and clear by the rest of the world. As the largest historical emitter of CO2 and other GHGs, the US bears a large amount of responsibility for the current predicament of climate change. In fact, even though China has overtaken the US as the largest total contributor of CO2, the US still holds a commanding lead in per capita CO2 emissions. Fortunately, even as the federal government has taken steps backwards on climate action, many state and local governments (and even businesses) in the US have stepped up to fill the void. This is evident not only in local legislation but also in movements such as "We Are Still In" at the most recent COP in Bonn. [11] [12]

2c. The History of Emissions Regulations at the State Level

There is a long history of state involvement in environmental action and energy standards. As of current, twenty-nine states, three territories, and Washington D.C. have established Renewable Portfolio Standards (RPS) to help encourage renewables such as wind and solar to grow in scale and financial feasibility by requiring utilities to include a certain percentage of renewable energy in their overall energy mix. [13] The states in the Northeastern and Mid-Atlantic US, along with California, have been at the forefront. Many of these states have not only setup RPS, but have also established cap and trade systems to regulate their power generation sectors. The Regional Greenhouse Gas Initiative (RGGI), comprised mainly of states in the Mid-Atlantic and New England regions, requires all power generators of 25MW or greater

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[11] We Are Still In. 2018. https://www.wearestillin.com/COP23. Accessed April 2018. "We Are Still In is a movement of over 100 prominent leaders from the US state and local governments, private sector and academia that gathered in Bonn to show support for the Paris Agreement."
[12] Shear, Michael. 2017. Trump will withdraw US from Paris Climate agreement. NY Times. https://www.nytimes.com/2017/06/01/climate/trump-paris-climate-agreement.htmlAccessed April 2018.
[13] Durkay, Jocelyn. 2017. State renewable portfolio standards and goals. National Conference of State Legislatures. http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx. Accessed April 2018.

to participate in a cap and trade system. [14]Another similar system exists in California. RPS, cap and trade systems, a shift away from coal, and advances in existing technology are but some of the leading factors that have led to a marked reduction in emissions from the power generation sector, and these mechanisms have all largely been done at the state and regional level. Massachusetts has been front and center for much of this energy transition in the power sector. In addition to being a regional leader in initiatives such as RGGI, Massachusetts has also had an outsized, positive effect on federal air quality regulations. This is best exemplified by its initiation, and victory of the landmark Supreme Court case: Massachusetts v. EPA in 2007. This victory allowed the EPA to regulate GHGs and more specifically, CO2. This ruling would eventually become the foundation for President Obama's Clean Power Plan (2015). [15] One year after filing this Supreme Court case, Massachusetts again took a climate action leadership role and created the Global Warming Solutions Act (GWSA) (2008). The GWSA committed Massachusetts to reduce its

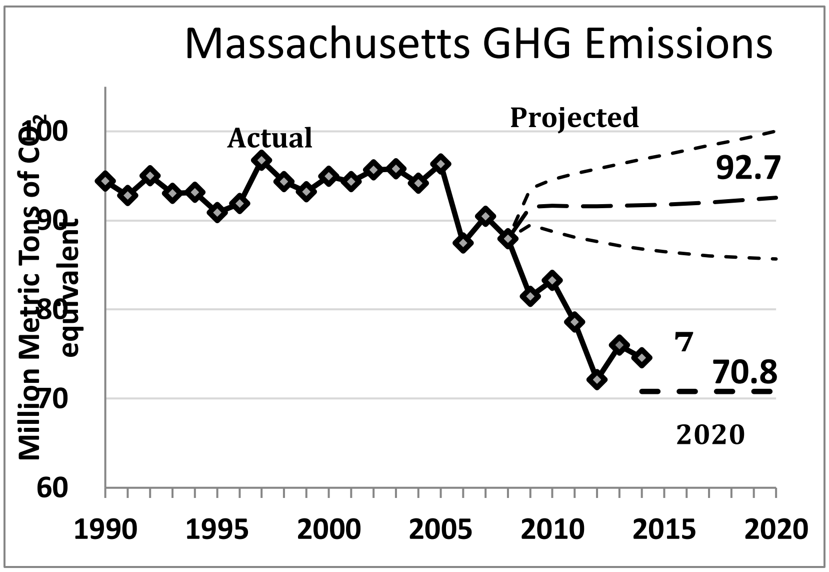

Figure 3: Massachusetts's GHG Emissions
Source: Mass DEP

[14] RGGI. 2018. Elements of RGGI. https://rggi.org/program-overview-and-design/elements. Accessed April 2018.
[15] Supreme Court of the United States. MA v. EPA 549 U.S. 497. https://www.supremecourt.gov/opinions/06pdf/05-1120.pdf. Accessed April 2018.

GHG emissions by 25% by 2020 and 80% by 2050, using 1990 as a baseline year when total statewide emissions were 94.4 million megatons (MMT) GHG. [16] Therefore, based off the 25% and 80% reductions outlined in the GWSA, 70.8 MMT and 18.9 MMT GHG are the Massachusetts emissions targets for 2020 and 2050, respectively. The GWSA applies across all sectors of the state's economy. While all other sectors, most notably the power generation sector, have made great strides in GHG reductions to comply with the GWSA, the transportation sector's GHG emissions have remained largely constant. In 2014, total statewide emissions were measured at 74.6 MMT (figure 3) with transportation accounting for 29.4 MMT, or 39% of statewide GHG emissions (figure 4). To put this in perspective, the next largest sector is the electricity sector at approximately 20%. [17] As shown in figure 3, Massachusetts is making great strides towards meeting its GWSA goals for 2020 even as the transportation sector lags behind. However, after 2020, the GHG emissions targets become increasingly aggressive, culminating at 18.9 MMT GHG per year by 2050. Transportation currently contributes 29.4 MMT GHG per year. Therefore, in a business as usual

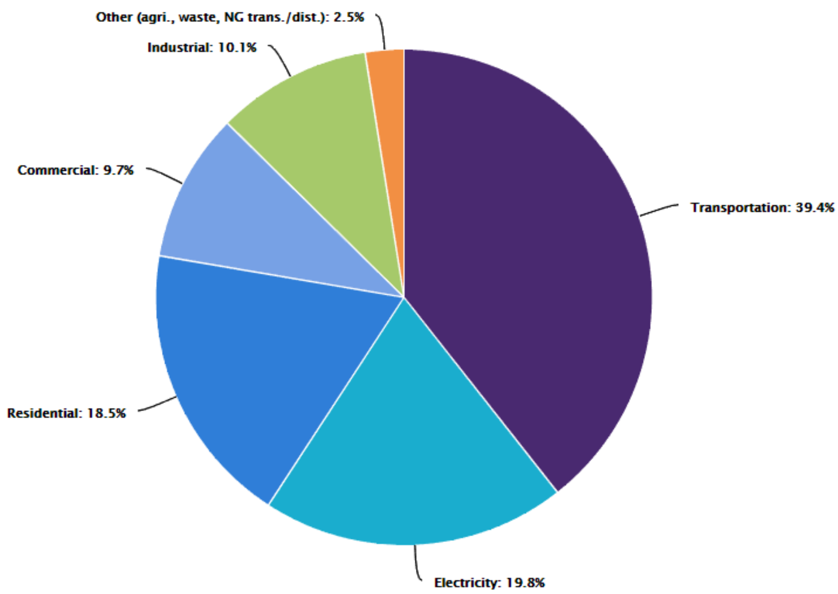

Figure 4: Massachusetts's GHG Emissions by Sector
Source: Mass DEP

[16] Executive Office of Energy and Environmental Affairs. 2018. GWSA Dashboard. Commonwealth of Massachusetts. https://www.mass.gov/massachusetts-progress-towards-reducing-greenhouse-gas-ghg-emissions-by-2020. Accessed Feb 2018.

[17] Executive Office of Energy and Environmental Affairs. 2018. MA GHG Emission Trends. Commonwealth of Massachusetts. https://www.mass.gov/service-details/ma-ghg-emission-trends. Accessed March 2018.

scenario, by 2050 transportation alone would be responsible for 153% of the allowable statewide emissions. Clearly, this isn't feasible and the issue must be addressed. It is tempting to think that transportation emissions will naturally fall due to technological advancements or tighter fuel standards. However, historical data has shown otherwise as the total VMT in the US has tended to be on the upswing since the end of the Great Recession. Additionally, the Trump Administration has vowed to rollback auto efficiency standards. Back to the state level, per records kept by the Massachusetts Department of Environmental Protection, transportation emissions have remained in the 29-35 MMT per year range since 1990. This highlights the urgency in finding ways to reduce the emissions of the transportation sector since a business as usual approach is not yielding results.

It is against this backdrop that the Climate Policy Lab of the Fletcher School's Center for International Environment and Resource Policy (CIERP) at Tufts University, the Acadia Center, and Transportation for Massachusetts (T4MA) hosted the "*Future of Transportation Symposium"* on 11 January 2018. This event served an urgent and timely need for leading companies, academics, advocates, state and regional decision-makers to collaborate and explore the rapidly shifting transportation landscape and how technology and policy will shape transportation over the next several decades, and beyond. This paper builds upon several concepts floated in that symposium and seeks to answer the question: Can Boston reduce congestion on the Route 93 Southeast Expressway in both the short and long-term in an actionable, affordable, and effective manner to ease congestion and serve as the first step in reducing the emissions of Massachusetts' transportation sector in order to ensure that future GWSA emissions targets are achievable?

