Alleviating Carmageddon with a research-driven Rapid Transit approach

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Abstract

A growing number of cities and metropolitan areas in the United States are experiencing historically high rates of congestion on roads and highways. Many of the same places have extensive, although not always well maintained or efficiently operated, transit and Commuter Rail systems. Ridership has plateaued or declined on many of these systems, highlighting their currently limited attractiveness as a modal choice.

Metropolitan Boston serves as a case study into what measures would be effective in inducing a meaningful level of mode shift from automobiles to rapid transit (rail) options. In 2019 four new reports identified Metro Boston as having some of the most congested roads in the nation. Motorists nevertheless continue to drive on these highly congested roads while a developed Commuter Rail, subway and bus transit system exist across the region.

This thesis uses a standardized online questionnaire distributed to motorists across Massachusetts and Rhode Island to understand individual attitudes toward mode shift, and specifically using Rapid Transit instead of driving for their regular daily commute. It targets motorists on the 10 most congested corridors in Massachusetts.

402 completed questionnaires were received from ZIP Codes across Massachusetts and Rhode Island revealing individuals' attitudes and feelings towards shifting to transit for their commute. Specific demographic considerations, other than geographical spread and origin and destination data, were not considered in this study. The findings indicate that the high level of free or subsidized parking provided across the study area draws Metro Boston commuters away from transit and that 63.7% of respondents would consider shifting to Rapid Transit if the cost of driving went up substantially (50% higher cost). Respondents further indicated that access & network limitations of the MBTA rail transit system, travel time by transit combination (including all legs of the trip), the transit system reliability, frequency of trains on a number of Commuter Rail routes and relatively high fare prices are considered factors preventing significant mode shift to transit.

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Title: Lecturer, Department of Urban Studies and Planning

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Terms and Definitions

Rapid Transit

Rapid Transit as used in this thesis means those transit and rail modes that do not travel in mixed traffic with cars and trucks. Thus, the term encompasses Commuter Rail, subway (heavy) rail, Light Rail and buses or trolleys in dedicated lanes. The term Rapid Transit, for our purposes, does not include conventional buses that travel in regular traffic lanes. As such the MBTA's Silver Line has not been considered a Rapid Transit mode. Buses in regular traffic are used by vast numbers of people, but in the Metro Boston area, at an average bus speed of nine of ten miles per hour, according to Transportation Secretary Stephanie Pollack (Pollack 2019), this is not an improvement for most people over travelling in automobiles. A full set of dedicated lanes on major corridors would be needed to meaningfully reduce congestion over time. **In simple terms Rapid Transit in Metropolitan Boston means rail.**

SOV – Single Occupancy Vehicle
BRT – Bus Rapid Transit
LRT – Light Rail Transit or Light Rail
Heavy Rail – High capacity metro lines including subways and commuter rail but excluding the Green Line.
Commuter Rail – Also Heavy Rail, specifically regional rail linking suburbs to the city
PT – Public Transportation
TOD – Transit Oriented Development
MBTA – Massachusetts Bay Transportation Authority
MassDOT - Massachusetts Department of Transportation
MAPC – Metropolitan Area Planning Council
BPDA – Boston Planning and Development Agency
CTPS – Central Transportation Planning Staff
Ride Hailing – Procuring of vehicle trips via cell phone applications such as Uber or Lyft
Inner Core - The Inner Core Committee (ICC), consisting of 21 cities and towns within the Metropolitan Boston area.
Road Pricing – The practice of instituting direct charges or levies for the use of the road such as tolls, distance or time-based fees, congestion charges.
Personal Mobility Device (PMD)– typically are two-wheeler scooters either motorized or non-motorized used for localized transportation.
MARC - Maryland Area Regional Commuter train service
WMATA – Washington Metropolitan Area Transit Authority
BART – Bay Area Rapid Transit
ROW – Right Of Way
GIS – Geographic Information Systems – Typically mapping of data.

The Study Area

The study area includes areas in Massachusetts and Rhode Island served by the MBTA. The MBTA service area is essentially the same as the MAPC definition of Metro Boston.

Chosen Congested Roads

- I-93 North of central Boston
- I-93 South of central Boston
- Route 2 (Between I-95 and Alewife)
- Route 28
- I-95 between Peabody and Route 2 (Lexington)
- Route 9 (Between Boston and Worcester)
- US Route 3 (Between Burlington & Chelmsford)
- I-90 between Worcester and Boston
- Route 1A between Revere/Lynne and Boston (Including the Ted Williams Tunnel)
- Route 1 between Revere and Boston

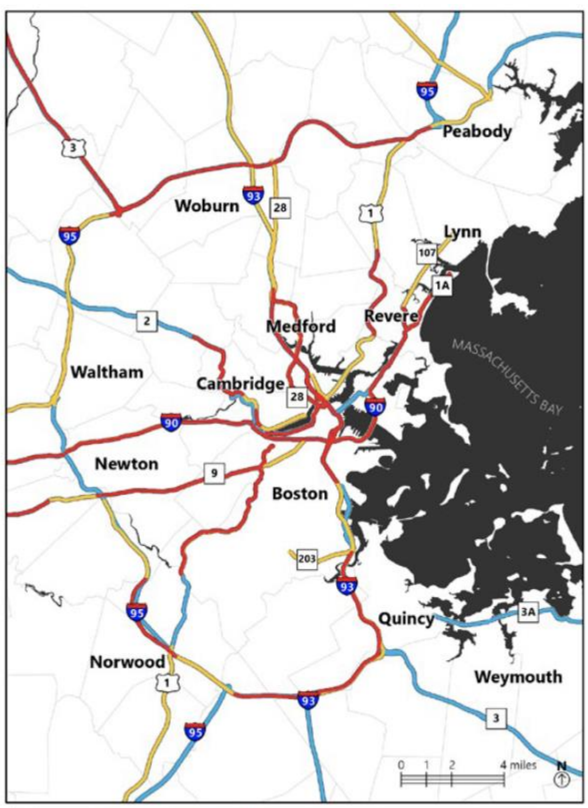


Figure 1: Map of chosen congested Roads – Source: MassDOT 2019

1. Background

1.1 The congestion phenomenon and current state of play

In 2019, three reports identified the most congested cities and the most congested highways in the United States. These reports demonstrated that congestion in many cities and regions is on the rise, and the Metropolitan Boston region is experiencing congestion conditions more severe than most. (*TomTom Traffic Index*, 2019) (Inrix, 2019) *(Texas A&M, 2019)*. Further to these reports, the Massachusetts Department of Transportation (MassDOT) published its "Congestion in the Commonwealth – report to the Governor 2019" (MassDOT, 2019) in August 2019 acknowledging massive congestion problems in the Metro Boston area. (MassDOT, 2019). In 2020 Inrix again released its report ranking Boston as having the worst congestion in the nation (Reed, T., 2020). Ride Hailing appears to have made this situation worse, especially closer to the Inner Core, by adding to vehicle miles travelled or numbers of vehicles on the road (Henao, 2017)(Tirachini & Gomez-Lobo, 2020)(Gehrke, 2018). These emerging trends make congestion a matter of much frustration, ripe for intervention.

Metro Boston's traffic congestion imposes significant direct costs on drivers and both direct and indirect costs on all residents of the region as demonstrated recently in the *Transportation Dividend Report* presented by A Better City (A Better City/ AECOM, 2018). It acts as a constraint on access, with real impacts on private sector investment (Weisbrod, G., 2009), social equity and quality of life, *e.g.* hours lost in congestion (Reed, T., 2020). These costs are often hidden, but cannot be ignored.

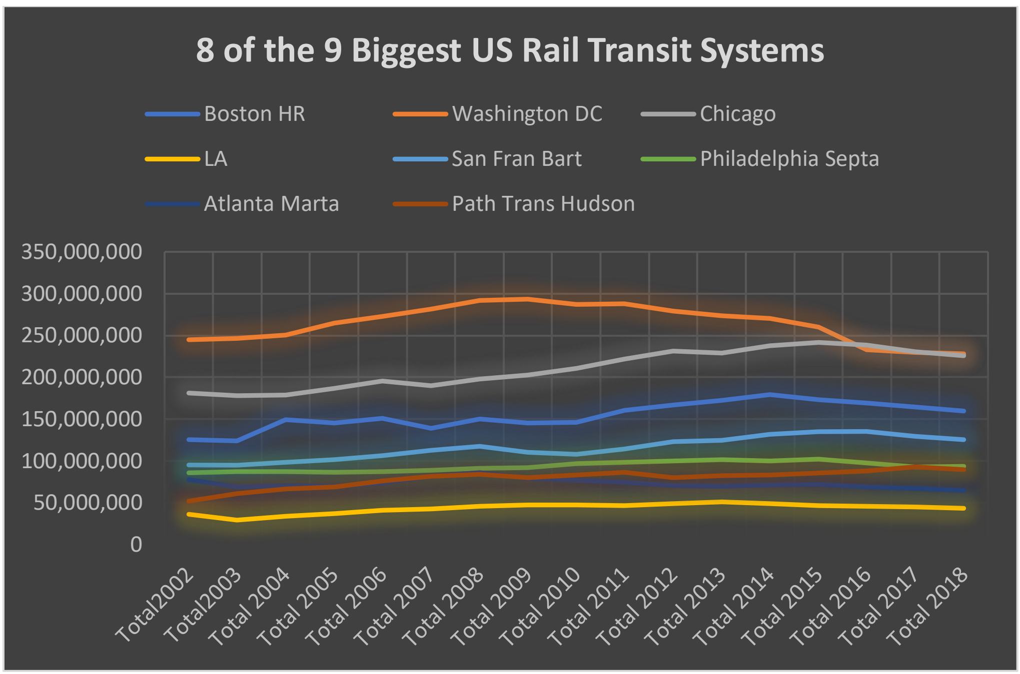
Road pricing requires the provision of viable alternatives to be most effective in the long term. Without viable transit alternatives, road pricing may lead to a shift of the traffic to other roads, or be viewed by the public as simply a tax. A shift to other modes is required for long term sustainable congestion reduction, and for longer distances this means mode shift from automobiles to Rapid Transit.

Focusing primarily on the Metro Boston area, this thesis explores the ways Rapid Transit infrastructure, equipment and service delivery models can be used as a critical component of an overall strategy to alleviate congestion in the US context. The aim is to identify reasons why Rapid Transit is not used to a greater extent by commuters who opt currently to sit in traffic in highly congested corridors. Factors such as insufficient station parking, unreliable or slow rail service, inaccessible stations and fare policies are examined, together with pricing policies and the impact of free destination parking. The thesis develops a set of concrete proposals to encourage Rapid Transit use on significantly congested corridors in Metro Boston and aim to establish more generalized policy alternatives for use elsewhere.

1.2 Transit Ridership trends – National and Local

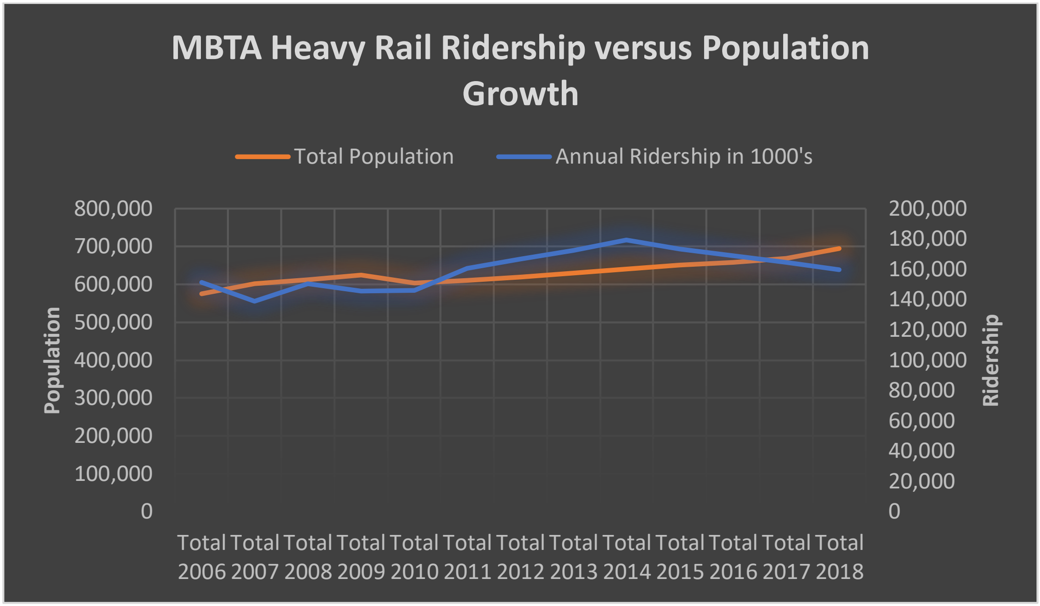
As traffic congestion grows, in many urban areas transit ridership, and in some cases quality of transit service, is static or declining. Cities and surrounding metropolitan areas are growing in population. Metro Boston has seen both population and the built form of Boston and its metro municipalities grow steadily in recent decades as the growing local economy brings people in from other regions. Yet public transportation struggles to maintain modal share.

The Figures below show ridership trends for the nation's largest systems and more specifically for the MBTA.



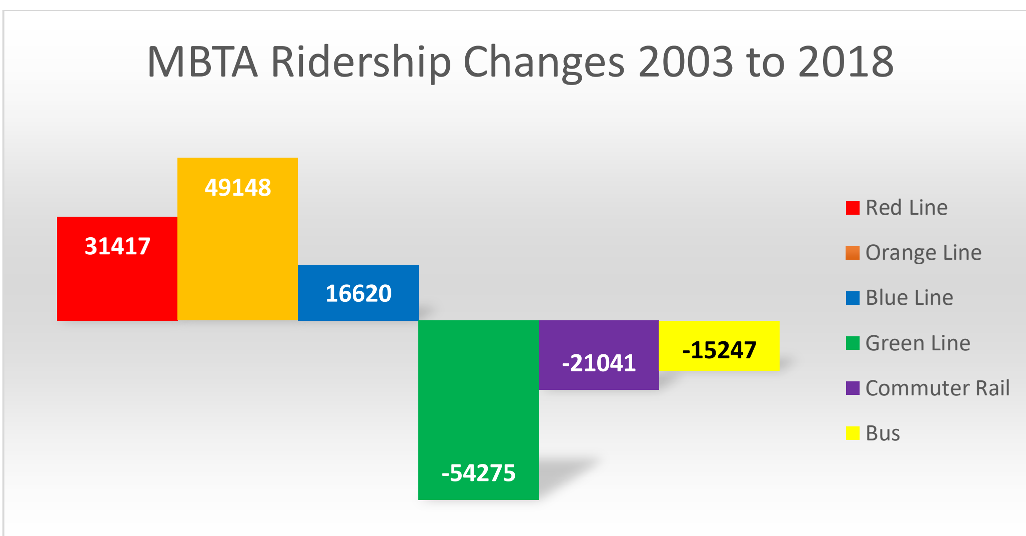
Graph: Ian Ollis, June 2019. Data from the Federal Transit Authority, 2019.

Figure 2. Ridership of the nine largest U.S. rail transit systems, minus New York



Population data: American Community Survey; Ridership from the National Transportation Database

Figure 3. Metropolitan Boston MBTA Heavy Rail ridership versus City of Boston population



Graph: (Ollis, I & Sullivan, G., 2019) *Data Source: MBTA Blue Books/MBTA Tracker*

Figure 4. Comparison of average typical weekday MBTA ridership, FY2003 vs FY2018

1.3 Study Motivation and Research Questions

The Research question:

What combination of interventions will most effectively induce mode shift away from single occupancy automobile travel to Rapid Transit at a scale that would meaningfully reduce congestion on major routes in Metropolitan Boston?

Objectives:
The motivation for this study comes primarily from the need to understand and respond to three phenomena in modern commuting:

- The current and prevailing attitude on the part of many drivers to continue to drive on increasingly congested highways and arterial roads
- The paradox that increasing lanes on existing highways does not solve the long-term congestion problem due to pull factors associated with the extra capacity
- The negative externalities that occur from increased auto driven commuting. These include poor or inefficient land use choices, rising vehicular emissions, and a variety of costs to the commuter arising from the ownership and operation of an automobile.

Mode shift is seen as one alternative solution to these ongoing concerns and indeed the alternative with which this study is primarily concerned.

What is meant by "combination of measures?
The goal of the study is to identify a basket of interventions that will cause meaningful modal shift from car-centric commuting on congested highways to Rapid Transit modes. This will be undertaken in the context of research and analysis that considers current extant research and an examination of the stated preferences of people who experience traffic congestion on a daily commuting basis.

This study does not attempt to isolate numeric comparisons between alternative baskets of mode shift tools in an attempt to find the largest additional premium obtained from the "sum of the parts". That would be an interesting area for further study. This study specifically aims to establish the combination of measures that research and analysis show are a) individually effective at shifting people from regularly taking a car to regularly taking Rapid Transit, and b) have been demonstrated to produce mode shift in larger numbers. Cumulatively this resultant combination of measures will be a group of the most effective tools at achieving mode shift at a meaningful scale.

What scale would be meaningful?
The aim is to find a combination of measures that together could produce a degree of mode shift that would be large enough to alleviate some of the congestion on the most congested corridors in Metropolitan Boston. A meaningful or "significant" level of mode shift for the purposes of this study means a 10 to 15 % shift of drivers on the top congested corridors in the "rush hour"

from cars to Rapid Transit, a metric that follows from prior research studying congestion reduction measures that have proved efficacious. The study by Winnick *et al.* indicates that to significantly reduce congestion, and allow free flow traffic or maximum throughput of traffic in cities like the Washington DC Metro area would be in this range: "We established that in general a 10 to 14 percent decrease in traffic on congested freeways will reduce delay by approximately 75 to 80 percent" (Winick *et al*., 2008). The TCRP report "Cost Effectiveness of Travel Demand Management Programs", also found that "The average reduction in vehicle trips among 'successful' programs was 15.3%." Quoted in (Luten, K. *et al*., 2004).

The question of the shifting nature of congestion itself will be addressed as necessary. It is perhaps important to note that we are measuring the cumulative mode shift effect and not the congestion reduction itself. Measuring changes in congestion itself is a separate exercise entirely.

Methodology
The analysis contained in this thesis is informed by:

- A literature review that identifies which interventions work and to what extent they have been shown to work, and which do not
  - What interventions have been shown to shift commuters to Rapid Transit
  - How these interventions were successfully implemented
  - What data have been produced thus far to support such analysis.
- A survey of commuters who travel regularly on the corridors that are being studied. The survey will aim to solicit reasons current commuters do not take Commuter Rail, subway, Light Rail or dedicated bus lane offerings currently in the area (stated preference methods will be used)
- Statistical Analysis of survey responses
- GIS mapping of survey responses
- Propose interventions: Applications in Metropolitan Boston
  - The analysis and survey work must lead to proposed interventions in metropolitan Boston in the US which is experiencing highly congested road corridors.

The highly congested corridors:

The chosen roads in the study area (listed above) are considered the most congested corridors in Metro Boston for purposes of this study (chosen based on existing studies such as the TomTom 2019 Traffic Index, the Inrix 2018 Global Traffic Scorecard, the 2019 Texas A&M Transportation Institute's 2019 Urban Mobility Report and the 2019 MassDOT's "Congestion in the Commonwealth – report to the Governor 2019").

Data sourcing and evaluation:
Data for this study was sourced in three ways:

1. Data available through the literature review
2. Data sets from current authorities such as the MAPC and CTPS
3. A stated preference survey of commuters in Metropolitan Boston, Massachusetts

The primary purpose of the literature review is to identify which factors have been associated with increased Rapid Transit ridership (as defined above) or mode shift away from automobiles and which factors have not had the desired impact.

The primary purpose of the survey will be to identify what factors motorists themselves identify as preventing them from making a mode shift to Rapid Transit and comparing these in the analysis with the factors identified in the literature review.

Coupled with this will be an analysis of the current and latent Rapid Transit infrastructure such as Commuter Rail lines, BRT bus systems, subway train systems, Light Rail lines and rail lines not currently utilized for passenger transportation.

Recommendations will be proposed based on the literature review, analysis of existing data, and survey of commuters to synthesize a combination of measures that is likely to most effectively induce a mode shift away from automobile travel at a scale that would meaningfully reduce congestion on the congested corridors identified.

Contribution and limitations of the study:

The study contributes to the field in a number of ways:

- The study links global research on the topic of mode shift with research designed to explore attitudes regarding congestion and transit conditions in Metro Boston.
- The stated preference survey data collected enriches the extant data specific to Metro Boston with qualitative questions around the "why" of taking a particular mode of transport and not another mode, rather than demographic and other characteristics of the traveler. The Central Transportation Planning Staff (CTPS) has gathered quantitative and demographic survey and operation data relating to Transit in Metropolitan Boston.
- The survey covers a very specific cohort of motorists who travel on a specifically chosen set of roads indicated in a number of recent studies as the most congested in Massachusetts. The specific cohort was chosen as these are motorists driving in the most congested conditions and inevitably contributing to it.
- The study uses statistical analysis and GIS mapping of the results of a stated preference survey to identify localized variation in the data that contributes to our understanding of what interventions would be efficacious in specific geographical locations

Limitations of this study include:

- Unforeseen constraints and closures of computational facilities impeded planned ridership and mode share modeling. In future research, this study's initial efforts toward such modeling (e.g. the Use of TBEST software) could be brought to completion, creating an additional point of comparison with the survey results.".

- By definition, the global nature of the Literature review (*e.g.* very different demographics such as density variations, and cultural differences such as dealing with crowding) makes comparisons less directly applicable to some degree. Nonetheless, lessons and patterns can be gleaned that are useful to the present study area.

2. Literature review

This chapter examines the relationship between mode shift from auto to Rapid Transit and the range of possible causal factors. Many researchers focus on ridership increases or decreases and not specifically on mode shift. However, ridership is no direct proxy for mode shift, unless an identifiable relationship between the two is established with an indicator of magnitude and direction.

Research into identifying and measuring mode shift follows three broad methodologies. The first uses econometric modelling to predict mode shift and transit ridership, based on an equation of variables, and tests theoretical assumptions about factors associated with mode shift.

The second method is the use of surveys, either stated preference or revealed preference surveys or both. This method typically asks transit riders, motorists, or census takers, what their travel preferences or attitudes are. Shifts in travel patterns are then inferred from the results of such surveys.

The third method estimates mode shift based on statistical data before and after the implementation of new infrastructure or technology, such as a new transit line, or a new smart parking system. This method is based on traffic counts, ridership counts, parking use and so on.

Occasionally surveys are combined with either or both of the other two methods to obtain additional data. This chapter considers literature demonstrating each of these methods to understand factors that induce mode shift.

General principles

Congestion is a dynamic phenomenon with constantly shifting parameters. It is usually represented by the significant reduction of throughput of vehicles on a road as the demand (vehicles) exceeds the capacity of the roadway.

People need to travel for a whole range of activities, and also *want* to travel. Travelling to work and school is major contributor to congestion (along with freight deliveries) as these activities usually begin and end each day in a given region around the same time, leading to the rapid increase in vehicles on roads and freeways during what we commonly refer to as “rush hour”.

Across countries in different regions of the world, people travel roughly the same amount of *time* each week (Schafer, A., 2000) although distance and cost will vary, which may indicate that travel demand per capita will remain in place, no matter what measures are implemented to contain it. This phenomenon needs further study, but if this pattern holds, this means that we can only redistribute human travel but not meaningfully reduce it. This has significant implications for how we deal with congestion from a policy perspective. It may mean that policy makers and transportation planners can shift the time of travel, the mode of travel, the destinations of travel or the speed of travel, but may not be able to reduce the overall quantity of travel. It may put a cap on how much congestion reduction we can achieve by encouraging telecommuting, for example, although telecommuting may shift the quantity of travel demand outside of peak hours or to later in the week, as Shafer(2000) Marchetti(1994) and Zahavi's(1974) research implies: people will travel roughly the same amount, even if the travel is not to the office or at peak times.

Continuously expanding highway capacity to accommodate increasing automobile traffic during peak hours is neither effective nor sustainable in the long term. It is not effective because it doesn't actually solve the congestion problem. The Downs-Thomson paradox shows how adding extra highway capacity can leave motorists and transit users worse off after new highway lanes open, although Zang et. al. show that there are exceptions where this may not be the case, particularly if the two modes of transportation are not near perfect substitutes (Zhang *et al*., 2016)

Duranton & Turner have investigated the effects of increasing highway and other road capacity on travel demand and found "suggestive evidence that road congestion increases with expansion on both interstate highways and major urban roads. These results suggest that increased provision of interstate highways and major urban roads is unlikely to relieve congestion of these roads." (Duranton & Turner, 2011).

While total travel demand across all modes is likely to remain the same on an average per person basis (Shafer 2000), essentially evidence suggests that *automobile* traffic on highways and roads will grow to fill the additional capacity that is provided (Duranton & Turner 2011), as there is almost always pent up demand, and will again cause congestion after a period of adjustment, albeit at a greater quantity of vehicles or VMT. This raises the question: Can effective transit alone meaningfully reduce that pent up demand?

Continually expanding highway capacity to solve congestion is also *not sustainable*. This thesis will assume that alternatives to highway building or expansion must be found to ease congestion and provide for future growth as this method (adding road lanes) will inevitably face severe restrictions as a result of limited land available for road building, and environmental regulations. These restrictions will likely make adding significantly more lanes politically challenging and economically unaffordable in dense metropolitan regions and cities.