3. The Problem: Traffic Around Greater Boston

3a. The Problem

Boston has always been a city that revels in competition and celebrates its achievements. However, in 2017 Boston earned the dubious distinction of being one of the most traffic congested city in the United States – clearly not an achievement that residents or city officials will tout. Additionally, the portion of the Route 93 Southeast Expressway between downtown Boston and its southerly neighbor, Quincy, was rated by INRIX, a big-data company focused on macro-level traffic trends, as the 10th most congested road in the US (Figure 5). [18] Things are not trending in the right direction. Yet, this is not to say that Massachusetts has not taken proactive steps to ease traffic in the past, with the most notable example being the "Big Dig", a massive and controversial construction project that replaced an elevated six-lane highway that had previously cut through downtown Boston with a series of tunnels beneath the city. The project truly was massive, beginning in 1991 and finishing in 2006 at a cost of over $14 billion USD. [19] This project alleviated traffic in the short-term by all measurable criteria, but as any Boston driver can attest to, the medium and long-term alleviation has not proven effective. Only a decade removed

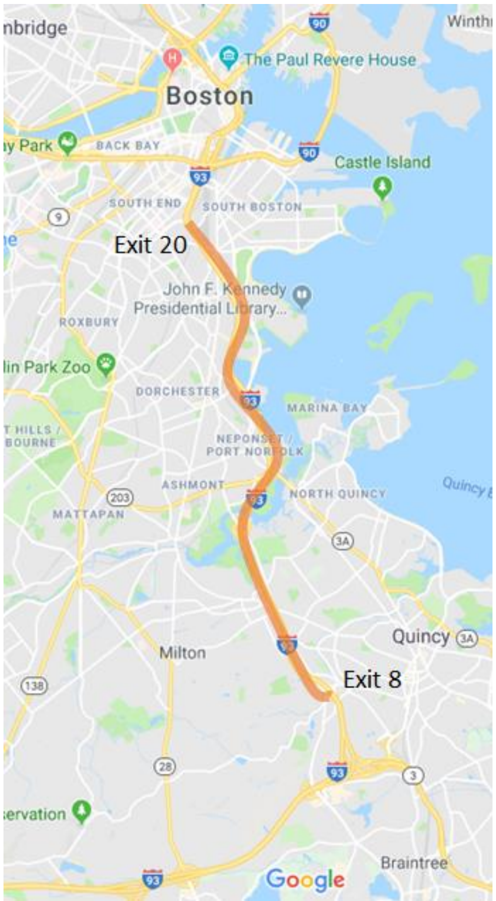

Figure 5: The High Traffic Area of Route Southeast Expressway, Boston, MA
Source: Google Maps

[18] Frias, Lauren. 2018. Boston Ranks Among the Top 10 Most Congested Urban Areas in the Country. Boston.com. https://www.boston.com/cars/car-news/2018/02/06/boston-traffic-congestion-worst. Accessed Feb 2018.
[19] Mass Dept. of Transportation. 2018. The Big Dig. Commonwealth of Massachusetts. http://www.massdot.state.ma.us/highway/TheBigDig/ProjectBackground.aspx. Accessed Mar 2018.

from the Big Dig, the city is again plagued by increasingly debilitating levels of congestion as well as the economic losses in dollars and time that go along with it. Besides the economic issues, increased traffic congestion is also a huge laggard on Massachusetts' ability to meet its GHG reduction goals as outlined in the GWSA, as well as a public health issue.

3b. How bad is Boston's traffic and who does it affect?

Traffic is bad now, and it is going to get worse. Boston drivers spent an average of 60 hours in rush-hour traffic in 2017, accounting for 14% of their total commute time. Additionally, per INRIX's ratings, Boston ranks #7 out of 297 cities in the US and #19 out of 1,360 cities globally for congestion. [20] To further complicate matters, Boston's population is predicted to grow by 5% and the total VMT are also expected to increase by 5% by 2030. [21]

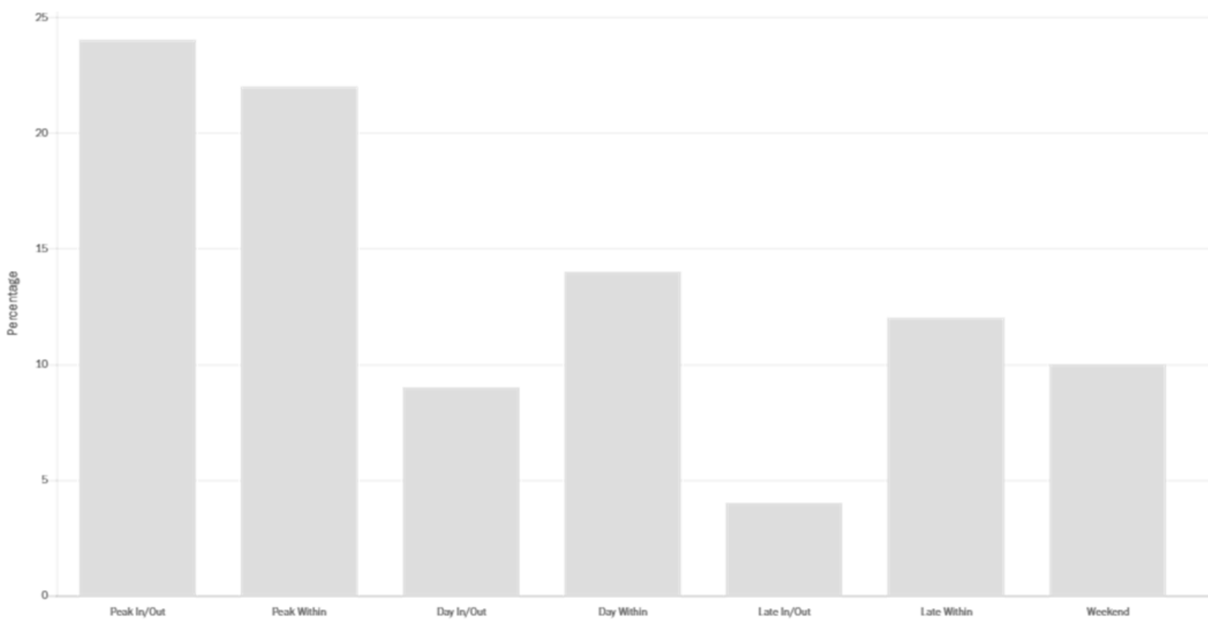

Figure 6: Boston Drivers Spend Most of Their Time Driving into or Out of the City Source: INRIX's Boston Scorecard 2017

[20] INRIX. 2018. Traffic Scorecard 2017: Boston. http://inrix.com/scorecard-city/?city=Boston%3B%20MA&index=19. Accessed Feb 2018.
[21] Slade, Rachel. 2017. Boston Traffic Sucks - Here's How to Fix it. Boston. https://www.bostonmagazine.com/news/2017/04/30/boston-traffic/2/. Accessed Jan 2018.

Figure 6 breaks down when and where people experience congestion during their commute around Boston. In/out refers to roads leading into or out of the city and within refers to roads within city limits. As shown, the worst congestion is on roads that lead into and out of Boston. Not surprisingly, the Route 93 Southeast Expressway falls into these categories.

3c. Traffic Congestion: A Non-Linear Problem

Much research has been done regarding the causes behind traffic. Pravin Varaiya, a professor at the University of California Berkley, defines congestion as "when traffic switches from a 60 mph, high-volume free-flow state to a chaotic, low-speed, low-volume glut of vehicles. The transition occurs when vehicle density (the number of vehicles per mile in a lane) exceeds a critical level." This same study highlights that "once traffic enters the congestion state, it takes a long time for it to return to free-flow." During observations in Los Angeles, Varaiya noted that traffic slowed below 60mph shortly after 5am, and it did not exceed 60mph again until approximately twelve hours later. [22]

Another important fundamental of understanding traffic is that it does not follow a linear scale. This non-linearity is a large cause of congestion since each car is affected by the car directly in front of it, and the car in front of it is affected by the one in front of it, and so on. This means that the amount of congestion caused by an extra 5% of cars is not equal to an increase in congestion of 5%, but instead has a much larger effect. Since non-linearity is a root cause of traffic, it makes sense that our solutions also must be non-linear. One way to use non-linear computations to alleviate traffic is by flipping the logic of previous studies around. For example, a 2005 study determined that "if travel demand (number of cars) increases by 2%, then traffic

[22] Varaiya, Pravin. 2005. What we've learned about highway congestion. Access: Number 27 Fall 2005. https://www.accessmagazine.org/wp-content/uploads/sites/7/2016/07/Access-27-02-What-Weve-Learned.pdf. Accessed April 2018.

congestion can be expected to increase by 10%." [23] Read another way, if you reduce the number of cars by 2%, you will see a decrease in congestion by 10%. This idea is corroborated in a joint study by MIT and University of California Berkley engineers who found that in Boston, removing a small percentage of cars from the road has a non-linear, exponentially greater effect on traffic alleviation than a standard, linear, 1 to 1 ratio. [24] Chris Dempsey, director of Boston's own Transportation for Massachusetts (T4MA) advocacy groups agrees with this logic, and is quoted in a Boston.com article as saying that "when you are way up that exponential (traffic congestion) curve, you only have to get a small number (of cars) off to drop the traffic way down. The rule of thumb that most economists use is if you can get 5% of the cars off the road, you can reduce your traffic by 20%. " [25]

3d. Traffic Congestion: A Supply vs. Demand Problem & The Perils of Lane Expansion

There are basic supply and demand forces at work in traffic congestion. According to Allyn West of the Houston Chronicle, "…the basic idea (behind the Fundamental Law of Road Congestion) is that the easier it is to drive, the more people will in fact, drive. By adding capacity (or supply) via widening a highway, you increase the attractiveness of driving, which induces more people to drive which then leads to similar levels of congestion in the long-run." [26] Houston is the poster-child of the futility of highway widening. Several billion dollars were spent in the early 2000's to widen the Katy Freeway to an incredible 26 lanes. At first the congestion eased as planned, but as more people saw the lack of congestion they decided it was okay to

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[23] Varaiya, Pravin. 2005.

[24] Wang, Pu. Hunter, Timothy. Bayen, Alexandre. Schechtner, Katja. Gonzalez, Marta. 2012. Understanding road usage patterns in urban areas. Scientific Research 2, Issue 1001. Doi:10.1038/srep101001. Accessed April 2018.

[25] De Costa-Klipa, Nik. 2018. Traffic congestion is taking a toll on Boston. Should Boston take a toll on congestion? Boston.com. https://www.boston.com/cars/car-culture/2018/02/20/boston-traffic-congestion-pricing. Accessed April 2018.

[26] West, Allyn. 2017. Adding lanes does not reduce congestion. So, what is TxDOT doing? Houston Chronicle. https://www.houstonchronicle.com/local/gray-matters/article/Why-TxDOT-s-upcoming-project-won-t-reduce-12287710.php. Accessed Mar 2018.

drive again and one by one, more cars joined the peak time commute until eventually the commute times were greater than they were before the project. Figure 7 shows this increase in commute times from 2011 to 2014. The construction of the new lanes was done less than 10 years prior, meaning that traffic alleviation in Houston was only achieved in the immediate short-term and traffic actually has gotten worse in the long-run. [27]

Houston is not the exception, it is the rule. All one must do is think of their hometown and a lane widening project - did it improve traffic in the long term? Likely not. A prime example is Boston and the aforementioned "Big Dig". While the project has had positive impacts on freeing up space in Boston and helping reconnect neighborhoods previously cut off by the central artery highway, the traffic during peak times is just as bad now, if not worse, than it was previously. About the closest thing to an "infinite" supply of road capacity is Houston's 26 lane highway - and even that became congested again within several years. Therefore, it is safe to say that the historical prescription of adding lanes to ease congestion is a losing battle and provides short-term gains at best. As mentioned in the previous section, large scale traffic is bad for the people who live near it, the people who sit in it, and the environment. Therefore, it is reasonable to conclude that adding lanes creates a long term *negative* effect on the surrounding area.

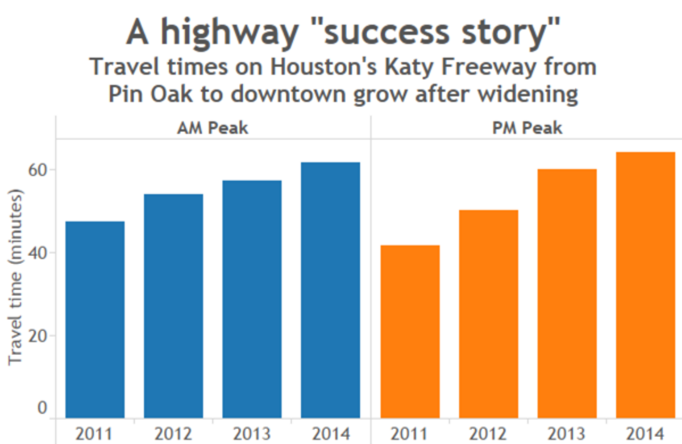

Figure 7: Widening Houston's Kate Freeway Led to More Traffic Source: City Observer 2017

[27] West, Allyn. 2017.

3e. Boston: A Growing City

The number of people who live and work in a city like Boston with a booming economy is not going to decrease anytime soon. The traffic problem will not be naturally resolved by people or jobs moving out of the city. Boston is home to 670,000 people, but the Greater Boston area is home to 4.7 million, making it the 10th largest metropolitan region in the US. In addition to total population, Greater Boston is the "4th most densely populated region in the US...with 13,841 people per square mile" according to The World Population Review's 2018 study. Also, according to this same study, Boston is truly a commuter city, with its population doubling from 670,000 to 1.2 million during daytime work hours. This influx of people into the metro area will only accelerate in the years to come as the local economy is expected to continue to grow at between 1.5 and 3% per year. [28]

3f. The Environmental Impacts of Traffic

Damage to the environment, and GHG emissions more specifically, are categorized often as externalities of human nature. The prominent economist Nicholas Stern, goes as far as to call GHG emissions the "biggest market failure the world has seen." [29] This market failure pertains to all human activities that emit GHG, however, nowhere is it more evident than when dealing with traffic congestion. If vehicles travel either very fast or very slow, they emit more GHG than when they travel at reasonable speeds (30 to 65 mph). This is best exemplified by a study by Matthew Barth and Kanok Boriboonsomsin (Figure 8). The premise is that when cars are

[28] The World Population Review. 2018. Boston. http://worldpopulationreview.com/us-cities/boston-population/. Accessed April 2018.
[29] Stern, Nicholas. 2008. The Economics of Climate Change. American Economic Review: Papers & Proceedings 98:2, 1-37. http://www.aeaweb.org/articles.php?doi=10.1257/aer.98.2. Accessed Mar 2018.

travelling less than 10 mph they emit almost double the CO2 they emit at 30mph. [30] This has serious implications for people both locally and globally, as GHG emissions are not localized in their effect and impact all of humanity. Environmental degradation has long been viewed as a local issue with local solutions, however, GHG emissions and the associated dangers of climate change have changed that notion. With each GHG gram emitted, the parts per million (PPM) of CO2 equivalent (CO2e) in the atmosphere increases. With each increase in PPM we face a greater risk of massively disruptive average global temperature rise. Table 1 gives Nicholas Stern's estimates (in percentage of likelihood) of exceeding different temperature thresholds at certain PPM measurements.

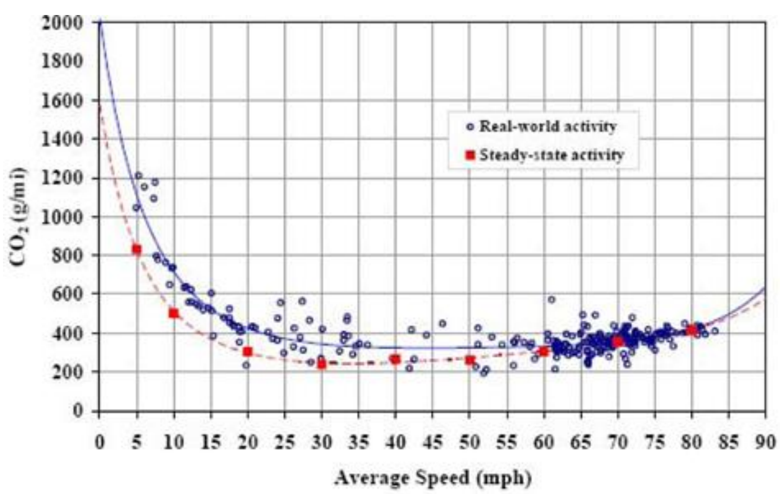

Figure 8: Emissions as a Function of Average Traffic Speed
Source: Barth, M. and Boriboonsomin, Kanok 2008

With the transportation sector recently taking over the top emitter ranking in the US for the first time, transportation sector emissions must be recognized as the serious threat they are to our efforts of staving off the worst effects of climate change. More specifically, traffic congestion must be recognized as a significant contributor to the total emissions of the transportation sector. By framing the problem in this manner, one can recognize that traffic congestion creates both local, regional, and global environmental and public health problems and therefore must be dealt with aggressive and innovative solutions. Policy makers and decision makers in Massachusetts

[30] Barth, M. and Boriboonsomsin, K. 2008. Real world carbon dioxide impacts of traffic congestion. Transportation Research Journal No 2058. Transportation Research Board of the National Academies. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013. Accessed Mar 2018

have found ways since 1990 to reduce emissions in other sectors, and now the same must be done in the transportation sector. To put off action further will jeopardize future attainment of the goals set forth in the GWSA and the well-being of the residents of Massachusetts.

Stabilization level (in ppm CO_2e)	2°C	3°C	4°C	5°C	6°C	7°C
450	78	18	3	1	0	0
500	96	44	11	3	1	0
550	99	69	24	7	2	1
650	100	94	58	24	9	4
750	100	99	82	47	22	9

Table 1: Likelihood (%) of Exceeding a Temperature Increase at Equilibrium
Source: Stern Review 2007

3g. The Economic Impacts of Traffic

Per a 2014 issue of The Economist, "A 2014 study published by Britain's Center for Economics and Business Research in conjunction with INRIX, estimated the cost of traffic congestion across four nations (France, Britain, Germany, and the US) by exploring three distinct categories: reduction in workforce productivity due to idle time in traffic; increased price of goods due to higher transport costs; and the carbon equivalent cost of emissions." The findings were startling: $200 billion across the four nations (0.8% of total GDP) was lost due to factors that could be placed in one of the three categories. These losses are expected to grow by about 50% in the next decade, with most being directly associated with wasted fuel and the opportunity cost of sitting in traffic. [31]

[31] W, C.S. 2014. The cost of traffic jams. The Economist. November 2014. https://www.economist.com/blogs/economist-explains/2014/11/economist-explains-1. Accessed Mar 2018.

To make this more Boston specific, the following facts are helpful to highlight: in 2017 the average driver in Boston accrued an estimated cost of $2,086 in wasted time/opportunity cost and vehicle costs (i.e. wasted fuel). On a macro scale, the total cost to the city in 2017 due to traffic-related issues was estimated at $5.7bn. This figure does not even factor in the costs due to traffic accidents, which, in 2010, were estimated to total $242bn nationwide, or the equivalent of about $800 per US resident. [32] When you combine the wasted time and fuel costs with the cost of accidents per driver, you get about $2,800 per Boston driver per year in added costs.

3h. The Social Equity Impacts of Traffic

The INRIX study captures the effects that congestion has on drivers, but what about the health effects on the residents who live alongside these congested highways? Over the years there have been several studies that have aimed to identify the public health risks associated with living near major roadways. In 2010, a literature review of such studies, conducted by the non-profit, independent research organization Health Effects Institute, found that there is a quantifiable increase in the instances of negative health episodes and diagnoses in people residing within 500m (approximately ⅓ of a mile) of a major roadway. [33] Negative health episodes, in this study, are things ranging from early onset asthma, to cardiovascular risk, to shortened adult lifespans. Some studies have gone a step further and found causal links between infant mortality numbers and the proximity to a major roadway. The most famous of these studies was completed in 2009 and found that when New Jersey implemented the electronic toll collection system (E-ZPass), traffic congestion around toll booths was greatly reduced thus

[32] Blincoe, L.J., Miller, T.R., Zaloshnja, E. & Lawrence, B.A. 2015. The economic and societal impact of motor vehicle crashes, 2010. Report No DOT HS 812 013. Washington, DC: National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013. Accessed Mar 2018.

[33] HEI Panel on the Health Effects of Traffic-Related Air Pollution. 2010. Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects. Health Effects Institute. https://www.healtheffects.org/system/files/SR17Traffic%20Review.pdf. Accessed Mar 2018.

reducing emissions. This in turn reduced prematurity and low birth weight among mothers who lived within 2 kilometers (approximately 1.2 miles) of a former toll booth site by about 10%. [34] California has taken these findings seriously and undertaken proactive legislation that prevents new schools from being built within 500 meters (1/3 of a mile) of major highways. [35] As shown in several other studies, homes near public transportation are valuable, but homes too close to heavily congested highways tend to be less valuable on average. Route 93 is a bit of an outlier in this sense, as most homes along it do not exemplify the overtly negative home valuation to congested highway proximity relationship we see in other cities since it passes through desirable commuter suburbs such as Quincy. However, when looking at median rent prices along the Route 93 corridor from exit 20 to exit 8 via Trulia's Interactive Price Map, one can see a gradual rise in median rent as you move further away from the highway. [36] There also are a much higher number of renters than homeowners closer to the highway. Again, while not as noticeable as the massive dip in home prices one may see along other congested highways in the US, the slightly reduced rent, the higher prevalence of renters versus homeowners, and the well-studied negative health effects all point in the direction that lower income people, children especially, suffer greater exposure to harmful air pollutants from traffic than do the wealthy, along Route 93's Southeast Expressway corridor. [37]

Another way in which low income residents are impacted by congestion, according to Michael Manville, professor of urban planning at UCLA's Luskin School of Public Affairs, is

[34] Currie, Janet and Walker, Reed. 2009. Traffic Congestion and Infant Health: Evidence from EZ-Pass. American Economic Journal Applied Economics 3(1): 65-90. October 2009. https://www.researchgate.net/publication/227346520_Traffic_Congestion_and_Infant_Health_Evidence_from_E-ZPass. Accessed April 2018.

[35] Brugge, Doug; Durant, John; Rioux, Christine. 2007. Near Highway Pollutants in motor vehicle exhaust: A review. Environ Health. 2007. 6:23. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1971259/ Accessed April 2018.

[36] Trulia Housing Pricing Map. 2018. https://www.trulia.com/home_prices/Massachusetts/Boston-heat_map/. Accessed Mar 2018.

[37] Salomon, Sanjay. 2015. Boston Renters are stuck in a vicious spiral. Boston. http://realestate.boston.com/news/2015/07/31/boston-renters-are-stuck-in-a-vicious-spiral/. Accessed Mar 2018.

that the poorest people generally cannot afford cars and are reliant upon buses and other forms of public transportation. These buses then sit in the same traffic congestion as single-occupancy cars, thus not providing any true time benefit to those who ride the bus.[38] Furthermore, lower income people tend to have a smaller carbon footprint than the wealthier, meaning they contribute less to GHG emissions but are impacted more by the negative outcomes associated with climate change and air pollution.