Density and land use

This study does not investigate land use and densification measures specifically to deal with congestion or mode shift, as others have thoroughly investigated that connection. This study considers measures connected to transportation modes that may produce some level of mode shift. However, it is perhaps important to note briefly that land use densification geographically close to transit should not be forgotten in the discussion of policy measures. There is an established link between land use, density and transit ridership, albeit that it may be the effect of self-selection, as people who prefer transit use choose to live close to transit stops in greater numbers or may represent mode shift of people giving up or reducing their auto use. Gutiérrez *et al.*(2011) and Seskin & Cervero(1996), point out that density is an important driver of transit ridership. Liu *et al*. points out how government at local and regional levels need to take this into account when dealing with congestion, transit and mode choice: “However, increasing densities must be in conjunction with improved transit service levels, parking, and feeder bus services to take full advantage of rail transit.” (Liu C. *et al*., 2016).

Transit agencies by and large can do much more with their land assets to promote mixed uses and densification around station precincts and work with local authorities to achieve denser nodes around transit stops; the MBTA in Massachusetts is no exception.

2.1 Accessibility & network convenience

A transit trip is made feasible when specific conditions converge: an access point near a point of origin, an egress point near a destination, and limited transfers during the trip. The transit mode transfers required to complete the trip between origin and destination may influence the real or perceived feasibility of the trip. Changing between modes has a different impact than a transfer between vehicles of the same mode at a particular station or stop.

Many factors, including distance to the station, “first mile, last mile” options, and number and difficulty of transfers involved, all contribute collectively to the inertia that mounts up against using transit or mode shift for commuters. Many questions arise: How close to my point of origin must the station or stop be to be an incentive for me to leave the car at home? How close to my destination point must there be another stop for me to choose to use the train or bus? Planners and transit operators typically consider a half mile walkshed to be the area that will draw additional walking riders to a system (Metropolitan Washington Council of Governments, 2019). However, with rail, the presence of parking, bicycle infrastructure or feeder bus connectivity increases the footprint of accessibility substantially.

First-mile and last-mile accessibility

Distance to transit origins and destinations as a factor in determining accessibility has been studied by researchers over many years and using a variety of tools (T. A. Litman, 2020). From this work comes measurable metrics dealing with accessibility: the distance to the closest station or stop and the means and ease of getting there. Typically reducing the time taken for the “first mile” and “last mile”, and making the transfer at the station between modes less time consuming, easily traversed, safe and comfortable increases accessibility and encourages mode shift towards Rapid Transit (Wardman, 2006)(Brons *et al*., 2009).

Estimating these effects requires detailed analysis and modeling. Typically, researchers create a half mile (or 800m) walkshed using GIS and other technology, with a population count to estimate accessibility metrics for transit ridership and indicate the possible population that has access to a particular station.

Transit service to both the origin station and the “last mile” are critical elements of access leading to higher transit use. Brons *et al.* (2009) point to ease of access being an even higher priority for infrequent rail passengers, offering promising results for mode shift if station access is improved. Notably “improving the journey to the station is more important than facilitating the transfer between the access mode and the rail through better parking facilities”(Brons *et al*., 2009). Frequency of service at the “first mile” level is key. “The higher importance passengers have assigned to this dimension in surveys over time means continuous improvements are required and at a higher rate (Brons *et al*., 2009).

Huanmei Qin *et al*. have completed an analysis of park-and-ride decision behavior designed to understand accessibility. Their research showed the growing significance of intermediate stops and “trip chaining”. Most stops were to “pick up or drop off children (27% of trip chains), followed by shopping (21%), personal business (21%), eating (13%), and social-recreation (8%)”(Qin *et al*., 2013). They identify the need to place multiple uses, such as child-care centers and retail shops, in and around transit stations to enable workers to consolidate trip ends(Qin *et al*., 2013).

Transfer penalties

The transfer penalty is a measure that represents the perceived impact on a commuter of changing between vehicles or modes of transportation when a one-seat ride to the final destination is not possible due to network limitations. The literature on the subject demonstrates that transfer penalties do have an impact on mode shift and that downtown Boston stations have very moderate transfer penalties. Greater frequency of service reduces transfer penalties greatly.

Algers, Hansen & Tegnér explain the impacts waiting time and the number of transfers have on riders’ mode choice. They use survey data for commuter trips in Stockholm, to show significant variation of the transfer penalty among different transfer types. Bus to bus transfer had the highest transfer penalty. “The value of transfer penalty between rail modes is less than a third of that between buses” (Algers *et al*., 1975). They do not examine the magnitude of mode shift that results from changes in transfer penalties.

Guo puts the transfer penalties for downtown Boston in context: “In most transit systems in North America, 10% to 30% of riders make at least one transfer to reach their final destination, and in some systems, this percentage exceeds 50% (APTA, 2000). In Boston, 24% of subway trips involve at least one transfer, while in Chicago, more than 50% of CTA passengers transfer during their typical trip” (Guo, 2003).

His study shows that the transfer penalty among MBTA subway riders is less impactful than other systems elsewhere. This is partly good news for the MBTA. He finds that “three quarters of the transfer penalty can be explained in terms of the physical characteristics of the stations”(Guo, 2003). The layout of stations, stairs, elevators etc. will affect this metric. Guo further believes that familiarity with the station, and the transit system generally reduces the transfer penalty. (Guo, 2003). The compactness of downtown Boston also has an impact: “MBTA subway riders are “generally willing to transfer if one transfer saves more than 9.52 minutes of walking time”(Guo, 2003).

Guo does not examine transfer penalties at stations outside of the downtown Boston area or those that involve different modes, such as Central Square (subway to bus) or Porter Square

(Commuter Rail to subway). Outside of Boston's downtown core, there are no subway-to-subway transfer opportunities. This means that the transfers usually involve mode changes, either Commuter Rail to subway, bus to subway, Commuter Rail to bus and so on. These transfer penalties will be higher than in the downtown core system. Guo's work does not imply that new connections such as the Red-Blue connector should not be built, but rather that existing, individual core transfer penalties in Boston are generally not as high as a number of other transit systems. In fact building new connections such as the Red-Blue connector would reduce the number of transfers for many and thus reduce the total disutility of the trip.

Penalties vary per *type* of transfer, and that the car-to-rail transfer penalty is three times as impactful as a rail-to-rail transfer penalty (Liu 1997). Wardman *et al*., estimate that one transfer is valued at 4.5 in-vehicle minutes for bus users, 8.5 in-vehicle minutes for car users, and 8 in-vehicle minutes for train (rail) commuters (Wardman, M. *et al*., 2001). This study suggests that where the transfer in the study area involves different modes, particularly outside of Boston's downtown, the impact may be greater.

Algers *et al.* refer to a study by Gustafson, Curd, and Golob, which found that a "no transfer" trip, and less waiting time, were more important than lower fares (Algers *et al*., 1975).

Iseki and Taylor have looked at transfer penalties more generally from an economic theory perspective. They consider metrics of waiting time, number of transfers, walking distance between transfers and reduce the impact of these factors to a mathematical equation which can evaluate connectivity. In econometric fashion, they convert "all time, fare and qualities of travel into comparable costs" and then isolate transfer penalties, giving each delay a monetary value related to time (Iseki & Taylor, 2009). Station attributes such as the quality of lighting, signage, presence or absence of escalators, ease of access and transfer between modes, benches, restrooms, shade, and security, which might contribute to the "burden" of travel are weighted in an index to determine the total transfer cost to a commuter (Iseki & Taylor, 2009).

They conclude that transfers can be made less impactful for riders and therefore "influence transit use" and point to on-time performance as one method of reducing the transfer penalty (Iseki & Taylor, 2009). Their work provides a good theoretical analysis of the problems faced by transit agencies attempting to quantify what turns potential transit riders away and provides a monetized way to attempt to calibrate the degree of impact of each factor. They indicate a methodology for connecting transfer penalties to ridership numbers, however they do not make the connection to mode shift.

Legibility (information and wayfinding services) may contribute to the transfer penalty. However, regret-based models and simulations have suggested that the effect of transit information alone on modal shift is not high (Chorus *et al*., 2006).

Mode shift induced by opening new transit lines

New transit lines, particularly Heavy Rail are demonstrated over time in the literature to be one of the most significant ways of inducing mode shift. New Light Rail and Bus Rapid Transit

(BRT) lines do induce mode shift, but the impact on congestion is lower than Heavy Rail due to the lower capacity of such systems, all else being equal.
When examining the mode shift induced by the opening of a new BRT system, Light Rail system (LRT) or Metro System, Ingvardson and Neilson have collated a number of studies that summarize mode shift magnitudes for some transit systems. This shows a mode shift magnitude of 0% to 50% from car to Light Rail or a Mode shift of 8% to 35% for Metro rail/Commuter Rail (Ingvardson & Nielsen, 2018). These findings relate to new lines or new routes, not individual new stations. Capacity matters, as the research shows that, with some exceptions, "*metro systems can have larger impacts on road congestion than BRT systems*. (Yazici *et al*., 2013)" (Ingvardson & Nielsen, 2018). The wide range of impact can be understood in terms of the differences in local conditions and capacitity of the different systems.

Cities in Norway, Germany, France, and Switzerland had lower mode shifts in the meta-analysis of Ingvardson and Neilson (2018) This may be explained by research suggesting that congestion reduction for dense, established cities with already well-developed transit will be low when new lines are opened unless additional car restrictions are instituted. Olesen (2014)

In the US and UK studies have shown a degree of mode shift for Light Rail (Hass-Klau, C., Crampton, G., Biereth, C., & Deutsch, V., 2003), (Giuliano *et al*., 2016),(Chakrabarti, 2017), but the construction of the metric used is problematic. If riders are counted on new transit lines that have switched from their automobiles, often the shift is easily quantifiable and is often a healthy percentage of new transit riders. However due to the dynamic nature of traffic, congestion on the roads nearby offering a comparable alternative to transit, may remain as motorists from other routes may shift to the now less congested transit alternative routes from which transit riders have shifted. A multi-pronged approach to mode shift will be required to reduce the impact of this effect.

Below is a table constructed from many of the studies reported of the various Light Rail and Heavy Rail or metro services indication ridership that has shifted. Note that the figures in the table indicate *percentage of current ridership that has shifted from automobiles*, not the percentage of automobiles that have been removed from local roads.

Light Rail		
Angers Tramway (LRT, Angers)	0.0%	Olesen (2014)
Midland Metro (LRT, Birminigham)	13.0%	Harper and Bird (2000)
Croydon (LRT, Croydon)	19.0%	Copley, Thomas, Maunsell, and Georgeson (2002)
Metrolink (LRT, Manchester)	27.0%	Knowles (1996)
Blue Line (LRT, Los Angeles)	21.0%	Lee and Senior (2013)
Sheffield Supertram (LRT, Sheffield)	22.0%	Lee and Senior (2013)
Blue Line (LRT, San Diego)	30.0%	Lee and Senior (2013)
Orange Line (LRT, San Diego)	50.0%	Lee and Senior (2013)
Nantes LRT (LRT, Nantes)	17.0%	Lee and Senior (2013); PTEG; Hue, R.
Paris Light rail Sait Denis	4.0%	RATP
Paris Issey Light Rail	7.0%	RATP
Nantes Line 1 LRT	37.0%	UITP 1998 page 138
Mean	20.6%	
Avg. 14 European systems (LRT)	**11.0%**	**Hass-Klau, Crampton, Biereth, and Deutsch (2003) quoting UITP (Hue, R)**
Metro/Heavy Rail		
Copenhagen Metro (Metro, Copenhagen)	9.8%	Vuk (2005)
BART (Metro, San Francisco)	35.0%	Richmond (1991)
Madrid Metro	26.0%	Monzon (2000)
Xi'an Metro, China	7.8%	Wang (2013)
Delhi Metro	28.8%	Chauhan (2016)
Athens	16.0%	Golias (2002)
Mean	30.9%	

Table 1. Summary of ridership shift on new transit routes.

Note that a given percentage of riders who formerly drove will be a higher absolute number of former drivers for a higher capacity mode (e.g. Metro). If Heavy Rail moves more people faster than Light Rail or buses, it stands to reason that it should have a higher impact on mode shift, all else being equal.

The growth of traffic generally may reduce the apparent mode shift effect even of a new transit line, unless a multipronged intervention is implemented to prevent this from happening. In the case of the Madrid Metro extension project, Monzon (2005) points out: “the new metro line, together with bus services, has reduced car patronage by 6 per cent since its implementation.” However the car traffic was actually still increasing overall (8601 daily trips in 1996 to 8912 daily trips in 2001) while mode shift was happening towards the newly opened metro line (Monzón, A., 2005). So *while mode shift was significant at 6% of total trips, congestion may have actually gotten worse at the same time*, although the *rate of increase may have been slowed* by the new Metro Lines.

The weight of available research indicates that opening a new Heavy Rail or subway line will cause mode shift, although by itself traffic reduction may be lower than expected. In Manchester, England, Richard Knowles indicates that while rail use after the introduction of the new Metrolink line “had doubled to 8% in 1993”, car use had dropped by 3% (Knowles, 1996). In Athens, Greece, J.C. Golias noted that the Metro system has attracted 24% of riders from car use (Golias, 2002). This new Metro line, “helped alleviate traffic, on the corridors it serves”(Golias, 2002).

The quantum varies, and often traffic will divert from other routes and areas to fill up the some of the space on routes where the shift has occurred. This can give the appearance in some instances of little improvement in traffic flow. In the case of Light Rail, it is more difficult to identify the traffic improvement than a new Metro line which has much greater capacity.

This is not to say that Light Rail cannot impact congestion. Giuliano *et al*. point to the work of Bhattacharjee and Goetz (2012) who examined the Denver LRT system on highway traffic over a 16-year period and found "evidence that average VMT in the control zone of the fully built system increased by about 41 percent between 1992 and 2008, *compared to* a relatively smaller increase of about 31 percent in the corresponding influence zone."(Giuliano *et al*., 2016).

If we summarize the effects of a new line on mode shift, and remove the extreme outliers, we would find a shift magnitude of 4% to 37% of Light Rail ridership or a shift of 8% to 35% of metro rail/Commuter Rail ridership. However this may only translate to 1% to 5 % mode shift *of drivers on the substitute highways* or roads due to pent up demand in the area and drivers shifting from other routes as the congestion eases up.

Effect of new stations:

Opening a new station will not have the same effect as opening an entire new rail line and the literature indicates that new stations that are successful in promoting mode shift in larger numbers are connected to new Transit Oriented Development (TOD) projects.

Mode shift from the introduction of a new station is a function of the land use and development around that station (Zhu *et al*., 2018), and a study focused on Austin (Texas) shows that "TOD helps reduce traffic congestion by around 4% and reduce VMT by 22%" (Zhu *et al*., 2018).

It may be instructive to consider a case study of two Metro Boston Commuter Rail expansions: the Greenbush Line and the Boston Landing Station on the Worcester Commuter Rail line. Ridership attracted to Boston Landing Station exceeded expectations, while ridership along the Greenbush Line failed to meet reasonable expectations (Moskowitz, E., 2010). Further study needs to be done to establish whether land use patterns and densities were different to those used in the modelling by the Massachusetts Department of Transportation and whether the actual transit service availability was the same as that used in the modelling.

Arentze *et al*. have studied the introduction of a new Dutch railway station in Voorhout, Netherlands. They examined household transportation behavior before and after the station opening and found that commuter behavior changed, not just in terms of mode choice. (Arentze *et al*., 2001). By examining the average behavior for participants in the study they found that "The share of car in the total distance traveled has decreased approximately 9 percent"(Ibid).

Parking availability

Parking impact on mode shift depends largely on two factors: its cost and availability. The cost of parking at transit stops or at commute destinations influences ridership on transit and mode shift but in the inverse direction. Increasing parking pricing at the destination pushes mode shift towards transit, while increases in parking pricing at transit stops drives traffic away from transit.

Availability of parking has a similar inverse impact. More parking at transit stops (origin stops) increases ridership demand and more parking near commute destinations reduces transit ridership. This has been shown in a study of Montreal Commuter Rail ridership (Vijayakumar *et* *al*., 2011), and a more recent examination of the Washington D.C. Metro where stations with higher available parking attracted higher ridership numbers (Iseki *et al*., 2018).

Qin *et al*. have done an analysis of park-and-ride decision behavior based on decision field theory on data in China. They find that measures such as information providing park-and-ride facility locations, parking fee, available parking spots might improve the decision process for commuters and increase the utility of park-and-ride facilities. They find providing free parking for the park-and-ride facility would push travelers to choose Park and Ride (Qin *et al*., 2013).

Parking at outlying MBTA stations

Parking availability contributes in a measurable way to increased ridership. The MBTA has at least 100 parking garages covering over 44,000 spaces (*Parking | MBTA*, n.d.). Parking is also provided "at another 175 locations near Commuter Rail and subway stations" by other landowners (Vaccaro, A., 2019).

Kuby, Barranda and Upchurch have examined Light Rail boardings in the US at 9 cities and find "All else being equal… each 100 park-and-ride space (leads) to 77 boardings; each bus to 123 boardings; and an airport to 913 boardings."(Kuby *et al*., 2004).

The Central Transportation Planning Staff (CTPS) of the Boston region Metropolitan Planning Organization have been modelling the future parking needs of the Commuter Rail and Rapid Transit systems of the MBTA in a future no-build scenario. With their model, "stations such as Alewife and Malden were filled to capacity,… and in the South, Braintree and Forest Hills stations had medium demand for additional parking," (CTPS, 2019).

Further study of governance issues (who owns the land, who sets the rates) affecting the control of supply and demand of parking as it affects mode shift and transit ridership needs to be done, and specific roles delineated for private and public real estate owners including the MBTA.

Destination parking

The availability of parking at one's destination plays a large role in the use of a personal vehicle for daily commuting (Bianco *et al*., 1997). Taylor & Fink point to the earlier work of Morrall and Bolger (1996) on the question of parking supply: "They found that the number of downtown parking stalls per CBD employee explained 92 percent of the variation in percent transit modal split for Canadian cities and 59 percent for …U.S. cities" (Taylor & Fink, 2003).

Smart parking & transit

Smart parking is a relatively new phenomenon for transit authorities. Smart parking consists of using technology to help motorists locate, reserve, and pay for parking from their phone or computer with parking availability displayed on electronic message signage. Rodier *et al*. examine a new transit-based smart parking product launched in the San Francisco Bay area. (Rodier & Shaheen, 2010).

Results were significant. In the San Francisco area, "It is estimated that an average participant reduced their monthly VMT by 9.7 miles." With the introduction of smart parking, "55.9% of users, shifted their long-haul commute mode from drive alone, to BART for off-site work commutes. Smart parking also encouraged 30.8% of respondents to use BART instead of driving alone to their on-site work location"(Rodier & Shaheen, 2010).

The idea is to improve accessibility to station parking and convenience for commuters. This allows for more efficient parking use. The net effect indicated in a survey of commuters is that of increased transit use and some degree of mode shift as indicated.

Rodier, Shaheen and Blake followed this study up subsequently with a further study in San Diego. A website has subsequently developed to facilitate smart parking in California and can be found at www.parkingcarma.com

Parking for bikes & PMD's & bike access

The literature indicates that parking and lock up for bikes and personal mobility devices (PMD's) such as scooters and the availability of bike lanes does increase mode shift, but of a small quantity. There are indications that bike facilities including both parking and cycle lanes can change mode of access to a train station, but the shift from car to bike plus train takes some change in the culture and behavior of a community.

The OLS regression estimates in Zhao *et al.* (2013) suggest "an increase of six [metro] riders for each bicycle P&R space"(Zhao *et al.*, 2013).

Cervero *et al*. (2013) analyze several Bay Area Rapid Transit (BART) stations, confirming the positive effect of the quality of bicycle parking facilities but suggesting that this effect concerns primarily residents living near the station. In the Netherlands, Williams (2017) notes that bicycling accounts for 47% and 12% of first-mile and last-mile modes for train trips respectively but makes no finding with regard to the bike-train mode and mode shift from automobiles.

Semler**,** and Hale point out that "most agencies achieve bicycle access mode shares around 2-5%" and that "international research shows that bicycle access mode shares up to 40 percent are attainable (Parsons Brinkerhoff 2009; Martens 2004; Herman *et al*. 1993). Indeed, 47% of respondents in a survey of New Jersey rail commuters stated they would consider cycling from home to the train station, if facilities were improved (Herman *et al*. 1993)." (Semler & Hale, 2010).

Overall, the literature on the mode shift potential of bike and PMD access and parking at stations describes only limited impact on mode shift from auto to bike plus transit while recognizing the "leverage effect of bike parking availability, in quantity and quality, on the practice of bicycle-train integration" (Martens, 2007; Givoni and Rietveld, 2007, 2008; Krizek and Stonebaker, 2011; Arbis *et al*., 2016; Sherwin and Parkhurst, 2008)" (Midenet *et al*., 2018). The MBTA may be able to find ways to accommodate bikes for hire and bike lock up spaces closer to train platforms to encourage commuters to leave the car at home.

Pedestrian access.

The relationship between pedestrian access to train stations and mode shift implies that better pedestrian access might persuade commuters to use transit instead of taking the car all the way to the office. The concept could be understood in a similar fashion to transfer penalties. Increasing the difficulty of access adds one more hidden "cost" to taking transit.

Akbari *et al*. have studied access to transit stations Greater Toronto and Hamilton Area. They find that demand is significantly associated with population density and walkability in the surrounding vicinity of the station, among other factors. "We draw a conclusion that the urban form attributes surrounding TOD stations and the station level attributes have statistically significant relationship with transit ridership by walk access/egress." (Akbari, S. *et al*., 2016).

Semler & Hale (2010) explain that traditionally it was accepted that "people are willing to walk an average of 800 metres, and many will walk considerably farther to high quality rail transport (Martens 2007; Dantas 2005)" Many factors are considered by pedestrians walking to transit stations such as sidewalk conditions, crime and safety and many others. Rail agencies should "support or encourage development in the vicinity of the station"(Semler & Hale, 2010).

Bus connections

Research supports the conventional wisdom that good bus connections to train stations are associated with mode shift to transit. For example Akbari *et al*., have found that "station-level passenger trip production is significantly associated with… the number of bus feeder lines ..." (Akbari, S. *et al*., 2016). Gutiérrez *et al*. find a similar association (Gutiérrez *et al*., 2011). Lownes makes an interesting observation of the history of Commuter Rail in the US: "Existing rail ROW does not often coincide with current commercial and residential demand centers and necessitates the use of a circulator system (bus) to expand the service... Because Commuter Rail eventually seeks to reduce congestion." (Lownes, N., 2007).

It seems that *frequency* of feeder buses is the most significant factor in increasing ridership via feeder buses and so promoting a high degree of mode shift (Cervero, 2006). Brons *et al*. find that in an average Dutch neighborhood if the frequency of public transport services *to* the station would increase from two to three services per hour "an additional 6357 trips per year can be expected, which constitutes an increase of 5.18%; not a minor increase in rail use" (Brons *et al*., 2009).

Interviews conducted by Hale & Scott showed the need to reduce the time taken in transfers and providing real time information to riders at transfer stations being crucial to improving feeder bus mode share (Hine & Scott, 2000).

It is difficult to find hard numbers on the relationship between adding feeder buses to rail and mode shift. Two studies give some indication.

In Maryland, Liu *et al*. experiment with direct ridership models and find that "for Light Rail stations, employment… service level, *feeder bus connectivity*, station location in the Central Business District (CBD), … are significant factors influencing ridership. However for Commuter Rail stations, (MARC) *only feeder bus connections* are found to be significant."(Liu C. *et al*., 2016) Among all the independent variables, only feeder bus connections are statistically significant. "The effect of feeder bus services is dominant and the elasticity is 96.32%" (Liu C. *et al*., 2016). Presumably this will induce an amount of mode shift as a result.

Zhao *et al*. have investigated Metro ridership in NanJing, China and Seoul, Korea and point to the need for free transfers to increase the transfer rate from buses to trains. "For each feeder bus line, an increase of 503 passengers would be expected in Nanjing. However, the bus–Metro transfer riders were much fewer than that (+1,382) of Seoul" (Zhao *et al*., 2013). Seoul had offered bus riders free transfers to Metro, but this was not done in Nanjing. (Zhao *et al*., 2013). Again multiple factors influencing the change were operating simultaneously to achieve a greater shift.

Advertising and marketing

Advertising promotes knowledge of the transit service and encourages mode shift, particularly when new services or facilities are opened. The advertising impacts on mode shift seem to have received a disproportionately low level of attention verses other factors. Carol Lewis has examined the question of marketing to boost transit ridership. The report suggests that marketing techniques that are both low-cost and cost-effective are needed by transit agencies and may be "crucial to their viability"(Lewis, C., 2012).

Sharp's research is discussed below but he has highlighted positive results of Metrolink's efforts at marketing their service. Officials were quoted as saying that the key to ridership growth was their marketing efforts. (Sharp, S., 2019). However as pointed out below, other factors were at play and it is uncertain that the marketing efforts on their own can be separated out from the service improvements as the primary cause of ridership growth.

Jones & Sloman in their 2003 study point to substantial reductions in car use in favor of alternative modes including walking, taking a bus, and the use of car clubs. However their study points out that a combination of methods were jointly employed including advertising, informational services and assistance with travel planning. It is the *combination* which produces the larger than usual mode shift from advertising and informational services(Jones & Sloman, 2003) The table below is illustrative of their results:

Type of measure	'Enlightened' business as usual scenario	'Ambitious' change scenario
Personalised travel planning	-2.7%	-5.5%
Workplace travel plans	-3.4%	-6.9%
School travel plans	-0.9%	-2.8%
Bus information & marketing[7]	-1.8%	-6.0%
Car clubs	-0.14%	-0.3%
Total*	**-8.9%**	**-21.5%**

Source: Derived from Sloman (2003)

* Totals assume that the combined effect of separate soft factors is additive i.e. equal to the sum of the parts. See section 5 for discussion of the validity of this assumption.