3i. A Summary of the Problem and Metrics for Success

The purpose of this paper is to provide actionable solutions aimed at reducing the number of cars along Boston's busiest highway (The Route 93 Southeast Expressway) by 5% during peak time in order to experience non-linear traffic flow improvements. This has both short term goals and long-term goals and metrics for success:

Goals

- Short-term: Free up traffic along this one road to ease congestion in and around Boston which in turn improves the economic well-being of citizens and the public health of low-income citizens who live near the highway.
- Long-term: Serve as the first step in an actionable, affordable, and effective plan to reduce the emissions in Massachusetts' transportation sector in order to ensure that future GWSA emissions targets are achievable.

Metrics for Success

- Total number of cars per hour between exit 20 and exit 8 during peak times reduced by at least 5% in the short and long-term.

[38] Manville, Michael. 2017. Is congestion pricing fair to the poor? 100 Hours. https://medium.com/100-hours/is-congestion-pricing-fair-to-the-poor-62e281924ca3. Accessed Jan 2018.

4. The Solution Part 1: Bus Rapid Transit

4a. What is BRT?

Bus rapid transit, or BRT, is public transportation that "weaves together elements of bus and rail to create a unique mode of transportation with high levels of speed, capacity, and comfort", according to the Boston BRT Advisory Committee's website. [39] What does this mean?

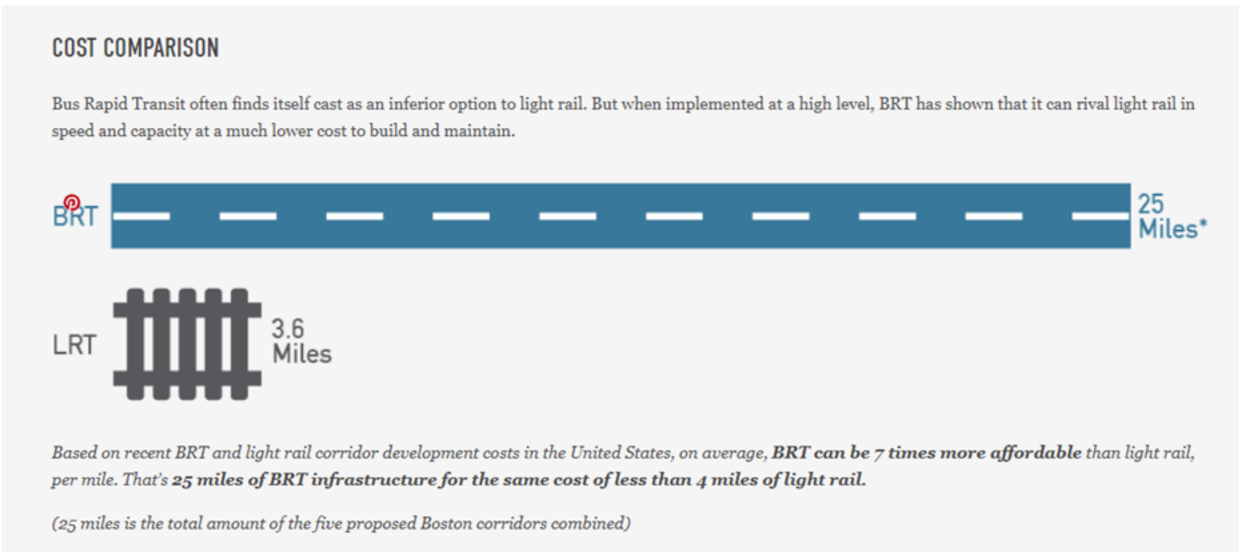

Figure 9: Cost Comparison BRT vs. Light Rail
Source: Boston BRT 2017

[39] Boston BRT Committee. 2017. Boston BRT: The Benefits of BRT. http://www.bostonbrt.org/benefits-of-brt/. Accessed January 2018.

In short, BRT uses existing roadways and existing buses and cordons off an entire lane of said roadways and dedicates it solely to BRT buses, thus creating a dedicated "track" similar to light rail. Hence, you get the speed of light rail at a fraction of the cost because you are using buses instead of train cars and asphalt instead of costly and maintenance-heavy rail tracks. The cost savings are also impressive; BRT tends to be about seven times more cost-effective than light rail (Figure 9).

This is a simplified explanation of BRT, but it helps give an overarching idea of what a BRT system is and what it looks like. However, BRT is not as simple as dedicated bus lanes. Instead, it is an aggregation of smart public transportation methodologies synergized to create a unique, affordable, clean, and efficient mode of transportation. It also seeks to reduce the negative stigma of riding the bus by creating stylish stations that blend into their respective neighborhoods.

There are five essential elements of BRT, which are explained in detail in the 2015 Boston BRT Report and paraphrased in the following five bullet points. Additionally, the elements of BRT are exemplified by a picture of BRT in action in Ecuador below the bullet points. [40] [41]

- *Dedicated Right of Way*. BRT must have a dedicated right of way lane that is closed to all other traffic. This can be done via physical boundaries and/or enforcement. This allows unimpeded travel for BRT vehicles that mimics a rail line and allows for smooth and fast movement of the vehicles.

[40] BostonBRT: The Greater Boston BRT Study Group. 2015. BRT Report: The potential for Gold Standard bus rapid transit across the metropolitan area. https://static1.squarespace.com/static/54784f54e4b01fb132fab284/t/555a5ed1e4b04d1c654a4f1c/1431986086477/The+BRT+Report. Accessed January 2018.
[41] What is BRT? 2018. Institute for Transportation and Development Policy. https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/what-is-brt/. Accessed March 2018.

- *Busway Alignment.* BRT lanes that avoid conflict with other modes of transportation (cars, pedestrians, bicycles etc.) are crucial. Often times the most successful BRT lanes are center lanes that sit in the middle of a two lane road in order to best deconflict with other transportation modes and allow dual side boarding.
- *Off-Board Fare Collection.* Advance payment, as opposed to the current bus structure of each customer paying upon entrance, greatly reduces time spent boarding, speeds up transit times greatly, and negates the problem of producing a payment method on the spot.
- *Intersection Treatments.* Wait times at intersections are another main time drain for current bus systems. These wait times can be reduced several ways, including but not limited to: making it illegal to turn across the BRT lane, reducing the number of traffic signals along the route and/or assigning traffic signal priority to BRT.
- *Platform-level Boarding.* This is a fancy way of saying that there are no steps up required as in a conventional bus nor are there gaps between the platform and the bus itself that could pose a tripping hazard. This helps all passengers, especially those with strollers, wheelchairs, or with limited mobility, board quickly and comfortably. [42]

[42] BostonBRT: The Greater Boston BRT Study Group. 2015.

Figure 10: Essential Elements of BRT in Ecuador
Source: ITDP 2018

In addition to these five essential elements, BRT systems are further categorized via a rating scale ranging from Gold (85-100 points), Silver (70-84), Bronze (55-69), or Basic (less than 55 points). This scoring system was created by a panel of international experts in 2010 and the rating for a particular system depends on how well each of the five elements of BRT are achieved in a respective city's BRT system, as well as other factors such as: service planning, infrastructure, bus station setup, communications, and access and integration. Points can also be deducted for things such as: overcrowding, under usage, bus bunching, or lack of enforcement for right of way lanes. [43] (A comprehensive overview of the scoring system is not necessary for this paper, but for further review of said system, one can download The BRT Standard Report on the Institution for Transportation & Development Policy's (ITDP) website)

4b. Case Study: BRT in Mexico City

With a metro population of over 21 million people and old, narrow streets, Mexico City was a formidable task for BRT. However, BRT has met, and largely exceeded expectations in

[43] ITDP. 2014. The BRT Standard. https://www.itdp.org/wp-content/uploads/2014/07/BRT-Standard-20141.pdf. Accessed March 2018.

ridership, efficiency, improved traffic flow, and higher air quality in vicinity of the corridors. With over 850,000 riders per day on 65 miles of BRT routes, many travel times have been cut in half. [44] Additionally, a study by Metrobus suggests that air pollution has been cut by 35%, 122,000 tons of CO_2 per year avoided, and traffic accidents have decreased by 54% since BRT was put into place. Creating BRT in Mexico City was a way to reduce traffic congestion as well as improve air quality. The project was launched in 2005 for a relatively modest price tag of $80 million USD to build stations, lanes, and buses. [45] Traffic flowed easier due to the BRT lanes because buses were not slowed down by cars, and car traffic flowed easier because cars were not hindered by buses making frequent stops on the road's shoulder. [46]

The reduction in GHG emissions was due to two complementary factors. The first is that upon securing funding for BRT, Metrobus replaced "older, obsolete, polluting buses with higher capacity, low emission buses." Surprisingly, the buses in Mexico City are not hybrid, electric, or compressed natural gas (CNG). Instead, they are Low Carbon Emissions Buses (LCEB), which are diesel buses manufactured in Europe but advertised to emit approximately 30% less GHG than traditional diesel buses. [47] Mexico City, along with 18 other Latin American cities signed The Clean Bus Declaration in 2015 which codified their commitment to transitioning fully to zero, or near zero-emission fleets but have not yet made as much progress as envisioned. This lack of progress has been mainly due to the higher cost of electric or hybrid buses (sometimes upwards of two times more expensive than a regular diesel or CNG bus) and a general political

[44] BostonBRT: The Greater Boston BRT Study Group. 2015.
[45] Schipper, L., Deakin, E., McAndrews C., Scholl, L., Trapenberg, K. 2009. Considering Climate Change in Latin American and Caribbean Urban Transportation: Concepts, Applications, Cases. University of California, Berkeley. Report by the Center for Global Metropolitan Studies. Transportation Research Record: Journal of the Transportation Research Board. Volume 2191. https://doi-org.ezproxy.library.tufts.edu/10.3141/2191-16. Accessed March 2018.
[46] Bel, Germa and Holst, Maximimilian. 2018. Evaluation of the impact of bus rapid transit on air pollution in Mexico City. Transport Policy. Volume 63, April 2018, pages 209-220. https://doi.org/10.1016/j.tranpol.2018.01.001. Accessed March 2018.
[47] Low Carbon Vehicle Partnership. 2018. What is a low carbon emission bus? https://www.lowcvp.org.uk/initiatives/lceb/what-is-lceb.htm. Accessed April 2018.

fear of placing stock in relatively new technology. [48] Yet, the fact that Mexico City and most other Latin American cities with BRT have not transitioned fully yet to hybrid or electric buses, but still have seen noticeable improvements in air quality, is encouraging. The current GHG emissions savings per year of 122,000 tons has been accomplished with diesel buses. Electric buses emit about 5 times less GHG, therefore once Mexico City transitions to a fully electric fleet, as they have pledged to do, the total GHG emissions reductions per year could amount to over 500,000 tons GHG. [49]

The second factor which attributed to emissions reductions in Mexico City is directly relatable to solving our Route 93 traffic issue in Boston and is quite exciting. It is as follows: once BRT began to meet and exceed expectations in Mexico City, there was a behavioral shift in the sense that car owners shifted their transportation preference from their own private vehicles to BRT. At last estimate, 15% of BRT riders in Mexico City are also car owners. [50] [51] This modal shift was due largely to the immense travel time savings that BRT riders experienced (upwards of 40%), and the inherent fuel savings realized by not driving. [52]

In addition to the large-scale GHG reductions along the actual BRT corridors, the city's overall air quality also saw a marked improvement up to 10km away from each respective BRT corridor. Using 78 monitoring stations throughout the city, significant reductions in carbon monoxide (~6%), nitrogen oxides (~5.5%), and particulate matter of less than 10 micrograms per

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[48] Castellanos, Sebastian and Maassen, Anne. 2017. The City Fix by World Resources Institute. http://thecityfix.com/blog/whats-holding-back-latin-american-cities-clean-bus-transition-sebastian-castellanos-anne-maassen/. Accessed April 2018.
[49] Aber, Judah. 2016. Electric bus analysis for New York City Transit. New York City Transit and Columbia University. http://www.columbia.edu/~ja3041/Electric%20Bus%20Analysis%20for%20NYC%20Transit%20by%20J%20Aber%20Columbia%20University%20-%20May%202016.pdf Accessed April 2018.
[50] BostonBRT: The Greater Boston BRT Study Group. 2015.
[51] City of Mexico: Metrobus. 2018. Metrobus project certified by UN Clean Development Mechanism. http://www.metrobus.cdmx.gob.mx/dependencia/acerca-de/reduccionemisiones. Accessed March 2018.
[52] New York City Global Partners. 2012. Best Practice: Metrobus Rapid Transit System. http://www.nyc.gov/html/ia/gprb/downloads/pdf/Mexico%20City_Metrobus.pdf. Accessed April 2018.

cubic meter (~8%) were annotated over a two-year study. [53] One notable difference between Mexico City and Boston is that this example of BRT is inside the city, whereas this paper examines the positive aspects of BRT along a major highway leading to and from the city. However, the positive outcomes of BRT in Mexico City: the relative low cost, the GHG reductions in CO2, NOx, and PM10, and the high demand/ridership all also apply to Boston.

Furthermore, it is important to note that Mexico City undertook this venture in 2005. This timeframe shatters the often-held idea that BRT is a pipedream or a thing of the future. In fact, BRT is rather old news in Latin-America. In Latin-America there are currently "...over 60 cities using BRT, moving about 20 million people each day; that is 62% of global demand for BRT." The US lags behind, with its total BRT daily passenger rides making up only 3% of global demand. Of this demand, New York City makes up about 60% of the total US ridership. Smaller cities like Alexandria, VA only move about 1,000 passengers per day but still exemplify another attractive attribute of BRT which is its scalability, due mostly to its relative low-cost and flexible use of infrastructure. [54]

4c. Could BRT work in Boston?

While the 15% shift in personal vehicle usage to BRT ridership that Mexico City experienced might be a bit overzealous for Boston, there is an appetite for BRT in Boston as evidenced by the multiple pilot programs being phased in in 2018. Of the 17 US cities with BRT, not a single Gold Standard system exists. This opens the door for Boston to seize on this opportunity to become a world leader once again in public transportation. Boston does not have a true BRT system, but it does have the Silver Line (not to be confused with a Silver rating). The

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[53] Bel, Germa and Holst, Maximimilian. 2018.
[54] BRT Data. 2018. BRT Data for North America. https://brtdata.org/location/northern_america/united_states. Accessed March 2018.

Silver Line in Boston is an example of partial BRT but does not qualify for even Basic BRT status. The Silver Line connects portions of downtown Boston with one another and also offers service to Logan International Airport. I refer to it as a partial BRT experience because it only has certain elements of BRT and those elements are only available during certain stretches of its route. For example, there exists a dedicated right of way lane when the route goes

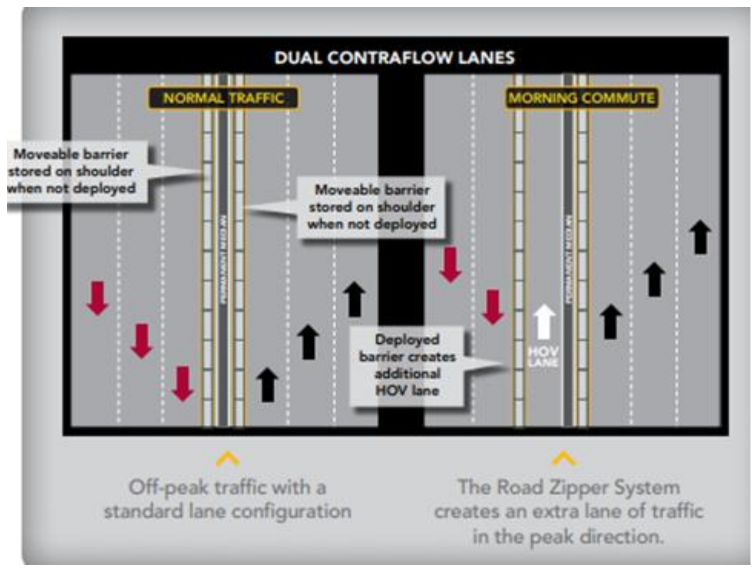
Figure 11: The Silver Line
Source: MassDOT 2009

underground (Figure 11) but once it comes back to street level it is mainly integrated with the normal traffic flow. It also does not have central lane bus stations, as shown in the Ecuadorian BRT picture. Of note, the portions of the Silver Line that have one or more BRT basic elements are rated the highest amongst riders. [55] The important takeaway from this partial BRT service is that people respond very positively to BRT elements and there is an appetite amongst public transit users in metro Boston for the benefits that BRT brings.

The Massachusetts Bay Transportation Authority (MBTA) recognizes this demand, and is planning to implement BRT pilot programs along three strategic corridors around the Boston metro area during 2018, in the cities of Arlington, Cambridge, and Everett. These pilot programs will show passengers the benefits of BRT by transitioning several miles of existing bus lines into partial BRT services. Everett, for example, will enhance its dedicated right of way bus lane, implement platform level boarding, and configure certain traffic lights to give southbound buses

[55] BostonBRT: The Greater Boston BRT Study Group. 2015.

(towards Boston) priority during peak times. [56] None of the pilot programs implement even the five Basic Elements of BRT, let alone approach the Gold Standard argued for in this paper. Of course, these pilot programs are not permanent solutions, instead they are intended to be information gathering programs that can lead to future improvements in the Boston area public transit system. The significance of these pilot programs should not be overlooked, as they signal a normative shift in the acceptance of, and desire for a better public transit system such as BRT. This demand for BRT in and around



Figures 12 and 13: The Road Zipper and Movable Barriers to Form Temporary HOV Lanes
Source: Barrier Systems 2010

Greater Boston is a vital driver for change. It means people are fed up with traffic congestion and want to try a new approach to dealing with it. Tackling the traffic congestion problem inside a city is important of course, but countering that traffic before it ever reaches the city is even better. The number of people living in, and commuting to, Boston is only going to increase in the coming years. Therefore, we must seek to proactively solve this solution in the present and in the future. Fortunately, there exists an opportunity to do so.

[56] BostonBRT. 2018. http://www.bostonbrt.org/local-pilots/.

This paper proposes that a fourth BRT pilot program should be undertaken along the Route 93 Southeast Expressway, in addition to the other three planned for Everett, Arlington, and Cambridge. There already exists a vehicle called a "Road Zipper" (Figure 12) that operates between Exit 15 and Exit 7 during peak hours to add an extra lane for either Northbound traffic during the morning commute or southbound traffic for the afternoon commute. It does this by moving the centerline barriers depending on the predicted flow of traffic (Figure 13). However, from our previous discussion about the supply and demand relationship between capacity and usage, we know that adding an extra lane, even in such an ingenious way, does not solve our congestion issues. [57] For the BRT pilot program to work, the highway lanes that are currently turned into morning or evening-commute HOV lanes by the Road Zipper should be converted to BRT lanes. Many people will object to the transition of the HOV lane to BRT, claiming that the HOV lane provides an integral service and frees up traffic. However, the HOV lane does not actually handle nearly as much traffic as one might think. According to data from the Massachusetts Department of Transportation's Highway Division and Boston's Central Transportation Planning Staff (CTPS), there are approximately 108,000 cars each day travelling south on the Route 93 Southeast Expressway by exit 15, where the HOV lane starts. Of these 108,000 cars, only 4,500 or 4.2% divert to the HOV lane. [58] Counting the HOV lane, there are 5 total lanes on each side of the highway. This means that the other four lanes handle 95.8% of the traffic and thus the HOV lane makes traffic congestion worse by placing a greater burden on the other lanes to handle traffic. This is in line with the findings of a 2005 study in California in

[57] Road Zipper. 2015. Boston I-93 HOV Lane. Lindsay Company. http://www.barriersystemsinc.com/stuff/contentmgr/files/0/c0a0053d6a03f88d12ab6702fd439dc7/files/boston_hov_lq.pdf. Accessed April 2018.