Table 2: Jones & Sloman table of cumulative advertising and informational impacts

Currie and Wallace have completed a study in Australia and find advertising, marketing and informational services to be the most cost effective method of inducing ridership on buses and trains. They find an overall public transportation mode share increase of between 6 and 7.1% for very successful bus marketing and passenger information service campaigns in South Perth, Victoria and the Melbourne Tram marketing campaign (Currie & Wallis, 2008). This is for time bound specific campaign interventions.

Sorrel finds more muted effects for social media marketing campaigns (Sorell, 2005). Cairns *et al.* reviewing a study by the British government conclude that public transport information and marketing can produce between 0.1% and 1.1% percentage reduction in car kilometers, and travel awareness campaigns between 0.1% and 1% (Cairns *et al.*, 2008).

The six studies taken together indicate that marketing on its own has a small positive effect on mode shift, but produces larger effects when coupled with other measures such as transit service improvements.

2.2 Service level, comfort & safety

The level of service of a transit system affects commuters and will have an effect on mode shift including hard metrics like frequency, travel time, reliability and less tangible qualities such as comfort and safety. A number of researchers discuss "quality of service" which can be a very nebulous concept, as its definition is somewhat subjective. This makes it difficult to decide what "quality" of service is acceptable and what minima apply. We shall first examine the "hard" metrics of transit service levels.

Speed and travel time

Travel time repeatedly appears in studies of mode shift and transit use. Researchers have attempted to understand how both motorists and transit users perceive time and how this affects their mode choice decisions. How travel time is valued will impact mode choice depending on congestion on the roadways on individual commutes and the travel time on the realistic alternatives.

Van de Walle and Steenberghen find a link between travel time and mode choice. "On the trip chain level, travel time variables for the whole trip chain such as the maximum and the range in the travel time ratio provide a significant improvement to the explanatory power of the regression model." (Van de Walle & Steenberghen, 2006). Frank *et al*. similarly find travel time and cost were associated with mode choice in their study of transportation in the Puget Sound area. "Travel time was the strongest predictor of mode choice". (Frank *et al*., 2008).

While travel time has been shown to be a predictor of mode share, it is important to remember that travel time is a relative concept. Mode choice is decided on the relative travel time and the impact on some modes has a higher predictive value than others.

Chakrabarti, for example finds travel time to be a primary factor in predicting mode share. His study in California finds that "reduction in transit-to-auto travel time ratio can increase the odds (likelihood) of choosing transit by 25%; reduction in headway by 10 minutes can increase odds by about 30%." He finds similarly that reducing schedule unreliability from over to under three minutes deviation can result in 2.6 times increase in the likelihood of choosing transit (Chakrabarti, 2017).

Reliability of service

Transit reliability and auto time travel reliability are both factors that affect mode shift. Often it is the magnitude of the difference between these factors that spurs the mode shift where commuters are able to make a choice between modes.

The Washington DC Metro, according to ridership data from the Federal Transit Agency, has had the largest ridership drop of any transit system in the past 10 or 15 years. The WMATA Board reported: " research has found that at least 30% of our ridership losses in 2013-2016 were due to decreasing customer on time performance"(WMATA Board, 2017).

Service reliability does not always impact mode shift to a large degree. Perk *et al*., (2008) discuss travel time reliability and rider retention in their study for the Florida Department of Transportation. They record that in Chicago, "PACE responded to complaints of irregular bus service on Route 350, in June 2006." They adjusted headways and improved reliability. "Between June 2006 and June 2007, ridership on Route 350 increased by 21.9 percent, compared to a system-wide increase in ridership of 5.2 percent." (Perk, V. *et al*., 2008).

Southern California Regional Rail Authority (SCRRA) showed that in the case of Metrolink (the provider of Commuter Rail service in the Los Angeles area) "on-time performance was the second most important determinant of customer satisfaction"(Perk, V. *et al*., 2008). In Sacramento a different picture emerged. The Sacramento Regional Transit found that on route 30, "ridership … decreased over time in spite of the substantial improvement in schedule reliability." (Perk, V. *et al*., 2008).

Sweet and Chen's study creates a regional measure of travel time unreliability and explores mode choice responses in Chicago. Their results indicate that unpredictable road travel conditions induce mode shift *towards* transit and this effect is larger when service by train is faster (Sweet & Chen, 2011). Their study shows that "one standard deviation drop in travel time reliability… is associated with approximately a 23% reduction in the odds of using the car" (Sweet & Chen, 2011). Bhat & Sardesai also find that travel time reliability is key in commute mode choice (Bhat & Sardesai, 2006) and Imaz *et al*. in Toronto, Canada, find that "service quality and reliability attributes are the main drivers of public transportation customer loyalty"(Imaz *et al*., 2015).

Ironically, Brons *et al*. find that although the **perceived reliability** of the rail service is important "the **actual** reliability of rail service has no significant effect on the level of rail (and car) use"(Brons *et al*., 2009).

Frequency of service

Service frequency is a crucial metric of the level of service of a transit system but may stand as a proxy for travel time or reliability in the minds of the public. Increased frequency may be able to mask shortcomings in speed and reliability of the train service to some degree.

Noland uses a model of schedule disutility to show that transit service reductions result in reduced ridership and highway capacity increases "result in both an immediate reduction in transit use and potentially a long-run reduction along the lines of the Downs-Thomson paradox" (Noland, 2000), but similarly to Mohring (1972) increasing frequency of transit or reducing fares could, reduce automobile travel (Noland, 2000).

Crowding and comfort

Crowding relates to comfort and public perceptions. However public perceptions cause mode shift as Gao *et al*. detail in their study of mode shift in China, which is discussed under the heading "Multi-factoral research" below. Their research does however find that in-vehicle crowding of public transit is a much more crucial factor for mode shift to public transit compared to cost and travel time.

Cox *et al*. examine rail passenger crowding, stress, health and safety in Britain. They point to the success of the Japanese rail network, which can cope with enormous demand. "Part of its apparent success is attributed to passengers' willingness to accept a level of discomfort within densely packed trains when offset against the guarantee of expedient, reliable and predictable transportation (Meyer and Dauby, 2002)"(Cox *et al*., 2006). This is inherently a behavioral perspective on crowding together with an engineering one. However with the advent of the Covid-19 worldwide pandemic in 2019/20, this is going to be a much more problematic facet of transportation for transit agencies to deal with in future.

The understanding of crowding described by Cox *et al*. suggest that crowding is both a measurable factor and a perception matter. Their study further indicates that crowding has a real impact on mode choice, but do not indicate the magnitude of shift (Cox *et al*., 2006). It behaves similar to congestion which is more dynamic in real time.

2.3 Pricing & taxes

Fare pricing, road pricing, gas taxes and even parking prices are elements of the relative cost balance between driving and taking transit. It is this relationship between the relative cost of these two forms of transportation and the public's understanding of the relative costs of these modes which inform their mode choice decisions, either consciously or subconsciously. Below we look at these cost items separately in order to understand the direction and magnitude of their impact on mode shift and mode choice. First we examine fare pricing.

The Transit Cooperative Research Program (TCRP) connected to the Transportation Research Board (TRB) has collated research on transit fare pricing. Their report indicates that "observed values of fare elasticities for transit usually range between zero and -1.0, which in economic terms, means rider response to fare changes is *relatively inelastic*." If a transit authority increases fare prices, it should expect some ridership loss. Reducing fare prices will usually increase ridership, but with a financial cost.

Researchers typically find that, "the most commonly observed range of aggregate fare elasticity values is from 0.1 to 0.6"(Webster, F.V. & Bly, P.H., 1980). The average fare elasticity for U.S. cities, excluding those with Heavy Rail/Metro, is about 0.4 (McCollom, B., 2003). Heavy Rail Transit fare elasticities typically average between 0.17 to 0.18.

From these studies, Rapid Transit ridership appears to be approximately twice as resistant to fare change as bus ridership. The income levels of bus riders may be typically lower than rail ridership, which is an additional consideration and they likely have fewer modal choices. The fare price can be used to increase or decrease ridership and therefore impact mode shift in either direction. However the elasticities indicate that there are limits to using fare prices as a mode shift tool.

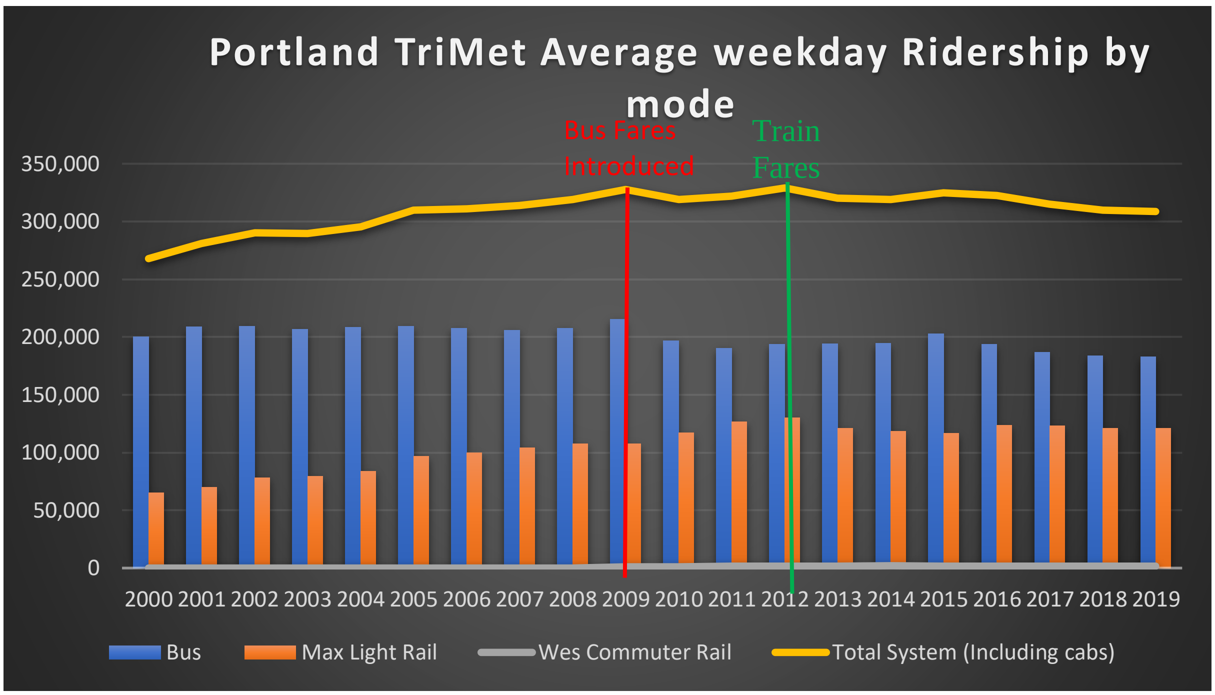
Reduced fare experiments:

The City of Lawrence, MA recently tried a free bus fare experiment. The results saw an increase of about twenty percent in ridership, according to MVRTA administrator Joseph Costanzo (Ramos, N. *et al*., 2019).

Some historical data exist for changing of free fares in Portland, Oregon, and Seattle, Washington. TriMet, in Portland, in 1975 introduced a free bus service that was later rolled out to Light Rail and trains. In 2010 TriMet began charging fares again on buses and on the whole system in 2012. The effect on ridership is instructive.

In 1975 In Portland, a nine-fold ridership increase in CBD trips occurred after fares were abolished and the service improved (Pratt and Copple, 1981). In Seattle, surveys showed that the free service had resulted in a “three-fold increase after eight months over the intra-CBD ridership previously carried on all buses” (Colman, 1979).

Rides in downtown Portland were free from 1975 until 2010. “In 2010, free rides became limited to light-rail and streetcar service – no longer covering bus service – and the zone was renamed the "Free Rail Zone". In September 2012, the fareless zone was shut down and immediately a reduction in trips on the total system occurred as a result. The graph below indicates the points at which the downtown fares were introduced and how ridership numbers changed over time.



Map: Ollis Data Source: Trimet (https://trimet.org/about/pdf/trimetridership.pdf)

Figure 5. Trimet Portland Oregon ridership numbers

Ridership on the buses dropped when the fare was implemented in 2010 and on the trains when the fare was implemented in 2012. These figures are for the whole system, whereas the figures for 1975 were just for the downtown area where the free fares on buses operated. This may be the reason the drop is more muted than the increase observed on only the CBD buses in 1975. The data for downtown cannot be isolated from the overall transit data for the system unfortunately.

The TCRP report compared results across multiple systems. They conclude: "On balance, it seems most likely that CBD free-fare programs do attract more ridership than average bus fare elasticity values would predict, but that other applications fall within normal ranges"(McCollom, B., 2003). However, fare increases generally cause a "greater reduction in ridership than the same size fare reduction will increase ridership" (T. Litman, 2004).

Distance based fare effects

The Washington Metropolitan Area Transit Authority (WMATA) administers the Washington Metro. Metro charges "distance-based" fares to commuters and has experimented with a peak hour fare pricing system.

Recent research by Drs. Hiro Iseki, *et al.* of the University of Maryland's National Center for Smart Growth (NCSG) into transit demand on the D.C. Metro looks at ridership and elasticities on this system in some detail. One variable in the research with substantial effects on ridership is transit fares per mile. Other factors affecting ridership include "Service frequency, the cost of alternative modes of travel (including driving) and fares"(Iseki *et al*., 2018). The study shows that fare elasticity, or the change of ridership in response to transit fare price changes, varies by travel distance. Short distance trips, for which there are many alternatives to the train tend to be more sensitive to fares. (Iseki *et al*., 2018)

Fare changes in conjunction other strategies

A study on mode shift conducted for Atlanta and Los Angeles shows what can be achieved with fare reductions in conjunction with service increases, specifically diversion from the automobile "ranging from 64 percent of new riders in Atlanta to 80 percent of new riders in Los Angeles. Note that these data are for ***new riders***, not new rides, at least in the case of Atlanta. (Bates, 1974; Weary, Kenan and Eoff, 1974)." Quoted in TCRP (McCollom, 2003; emphasis added)

The TCRP report re-iterates that fare changes achieve the greatest ridership shift when they are implemented in conjunction with other strategies. "Fare decreases in conjunction with transit service increases have a synergistic effect to the extent that while both divert a measure of travel to transit from the automobile, service increases tend to produce an excess of capacity that can absorb additional riders attracted by reduced fares" (McCollom, B., 2003).

Vanichkitpisan and Temiyasathit in their analysis of attitudes affecting behavior towards using mass transit in Bankok find that price is the third highest characteristic affecting car drivers attitudes after geographical place and the product (service) itself (Vanichkitpisan & Temiyasathit, 2017).

Pricing auto mobility

Gasoline taxes and road pricing are related: Both increase the cost of driving an automobile. Studying a decrease in US driving between 2004 and 2014, Manville *et al.* (2017) compare potential explanations: a voluntary shift away from driving, or shift caused by economic hardship. They acknowledge imperfect data, but find that there is little evidence for drivers voluntarily driving less and find no simultaneous increase in transit ridership. “However, even as the US dramatically expanded its supply of public transportation and bicycle infrastructure in the 2000s, demand for these modes remained flat or declined while driving fell”(Manville, M., 2017). They argue that the evidence points to an economic explanation. “During the downturn the costs of driving rose while median incomes fell” (Manville, M., 2017). Their study points to the probability that increased gas prices and the erosion of economic well-being of the middle class correlate most closely to the drop-in driving and drop in transit use at the same time. This suggests that merely making it expensive to drive, without making affordable alternatives available, may result temporarily in less travel, rather than lasting mode shift.

Gasoline pricing & taxes

In contrast to the finding of Manville *et al.* regarding economic factor’s apparent lack of impact on mode shift, a time-series analysis of gasoline prices and public transportation in US metropolitan areas by Bradley W. Lane in 2011 does show an impact on mode shift.

His analysis points to transit ridership changes often following gasoline prices, but that ridership increases lag. “Every 10% increase in gasoline prices can lead to ridership increases of up to 4% per significant lag for bus and 8% for rail” (Lane, 2012). The implication is that car drivers shift to transit as gasoline prices rise and suggests greater preference for rail transit over bus among motorists. The results suggest that with “proper price structuring and improvements in transit provision there is significant untapped potential for transit to attract abandoned automobile trips”(Lane, 2012).

Iseki completed an analysis into gasoline prices published in 2015. His analysis found strong evidence for “aggregate 0.61-0.62 percent (bus) ridership increase with a 10 percent increase in gasoline prices” (Iseki, H., 2015). However in the long term, his research suggests that there is an impact on all modes.

Melbourne is served by a multi-modal transit system that over the last six years has seen ridership increase by almost 4.5% annually, an increase that is strongly correlated with gas prices (Odgers, 2009).

The evidence is that fuel prices impact mode shift. The difference between these studies and the study by Manville *et al.* (2017) is around the *relative* price increases. The Manville study examines a period when the most significant economic impact on the middle class in terms of incomes and unemployment was due to an economic crisis. People without work couldn’t afford *any* travelling expenses, not just in an automobile. These latter studies show gas prices increasing without an increase necessarily in transit fares, or a more muted increase than the gasoline price.

Road pricing

Pricing roads can be implemented in many ways: through an all-day tolling scheme; a congestion charge based on time of day or traffic flow; a form of cordon pricing; or pricing based on Vehicle Miles Travelled (VMT).

Winick *et al*. have examined the effects of congestion pricing in Seattle, Singapore, London, California and a number of other locations including the use of tolls and High Occupancy Vehicle (HOV) lanes and find that: “The introduction of tolls results in traffic reductions ranging from 7% to 30%”(Winick,R. Matherly, D. and Ismart, D., 2008). This, in their view, is to be achieved by a combination of shifting discretionary and essential trips to other time periods, other roads or shifting motorists to transit, carpool and vanpool programs.

Krol believes that the Singapore experience demonstrates, over a long period of time, that congestion pricing causes a shift to public transit. In his 2016 article he highlights some of the significant changes in Singapore after the introduction of the congestion fee: “In 1975, 46 percent of all trips into the zone were made by bus. By 1998, 67 percent of all trips into the zone were made by bus or Rapid Transit.”(Krol, 2018).

Cools *et al*. looked at road pricing from a behavioral perspective. They find that behavioral mode shift depends on road pricing charges “surpassing a minimum threshold”. (Cools *et al*., 2011). They refer to the study by Jakobsson *et al*. into the effects of economic disincentives on car use to indicate that “*road pricing alone will not counterbalance the growth in car use”* (Cools *et al*., 2011). Their results indicated that longer term impacts of road pricing VMT reductions are difficult to sustain and drivers may return to previous practices entirely once the disincentive is removed. They also indicate that shopping trips were the first to go. (Jakobsson *et al*., 2002).

Karl Kottenhoff and Karin Brundell Freij have examined a trial congestion charging regime in Stockholm (cordon pricing) that was connected to increased public transportation (express bus service). In the trial, congestion charges and expanded public transport services were linked together in their marketing. “The official evaluation… showed that the number of cars over the charging cordon decreased by about 21–22% on weekdays 06.30–18.30 during the trial. The travel survey shows an overall 3% increase in PT journeys. Stockholm Transport reports that overall ridership in the county increased by 6% ” (Kottenhoff & Brundell Freij, 2009).

Washbrook *et al.* completed a discrete choice experiment on hypothetical transportation choices of 548 commuters in Vancouver who presently drive alone, “Results indicate that… increasing the cost of SOV travel by introducing new charges had a substantial and significant effect on demand for driving alone. Among the sample, responses to road and parking charges differed most at mid-range pricing levels ($5, $3.18 US), with road pricing being more effective at reducing demand.” (Washbrook *et al*., 2006). They compare how the introduction of charges in Singapore reduced vehicle volumes in the city center by 45% (Toh and Phang 1997) and results that in London a 25% reduction in chargeable traffic volumes (Transport for London 2003), (Washbrook *et al*., 2006).

Parking costs

Parking costs at both ends of the journey do seem to affect mode choice. The question is to what extent this can be used as a demand management tool to effect mode choice decisions. The extant research indicates that most parking price changes at origin stations has very limited effect on mode shift, but that parking pricing at commuter destinations does have an impact on mode shift.

Parking pricing at origin station

Parking at the station of origin for commuters is sometimes referred to as "park and ride" facilities. Transit agencies may use parking pricing as a demand management tool or to recoup costs of construction of the parking itself. The evidence suggests that parking pricing changes at origin stations tend to have small or muted effects on mode choice for the trip as a whole but may affect the mode choice of accessing the station, particularly if stations were regularly filled to capacity.

Habib *et al*. investigate the effect of increasing parking charges at park-and-ride stations on mode choice for current users at 14 transit stations in Vancouver, Canada. "The model results show that an increase in parking charges at park-and-ride stations is more likely to divert current park-and-ride users to the transit all-way option compared with the private car all-way option" (Habib *et al*., 2013). Some will take a bus to the station if available instead of their car.

Their model shows that there are two groups of travelers currently using the park-and-ride option. One group consists of choice users for whom parking cost is highly elastic and pricing affects mode choice. The other group is smaller and represents riders for whom the parking price is inelastic and seldom impacts mode choice. (Habib *et al*., 2013)

Sarah Syed, *et al.* conducted a study of San Francisco Bay Area's Bart system and find that new parking fees did not cause a change in access mode, or overall trip mode and that the overall cost of the transit trip is "lower than the cost of driving" (Syed, S. *et al*., 2009), while Semler and Hale (2010) warn that "Parking management alone has not been shown to increase ridership".

The evidence does suggest that parking pricing changes at origin stations have muted effects on mode shift, particularly if the parking facility is regularly full. In some cases the increase of parking charges actually increases ridership on the transit system. The assumption is that those who live closer chose to walk or bike to the station, freeing up parking bays for those willing to travel further, thus increasing the total accessibility to that station.

Destination parking pricing (Typically work or school)

Destination parking pricing seems to have a somewhat greater impact on ridership and mode shift and is being used to induce mode shift in various places. Transit Cooperative Research Program has released various publications summarizing the trends, particularly in the US. The TCRP research Report 40 has found that parking price does have an effect on transit ridership:

"in fact, the effect of parking price was found to be greater than improvements in transit service. The most effective means of increasing transit ridership, however, is to increase the pricing of parking *and* improve transit service… Finally, raising parking prices at the low end… is likely to have a greater effect on transit ridership than raising parking prices at the high end by the same amount" (Dueker *et al*., 1998).

Watters el al surveyed city employees in Dublin. When asked if there was no longer free parking available to them and they had to pay £5 per day for parking, 44.6% of respondents indicated that they would partially or completely shift to public transport (Watters *et al*., 2006).

Results of a case study of parking at the UC Berkeley campus suggest that parking pricing has a greater impact on parking location than mode choice: "The majority of the employees who are currently driving will still continue to drive, apart from low income employees, but there will be a shift in parking choice" (Ng, 2014).

Hamre & Buehler examine commuter mode choice related to free parking, public transportation benefits, showers, lockers, and bike parking in Washington, DC with a study that used revealed preference data on 4,630 regular commuters. They find that: "Free car parking alone is associated with a 96.6 percent probability to drive alone to work—an increase of about 20 percentage points compared to when no benefits are provided."(Hamre & Buehler, 2014)

Erik Ferguson has examined the influence of employer ridesharing programs on employee mode choice, by means of a survey of companies offering free employee parking which was not costed. He finds that "parking pricing and supply control measures probably would have a larger impact on employee mode split overall" than matching assistance with carpools.(Ferguson, 1990).

MIT's own program of new parking charges coupled with free transit passes is discussed below. According to (Rosenfield, 2018) these joint strategies caused full or partial mode shift to public transit of around 24%. This is a significant share of mode shift which should be taken seriously in the basket of tools.

Parking pricing at destinations has the potential to cause mode shift in the 10% to 45% range depending on the quantum of the parking charge - a significant proportion. Workplace and destination free parking seems to be one of the biggest factors encouraging "drive alone" mode choice.

2.4 Multi-factoral research

It stands to reason that if individual factors each have an effect on mode shift, even if in some cases a small effect, that the most impactful results should come from combinations of the most effective individual factors. This study however does not attempt to isolate numeric comparisons between different sets of baskets of mode shift tools in an attempt to find the largest additional premium obtained from the "sum of the parts". That would be an interesting area for further study. A difficulty would be to translate all tools/factors or mode choice results from each available study into the same metrics for comparison purposes as the research methodologies and results are often not immediately comparable. This study instead seeks to identify results achieved by combining different tools or factors to illustrate that combining them is necessary to achieve the mode shift at the scale targeted by this study.

For example, Blainey, Hickford & Preston investigate non-financial barriers to passenger rail use, mostly in the UK. They identify 37 distinct barriers (Blainey *et al.*, 2012). The paper is largely speculative, but it does illustrate that a combination of factors will explain mode shift more accurately and will lead to better planning.

Often transit agencies themselves are not aware, or choose to ignore that a combination of factors are at play. Metrolink in Los Angeles for example saw recent (2018-2019) ridership increases. “Metrolink officials attributed the 2.1 (percent) increase from 2017-2018 - the fifth straight year of ridership increases - to increased marketing, an improved economy, and discounted fares on some lines…” (Sharp, S., 2019). Officials were quoted as saying that the change factor was their marketing efforts. However as the Stephen Sharp article itself reports, the discounted fares had an impact too and further media articles had reported on the opening of new stations just prior to this (Sharp, S., 2019)(Downey, D., 2019). As is often the case, multiple factors are at work.

Examples based on surveys or interviews, and case studies

Cervero finds that “Mode choice models reveal that office workers are most likely to rail-commute if *frequent feeder bus* services are available, their employers help *cover the cost of taking transit*, and *parking is in short supply*” and that unless “the other end of the commute trip—the workplace—is also convenient to transit, transit will continue to struggle in winning over commuters in an environment of increasingly decentralized employment growth”(Cervero, 2006; emphasis added).

Hass Klau *et al*. point out that measures which have been shown to work more effectively at mode shift are *car parking charges and road pricing*. But this is often complicated .“The results in Oslo, Norway showed that about half of the commuters received some financial help towards the road pricing charges”. (Hass-Klau, C., Crampton, G., Biereth, C., & Deutsch, V., 2003) This can bias the results which is unhelpful.

Gao, Shao and Sun have completed a study in China of psychological resistance to mode shift between cars and transit or vice versa. Their findings point to a connection between a number of factors that either cause or prevent mode shift. *In-vehicle crowding, cost of the transportation and travel time* being three metrics encouraging or preventing mode shift, and in China at least, in-vehicle crowding being the *most* significant of the three (Gao *et al.*, 2019).

Fearnley *et al.* used large datasets from multiple countries and observations that: “The impact of *car travel time* on public transport is, on average, 14 times larger than the reverse impact of public transport travel time on car. Policy makers should therefore understand that 'carrot' measures of improving public transport or… walkability with the goal of reducing car use, are likely to be exceedingly optimistic”(Fearnley *et al.*, 2017). He also elaborates that a “1% increase in car costs increases public transport demand on average by 0.248%” (Fearnley *et al*., 2017).

Nurdden *et al*. find that *reduced travel time, reduced distance to the station and subsidized fares* are the factors promoting the most shift in their study of transportation policy approaches in Malaysia (Nurdden, A. *et al*., 2007). Diab *et al*. using survey results reveal “stations with *higher parking capacities* have higher GO service mode shares. while the availability of *free parking at work* locations has a negative association with GO rail usage (Nurdden, A. *et al*., 2007).

Adam Rosenfield reports on the MIT program and a similar program at a private health care firm - Partners Healthcare (Rosenfield, 2018). Both involved more than one simultaneous intervention. The MIT initiative, consisted of a program of commuting benefit reforms for its 10,000 employees, branded as AccessMIT, included: "A free universal bus and subway transit pass… (and) daily parking pricing instead of annual permits. An increased Commuter Rail monthly pass subsidy… together with a new 50% parking subsidy at transit stations to encourage drivers to park at an MBTA transit station… (and) a multi-modal trip planner, carpool partner matching"(Rosenfield, 2018). The objective was to reduce parking demand by ten percent over two years (Rosenfield, 2018). For Partners Healthcare, "Fourteen work sites were relocated to one centralized, transit-accessible location. This move was combined with enhanced commuter benefits such as a subsidy of 50% for MBTA passes"(Rosenfield, 2018).

At MIT after the program was introduced, "Transit usage increased significantly, with 24% more staff using the MBTA bus or subway service on a regular basis"(Rosenfield, 2018). Partners HealthCare relocated to a site opposite a Rapid Transit station which, achieved a healthy degree of mode shift. Rosenfield indicates that "parking frequency dropped 12%... as reported by a post-relocation employee survey"(Rosenfield, 2018). The 50% transit pass subsidy seemed to be the significant factor in mode shift among employees.

Examples based on multifactorial econometric style modelling or travel demand modeling

Iseki, Liu and Knaap have used the WMATA as a case study in their attempts to grapple with multiple factors impacting mode shift and transit ridership. They find multiple factors at work: "variables with substantial effects on ridership include *transit fares* per mile, *travel time* between OD-stations by car and by bus, *parking capacity*, the level of *feeder bus service*, and *train service levels*." (Iseki *et al*., 2018)

Rashedi *et al*. have used the application of an advanced revealed preference and stated preference choice model to study mode choice in the Toronto-Hamilton area. (Rashedi *et al*., 2017). They found that:

- Providing Wi-Fi increases transit shares by 1.27%
- Introduction of parking fees at stations leads to losing transit users and increases auto use relative to price
- Doubling parking cost at workplaces "reduces the share of auto driver and auto passenger modes by 4.04%, and 0.11% respectively" and increases the share of transit modes by between 1.45% and 2.7%

    (Rashedi *et al*., 2017)

The Wi-Fi connection to mode share is interesting for transit agencies as current riders demand more in terms of modern service and convenience. If there are seats available on trains, and the rider can use the time productively working on a laptop, whether it is working on a memo for work, or something to unwind, the travel time disutility goes down substantially, and may even become valued by the commuter. Quality, high speed Wi-Fi is likely to be a very cost effective amenity to provide.

As seen above, Akbari *et al*. have studied transit ridership in the Greater Toronto and Hamilton Area. "The empirical models reveal that the station-level passenger trip production is significantly associated with population density… as well as the station's *frequency of trains*, (and) *number of bus feeder lines*." They also point to restricted parking having an effect (Akbari, S. *et al*., 2016).

Examples based on statistical counts or implementation results.

The Washington D.C. study of Winick *et al*. points to the need for a combination of measures acting simultaneously (Winick,R. Matherly, D. and Ismart, D., 2008). In their view *shifting discretionary trips* outside of the most congested periods will only shift half the necessary traffic needed significantly reduce congestion, but with *car-pooling* or *ride-sharing* and the use of *efficient transit*, a significant enough number of cars can be removed on the most congested road corridors during the most congested periods to virtually eliminate congested conditions on the highway system in Washington D.C. They recommend that mode shift to transit, car-pooling, and shifting vehicles out of peak travel times combined, "will be able to reduce congestion sufficiently to achieve free flow traffic" (Winick *et al*., 2008). However to achieve this would require a congestion charge, HOV policy implementation and transit improvements.

The study showed that a "10 to 14 percent decrease in traffic on congested freeways will reduce delay by approximately 75 to 80 percent" (Winick *et al*., 2008) They further established that from 7 to 9 percent of the longer trips in personal vehicles during peak periods are discretionary. "We have established *that modest pricing signals* for private vehicles can reduce traffic enough to significantly reduce congestion…, while at the same time increasing the "people-carrying capacity" of the roadway, by increasing the use of carpools… It therefore appears feasible to restore and maintain free-flow on the freeways in the Metropolitan Washington area, without adding capacity, by applying congestion pricing to the major facilities, and at the same time increasing transit, carpool and vanpool programs" (Winick *et al*., 2008).

Winnick *et al*. further point out that the increases in transit use after the implementation of congestion pricing were +3% in Seattle, +23% in Minnesota and +37% in London (Winick *et al*., 2008).

2.5 Literature review discussion and conclusions

A summary of the mode shift effects recorded in the literature is included in the table below. The literature points in many directions, but the unifying thread leads to a compelling observation: some factors have a larger effect on behavior and will, if taken together under the right local conditions, produce a significant effect.

Potential Factor	Evidence of Shift?	Direction	Magnitude	Souces
Accessibility	Yes	Better access = Mode shift to transit	Less than price & frequency	(Brons 2009)(Debrezion, 2006)
Transfer penalties	Yes	Greater transfer cost = mode shift away from transit	Medium	(Algers 1975)(Liu 1997)(Wardman 2001)(Algers 1975)(Iseki & Taylor, 2009)
New Light Rail	Yes	New lines = mode shift to transit	4% to 30% of new riders	(Hass-Klau, Crampton, Biereth, & Deutsch, 2003), (Giuliano 2016),(Chakrabarti 2017)
New Metro Line (HR)	Yes	New lines = mode shift to transit	8% to 35% of new riders	(Yazici 2013)Ingvardson 2018) (Iseki & Taylor, 2009)(Monzon 2000)(Wang 2013)
New Station	Yes	New Station = mode shift towards transit	Large with TOD	(Zhu 2018)(Arentze 2001)
Parking Pricing at Origin	Yes	Unclear, in dense areas higher prices may even increase transit	Small	(Iseki 2018)(Qin 2013) (Vijayakumar 2011)(Habib 2013)(Syed 2009)(Semler 2010)
Smart Parking	yes	More transit ridership	Medium	(Rodier & Shaheen, 2010)
Bike & PMD Parking	yes	More transit ridership	Small	(Zhao 2013)(Cervero 2013) (Michael Replogle & Harriet Parcells 1992)(Midenet 2018)
Pedestrian Access	yes	More transit ridership	Small	(Wibowo & Chalermpong 2010)(Akbari 2016)
Bus Connections	yes	More frequent feeder busses - more mode shift	Medium to large	(Akbari 2016)(Gutiérrez 2011)(Cervero, 2006) (Hine 2000)(Wang 2013)(Liu Chao 2016)
Speed & Travel Time	Yes	Faster relatvie transit increases mode shift	Large	(Vande Walle & Steenberghen, 2006)(Abrantes & Wardman 2011)(Frank 2008)
Reliability of service	Yes	Reliability increases transit ridership	Large	(WMATA Board, 2017)(Perk 2008)(Sweet 2011)(Bhat & Sardesai 2006)(Imaz 2015)
Frequency of Service	Yes	More frequent transit produces mode shift	Large	(Noland, 2000)(Mohring 1972)(Brons 2009)
Destination Parking Pricing	Yes	Higher prices lead to shift towards transit	10% to 45% of drivers	(Taylor 2003)(Ng 2014)(Hamre 2014)(Chatman 2014)(Rosenfield 2018)(Cervero 2006)
Fare pricing	Yes	Elasticities indicate mode shift	Small to medium	(Perk 2008)(Webster 1980)(McCollom 2003)(Colman 1979)(Litman 2004)(Haslam 2018)
Gas Pricing & Tax	Yes	At significant price increases there is mode shift	Small to medium	(Lane, 2012)(Hiroyuki Iseki, 2015)(Odgers, 2009)
Congestion Pricing & Tolls	Yes	Significant mode shift	Large	(Winick 2008)(Krol 2018)(Cools 2011)(Jakobsson 2002)(Gärling 2000) (Kottenhoff 2009)
Crowding & Safety	Yes	Excessive crowding reduces transit share	Unclear	Gao et al 2019)(Cox 2006) (Evans 2002)
Advertising & Information	Yes	Advertising increases transit share	Small	(Chorus 2006)(Steven Sharp 2019)

Table 3: Mode shift overview

The literature review taken together indicates a set of measures likely to produce a significant amount of mode shift when implemented collectively. Programs that include a basket of enhanced transit options and service *combined* with financial incentives and disincentives would be required if a large mode shift in the order of 10 to 15% necessary to significantly tackle congestion generally were to be contemplated.

The 'big guns' of mode shift from car to Rapid Transit around the world that can be combined in such a combination of measures are:

- Opening new Heavy Rail lines such as metro rail, subway or Commuter Rail lines
- Implement a form of road pricing
- Reduce free parking at work or trip destinations
- A gas tax increase (such increases will produce a response although sometimes delayed, and there must be a *significant increase* where gas is cheap)
- Open a new station on an existing rail line *with land use densification* around it (TOD style development)
- Increase train frequency, especially if the headway is higher
- Increase frequency of bus connections to train stations and improve catchment area covered. This is especially important for Heavy Rail such as Commuter Rail or metro train services.
- Improve travel time for transit *relative* to driving a car on the same route.
- Improve the reliability of the train service: perceived reliability apparently produces greater effects than actual reliability. This is more significant on timetables with larger headways (time between 2 trains on the same line).
- Implement a new Light Rail line or new Bus Rapid Transit system *with land use densification* – this has a higher impact on mode shift induced by new Light Rail and BRT than Heavy Rail.

Less impactful measures: The above measures can be enhanced by the use of the following items:

- Parking capacity increases at origin stations (reasonable pricing changes have little effect)
- Increased advertising and information services (must be *combined* with above measures to have a significant impact)
- Increased availability of bike lockup & easy access to bike lockup & train platforms (Station flow patterns)
- The introduction of smart parking technology to pre-book a parking bay at stations
- Reduction of the relative fare price (relative to driving). Low gas prices are a danger to mode shift towards transit.
- Reduce crowding on trains and in stations (Perceptions of crowding are reality to motorists).
- Introduce free, fast, Wi-Fi onboard trains and in stations.

Unlikely to affect mode shift: Longer distance bus trips in mixed traffic do not attract car drivers in large numbers. Efforts in this direction may not produce the desired impact.

In Summary: The combinations that produce higher degrees of mode shift would need to include a method of *road pricing*, a *reduction in free or subsidized workplace parking* and *increased availability, speed and frequency* of Rapid Transit and which the public *perceive as being reliable*.

This research project aimed to ascertain from drivers using the most highly congested roads in Massachusetts which of these factors will impact them most by means of a survey. What prevents them switching to transit? Many studies have analyzed this issue from a theoretical perspective and in the aggregate. This study used a stated preference survey to establish what combination of these factors might be most effective in causing mode shift to transit at a scale that would be meaningful. The attitudes of drivers on these congested highways were ascertained by means of an online survey and their views were then compared to the literature review.

3. Data and survey methodology

3.1 Metro Boston survey

This chapter summarizes an online study conducted of Metro Boston motorists who choose to regularly commute using the most highly congested roads, as listed above, instead of using Rapid Transit to commute.

The aim of the survey is to understand the factors, in the minds of the selected motorists, informing their mode choice of automobile over Rapid Transit and what, if anything would cause them to shift to Rapid Transit, as defined in this thesis. This requires identifying that they travel on the specified corridors, which of these they regularly travel on, identifying the origin and destination pairs for their regular commute, and teasing out their reasons for taking their car and not taking any form of Rapid Transit. The universe of possible respondents included anyone who regularly drives a motor vehicle on the specified corridors for the daily commute. It excluded those who travel regularly by any other means, or who drive a motor vehicle but not on the specified congested corridors. The study does not aim to tease out which drivers are more or less likely to switch, but rather what are the more important or less important factors in drivers' decision to switch or not to switch and which factors have no impact whatso-ever. As such demographic questions are of less import in this study, although this is an important area of research.

Jillian Anable in her analysis of "Complacent Car Addicts" points to six distinct psychographic groups of commuters and their mode shift potential. In her own words: "Each group represents a unique combination of preferences, worldviews and attitudes, indicating that different groups need to be serviced in different ways to optimise the chance of influencing mode choice behaviour. Socio-demographic factors had little bearing on the travel profiles of the segments." (Anable, J., 2005). This survey aims to add to the literature investigating commuter behavior, and to understand motorists' attitudes towards mode shift and to local transit offerings in order to understand what level of mode shift is possible and what the pressure points on commuters are.

The results of the survey will be compared to the theory gleaned from the literature review and with the aim of arriving of a combination of measures that could together shift a significant group of motorists (identified in this study as a ~10% to 15% mode shift target to strive for) to Rapid Transit if implemented properly as a whole.

Survey setup

The survey consisted of an online self-administered attitudinal survey of drivers on the 10 identified most highly congested roads in Massachusetts, administered via Amazon's Mechanical Turk survey platform which locates a randomized group of survey takers that are paid a small fee (typically less than a dollar) for completing each survey. Mechanical Turk describes itself as a "crowdsourcing Marketplace"(*Amazon Mechanical Turk*, n.d.). The survey questions are hosted on the Qualtrics platform on the internet and Mechanical Turk drives the traffic to the platform.

The potential for bias that may be introduced into the sample by the use of a system like Mechanical Turk is low, as a number of studies have been done which show that the results from using these systems show little difference to other methods of administering surveys. For example Coppock concludes after a detailed study that, "I provide evidence from a series of 15 replication experiments that results derived from convenience samples like Amazon's Mechanical Turk are similar to those obtained from national samples"(Coppock, 2019).

Theoretical population

The target population consists of all drivers of cars who travel on the specified 10 highly congested corridors for their regular commute. In calculating the population size, I have relied on the MassDOT online Transportation Data Management System (*Transportation Data Management System*, n.d.). Selected points on each highway or road where a recent detailed count was conducted were used for the measurements. In only one case (Route 28 North of Boston) was there no satisfactory data. In this case I have used an estimated traffic count by averaging the count of 5 of the other roads with the lowest 5 traffic count totals as it is not a large interstate. Traffic in one direction only was used in the sample (both ways daily total would double count the same drivers returning to their point of origin) and for the period 5am to 10am as the core commute time for most motorists. The MassDOT report (MassDOT, 2019) indicates that the commute towards Boston in the morning peak and away from Boston in the evening peak cause the highest congestion and I have thus used the morning commute towards Boston as the population to be studied. As such, the following totals are applicable:

Traffic counts	Total Vehicles AADT	AADT One way	Rush hour both ways	Rush Cars - one way	Location ID	Street location
A) I-93 North of Boston	181045	88410	36153.00	17655	4169	INTERSTATE 93 AT SOMERVILLE
B) I-93 South of Boston	198038	99041	29682.00	14844	691	YANKEE DIVISION HIGHWAY NORTH OF RTE.28
C) State Route 2	45632	23315	13948.33	7127	403	ELM STREET EAST OF REFORMATORY CIRCLE
D) Route 28 North of Boston	No classified data		Average Estimate	10212		
E) I-95 between Peabody and Route 2	131926	67299	37359.00	19058	595	YANKEE DIVISION HIGHWAY SOUTH OF PEABODY CITY LINE
F) State Route 9 (Boston to Worcester)	55385	28762	13542.00	7032	4905	ABERDEEN STREET BTWN I-95 & HAMMOND POND PKWY
G) State Route 3	112793	56799	35946.16	18101	4073	ROUTE 3 SOUTH OF TREBLE COVE RD.
H) I-90 Boston to Worcester	130053	64869	37771.00	18840	AET11	MASSACHUSETTS TURNPIKE EAST OF LOWELL AVENUE
I) I-90 Boston to Revere	93378	46554	24051.00	11991	AET14	MASSACHUSETTS TURNPIKE EAST OF D STREET
J) Route 1 Boston to Revere	84846	40219	21233.00	10065	80	NORTHEAST EXPRESSWAY NORTH OF SARGENT ST.
Total				**134925**		

Table 4: Traffic Counts on Congested highways

This gives a theoretical population of 134,925 drivers in automobiles between the 5am count and the 10am count in one direction (generally towards Boston) on the selected 10 Roads. There will be some duplication of drivers (*e.g.* Route 2 drivers in some cases will also be using one of the interstates also), but these will be offset to a large extent by the drivers who commute regularly before 5am and are not counted in this population.

Study population

The study population consisted of a sub-set of drivers who have access to a computer or smartphone in order to complete an online survey. As such this is not an intercept survey as drivers cannot be stopped while driving to give materials to. It would in all likelihood be impossible to determine which of these drivers has access to a smartphone or computer in order to complete the survey, but I assume that a very high proportion will.

I am not studying trips, but individual drivers. Trips would double count these drivers and lead to other complications with the data (The same person returns home or goes to 3 or four destinations in a day). As Schaller puts it: “In the survey process, customers who are encountered by surveyors more than once are surveyed only the first time”(Schaller, B., 2005).

The survey does have origin and destination sections but is primarily an attitudinal survey.

Sample frame

The frame lists the study population from which the sample will be drawn to be surveyed. "At a minimum it provides a means of identifying and locating the population elements"(Kalton, G., 1983).

In this case the sampling frame consists of Massachusetts and Rhode Island drivers who regularly commute to their daily activities on one of the 10 selected highly congested corridors, who have access to a computer or smartphone and who have registered on the Mechanical Turk platform to complete surveys.

This is a very large population (Amazon claims over 500,000 respondents in their pool), and consists of survey takers who have self-selected to complete surveys. Respondents were chosen randomly by receiving a randomized generalized request from Mechanical Turk (of those who live in the study area) via their online portal and then self-selecting to complete the survey.

Sample size

The sample is only stratified in the sense that drivers using certain congested corridors are chosen and not all motorists. All of these 10 roads do need to be covered, however, but there is no specific weighted sample.

In determining the sample size Schaller's methodology of calculating the number was considered. Using our 134,925 population size, at a 95% confidence level, a 5% sampling error would require a sample of 384 for a population of up to 1 million. For a 3% sampling error, the sample size grows to a 1066 person sample size.

Non-response errors will be limited as payment to Mechanical Turk for locating respondents only occurs if the full number of respondents completes the online survey.

3.2 The survey instrument

A full copy of the survey questionnaire is available under Appendix A. It consists of 16 Questions in a stated preference survey format. The final question only applied to certain respondents.

Question one was designed to identify which roads the commuter typically uses on their daily or weekly commute. The "None of the above" response was inserted to screen those who do not commute regularly by driving on one of the 10 selected congested corridors.

Questions two and four were intended to identify the origin and destination points of each survey respondent in order to understand the roads, highways and train routes available to them in order to understand their route and mode choices.

Questions three and five aimed to identify their times of regular travel and question six aimed at establishing how many respondents travelled alone.

Questions seven and eight aimed to determine the prior transit use of the respondents to determine whether they had experience of using trains or buses and whether they considered it occasionally as an option.

Question nine was designed to establish whether there was a connection to free or subsidized parking at work for the respondents' decision to drive instead of take transit.

Questions ten to thirteen are designed to identify the stated preference of the respondents and their attitudes to transit use versus a private car. Questions ten and twelve were open ended, allowing respondents to write any responses they believed relevant. This meant that for question ten at least, no prior question would prejudice their views by presenting a predetermined set of responses. The set alternatives were then placed in questions eleven and thirteen to prompt the respondents' thoughts on the matter. As many possible responses as were thought relevant were included making the list of options for questions eleven and thirteen quite lengthy.

Question fourteen was included to determine whether there was a relationship between a family owning multiple vehicles and the propensity to take transit, or more pointedly, if they responded that they would never take transit or were very unlikely to, a connection to multiple car ownership could be established.

Question fifteen aims to establish the likely effect of increasing the cost of driving through taxes, congestion pricing or increased tolling.

Question sixteen is aimed only at those who would be unlikely to take transit even if the cost of driving increased by 50 percent. The aim here was to understand why drivers would not shift to trains even under increased financial constraints

4. Survey findings and statistical analysis

4.1 Survey statistics

The survey was opened on February 14, 2020 and responses were received through March 19, 2020. A further set of responses was received between April 7-9, 2020, replacing surveys found to be incomplete or out of the study area states (Massachusetts and Rhode Island). Additional surveys that did not fit the basic criteria were screened out through branch logic in the online software as they did not come from motorists who drive on the ten congested roads regularly. Some duplicates appeared to be submitted by the same person with somewhat identical answers, including identical errors and were screened out. A number had ZIP Codes were unusable or incomplete. These were removed from the dataset, leaving complete and usable surveys of 402 respondents that fulfilled all criteria.

These 402 responses, representing opinions of a sizable sample of drivers who use the most congested roads in Massachusetts, allow results to be reported with a 5% margin of error (at a 95% confidence level), as calculated in the previous chapter).

Respondent demographics

Other than basic geographical data, demographic data such as gender, race, age, income group or education level were not identified, and all responses were anonymous. Geographic distribution and propensity to take various forms of transportation were regarded as important for the purposes of this study.

Geographical distribution

This is a key factor as the location of rail alternatives to driving on these highways depends on locational attributes. Two kinds of locational data was requested of respondents: Home and work locations, delineated by a ZIP Code, and a choice of which highways respondents typically travel on between these two ZIP Codes, to understand the nature of the trips taken regularly. A good spread of roads was found as the pie chart of road use distribution indicates.

4.2 Analysis

There is a good spread of respondents across the 10 selected congested roadways in the study are as the pie chart below highlights.

Roads traversed by respondents**:**

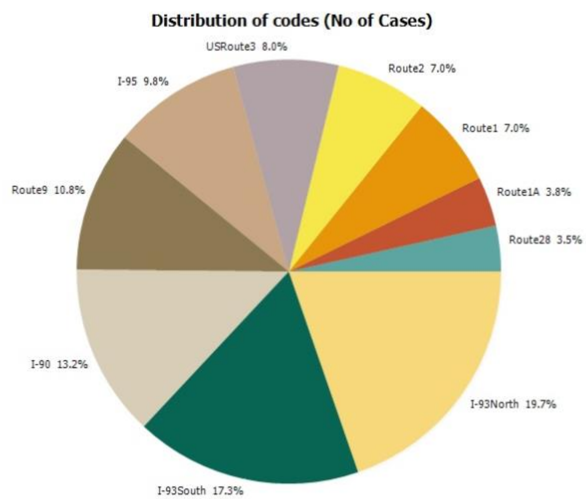


Figure 6. Distribution of road uses indicated by respondents.

The pie chart indicates percentage of individuals who identified a particular road as one they frequently traverse on their daily commute. The graphic highlights the propensity of drivers to use the main Interstate highways and Route 9. The lowest count for a road is 27 out of 402 respondents; with10 roads in the sample this is shows a good distribution across the roads.

Home locations

The geographical spread of home locations according to ZIP Codes is listed in Appendix 2 in detail. The following map indicates the spread of respondents by home ZIP Code.