[58] Central Transportation Planning Staff. Traffic Flow Diagrams. http://www.ctps.org/data_resources. And here for the actual diagram: ftp://ctps.org/pub/Express_Highway_Volumes/19_I93_Southeast.pdf. Disclaimer: This data is from 2010. It is the last data that I could find, however I would assume that the actual total traffic numbers are even higher now since people cut back on driving a bit immediately after the Great Recession.

which nearly 26,000 underground sensors were used to measure traffic flows. The findings confirmed that the negative effects of the HOV lane outweigh the positive carpooling effects and that traffic flows better when no HOV lane exists at all (Figure 14). [59]

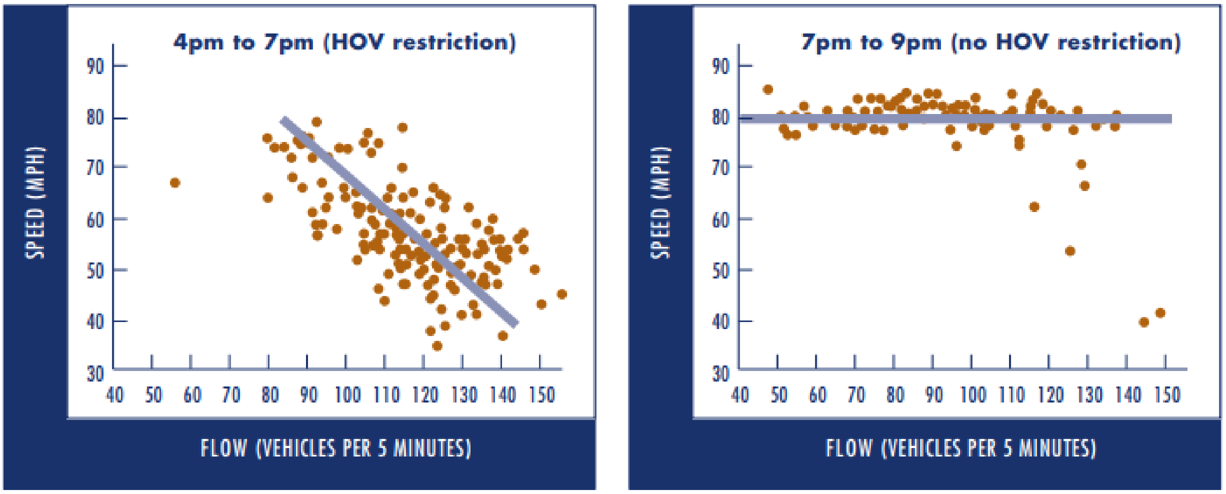


Figure 14: The Negative Effects of the HOV Lane
Source: Varaiya 2005

During the pilot BRT buses can use special access ramps from the existing bus terminal at South Station to get on Route 93 and then cycle into the BRT lanes. (Appendix A maps out South Station as well as an area where more movable barriers would be needed). As seen in figures 12 and 13, there are already movable barriers on each side of the highway that can be easily moved to create dual-BRT lanes. This is especially helpful because one of the downsides to BRT is that it's sometimes underutilized during off-peak hours. The movable barriers ensure that when BRT is not in high-demand, say during off-peak hours, the highway can resort back to its normal lane structure. The common retort about using BRT during peak-times is that it is taking away a potential lane of traffic when commuters need it most. However, we know from experience (Houston and it's 26 lane highway) that widening a road by adding a lane does not make a difference in the medium or long-run - it provides some short-term relief at best. Using

[59] Varaiya, Pravin. 2005.

the Road Zipper to add an HOV lane to a respective side of the Route 93 Southeast Expressway is the same concept, as any driver that has driven on the highway recently knows that the HOV lane is just as congested many days as the single-occupancy lanes.

Finally, any BRT solution should include electric or at the very least, hybrid buses to ensure that GHG and particulate matter reduction is maximized. Mexico City, along with the other Latin American cities mentioned earlier, has made great strides in its implementation of BRT, but has left much to be desired regarding the type of buses selected. The demand for electric buses in Massachusetts to reduce GHG emissions and improve air quality for low-income residents who live near busy roads, has been growing for several years, culminating in a 2017 letter signed by 19 mayors (including Mayor Walsh of Boston) sent to Stephanie Pollack, Massachusetts's Secretary of the Department of Transportation. The letter, which reads: "…transitioning to zero-emission electric buses will improve public health, especially in low-income communities most affected by traffic-related pollution" calls for a commitment by the state to electrify all bus fleets by 2030. [60] This kind of forward thinking by regional leaders and stakeholders must be extended to the electrification of the BRT fleet from the program's outset.

4d. Benefits and Costs of BRT

Benefits

- An actual medium and long-term traffic congestion solution
- Scalable and inexpensive to build, ride, maintain, and repair. With the movable barriers, the infrastructure for a pilot program is already largely in place.
- Reduction in air pollution and climate change-causing GHG emissions

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[60] Kotsopoulos, Nick. 2017. Worcester mayor joins call for all-electric bus fleets. Worcester Telegram. http://www.telegram.com/news/20170914/worcester-mayor-joins-call-for-all-electric-bus-fleets. Accessed April 2018.

- Socially and environmentally equitable
- Lowers emissions of transportation sector to help achieve Massachusetts' GWSA
- If the BRT Gold Standard is pursued, it will be the first such system in the US, putting Boston again at the forefront of public transportation

Costs

- Requires political will
- Removing the HOV/zipper lane will lack popular support at first
- Potential for lack of riders during non-peak times and overcrowding during peak times
- Potential for the traffic congestion to occur further south, BRT may just push the problem further away.

5. The Solution Part 2: Congestion Pricing

5a. What is Congestion Pricing?

Traffic is essentially a physical manifestation of a market failure or market inefficiency. Roads are free for all to use during all times of the day. Any desirable good that is underpriced (or free) tends to "sell" quickly, and a supply shortage ensues. The shortage in this case is the availability of physical space to allow vehicles to travel at a constant, and acceptable speed. [61] Congestion pricing is a toll, or a payment, which corrects this inefficiency by charging people a price to use the road commensurate with the demand. By linking the amount charged to the demand and supply of the roads, the market can naturally find an equilibrium price that people will pay. Congestion pricing is versatile and "can take many forms according to the time of day,

[61] Manville, Michael and Goldman, Emily. 2017. Would congestion pricing harm the poor? Do free roads help the poor? Journal of Planning Education and Research.
http://journals.sagepub.com.ezproxy.library.tufts.edu/doi/pdf/10.1177/0739456X17696944
DOI: 10.1177/0739456X17696944. Accessed April 2018.

road type, vehicle characteristics, and even current/real-time traffic conditions" according to de Palma and Lindsey. [62] To better understand how congestion pricing works, table 2 shows an actual congestion pricing mechanism used in Stockholm, Sweden. The first column shows the price (in Euros) to enter Stockholm city limits during different times of the day from 2006-2015, and the second column shows a recent price increase in 2016. Congestion pricing is technologically feasible now, and has been for quite some time. Many US states, Massachusetts included, have systems such as E-ZPass that electronically deduct tolls when drivers pass automated toll collection areas. The automated collection aspect of congestion pricing is easy and straightforward for both the user and the collecting agency. Where congestion pricing differs from the standard collection points along major highways is that instead of a flat rate, congestion pricing implements dynamic pricing to reflect demand. Congestion pricing has been shown to vastly reduce traffic and ease air pollution and GHG emissions, thus improving the lives of those that live near busy roadways. In one such study, ambient air pollution was reduced by between 5-15%, and

Stockholm Time	Inner-city cordon Introduced 2006	Inner-city cordon Introduced 2016
06:30–06:59	1.0	1.5
07:00–07:29	1.5	2.5
07:30–08:29	2.0	3.5
08:30–08:59	1.5	2.5
09:00–09:29	1.0	1.5
09:30–14:59	1.0	1.1
15:00–15:29	1.0	1.5
15:30–15:59	1.5	2.5
16:00–17:29	2.0	3.5
17:30–17:59	1.5	2.5
18:00–18:29	1.0	1.5
18:30–06:29	0	0

Table 2: Congestion Pricing in Stockholm, Sweden 2006 - 2016
Source:Borijesson, M. and Kristoferrson, J. 2018

[62] de Palma, A. and Lindsey, R. 2011. Traffic congestion pricing methodologies and technologies. Transportation Research Part C Emerging Technologies. Volume 19 Issue 6 pages 1377-1399. https://doi.org/10.1016/j.trc.2011.02.010. Accessed April 2018.

associated with a significant decrease in the rate of asthma attacks in local, young children. The same study observed that "given the sluggish adjustment of health to pollution changes, short-run estimates of pollution reduction may understate the long-run health benefits." [63] Congestion pricing leads to "reduced travel volumes and CO_2 emissions at relatively low net costs", according to the International Transport Forum. [64] Simply relying on greater fuel efficiency or infrastructure improvements to reduce GHG in the transportation sector has not, and will not be sufficient to meet Massachusetts's aggressive GWSA goals. Instead of focusing on supply, the demand side of the equation (in the form of congestion pricing) must be directly engaged to cut GHG emissions. [65]

5b. Case Study: Congestion Pricing in Stockholm

In 2006 Sweden introduced congestion pricing in and around the city of Stockholm. [66] This system has proven to be very successful at reducing traffic congestion and was expanded in 2016. [67] The results were threefold: First, congestion pricing had immediate initial positive effects in reducing traffic. Second, the reduction in traffic has become more pronounced with time. Third, public support for the toll grew rather quickly once people saw the positive effects.

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[63] Simeonova, E., Currie, J., Nilsson, R., Walker, R. 2018. Congestion pricing, air pollution, and children's health. National Bureau of Economic Research. Working Paper 24410. http://www.nber.org/papers.w24410. Accessed April 2018.

[64] International Transport Forum. 2010.

[65] International Transport Forum. 2010.

[66] Swedish Transport Agency. What does it cost to run the congestion tax? Transport Agency Website. https://www.transportstyrelsen.se/sv/Press/Kommentarer-och-fortydliganden/Vad-kostar-det-att-ta-ut-trangselskattinfrastrukturavgift-/. Accessed April 2018. This website can be translated into English for 2013 numbers. The 2016 numbers are found in a separate PDF that is not translatable but I was able to find the figures. https://www.transportstyrelsen.se/globalassets/global/om_oss/finansiering/arsredovisning/arsredovisning-2016.pdf.

[67] Borjesson, M. and Kristoffersson, I. 2018. The Swedish congestion charges: Ten years on. Transportation Research Part A: Policy and Practice. Volume 107, January 2018, pages 35-51 https://www-sciencedirect-com.ezproxy.library.tufts.edu/science/article/pii/S0965856417300782. Accessed April 2018.

[68] To better understand how and why congestion pricing works to reduce traffic, several studies have measured the price elasticity of demand and how it pertains to traffic, and more specifically, congestion pricing in Stockholm.

First, price elasticity refers to the economic observation that people's demand for a product is best represented by how much they value the product and how much they are willing to pay for it. If a product is said to be elastic then it means that as the price goes up, people are less likely to buy it because they have other options or do not require it enough to pay the higher price. A chocolate bar is an example of an elastic good. On the other hand, a product is inelastic if the demand for the product remains largely the same even with an increase in price. Water is an example of a largely inelastic good. An elastic product is represented as a value greater than 1.0 while an inelastic product is represented by a value of .99 or less. The further you get from these middle points, the more elastic or inelastic a product is. Traffic can also be measured in elasticity in the sense that each person might value their decision to drive differently. The person out on a joyride has a much more elastic demand for driving than the person driving their ill spouse to the hospital. Likewise, the demand to drive for a daily commuter who has access to safe, reliable, and efficient public transportation is likely to be more elastic than someone who lives far away from public transportation.

In the case of Stockholm, we can decipher some interesting long-term trends in the elasticity of demand to drive due to congestion pricing. Table 3 is a compilation of all the data needed to make elasticity calculations. The rows: "Elasticity Charged Hours Total" and "Elasticity Charged Hours Private" are the two most important for our discussion. (Note: elasticity is treated as an absolute value, hence -1.57 in this table is not a negative elasticity and

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[68] Borjesson, M., Eliasson, J., Hugosson, M.B., Brundell-Freij, K. 2012. The Stockholm congestion charges - 5 years on. Effects, acceptability, and lessons learnt. Transportation Policy. Volume 20, March 2012. pages 1-12. 10.1016/j.tranpol.2011.11.001. Accessed April 2018.

instead reads simply as 1.57. The important part is what side of the absolute value of 1 a given elasticity falls on and how close or far from 1 it is) The term “total” refers to all vehicles and “private” refers to private vehicles.