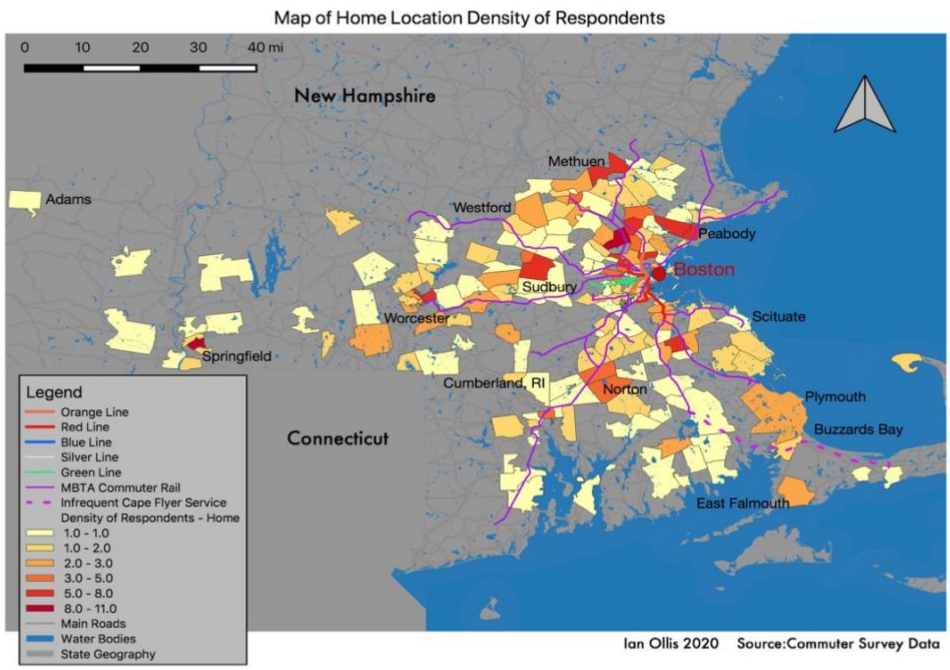


Figure 7. GIS map of home ZIP Codes by respondents per ZIP Code

As can be seen from the map, the spread is broad, but clustered around major dense centers across the two states. 402 respondents live in 186 ZIP Codes across Massachusetts and Rhode Island (The Study Area). As expected, there would be less from Rhode Island. Springfield, Worcester and certain Boston metro area suburbs are prominent.

Work locations:

In terms of work locations, these are listed in Appendix 3. Again 402 Respondents work or go to school in 142 ZIP Code neighborhoods. A map below indicates the spread of work locations of respondents.

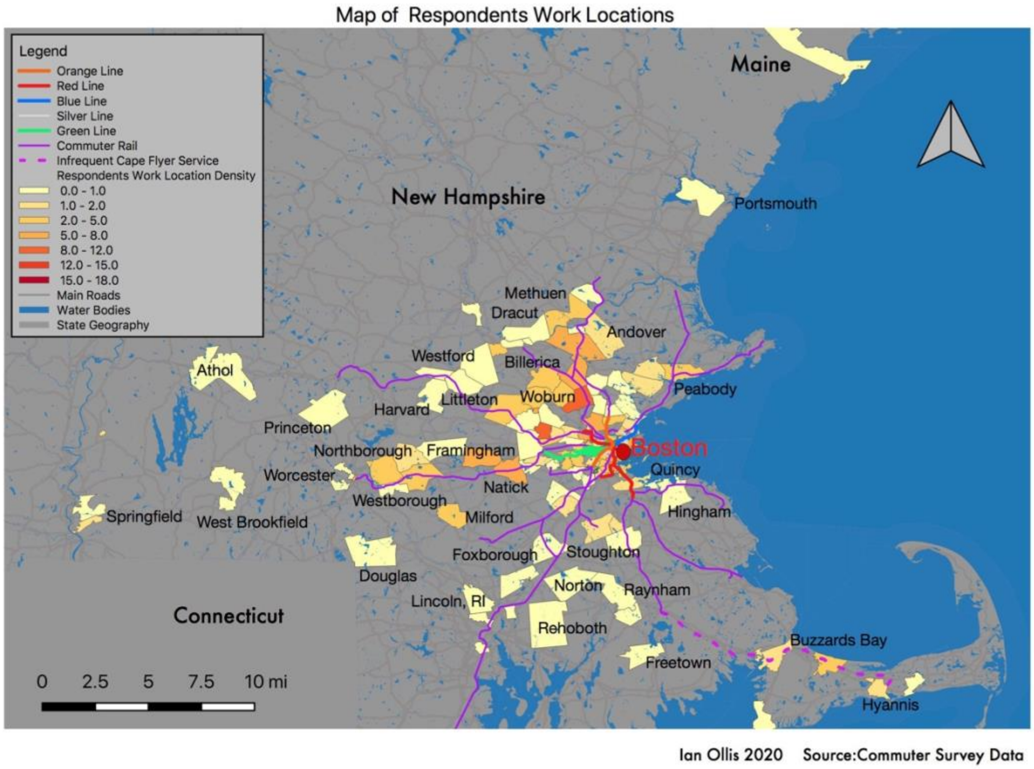


Figure 8. Geographical spread of work locations

Travel time spread

A further set of two temporal variables were included in the survey: Respondents were asked about the time they leave for their regular commute in the morning and the time they return in the afternoon or evening. The breakdown is listed below.

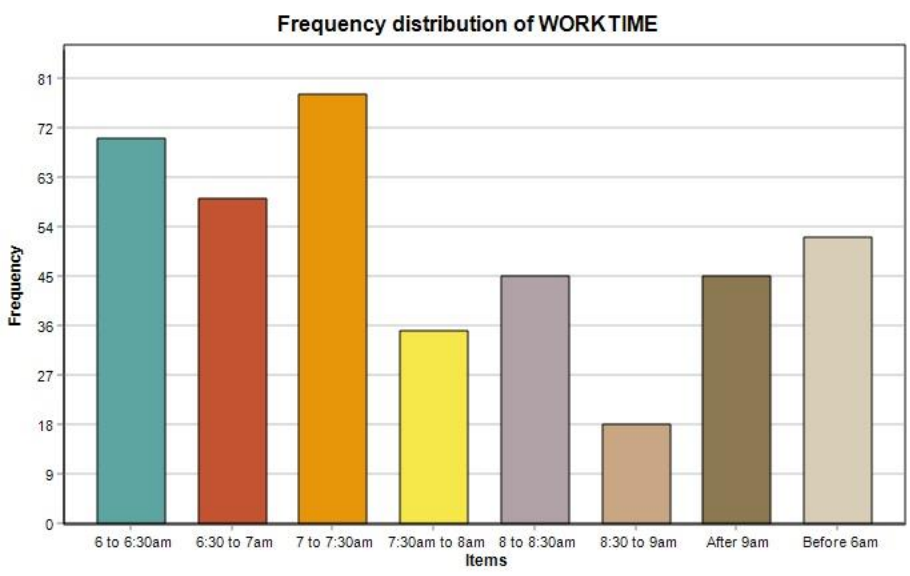


Figure 9. Spread of times respondents leave for work

The variable "Worktime" captures the time the respondent leaves home for work or school. "Hometime" represents the time the respondent leaves for home.

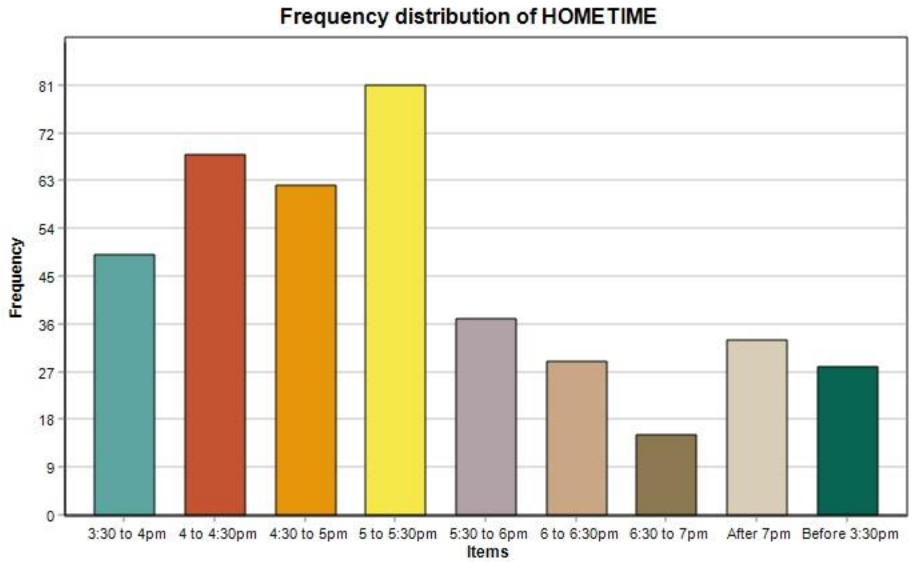


Figure 10. Spread of times respondents leave work or school for home

Understanding respondents prior travel behavior

In order to understand the respondents prior travel behavior, a number of questions were asked regarding their relationship to public transit in the past, their car ownership, and whether they receive free or subsidized parking. 71.9% of respondents indicated that they receive free or subsidized parking at work or school. This was a simple binary yes/no choice. 289 responded "yes" and 113 "no".

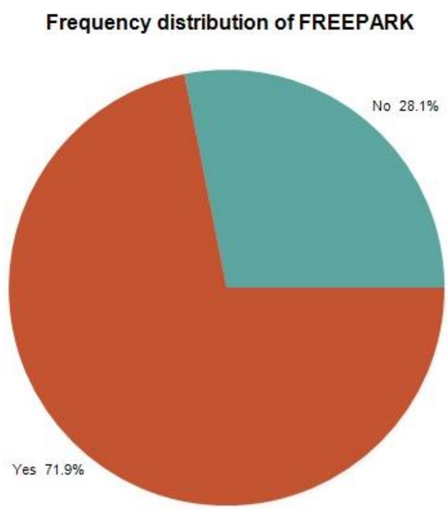


Figure 11. Incidence of free or subsidized parking

Question 7 asks regarding prior occurrence of respondents taking the train for their commute The pie chart below indicates break down of responses. The variable "TrainTake" captured the respondents previous experience of train use. A full 47.3% of respondents never take the train.

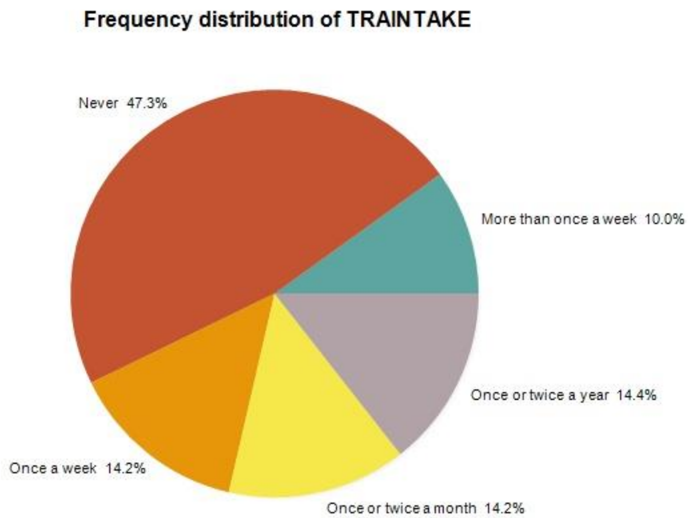


Figure 12. The frequency of taking the train.

Question 8 asks regarding prior occurrence of respondents taking the bus for their commute. The variable "BusTake" captures the responses. The pie chart below indicates break down of responses. A full 72.9% never take a bus.

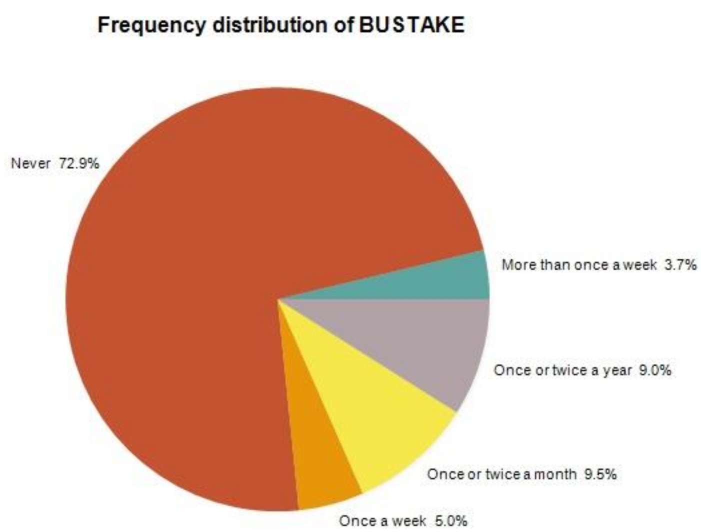


Figure 13. The frequency of taking the bus

Together the public transportation use responses are tabulated below:

Previous Train & Bus Experience

	Train	TRAIN PERCENT	Bus	BUS PERCENT
More than once a week	42	10.40%	15	3.70%
Once a week	57	14.20%	20	5.00%
Once or twice a month	55	13.70%	38	9.50%
Once or twice a year	58	14.40%	36	9.00%
Never	190	47.30%	293	72.90%
TOTAL	**402**	**100%**	**402**	**100%**

Table 5. Bus and train ridership habits

The table of results demonstrates that motorists who drive on the most congested highways and roads in Massachusetts and even Rhode Island do not take a train very often and take a bus even less frequently.

Question 14 asks about car ownership; "Does your household have more than one car.
This was also a simple binary yes/no choice. 259 responded "yes" they do have more than one car in their household and 143 responded in the negative. This represents 64.4% % who have more than one car in the household.

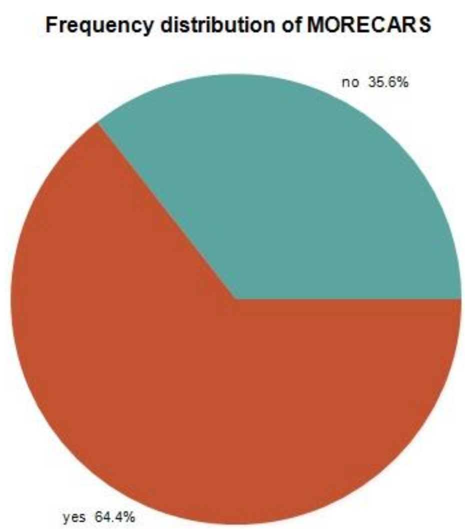


Figure 14. The frequency of having more than one car per household.

Finally in an effort to understand whether they travel alone, respondents were asked how many people, including themselves as the driver of the car, are in the car during their commute. 315 of the 402 respondents travel alone in the car regularly. More than three quarters of respondents are driving alone as a single occupant vehicle trip (SOV).

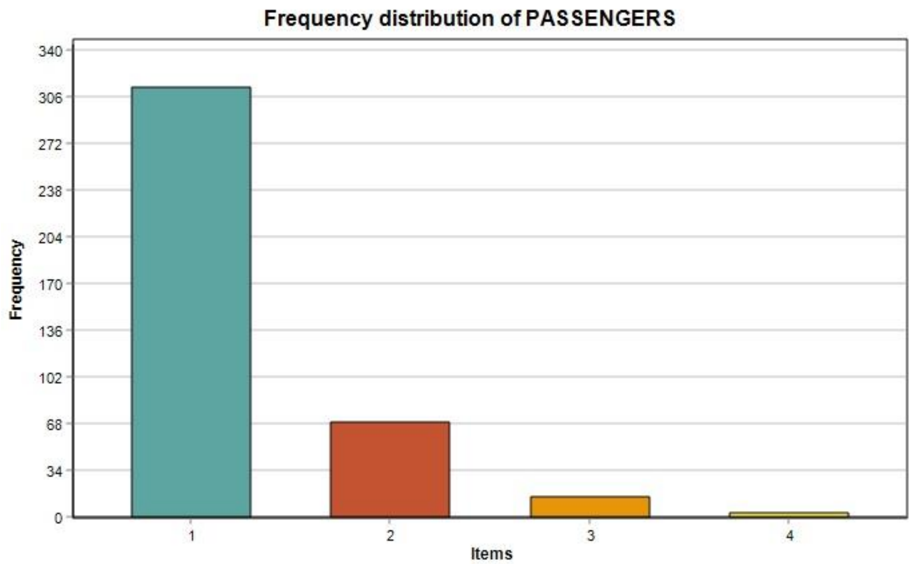


Figure 15. The number of people in the car during the daily commute

The substantive questions

Survey questions ten to sixteen are designed to elicit the "why" of driving rather than taking Rapid Transit.

Question 10

This question is crucial to the analysis. Respondents were simply asked "Why do you drive instead of taking a train (MBTA Commuter Rail, subway or Green Line)?" Answers were requested in long form with no limits. No prompts or options were provided that might have conditioned responses on this question. The open ended nature of responses provided the possibility that respondents would think of motivating factors for their mode choice that occurred outside of the choice options available in questions 11, 13 and 15. As such it reveals the unfiltered and initial thoughts of respondents when thinking about Rapid Transit as an alternative mode choice.

Responses were coded using QDA Miner software and grouped into categories of similar statements in order to sort and analyze responses. The following table illustrates the type and number of responses. The column "Cases" indicates the number of respondents. One case equals one respondent that has commented on this issue. The variable "DriveReasons" captured this variable in the software.

Why drive instead of taking the train?			
Category	**Code**	**Cases**	**% Cases**
DriveReasons	Convenience	111	27.60%
DriveReasons	Access and Network	107	26.60%
DriveReasons	Time Speed	101	25.10%
DriveReasons	Car-Love Comfort Privacy	51	12.70%
DriveReasons	Reliability	45	11.20%
DriveReasons	Health Safety Crowding	36	9.00%
DriveReasons	Frequency Schedule	24	6.00%
DriveReasons	Need Car Tools Locations	21	5.20%
DriveReasons	Costs Fares	18	4.50%
DriveReasons	Free/Subsidized park	9	2.20%
DriveReasons	Daycare Multiple Stops	8	2.00%
DriveReasons	No/Expensive parking	4	1.00%
DriveReasons	Carpool HOV	4	1.00%
DriveReasons	Advertising Info Wayfind	3	0.70%

Table 6. Collated & Coded Responses to Question 10

Responses were grouped and coded to include comments into each of the categories list in the table above under the heading "Code". Typical comments coded in each category are listed in Appendix 4.

These unfiltered perceptions of respondents show some interesting trends and views of public transportation in general and trains in particular, at least as far as the MBTA goes.

The cluster of concerns expressed most frequently by the respondents relate to **convenience, access and network issues** and **travel time and speed**. Around a quarter of respondents picked each of these categories in their unlimited responses. The percentages here are not cumulative, as there is some overlap as residents listed multiple concerns, but it represents a significant proportion of responses.

The next largest group of responses revolved around the variable I termed "**car-love, comfort and privacy".** This group will arguably be the most difficult to shift to public transit. Questions 14, 15 and 16 will shed more light on this group of respondents, particularly those who will not shift even if the cost of driving increases substantially. 12.7 % of respondents' first instinct is that they just love driving and privacy to a degree that transit agencies, like the MBTA, will find it difficult to attract these motorists. However given that only 12.7% mentioned this as their first thought on the matter means that a large percentage of motorists on congested highways in the study area may be shifted if the correct set of responses is applied over time.

Reliability is the next most prominent group of responses numerically. This group of concepts seems to fit closest with the speed time responses. The MBTA's record has been poor in this regard and it is reflected here. Words such as "erratic, unreliable, unpredictable" occur multiple times through the surveys, not only in this question. 11.2% of respondents highlight this as their initial comment on why they drive instead of taking public transit.

Health safety crowding comprises a mixed bag of responses ranging from concerns about crowding, bad smells, dirty stations and trains, and unwanted encounters with homeless people. A number of respondents are concerned with the spread of germs and bacteria and other health concerns, including poor disability access. The MBTA system is perceived as poorly maintained and dated, in need of renovation, cleaning and upgrading, particularly stations and trains. It is important to note that the majority of these responses were received *before* the Coronavirus "Covid-19" epidemic made headlines in Massachusetts.

Frequency & schedule. A number of respondents spoke of after-hours work and the limited train frequency in off-peak hours. There is a perception that, presumably mostly Commuter Rail, has very infrequent trains, resulting in long waits at stations, particularly outside of peak hour travel.

Specific reliance on cars for work 5.2% of respondents either needed to transport tools for work, needed the car during the day for work purposes, or needed to work in multiple locations during the day. 11.6% of respondents had reasons for not taking the train including the fare prices (4.5%) the availability of free or subsidized parking at work (2.2%) Daycare and multiple stops after work (2%) Carpooling or use of HOV lanes (1,2%) inability to find parking at the station, or it was expensive (1%) and lack of information, or wayfinding concerns (0,7%)

Question 11

The following questions begin to propose a range of answers for respondents to choose. Question 11 asks exactly the same question as question 10: "Why do you drive instead of taking a train (Commuter Rail, MBTA Subway or Green Line)". However this question asks for responses in the form of 19 preset multiple choice options. Respondents are asked to rank their top five choices with 1 being their most important reason and 5 the least. The table shows a heatmap of responses:

Options:	1	2	3	4	5	Total Occurrences
Inconvenient: no route	57	49	25	30	28	189
Trains too slow	38	41	36	35	29	179
Too many connections	39	38	29	29	36	171
Using my car is less expensive	26	29	45	32	39	171
Trains are unreliable or unpredictable	39	30	28	30	34	161
No station near origin	59	31	22	21	23	156
Trains are infrequent	38	19	24	26	32	139
Trains or stations are too crowded	23	30	16	35	24	128
Trains Inconvenient - multiple destinations	23	31	23	24	27	128
Trains or stations are dirty and poorly maintained	5	16	27	23	25	96
Trains & Bus combo inconvenient - multiple destinations	9	19	31	15	22	96
Trains are too expensive for me	5	19	22	23	14	83
Bus connections are unreliable or unpredictable	14	15	20	13	20	82
Struggle to find parking	12	10	20	18	16	76
Connecting buses are too crowded	2	11	15	16	12	56
No universal ticket/card	3	7	9	16	9	44
Difficult to purchase tickets	2	3	4	7	5	21
Inadequate or no disability access	5	3	1	6	5	20
Insufficient bike or scooter lock up	3	1	5	3	2	14

Table 7: Heatmap of ranked choices of question 11

The darker colors indicate a higher number of respondents ranking the item higher. The Total Occurrences column sums the first through fifth choices for the item.

As the question is identical to question 10, some comparisons can be made, although the categories will not be the same due to the preset choices for question 11. There is some shift in responses and some things the same or similar.

Question 12 "Change reasons"

Question 12 again asks for open responses: "Complete the following sentence: 'The change to the train or transit system that would cause me to switch to using public transit for my daily or regular commute would be…..'"; respondents are left space to write their thoughts.

Responses are coded in a similar way to question 10. The chart below gives a cumulative picture of responses indicating what respondents say they most want changed. "Car gone" or "car broke" is a new category which appears in response to the "Change would cause me to shift" question. Some respondents indicated that they would only shift if their vehicle was no longer available. "Road Diet Traffic" indicates a small number of responses that indicated that if the congestion became worse for a range of reasons, they might switch.

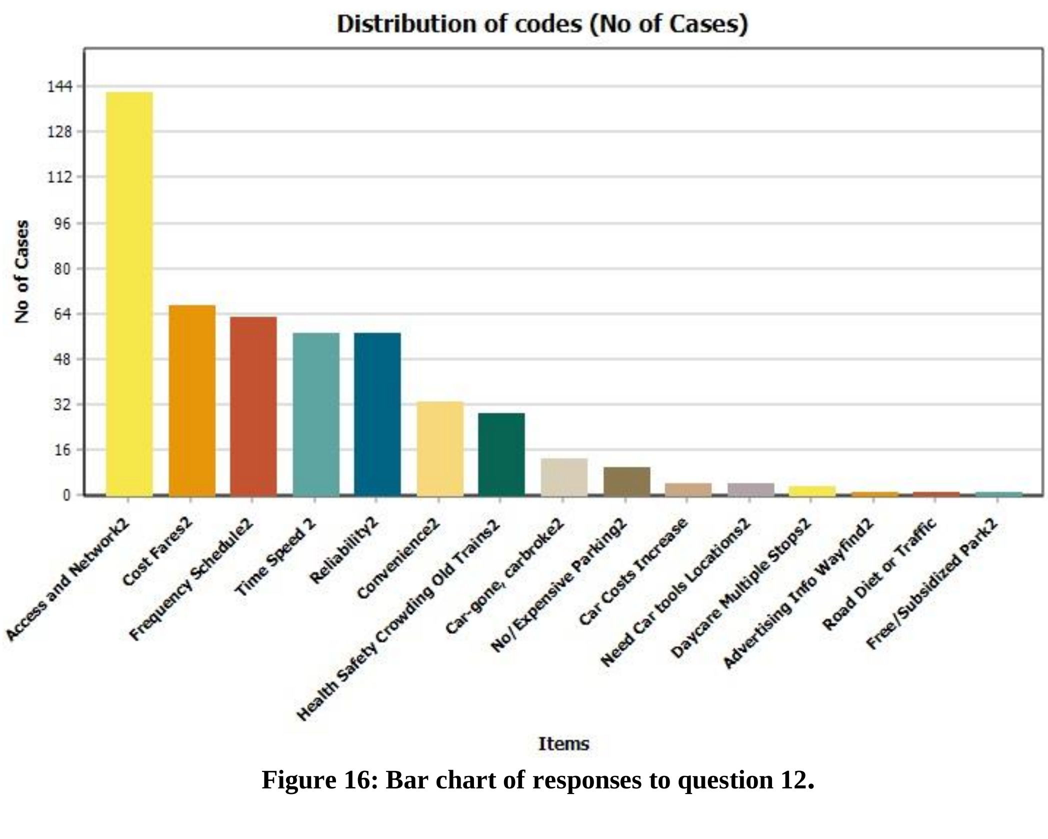


Figure 16: Bar chart of responses to question 12.

While Figure 16 indicates the number of respondents who proposed a particular solution, the pie chart below (Figure 17) itemizes the responses by a percentage of respondents noting a particular issue.

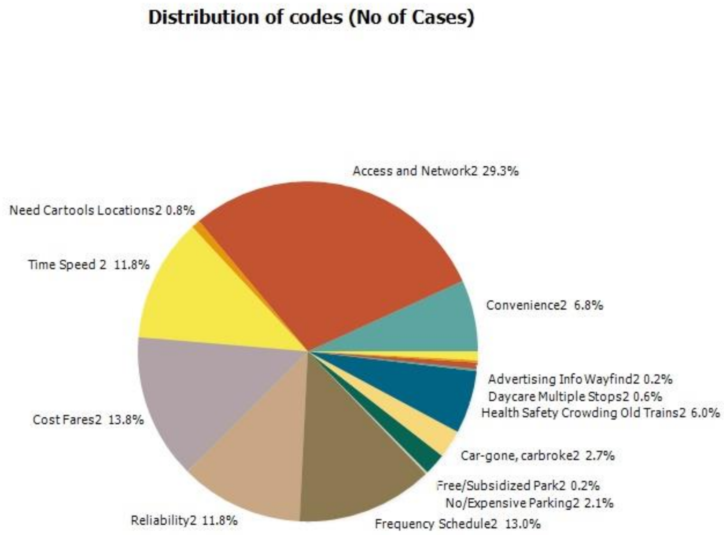


Figure 17: Pie chart of responses to question 12.

Both in absolute number of responses and in percentage terms, accessibility and network related issues (including stations, number of transfers required, access modes to reach stations, parking, and reach of the network) is the number one priority listed in question 12.

The next tier of primary issues highlighted by respondents includes fare prices, trip time, reliability and frequency. The percentages vary depending on how the question is framed, how much leeway the respondents have to tailor their answers, but these issues remain prominent. Convenience and the deteriorating environment of stations and trains follow up leaders in public perception.

Question 13

Question 13 is a multiple choice question with a preset set of options. The question reads: "Which five (5) of the following changes to the transit system would cause you to switch to using public transit for your daily or regular commute (pick the five (5) most likely to influence your decision?) Please rank 1 (most important reason) to 5 (least important reason)". In this question 22 optional responses are provided as a multiple choice option. The ranked choice responses are tabulated below.

Network, time and costs again featured prominently in the responses, together with train frequency and reliability issues.

Category	1st choice	2	3	4	5th choice	Total Occurences
Shorter journey time by train	36	37	29	43	31	176
If the cost of driving my car went up substantially	33	28	34	34	33	162
More frequent trains	36	30	28	36	28	158
A new station near my destination	45	33	30	21	22	151
Less expensive public transportation fares	26	16	36	26	41	145
A new station, stop or train line near my home	49	33	21	18	23	144
More reliable trains that don't break down or get delayed	28	27	28	24	21	128
Shorter journey time by train – bus Combo	26	22	27	24	27	126
Cleaner or better maintained trains or stations	8	25	21	23	19	96
Less crowded trains	10	20	18	17	25	90
Reduced number of connections (Transfers)	8	19	22	20	15	84
Less crowded stations or stops	9	15	16	15	21	76
Sufficient additional parking for cars at the station	9	15	13	18	18	73
More reliable bus connections	8	18	14	18	13	71
One universal ticket to use on all modes	5	14	15	18	14	66
A fare ticket which allows multiple stops	9	10	14	8	15	56
More frequent buses	11	13	11	13	8	56
Less crowded buses	7	10	15	8	10	50
Nothing would ever cause me to travel by train or subway	30	3	1	4	11	49
More ticket machines or methods of payment	1	5	5	6	4	21
Improved disability access at my station or stop	5	4	3	3	2	17
More bike or scooter lock up facilities	3	5	1	5	1	15
Total						2010

Table 8: Heatmap of ranked choices of question 13.

As previously, the darker colors indicate higher number of respondent choices. The numbers are total number of respondents who chose the item, not percentages. Again we see a number of the same categories being ranked as important by respondents. The outlier is of course the additional item of "Nothing would ever cause me to travel by train or subway" which a subset of respondents chose. These represent 49 out of 2010 responses (2.4%), but represents 12% of respondents (402) who chose it at some level of importance.

Journey time, driving costs, train frequency, an additional station located near the office, or home, and less expensive fares all score highly in respondents ranked choices. Reliability of trains and shorter linked trip also feature highly. Bus improvements, apart from access to the station or local "circulator" type buses extending the reach of rail by bring people to stations, do not seem to impress these respondents who travel in dense traffic regularly. They seem to have little interest in biking facilities or in ticketing system improvements.

Car ownership, price increases and mode shift

Analysis of car ownership and the impact of an increase in driving costs on mode shift shows trends which transit planners need to be aware of. Questions 14, 15 and 16 attempt to understand the relationship between substantial auto travel price increases, mode shift and car ownership.

Question 14 asks whether the respondent has more than one car in the household. The table below tabulates the responses recorded. 64.4% (almost two thirds) of respondents are from multiple vehicle households.

	FREQUENCY	TOTAL PERCENT
Yes	259	64.40%
No	143	35.60%
TOTAL	**402**	**100%**

Table 9: Household car availability

Question 15 asks whether the respondent is likely to shift to Rapid Transit if the cost of driving were increased by 50% (through the introduction of a gas tax, congestion pricing, a new or raised toll fee, or new fees on parking). 63.7% of respondents say that they will shift if the cost of driving goes up by 50%. 36.3% of respondents are unlikely to shift *as a result of price increases alone.*

	FREQUENCY	TOTAL PERCENT
Extremely likely	65	16.20%
Somewhat likely	191	47.50%
Somewhat unlikely	96	23.90%
Extremely unlikely	50	12.40%
TOTAL	**402**	**100%**

Table 10: Likelihood of mode shift with increased driving costs

Question 16 tries to understand the thinking of the 36 % who are unlikely to shift due to driving cost increases alone. The question asks: "If you answered unlikely or very unlikely for the previous question, what is the main reason for your answer?" This question attempts to understand the factors that would limit the effectiveness of increased road pricing or other taxes. The answers should speak to the combination of measures that would need to be considered in addition to pricing and taxes in order to realize the 10 to 15% mode shift that is the target of this thesis.

What is the main reason you are unlikely to shift if the cost of driving goes up?		
Code	**Cases**	**% Cases**
Inconvenience	28	7.00%
Access Network	24	6.00%
Car-love	24	6.00%
Time Speed3	19	4.70%
Reliability	18	4.50%
Safety Crowding health	12	3.00%
Equipment Multiple destinations	10	2.50%
Flexibility Kids	4	1.00%
Costs	4	1.00%
Frequency	3	0.70%
50 percent is not high enough	3	0.70%
I would leave or move	2	0.50%
Underlying Transit Failures	1	0.20%
Rolling Stock	1	0.20%
Locked into car payment	1	0.20%
Carpool HOV3	1	0.20%
Information wayfinding adverts	1	0.20%

Table 11: Reasons for no mode shift with increased driving costs

This question was only asked of respondents who had answered that they were somewhat unlikely or extremely unlikely to shift to transit if the costs of driving their car increased by 50%.

The chart below tabulates the reasons as a percentage of total respondents.

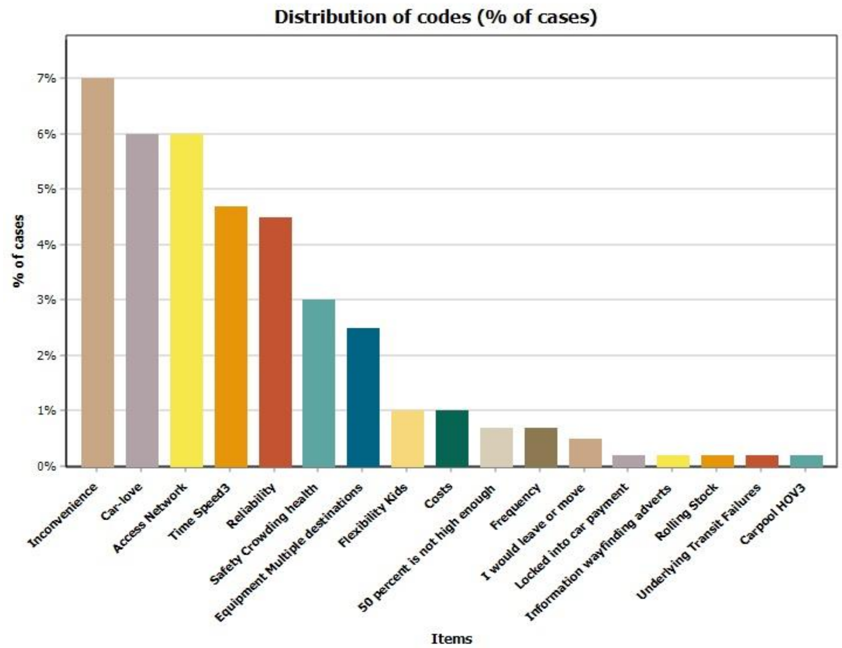


Figure 18: Bar chart of reasons not to shift to Rapid Transit

As with other questions above, four categories of factors that influence driver decision making appear to have the deepest resonance: (1) the inconvenience of public transit access and network limitations, reliability, time considerations, and frequency, (2) crowding, perceptions of safety and health, (3) the need to reach multiple destinations during the day, and (4) "car-love".

Comparing responses in 14, 15 and 16 we can see the following trends and cross correlations: Household car availability when compared with the likelihood to mode shift after a 50% increase in driving costs is tabulated in Table 11. There is a noticeable trend that drivers in households with only one car available are more likely to shift to trains or Rapid Transit than drivers from households with multiple cars. This may mean that commuters from higher income households will be less likely to shift.

Car ownership versus propensity to shift if driving costs increase 50%

	Extremely likely	Somewhat likely	Somewhat unlikely	Extremely unlikely	TOTAL
Yes	34	124	62	39	**259**
No	31	67	34	11	**143**
TOTAL	**65**	**191**	**96**	**50**	**402**

Table 12: Reasons for no mode shift with increased driving costs versus car ownership

These numbers indicate 60.6% of those respondents in households with more than one car have a propensity to shift if the price increases by 50% versus 67.13% of those respondents in households with one or less automobiles.

When comparing household car ownership with *reasons* respondents are unlikely to shift even with an increase in auto costs, a mixed bag of responses emerge. The chart below indicates percentage of respondents from the group that indicated they were unlikely to shift even if the cost of driving was increased by 50 percent.

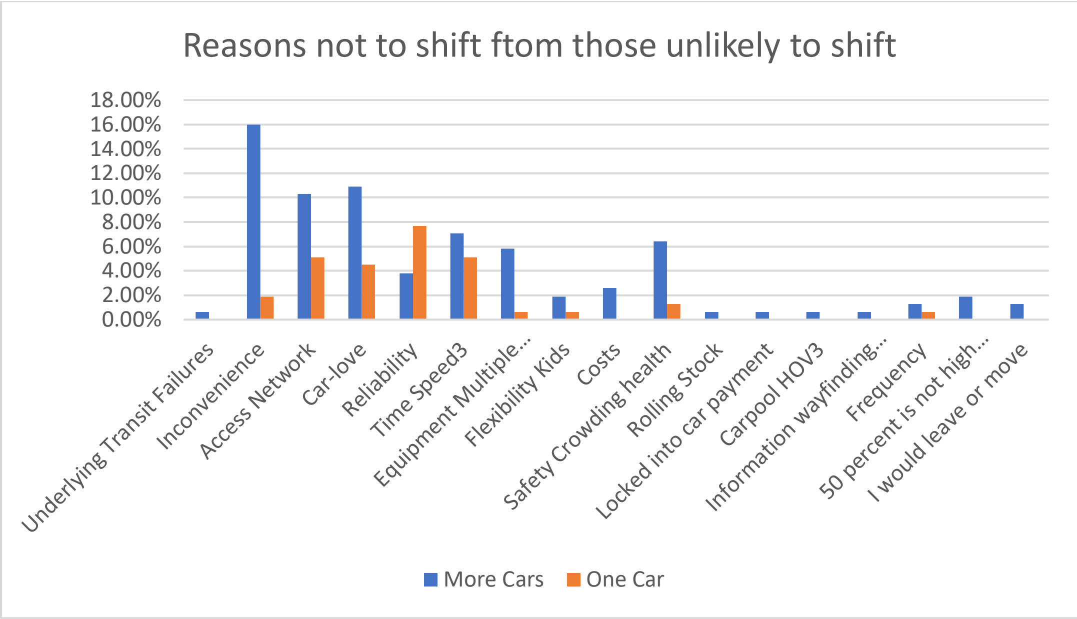


Figure 19: Bar chart of reasons not to shift to Rapid Transit vs Car Ownership

Interestingly those with fewer cars (who only represent 35.6% of respondents) have a higher number of complaints than those with more than one car per household *in one particular category* of concern: *reliability*. We would expect a rough two thirds – one third split between households with more cars versus only one car. This isn't the case for those who say that reliability prevents them shifting to transit even if costs increase substantially. It seems that the thing which most prevents those households with fewer cars from shifting to trains is the reliability of the train service and to a slightly lesser extent the time a trip takes followed by access and network considerations. In these cases, competition for the one vehicle may make reliability of transit a more acute concern for one car households. For those with more than one car per household, reliability of transit service is a lesser concern.

A further area of study would involve looking at location effects among this sample. It may be the case that there are clear geographical differences between those with one car per household versus those with two or more cars per household.

Health & safety concerns

A full 270 out of 402 or 67% of respondents described the trains, buses and stations as crowded, dirty, unhealthy or unsafe at least once across 5 survey questions. While this did not feature in any one question among the top 5 reasons for not taking transit, it still represents a significant factor in the minds of respondents and sometimes ranks as reason seven or eight. Over ninety percent of surveys were submitted before Covid-19 had resulted in a gubernatorial declaration of emergency. Post Covid-19 this concern will presumably retain or grow its importance in the minds of people.

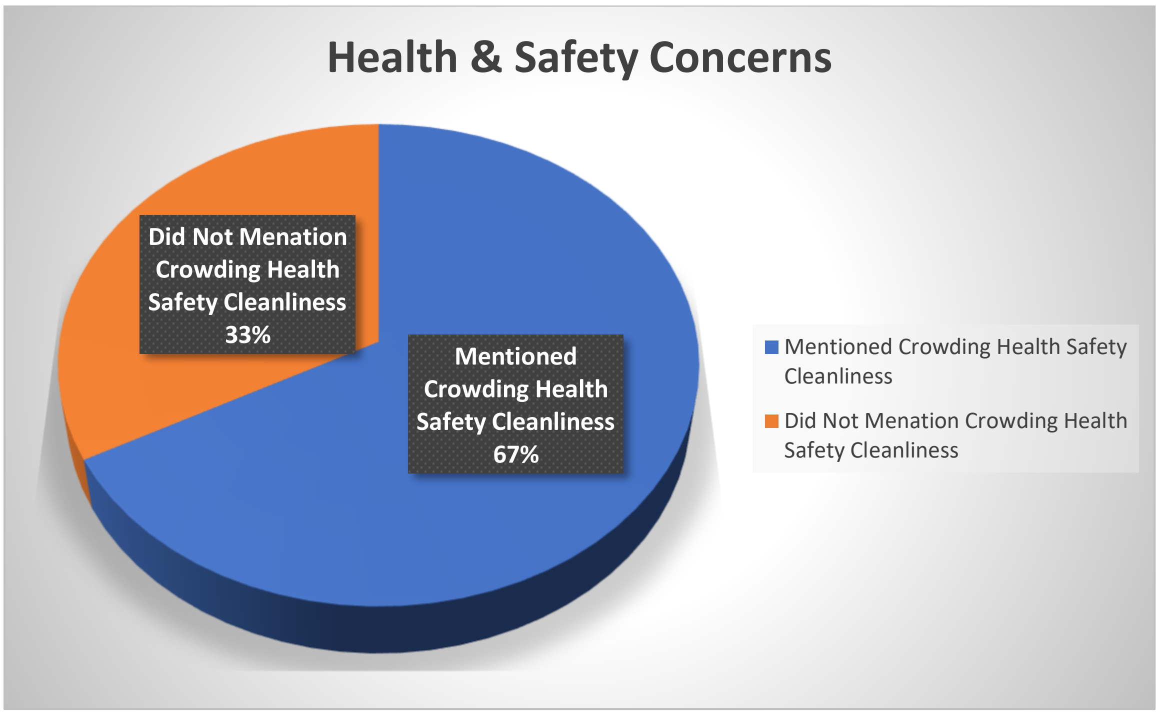


Figure 20: Health, safety, crowding, cleanliness mentions

Network related comments

The vast majority of respondents expressed concern about access, connectivity, number of transfers and sufficient extent of the operational rail network, particularly as it is proximate to their individual transportation needs. Of the ZIP Codes numerically most represented by respondents, the table below itemizes those ZIP Codes to receive the most comments about network insufficiency. This could mean buses to the Commuter Rail stop are insufficient or the station is too far from the work location or there is no stop on the line. This list should however be treated with caution and more study of accessibility and network related issues is necessary. A full study of accessibility issues must consider their representation in the sample and the population density of those ZIP Codes in order to make a fair assessment of the real needs for transportation in these areas. In some cases it may be a marketing and wayfinding issue, in other cases, access to the existing station may need improvement. Back Bay is a prime example. There is both a Commuter Rail and subway station. Yet people who work in this area mention access and network concerns. The GIS mapping in the next chapter takes this matter further.

Network Access Station Issues Highlighted		
Zipcode	Neighborhood	Origin/Destination
2474	Arlington	Home
2135	Brighton	Home
1867	Reading	Home
1844	Methuen	Home
1801	Woburn	Home
1109	Springfield	Home
1605	Worcester	Home
2148	Malden	Home
1864	North Reading	Home
1776	Sudbury	Home
1731	Lincoln	Work
1760	Natick	Work
2116	Backbay	Work
2155	Medford	Work
2210	West Broadway/South Boston	Work
2101	Beacon Hill	Work

Table 13: ZIP Codes of respondents noting access & network insufficiencies

In summarizing the findings from the substantive questions 10 to 13, it may be helpful to tabulate similarities.

If one converts totals for all four questions into either a percentage of total cases or a percentage of occurrences (multiple choice votes), one may then exclude those that do not meet a minimum threshold of respondents mentioning a topic or a percentage of total multiple choice votes. If we set the threshold at 5% of total respondents commenting or 5% of total votes cast, we get a very similar list of issues listed in results of the four question. Below is a table. Colors indicate similar issues per question.

10. Why Drive?	Cases	% Cases
Convenience	111	27.6%
Access and Network	107	26.6%
Time Speed	101	25.1%
Car-Love Comfort Privacy	51	12.7%
Reliability0	45	11.2%
Health Safety Crowding	36	9.0%
Frequency Schedule	24	6.0%
Need Car Tools Locations	21	5.2%

11. Why Drive?	Total Occurrences	% Choices
Inconvenient: no route	189	9.4%
Trains too slow	179	8.9%
Too many connections	171	8.5%
Using my car is less expensive	171	8.5%
Trains are unreliable or unpredictable	161	8.0%
No station near origin	156	7.8%
Trains are infrequent	139	6.9%
Trains or stations are too crowded	128	6.4%
Trains Inconvenient - multiple destinations	128	6.4%

12. Change Reasons	Cases	% Cases
Access and Network2	142	35.3%
Cost Fares2	67	16.7%
Frequency Schedule2	63	15.7%
Time Speed 2	57	14.2%
Reliability2	57	14.2%
Convenience2	33	8.2%
Health Safety Crowding Old Trains2	29	7.2%

13. Why Not Transit?	Total Occurrences	% Choices
Shorter journey time by train	176	8.8%
If the cost of driving my car went up substantially	162	8.1%
More frequent trains	158	7.9%
A new station near my destination	151	7.5%
Less expensive public transportation fares	145	7.2%
A new station, stop or train line near my home	144	7.2%
More reliable trains that don't break down or get delayed	128	6.4%
Shorter journey time by train – bus Combo	126	6.3%

Table 14: Summary of prominent factors in questions 10, 11, 12 & 13.

While the order of the cases changes and the percentage of respondents who either mention the item or choose it in a multiple choice question varies, this list of issues is quite similar. The cluster of issues in the perceptions of this set of motorists travelling in highly congested conditions regularly is that these are the issues that either prevent, or would encourage them to shift to transit instead of travelling, mostly as a single occupant in their vehicle. The next chapter includes geographical and cross cutting analysis.

5. GIS mapping of measures in the study area

The purpose of the GIS Mapping is to examine the survey data with a view to mapping factors that have been identified in the literature review and the survey data. Using this tool illuminates spatial commonalities to the factors stated by respondents as barriers to mode shift. In so doing, it brings to light informative patterns that would be difficult to identify from the numbers alone. For example, where are the complaints about inadequate station parking geographically located? Is there unhappiness with fare costs in all locations or are these concerns more aligned to ZIP Codes adjacent to Commuter Rail or adjacent to the subway lines? The fare price and fare structure on the MBTA system is varied and the Commuter Rail charges are significantly higher than subway fares. Does this have an impact on complaints about fare prices?

If the responses in the survey do have geographic differences, this will have an impact on policy and will inform the policy recommendations of this thesis.

5.1 GIS mapping methodology

The responses to the four substantive questions were extracted from the QDA Miner software in spreadsheets and collated by themes. As such multiple choice questions and free-form responses had to be combined into numbers of responses per topic. This was achieved by simply adding the number of mentions of a particular factor or topic. For the multiple choice questions, a weighting was not applied, but the total choices for a topic were registered and added to the total mentions of that same topic in the free form answers coded in QDA Miner. This meant that the ranking of multiple choice answers by respondents was not considered in the GIS Mapping. Intensity of responses was captured by the number of times a particular response was identified. For example one respondent could mention a particular concern multiple times in the four substantive questions and these could be captured at least four times.

However the respondents were not evenly spread among ZIP Codes. The home or work ZIP Codes for which there were no respondents were left blank and appear grey in the maps below. Further to this the results could be skewed by having many multiple respondents come from some ZIP Codes and only one or two respondents in other ZIP Codes. If not addressed, this would lead to conclusions that the problem is larger in some ZIP Codes than others, when in fact this is merely the result of more voices (respondents) being available in some ZIP Codes than others. To correct for this, the total number of mentions of a particular factor was divided by the number of respondents in that particular ZIP Code, to get an average number of mentions per respondent per ZIP Code. If some respondents did not mention the factor it would then lower the average. In this way both the intensity of responses was captured while limiting the over representation of responses in some ZIP Codes versus others. Each vote counted, but was averaged on a per person basis.

To illustrate: If there were 10 respondents in ZIP Code “A” producing 7 complaints about network accessibility and ZIP Code “B” had only 2 people producing 6 complaints about accessibility, the 7 complaints were divided by 10 to produce an average of 0.7 complaints per person for ZIP Code A, while the 6 complaints for ZIP Code B were divided by 2 to produce an average of 3 complaints per person for ZIP Code B. When mapped in GIS onto the ZIP Code map, ZIP Code B would display as an area with a higher intensity of concerns than ZIP Code A, although both would register concerns as above zero.

ZIP Codes that contained respondents by home or work locations depending on the map, were shown in a color even when there were zero mentions of a particular issue. If there were zero mentions by respondents in that ZIP Code, the ZIP Code was displayed in the lowest intensity color and indicated in the map legend as such. This also tells a story. If there were respondents in a ZIP Code but they did not raise a particular concern, they would still appear on the map but displayed as zero concerns. This informs planning in terms of what geographical areas have no concerns about, say, frequency of trains or high fare prices.

In addition to the four substantive questions, plus the home and work ZIP Code areas, free parking and the lack of free parking was also mapped to see if there was a pattern to the locations of free or subsidized parking.

It is also worth noting that ZIP Codes in some locations cover a wide area. We cannot establish where in the ZIP Code area the person lives or works. As such we cannot establish the exact distance to the nearest transit station or stop.

5.2 Modeling outcomes

Maps of the home and work locations are included in Chapter 4 above. Close up of the Boston Metro region show more local detail for this area:

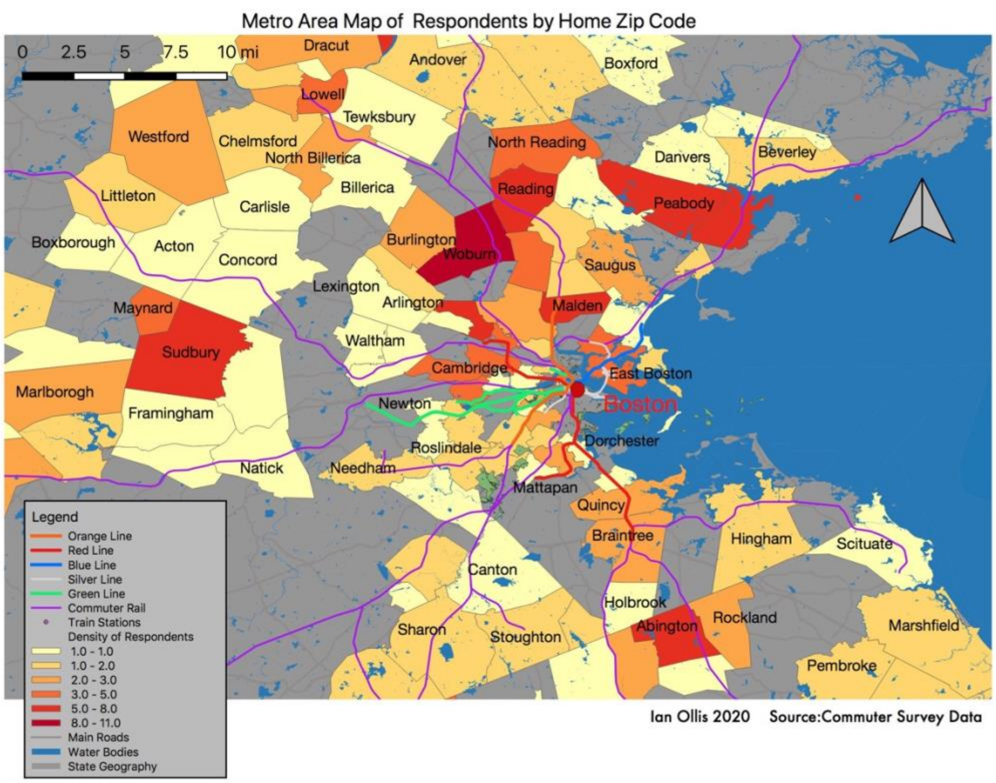


Figure 21. Density of respondents by home ZIP Code locations – Boston Metro area

The darker intensity colors indicate ZIP Codes with more respondents than ZIP Codes with lighter colors. Grey areas indicate no respondents or data available. An area of future research could be to redo the survey with the express intention of locating at least 5 survey takers per ZIP Code in

Massachusetts and Rhode Island. This will however take additional funds and time as the recruitment methodology will have to shift if this is a stated goal of the research setup.