	2005 (without)	2006 (with)	2007 (with)	2008 (with)	2009 (with)	2010 (with)	2011 (with)	2012 (with)	2013 (with)	2014 (with)
Total effect on traffic volume from external factors		0.51%	2.70%	3.15%	4.61%	3.59%	3.93%	3.50%	6.13%	8.51%
Real average trip cost excluding the charge (EUR)	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
Charged hours: total										
Traffic volume across the cordon adjusted to 2005 levels wrt external factors (veh/h)	37 291	29 324	29 514	29 601	29 162	29 280	28 526	28 128	27 439	27 283
Non-exempt traffic volume across the cordon adjusted to 2005 levels wrt external factors (veh/h)	30 021	21 114	21 783	21 614	20 839	21 153	20 721	20 843	20 697	20 550
Real average charge (EUR)		1.28	1.06	1.04	1.06	1.03	0.99	0.94	0.92	0.91
Elasticity charged hours		*−0.87*	*−0.93*	*−0.96*	*−1.05*	*−1.03*	*−1.13*	*−1.16*	*−1.21*	*−1.24*
Charged hours: private										
Traffic volume across the cordon adjusted to 2005 levels wrt external factors (veh/h) *private*	25 140	13 287	12 875	12 458	11 082	11 678	11 368	11 906	11 956	11 747
Real average charge private (EUR)		1.28	1.06	1.04	1.06	1.03	0.99	0.94	0.92	0.91
Elasticity charged hours private		*−1.57*	*−1.93*	*−2.06*	*−2.36*	*−2.26*	*−2.43*	*−2.38*	*−2.42*	*−2.49*

Table 3: Elasticity of Driving Demand With Congestion Pricing in Stockholm
Source: Borijesson, M. and Kristoferrson, J. 2018

The elasticity for private vehicles in the long-term has shifted from 1.57 in 2006 to 2.49 in 2014, meaning that private driving in Stockholm has become much more elastic over the last ten years since the congestion pricing system was put into place. The elasticity for all traffic (i.e. freight etc.) shifted from an inelastic position of .87 in 2006 to an elastic value of 1.24 in 2014, implying that over the long-term all drivers are more responsive to road pricing and thus they are more judicious about when they drive and they seek out alternate modes of transit for themselves and their goods. While the inelastic value of .87 in the first year of congestion pricing is at first glance surprising, it should not be as it reflects the inability of people to change certain driving habits (such as freight transport) in the short term. Conversely, the trend towards greater elasticity in the long-term accurately reflects people's ability to change their habits over a longer time horizon. Other studies corroborate this finding. In one such study focused on Singapore's foray into congestion pricing, it was found that "long-term elasticity to road pricing is about 42% higher than the short-term value." [69]

To address the findings in Stockholm that the public approves of congestion pricing, it is important to note that the level of enthusiasm and support amongst Swedish citizens prior to the launch of congestion pricing was largely dependent upon their political views. Not surprisingly, those with liberal views tended to support congestion pricing at a much higher rate in the beginning compared to those citizens with more conservative views. A decade later however, the pricing system enjoys widespread support by a majority of the population because it has reduced traffic. It is also important to understand the political ramifications of the system.

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[69] Olszewski, P. and Xie, L. 2002. Traffic demand elasticity with respect to road pricing - some evidence from Singapore. Conference Paper, Research Gate, International Conference on Seamless and Sustainable Transport. Center for Transportation Studies, Nanyang Technological University, Singapore. https://www.researchgate.net/publication/261712681_Traffic_demand_elasticity_with_respect_to_road_pricing_-_some_evidence_from_Singapore?enrichId=rgreq-1c0640128d64e8fd25b6aaa0aa1628c3-XXX&enrichSource=Y292ZXJQYWdlOzI2MTcxMjY4MTtBUzoxMDIzMDYyNTk0MDY4NTlAMTQwMTQwMzEyMTk0Mw%3D%3D&el=1_x_3&_esc=publicationCoverPdf. Accessed April 2018.

In 2006, just before congestion pricing went into effect, with the exception of the Swedish Green Party, no other established party supported the idea. While private citizens tend to base their support off their individual values such as thoughts on taxes, social equity and the environment, political actors and policy-makers are forced to view things through a different lens. Congestion pricing is a positive revenue generating mechanism for local governments, which is nearly always regarded as a good thing. However, some Swedish policymakers who opposed congestion pricing tended to do so because of their fear that if Stockholm were to be flush in cash from congestion pricing revenue, it would no longer be competitive for national grants for transportation infrastructure funding. This fear was allayed by a novel agreement between the regional and national governments stipulating Stockholm would "receive a major transport road investment package, 50% funded by revenues from congestion pricing and 50% by the national government." [70] Speaking of revenue, congestion pricing tends to generate a lot of it, especially when compared to its operating cost. In 2016 the yearly operating cost was $12.65 million USD while generated revenue equaled $172 million USD. That cash could go a long way in funding large-scale public transportation projects such as a Gold Standard BRT and subsidizing travel for low income citizens.

5c. Could Congestion Pricing Work in Boston?

In short, yes it could. There are myriad studies that examine the reasons behind why people do or do not support congestion pricing. Some people are concerned over social equity, or a lack thereof, in the sense that a price on driving could be regressive and effect the poor disproportionately. Others immediately shoot down any mention of anything resembling a tax. Yet, these theories do not fully explain the situation in Stockholm where just prior to instituting

[70] Borjesson, M. and Kristoffersson, I. 2018.

congestion pricing people were largely against the measure, yet after only a few years they were largely accepting of it. The easiest explanation is that people saw the benefits of the system as exemplified by a smoother traffic flow, and this is likely true. Yet, the most interesting study found that "an acceptance of the status-quo, tended to increase the support for the current situation." [71]

This realization is interesting but not too surprising when one thinks of all the things that we accept each day even though we may not be overly enthusiastic about them. A few examples are seatbelts and speed limits. Many people find them both to be cumbersome and resent that you can be ticketed for not wearing a seatbelt or driving too fast. Yet, if most are asked how they feel about either, they would likely be supportive because each has become ingrained in our daily routines. We (the clear majority at least) get in our cars and click the seatbelt into place and then proceed to pay heed to the numbers on the speed limit sign. Both instances are example of acceptance to regulations that have become status-quo but were not widely popular even three decades ago. We can then use this same rationale for our current acceptance of traffic. It could be argued that people currently accept being stuck in traffic every day because there is no available solution and therefore, they accept the status-quo. Instead of accepting traffic as the status quo, traffic should be reframed as the unwelcome and unacceptable market failure that it is, and congestion pricing should be brought forth as a proven solution. In short, congestion pricing should become the new status-quo. The idea will not be popular at first, as shown by people's initial hesitance in Stockholm, yet over time due to many reasons, not the least the idea of status quo acceptance, congestion pricing will make as much sense to people as wearing a seatbelt, driving the speed limit, or paying the electric bill based on electricity-usage and demand.

[71] Hess, S. and Borjesson, M. 2017. Understanding attitudes towards congestion pricing: a latent variable investigation with data from four cities. Transportation Letters: The International Journal of Transportation Research. https://doi-org.ezproxy.library.tufts.edu/10.1080/19427867.2016.1271762. Accessed April 2018.

Another reason congestion pricing can work in Boston is because the city already has tried and true electronic toll collection systems as seen on the Mass Pike (I-90) as well as a streamlined billing system in place either in the form of automated payments via E-ZPass or an auto billing system that sends bills to cars without an E-ZPass. Having the technological know-how and human capital already in place needed to build the automatic tolling infrastructure associated with congestion pricing should largely mitigate some of the initial construction and consulting costs that Stockholm experienced in 2005. Once installed, the operating costs are then relatively low, and the revenue high.

5d. Benefits and Costs of Congestion Pricing

Benefits

- Proven to reduce traffic congestion in the short and long-term
- Will save drivers money in fuel costs and opportunity costs
- Follows free market principles to price a good (roads) and correct market failure
- Improves air quality due to reduced emissions via reduced traffic
- Huge revenue generator that can be reinvested in public transportation and/or subsidization of travel costs for lower income residents
- Low operating costs and simple, preexisting infrastructure technology
- Widespread public and political support after implementation

Costs

- Can be seen as a regressive tax on the poor unless their travel is subsidized and social equity is considered
- Lack of public and political support prior to implementation

6. Conclusions and Recommendations

6a. Conclusion: BRT and Congestion Pricing Should be a Package Deal

By using BRT and congestion pricing simultaneously along the Southeast Expressway portion of Route 93 (and maybe the northern section in the future) we can proactively manage the number of cars that flow into and out of the city in the first place while raising revenue to fund future projects and help subsidize transportation costs for the poor. By confronting the problem of traffic congestion outside of the city, we can be far more effective than trying to manage the cars once they are already inside Boston. The Southeast Expressway has the implicit advantage of already having movable barriers that can be easily repositioned for BRT and then moved back for normal traffic flow. The location of South Station's bus terminal also lends itself quite well to a pilot program.

There are costs associated with converting the zipper lane from its current usage to a BRT lane and there will also be costs with implementing congestion pricing. These costs are mostly political. People would need to understand why the HOV lanes are being repurposed and why suddenly it is costing them money to drive on a road that was once free. Hence the need for an aggressive information campaign explaining the supply and demand aspects of traffic congestion. Once explained, this concept is quite simple, but this author will be the first to admit that he had never understood traffic in a supply and demand sense until he was exposed to it. The unfortunate example of Houston's 26 lane highway as well as Boston's own traffic woes is a sign that it is time to try something new. By combining BRT and congestion pricing on the Route 93 Southeast Expressway, we can ease congestion on the feeder highways, and ultimately downtown Boston, over the medium to long-term while improving air quality, the lives of residents in Greater Boston, and make progress towards reducing transportation GHG emissions to meet Massachusetts' GWSA goals. BRT is a capable program, but deployed without congestion pricing it will reduce congestion and thus incentivize people to drive again in the medium to long term when they see that traffic is moving along the highway. To "lock-in" these gains, the International Transport Forum recommends to "manage newly available (road) capacity through congestion pricing." [72] This paper echoes that recommendation for Boston.

6b. The Effect on GHG Emissions

The goal of using BRT and congestion pricing in concert is to reduce the total number of cars on the highway by at least 5% in the short-term to get the non-linear benefits described earlier in this paper, and then keep those cars off the road. Both BRT and congestion pricing have historically shown to be effective at reducing the number of cars on a given road when used individually, however the combination of the two, namely the usage of congestion pricing to limit demand, is the most effective way to reduce and keep demand low in the medium and long-term. This is evidenced quite clearly by the Stockholm example. This reduction in traffic will not only benefit individual drivers' wallets, local commerce, and public health. It will also be an important first step in reducing the GHG emissions of Massachusetts' transportation sector to meet the 2050 GWSA target of 18.9 MMT GHG. There are many different factors that must work together to begin the transportation sector's necessary GHG reduction.