A zoomed in map of work locations is below:

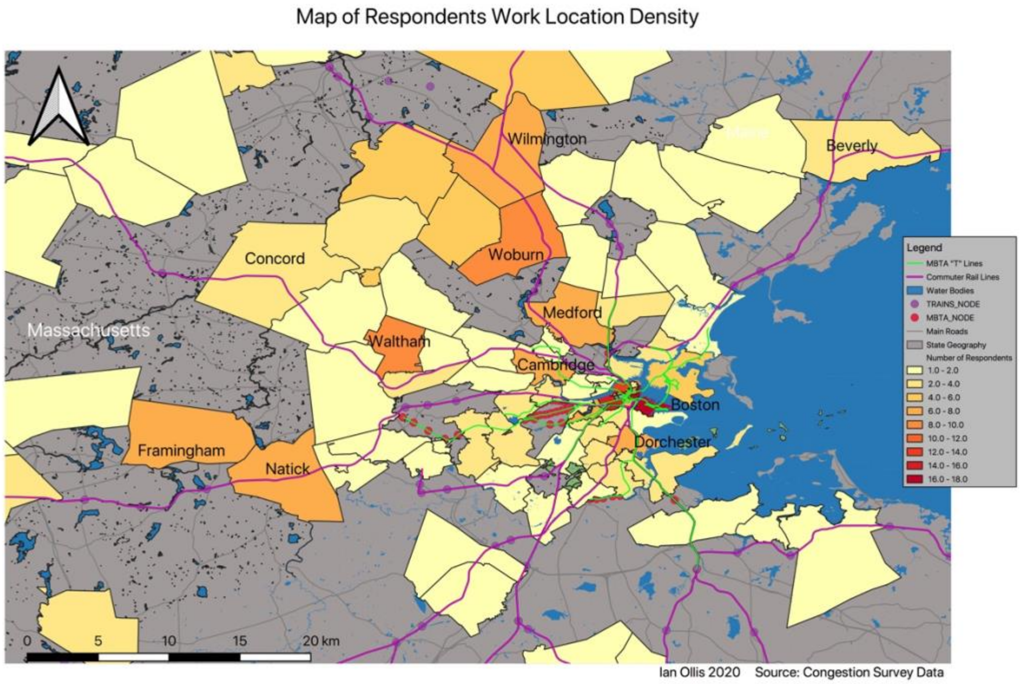


Figure 22. Work Locations of respondents – Boston Metro area only

The maps tell a story regarding parking, access, fare prices and perceptions of the service of the Rapid Transit in the region. Those that show geographical differentiation show at once both where problems are located while at the same time providing focus areas for further research. A number of interesting patterns emerge from the maps.

Free parking

Parking is a theme which permeates this research project. This is a primary issue which needs to be addressed in the region as it is associated with mode shift. Mapping of free and subsidized parking was done by work location of respondents as well as the work locations of those who pay for their parking.

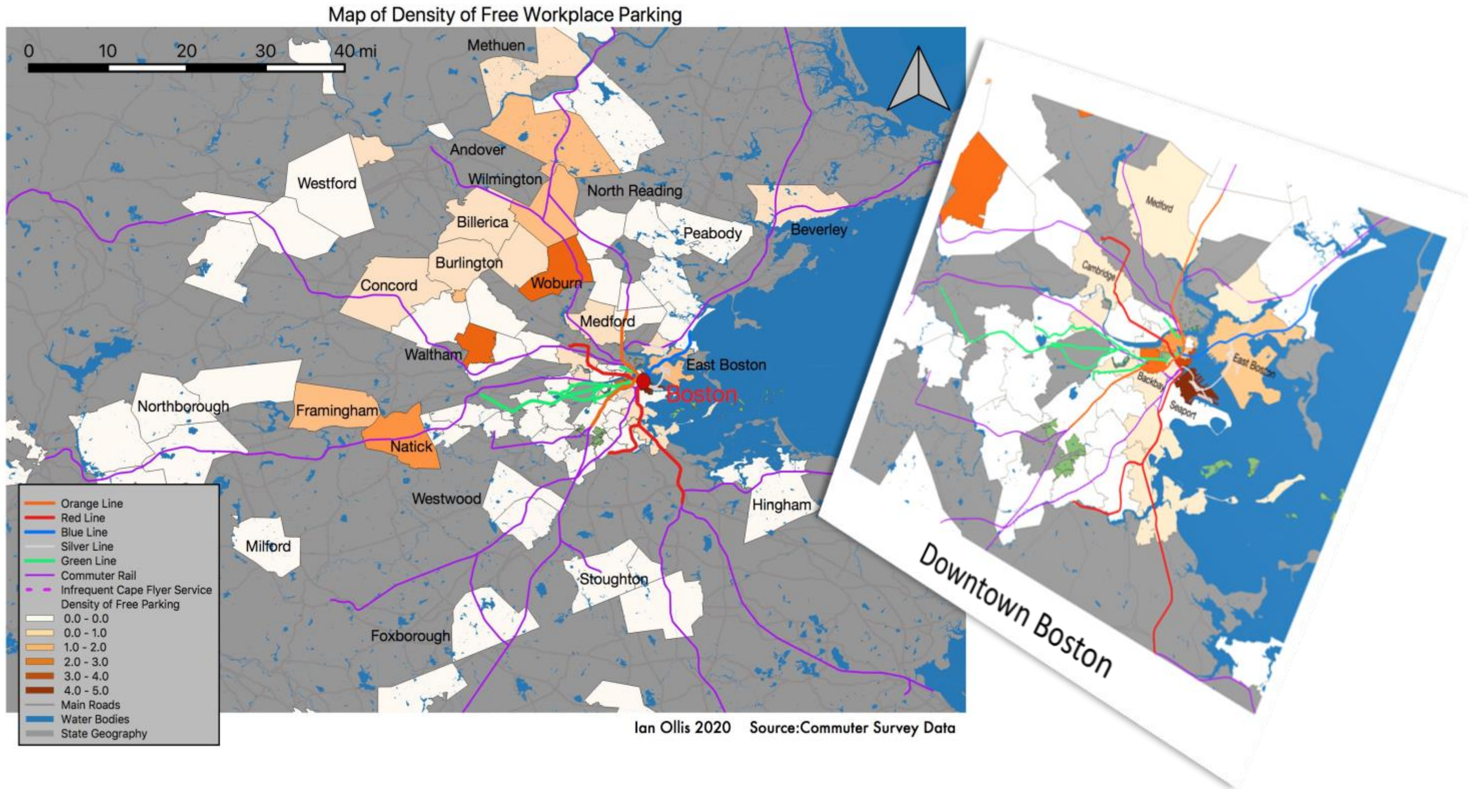


Figure 23. Map of Free and Subsidized Parking

The conclusions are unmistakable: There are more places of employment that offer free parking and *the locations are spread far and wide*. In the Boston CBD, *all* neighborhoods have workers with free or employee-paid parking as all CBD areas are covered. The predominant parking practices of employers encourage bringing a car to work. Paying for parking seems to be a phenomenon that increases as you get closer to Boston and often follows the Commuter Rail lines. Paid parking is located in many fewer locations, but covering all of Boston downtown central business district. Addressing the effects of free parking on transit ridership will need to be addressed across the Commonwealth.

Accessing the rail network

Encouraging mode shift requires access and both the literature review and the survey results point to the importance of this. Access at the origin point or home location is mapped geographically followed by mapping of parking availability issues at this end of a trip. The accessibility concerns at the other end of the trip are then mapped to complete the picture. Figure 26 shows the picture of accessibility concerns across the region:

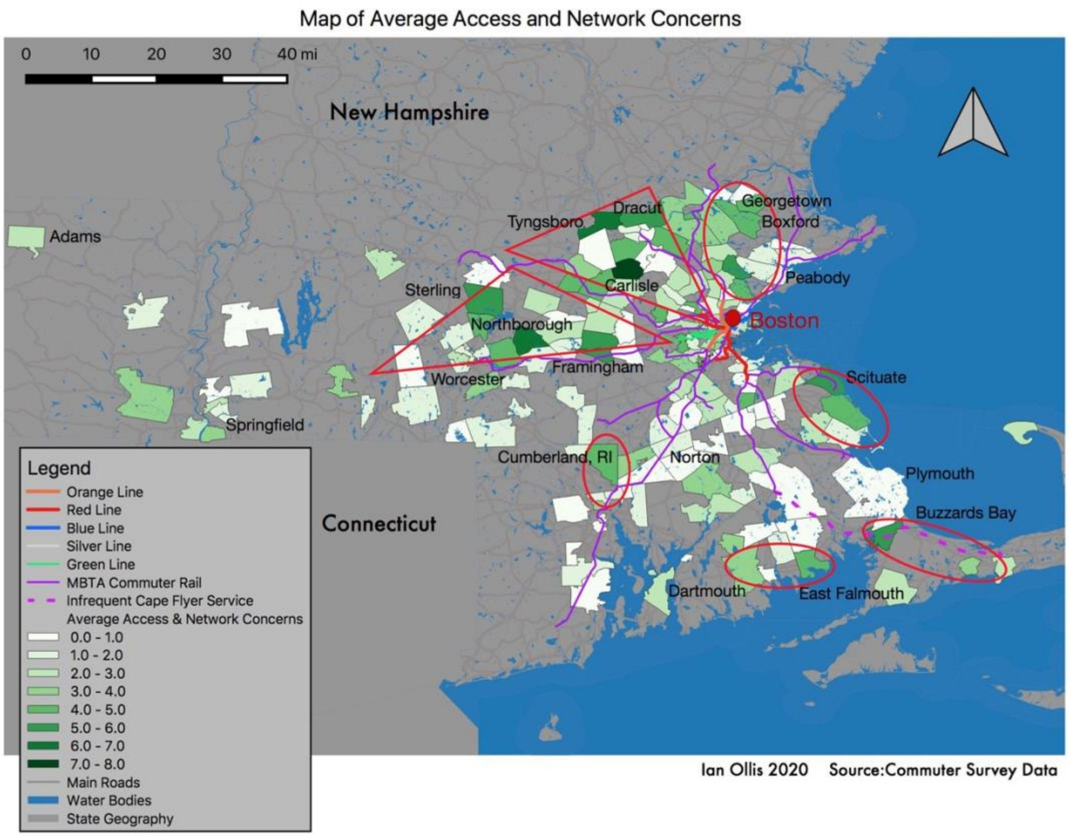


Figure 24: Access and network concerns by home ZIP Code

The pattern of accessibility concerns is revealing. Places in white have a very low percentage of accessibility concerns. For example, a number of ZIP Codes around Worcester, Plymouth and in Rhode Island have some satisfied customers. However unmistakable concerns exist in the following locations:

- between the Lowell and Fitchburg lines,
- areas past the end of the Lowell Line,
- between the Fitchburg and Worcester Lines,
- at the end of the Greenbush line,
- along the line of the infrequent Cape Flyer,
- Springfield as a city,
- areas between the Franklin line and Providence Line,
- at the very end of the South Coast line, and
- between the Haverhill and Newbury Port/Rockport Line.

Areas where there seem to be fewer concerns about the adequacy of the network are those ZIP Codes between the Worcester Line and Franklin Line, Between the Cape Flyer and the Plymouth Line, and areas either side of the Newburyport/Rockport Line on the Commuter Rail system.

Below is the map closer in to the Boston Metro with “Station nodes” as designed by the Central Transportation Planning Staff of MassDOT. (Some of the dots are nodes not currently served by the MBTA Commuter Rail system, as they have included defunct rail lines, and lines served by Amtrak and freight rail also)

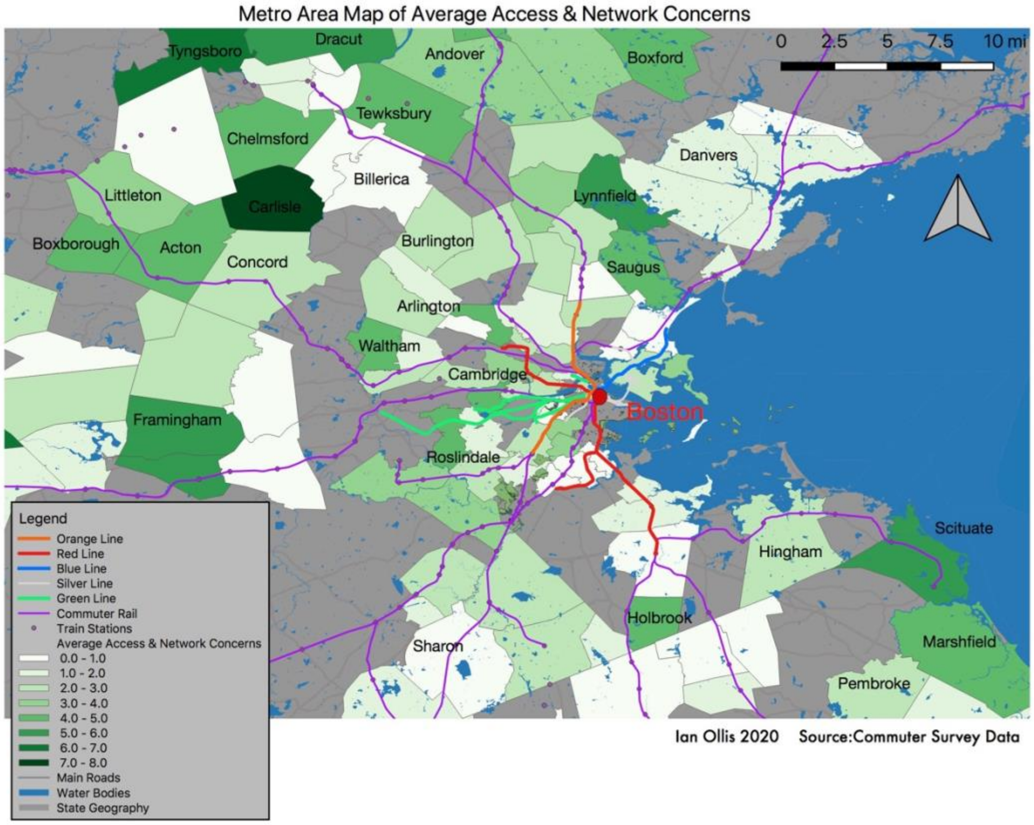


Figure 25 Map of origin access & network insufficiency concerns.

Looking at the inner transit system, where the subways and Green Line operate, a picture emerges here too.

In the inner core there are network concerns in:

- East Arlington,
- Waltham
- Newton and Oak Hill (served by the Green Line).
- Brighton is also an area with access concerns and
- to a lesser extent Dorchester and Roxbury (whether it is the inadequacy of the service on the D Branch of the Green Line or whether there is inadequate bus service to the Green Line stations needs further study).

Framingham access concerns are perhaps due to the lack of access to the network, particularly from the North rather than the rail network itself being defective or it may simply be that the access problem is at the other end of the trip – the trip destination - that most Framingham residents have problems.

Cumberland, Rhode Island, however appears to have a high degree of complaints and there is distance from the area to the nearest Commuter Rail stations. Forge Park Station on the Franklin Line or South Attleboro Station on the Providence Line are the closest. Possibly local transit options need to be explored for these commuters.

Finally Buzzards Bay which would be served by the Cape Flyer if it operated regularly and frequently note difficulty with accessing the network.

Parking at origin stations

Questions about parking at origin or "home" stations asked about two concerns: availability and price. Having seen the concerns on social media and in the regular media, one might expect Alewife, Braintree and Quincy area stations on the Red Line to be cause for concern plus parking at terminus stations on all but one branch of the Green Line and at one or two Commuter Rail stations where parking is constricted. A map of the region followed by a map showing a closer view of the Boston Metro area are provided below.

Map of Station Parking Concerns

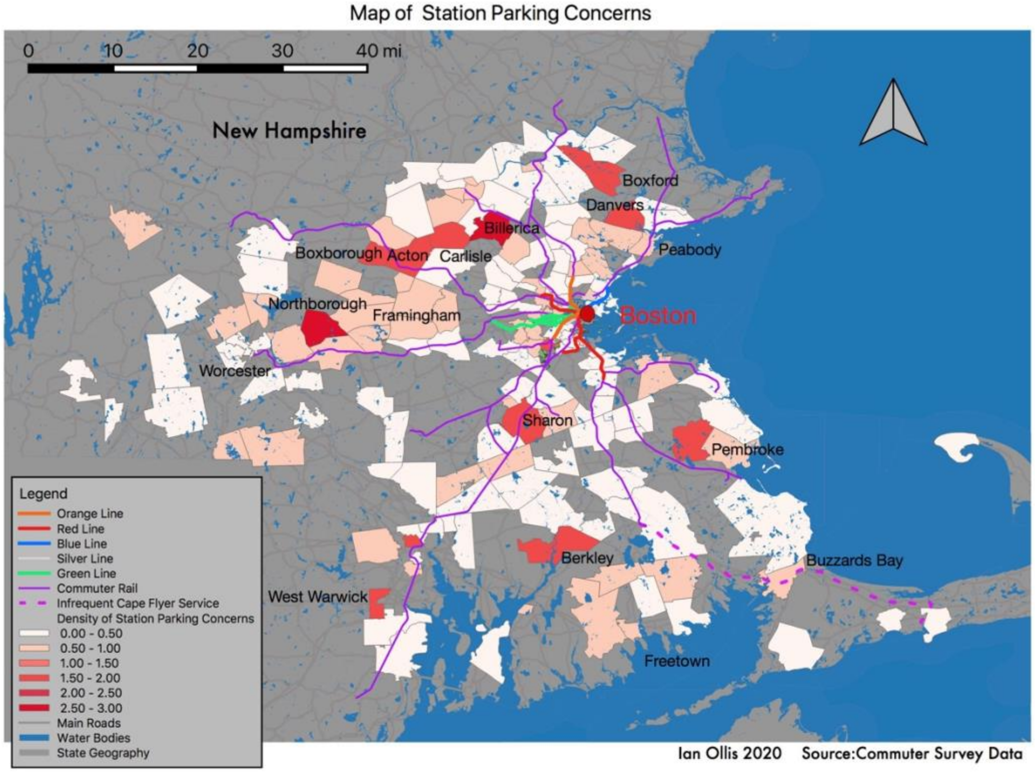


Figure 26. Average parking concern intensity across the network

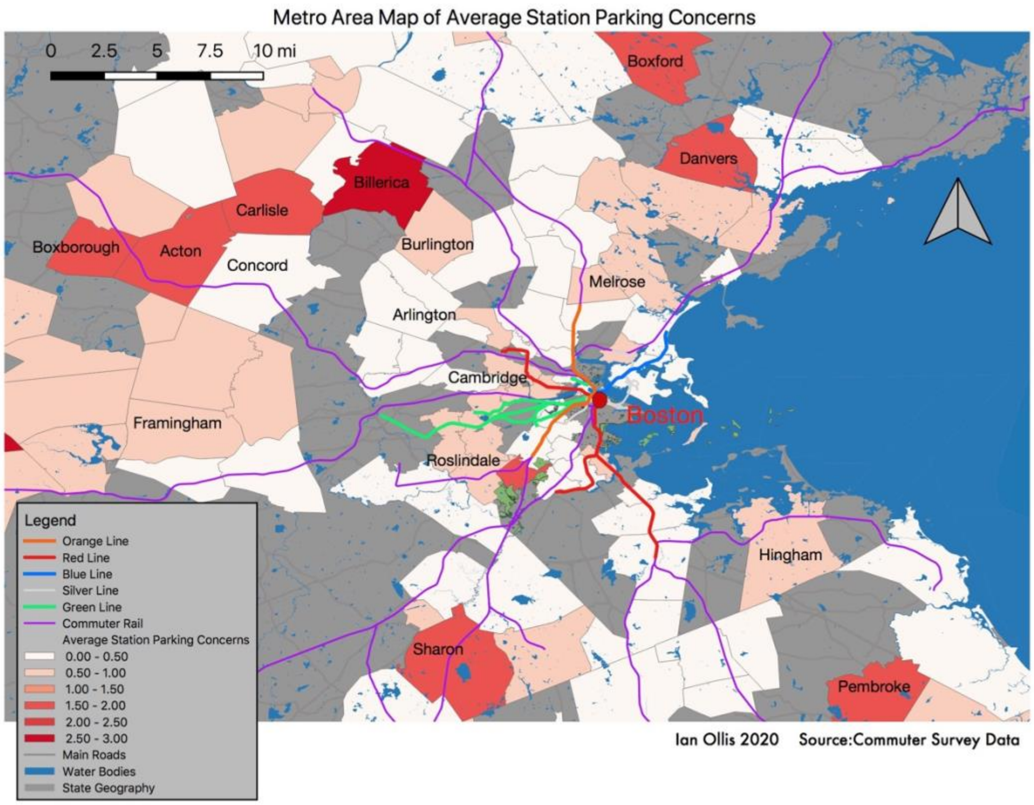


Figure 27 Average parking concerns among respondents

Comparing these two maps, one must consider that the higher percentages of concerns raised are with commuters who would naturally take Commuter Rails lines. The southern end of the Orange Line in the Roslindale ZIP Code shows some parking concerns and a lower level of concern at the outlying stations of the Green Line and the Northern Stations of the Red Line plus Dorchester. There is no perceived parking concern at Braintree or Quincy although these have been raised in the media. Perhaps the renovations at Braintree and Quincy stations have put on hold parking concerns among survey takers in or close to those ZIP Codes?

Accessing the rail network at work or school

Access at work or school locations is equally important to complete the trip via transit. Accessibility at the destination may include feeder bus frequency or coverage, and the convenient location of stations or lines and so on.

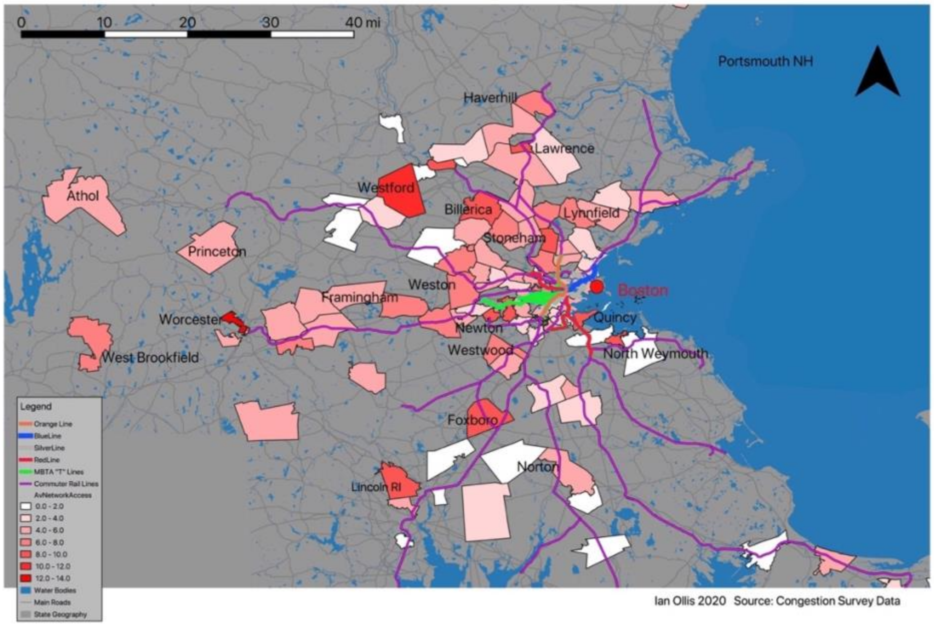


Figure 28 Average network concerns by ZIP Code

This presents a slightly different picture of those who are trying to get off the train and walk or ride a bus to work or school. Areas with accessibility concerns as indicated on the map include:

- Westford & Billerica
- Lawrence,
- Stoneham And Lynnfield
- The Northern part of Worcester
- Lincoln in Rhode Island,
- Foxboro,
- North Weymouth & Quincy

Bearing in mind that some of these ZIP Code areas in the South have a Commuter Rail or Red Line station going through them, it may be that at the extremes of the ZIP Code, getting to the station is difficult by bus, walking or biking. The location of the station may affect these concerns or limited bus connections. "Better bus connections" may mean route changes, frequency increases or new routes altogether. Shifting people out of their cars on the most congested highways in these cases requires accessibility from Commuter Rail to work locations. What Cervero calls the "Other end of the trip"(Cervero, 2006)

Looking closer in to the City of Boston, there are some curious cases. The two maps below show the average concerns by ZIP Code and the absolute number of respondents by work location in order to compare the two.