First, buses must be electric or at the very least diesel-electric hybrids. At current Boston has approximately 1021 buses, of which 50% are diesel, 33% are hybrids, and 17% CNG. [73] Diesel and CNG surprisingly have the same fuel efficiency/miles per gallon equivalent. The hybrid on the other hand is up to 44% more fuel efficient and emits about 54 tons of GHG less

[72] International Transport Forum. 2010. Reducing Transport GHG Emissions. OECD. https://transport.di.dk/SiteCollectionDocuments/Reducing%20Transport%20GHG%20Emissions.pdf. Accessed April 2018.
[73] The MBTA Vehicle Inventory Page. 2018. http://www.transithistory.org/roster/. Accessed April 2018.

per bus than CNG and 41 tons of GHG less per bus than diesel when using a full "well to wheels life-cycle analysis". [74] Each MBTA bus travels on average 86 miles per day, or 30,744 miles per year. [75] Combining this data from the MBTA with data from New York City and Columbia University that shows the average diesel bus emits about 100 tons per year, it can then be calculated that the average diesel bus emits about 2950 g/mile GHG. The same calculations can be done for the average electric bus which emits about 16 tons of GHG each year due to upstream electricity generation, or about 472 g/mile GHG. [76] These calculations are important when comparing the projected effects on GHG emissions of removing 5% of the cars from the Southeast Expressway during peak time.

Per the most recent data available, about 108,000 cars travel between exit 20 and exit 8 on Route 93 between 3pm and 7pm. [77] A reduction of 5% of would equal about 5400 cars. The average speed of traffic along the Southeast Expressway is about 20 mph. [78]At 20 mph, cars emit about 420 g/mile GHG. The distance of the traffic prone section of Route 93 is about ten miles long in each direction. Therefore, this means that by removing 5400 cars each day during peak time via BRT and congestion pricing we are removing 22,680,000 g or 25 tons GHG over a 4-hour period each weekday which equates to over 6,500 tons per year. This results in saving about 731,000 gallons of gasoline per year. To put GHG reduction in context, 6,500 tons of GHG is

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[74] Comparison of modern CNG, diesel, and diesel hybrid-electric transit buses: Efficiency and environmental performance. 2005. MJBradley. https://www.mjbradley.com/sites/default/files/CNG%20Diesel%20Hybrid%20Comparison%20FINAL%2005nov13.pdf. Accessed April 2018.

[75] MBTA. 2014. Ridership and Service Statistics. https://cdn.mbtace.com/uploadedfiles/documents/2014%20BLUEBOOK%2014th%20Edition(1).pdf. Accessed April 2018.

[76] Aber, Judah. 2016.

[77] CTPS. 2011.

[78] A Better City. 2016. State of the built environment. Northeastern University. http://www.northeastern.edu/dukakiscenter/state-of-the-built-environment-greater-bostons-infrastructure/. Accessed April 2018.

also equivalent to the yearly electricity usage for about 1000 homes. [79] As impressive as this is, it still must be measured against how many emissions would be coming from the usage of the BRT buses.

Since the BRT will be using the old HOV lane, it is safe to assume that the 5400 cars will be carrying about 11,000 people, assuming around 2 people per car. Each BRT bus can carry 90 people. The total time it will take a BRT bus to travel the 10 miles in each direction and pickup and drop-off passengers is approximately 40 minutes. Therefore, to move 11,000 people over a 4-hour period there will need to be 122 bus trips. Each bus can do the 40-minute loop five times in 4 hours, which means 25 buses will be needed. Assuming the buses are electric this will mean that the entire Route 93 bus fleet will emit about 400 tons GHG per year. If the buses are diesel, this number increases to about 2500 tons GHG per year. The net total GHG savings for taking 5400 cars off the road is therefore either 6100 tons GHG for electric buses or 4000 tons GHG with diesel buses. This is a tiny contribution to the overall GWSA numbers (those numbers are given in megatons) however, this BRT program can have larger aggregate effects. By removing 5% of cars, we get upwards of a 20%, non-linear reduction in traffic and commute times, meaning that travelling 10 miles in 30 minutes (20mph) with 100% of the cars would drop to 24 minutes with 95% of the cars on the road. Thus, by speeding up traffic you are lowering emissions on Route 93 by reducing the amount of time each car is emitting, reducing the number of cars that enter downtown Boston, and reducing the number of cars that will be on other feeder roads. Again, it is important to note that this suggestion is limited in scope to a 10 mile stretch of congested highway and by no means will make a tangible dent in the long-term GHG emissions goals of the GWSA. However, it is a crucial first step and can serve as an example of well-

[79] Greenhouse gas equivalencies calculator. 2017. EPA. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator Accessed April 2018.

crafted transportation policy aimed at driving down emissions for the transportation sector. This solution: combining BRT and congestion pricing for long-term gains can alleviate traffic congestion and, if done on a larger scale across Massachusetts, can lead to tangible, measurable reductions in GHG emissions.

To put all of these numbers in context, let us revisit our case studies: Mexico City and Stockholm. Mexico City's BRT moves about 850,000 passengers per day, which has the potential to negate 500,000 tons (or .5 MMT) GHG per year. For comparative purposes, this paper advocates for the pilot BRT program to carry about 11,000 people per day. Mexico City's example shows the potential for how beneficial BRT can be when used on a large scale. The transportation sector in Massachusetts accounted for 29.4 MMT GHG in 2014. If BRT was to be used on a scale similar to Mexico City, the GHG savings of that one program alone would account for nearly a 2% reduction in transportation sector GHG. Meanwhile, Stockholm's congestion pricing program reduced the total number of car passengers by about 100,000, which led to a GHG reduction of 38,000 tons per year. [80] This also does not solve Massachusetts's transportation sector GHG emissions issue, but it begins to make a dent. More importantly, congestion pricing, when used in concert with improved public transportation options such as BRT, serves to "lock-in" traffic alleviation by managing the demand to drive. Again, this paper aims to serve as a call to action for an immediate small-scale pilot BRT program on Route 93 with the intention of scaling up BRT in the coming years to a level that can make a measurable difference in statewide GHG emissions.

[80] Tools of Change. 2018. Stockholm Congestion Pricing. http://www.toolsofchange.com/en/case-studies/detail/670. Accessed April 2018.

6c. Recommendations

- Simultaneously implement congestion pricing in concert with BRT to help to free up the traffic flow and keep it flowing in the long-term. The fear is that using only BRT may thin traffic enough that more people start using the highway once they see better flowing traffic. Congestion pricing guards against this.
- Launch an immediate BRT pilot program. Move both sets of movable barriers on the Route 93 Southeast Expressway between exits 15 and 7 to open a dedicated BRT lane in each direction during peak times. Purchase new movable barriers for the portion of 93 north of Exit 15. Launch BRT buses from South Station. Ensure the BRT is meeting at least the 5 essential elements of BRT. Strive for Gold Standard for permanent implementation with low emissions buses only.
- Use revenue to subsidize tolls for low-income residents, and fund BRT.
- Use 30 mph as a minimum target for traffic flow. This cuts emissions nearly in half as compared to vehicles travelling at 10 mph or less and helps achieve the GWSA.
- Immediately halt any lane expansion projects along Massachusetts highways and reinvest that money into smart public transportation projects such as BRT and the expansion of light rail.

Source: Robbie Shade 2018

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Appendix A

BRT Infrastructure Is Largely Already in Place

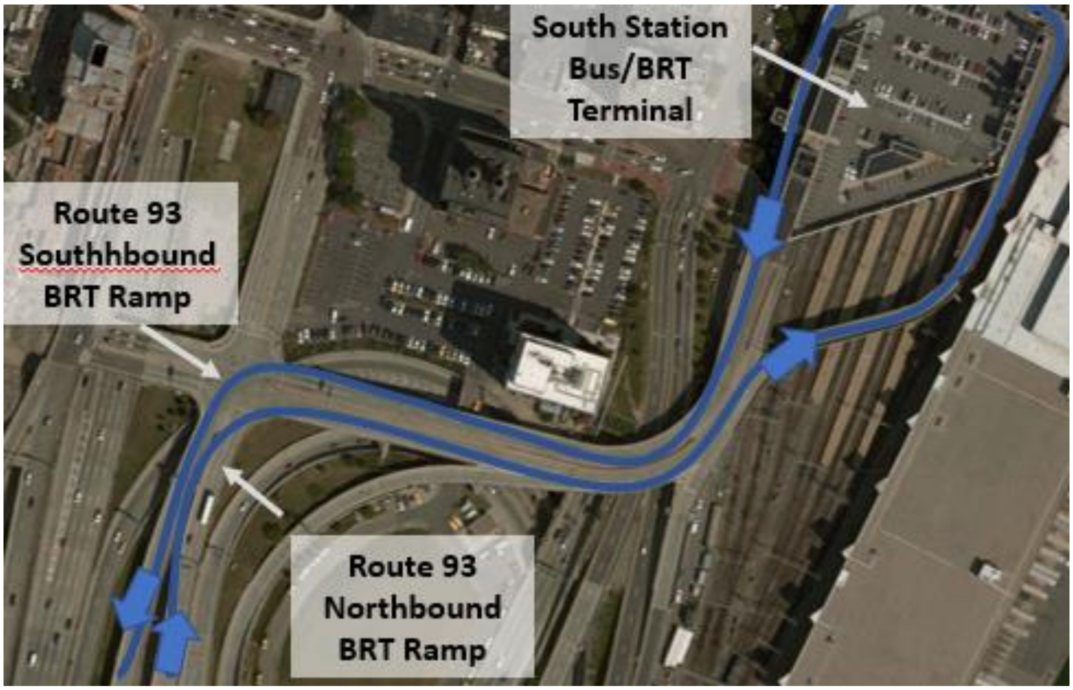

Figure 1: Boston's South Station will be the northernmost point of the Route 93 BRT Loop, with dedicated access lanes to and from Route 93 Southeast Expressway

Figure 2: Route 93 Southeast Expressway has movable barriers that are moved by the "Road Zipper" each morning and evening to add an HOV lane for the traffic heavy side. For example, in the morning the Northbound side is increased by one lane and in the evening the Southbound side is increased by one lane. The BRT program to be truly effective requires that these barriers are moved out on each side of the road during peak hours to create a BRT loop that connects South Station and Quincy. However, these movable barriers are only from Exit 8 to Exit 15. Thus, more movable barriers are needed for the highway from Exit 15 to South Station to create a continuous BRT lane on each side of the road. Without this improvement, the true impact of BRT will largely be negated as buses leaving South Station will immediately sit in traffic until Exit 15.