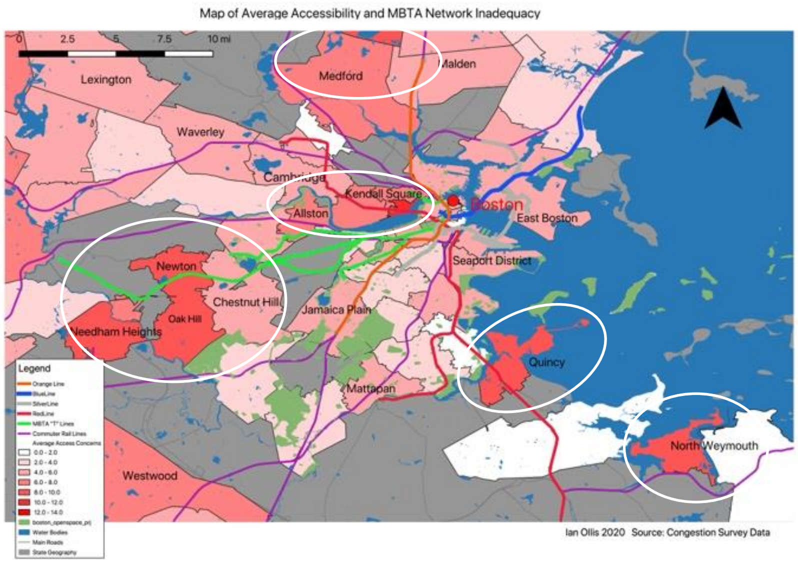


Figure 29: Accessibility concerns by work ZIP Code

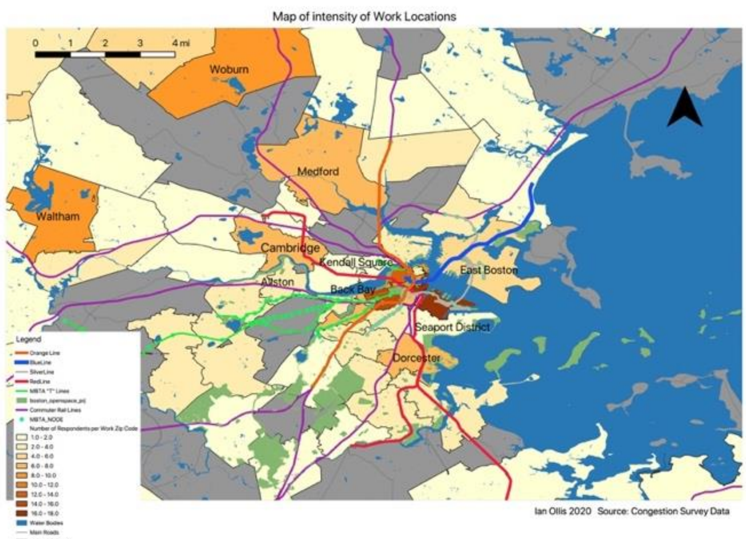


Figure 30: Work location density by ZIP Code

- Newtown & Oak Hill
- Needham Heights
- North Weymouth & Quincy
- Kendall Square
- Allston
- Medford & Stoneham

There are a number of interesting insights from the comparison. The Green Line Extension project (GLX) is sure to address the concerns in Medford and surrounding areas when it opens. A much lower relative number of accessibility concerns is found in the Seaport district that might have been expected from social media comments and regular media speculation. (There has been debate about the lack of a “one seat ride” to the Seaport for some time, but this survey only shows a limited number on average of concerns in this ZIP Code and a high number of respondents work there as can be seen by the other map.

Newton-Oak Hill, Needham Heights, Quincy and Kendall go in the opposite direction - A much higher degree of accessibility concerns are evident. In terms of Kendall and Quincy this must surely be a comment on the Red line service, and the buses that connect to it, or perhaps the number of transfers required to reach Kendall from say, Worcester, Framingham or Revere? The recent Red Line derailments and delays may have added emphasis to this accessibility measure, which should really relate to reliability.

Oakhill and Needham Heights ZIP Codes cover areas that can be quite a distance from a Commuter Rail station or a Green Line stop, as the case may be.

Fare prices

A large number of respondents pointed out that fare prices were preventing them switching to transit, that travel by car was cheaper or that reduced transit fare prices or increased driving costs would cause them to shift. When considering the geographical aspects of pricing, an unmistakable pattern emerges. The two maps below examine the fare price mention rate per respondent to determine a pattern.

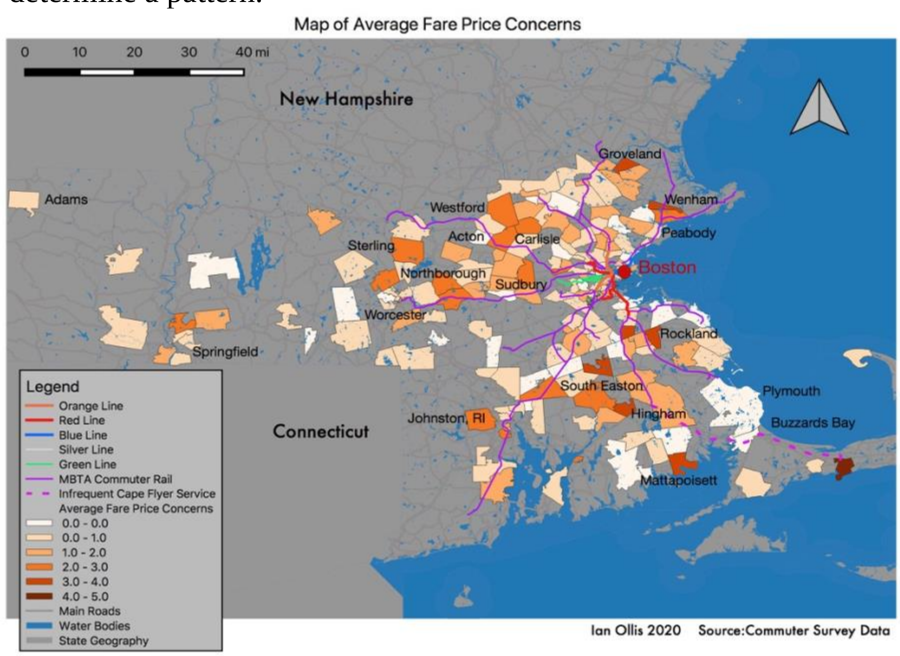


Figure 31 Average mentions of fare prices being too high regionally

Across the state there seems to be concern about Commuter Rail fares. Currently the MBTA does not provide a Commuter Rail service between Springfield and Boston, although this is being considered. However comparing this with inner metro areas which have access to the MBTA rapid "T" lines (subways etc.). shows an immediate pattern emerging:

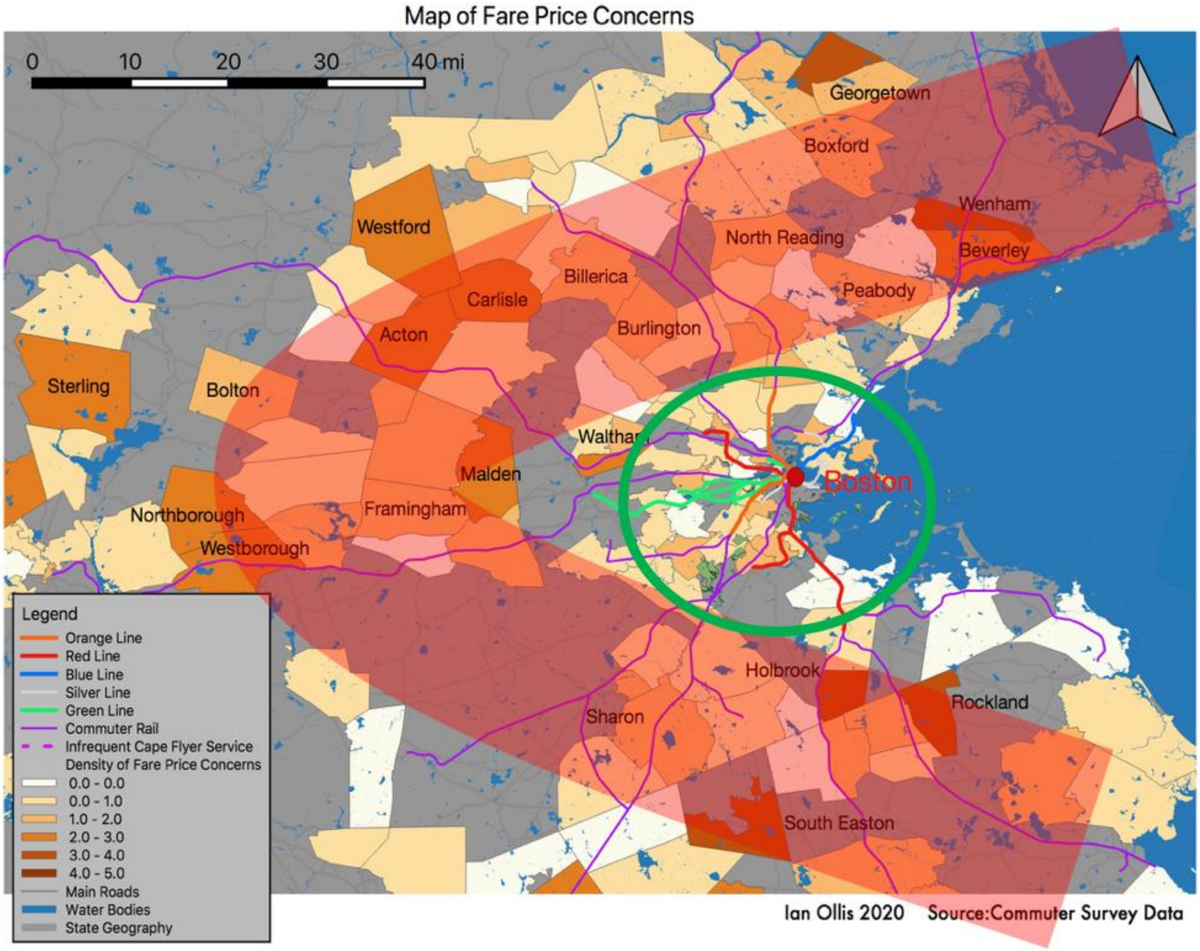


Figure 32 Average mentions of fare prices being too high.

The green circle indicates feeder areas for the subways and Green Line with lower fare concerns. The red-pink shaded area shows areas served by the Commuter Rail line with a higher average rate of fare price concerns.

Areas accessible by the subways and Green Line show a much lower per person rate of concerns regarding fare prices as a concern in their mode choice decision than those who have to make use of Commuter Rail. The South East shows this in the starkest contrast: as soon as you reach the Red Line, price concerns evaporate, but out past the Red Line, where only Commuter Rail is available, price concerns shoot up (darker brown color). In the North East similarly, past the Blue Line, the cost concerns begin to rise again. Similarly on the Worcester and Fitchburg lines there are price concerns. but very little in areas near the Green Line. The concerns are not entirely absent near the subways (see Mattapan and West Roxbury), but at a lower average rate per respondent. The very light off-white color indicates areas with zero mentions of price as a concern.

Trip time, frequency, reliability and frequency

While frequency, reliability and trip time or speed are very separate concepts for academics, engineers and researchers, in the mind of the regular riders who use the system, these concepts may overlap or even be interchangeable. They have been mapped separately for analytical purposes below:

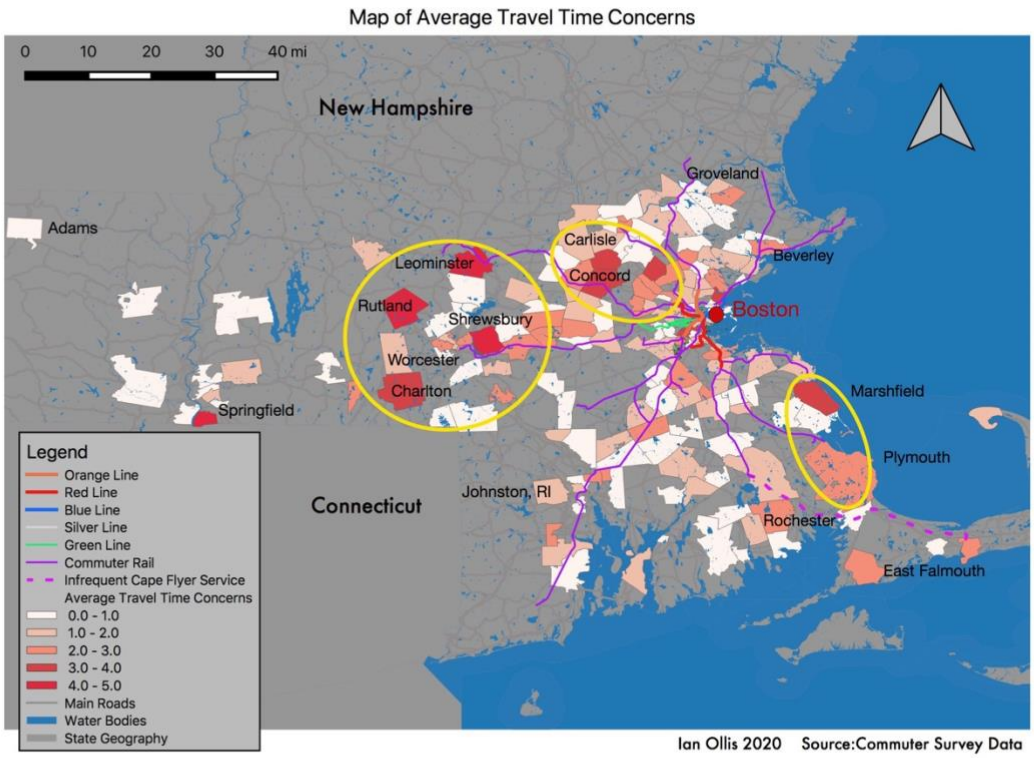


Figure 33: Density of average travel time concerns by ZIP Code

Metro West ZIP Codes have the highest density of travel time concerns. There is also a cluster between the Fitchburg and Lowell Lines and at the ends of the Greenbush and Plymouth Lines. The Worcester, Fitchburg, Greenbush and Plymouth Lines are perceived as too slow, perhaps coupled with the time for the home to origin station connection. The Map below gives a closer view of the Metro area. Drivers from Lexington, East Arlington, Winchester, Jamaica Plain and Revere consider travel time by transit too high.

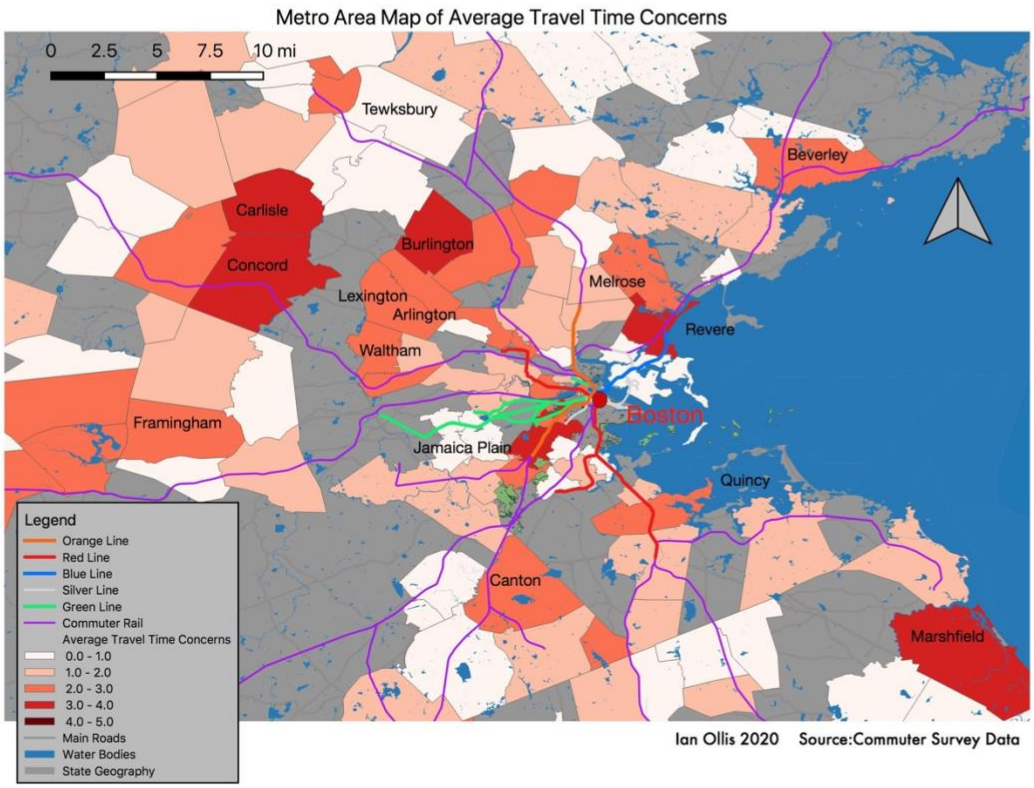


Figure 34. Metro area map of travel time concerns by ZIP Code

Reliability

The media have been filled over the past few years with stories of train delays, derailments, smoke or fires and the like. The first map below shows reliability concerns for the region and the second map focusses on the metro area.

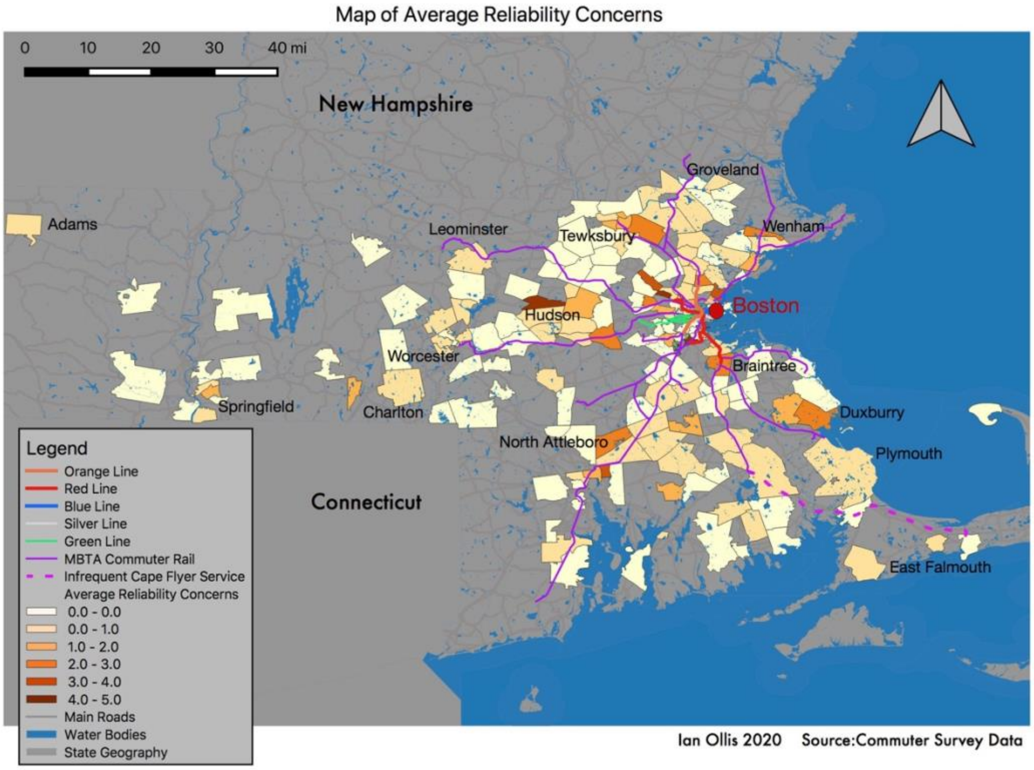


Figure 35 Map of reliability concerns across the MBTA service area and beyond

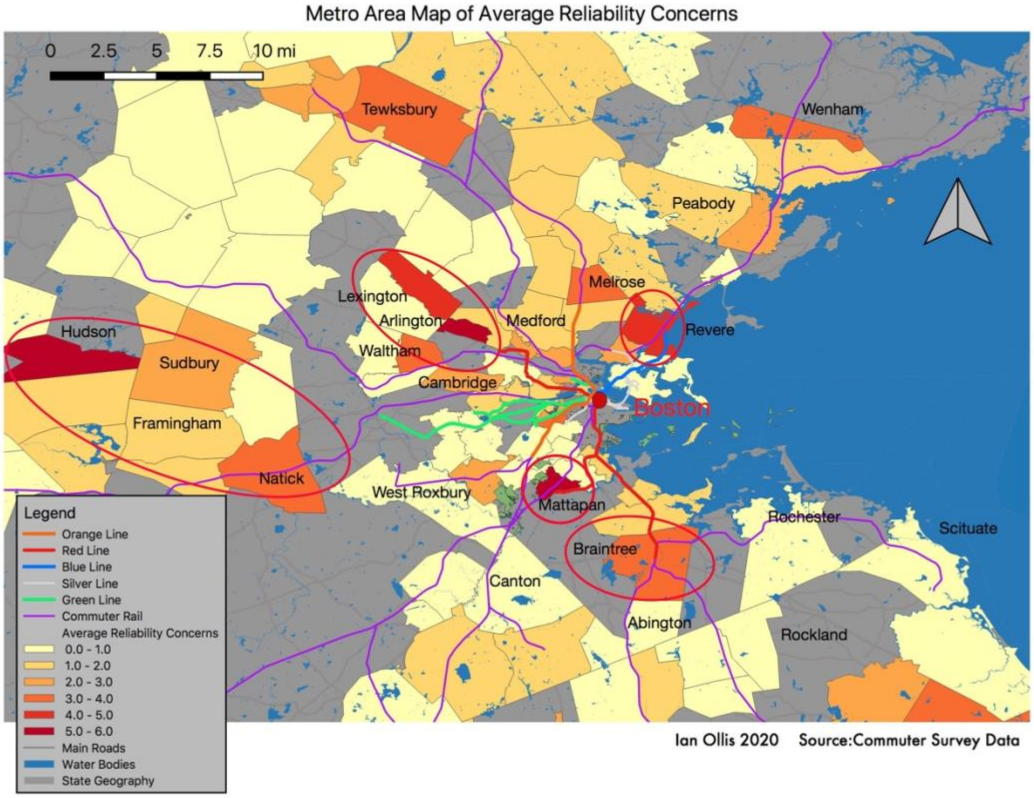


Figure 36 Map of metro area neighborhoods reliability concerns

The Worcester Line and Red Line show a large number of complaints. The ZIP Codes that are served by the Mattapan Line and areas past each end of the Red Line identify with this concern. This is understandable due to the massive derailment on the Red Line followed by repairs and delays registering for many months. The other Commuter Rail lines each have one or two areas of concern

The big news here seems to be the lack of reliability concerns on the Green Line. There were also a number of derailments and electrical cable faults on the Green Line over the past year, but only limited concerns were expressed in the survey. In the background one must consider that the Green Line has lost the most ridership of all MBTA modes and lines since 2003 (See chart in Introduction).

Frequency

Transit activists have recently been calling for an increase in frequency, particularly on Commuter Rail routes and after hours, on all routes for those who work late. The QDA analysis would suggest that, together with accessibility, reliability and speed, frequency of service is also a concern.

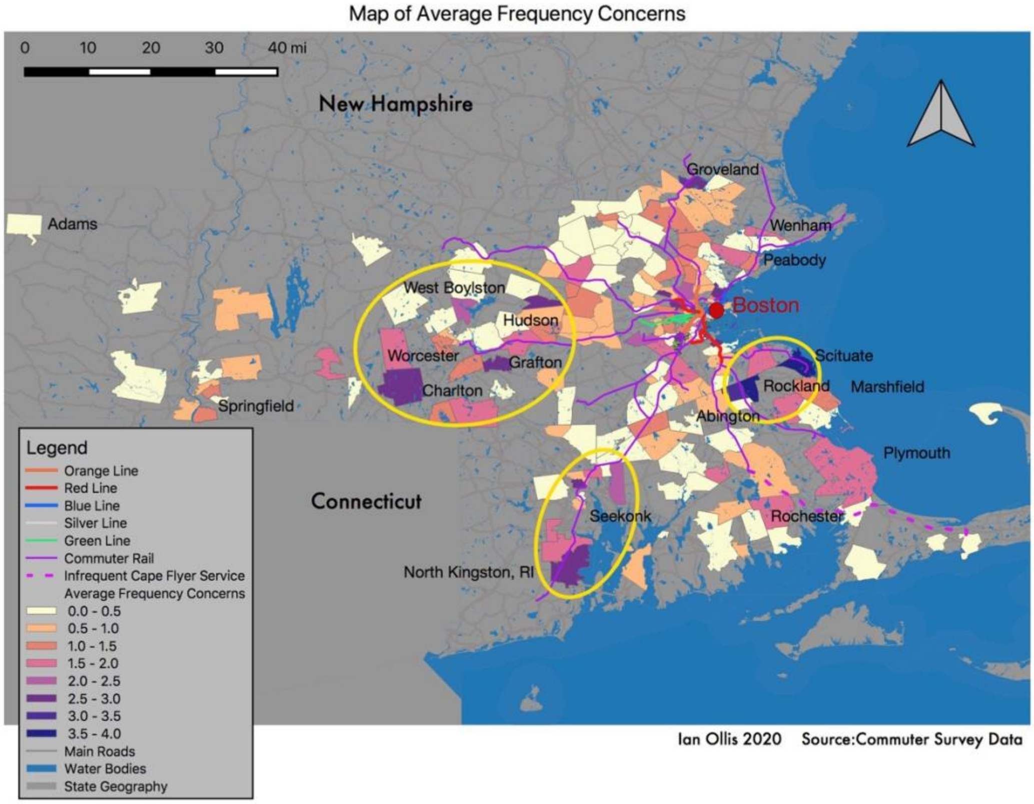


Figure 37. Map of frequency concerns across both states.

In the outer Commuter Rail catchment areas, there are three clusters of frequency concerns which relate to the Worcester Line, The Providence Line (The two most popular routes) and the highest concentration of complaints between the Greenbush and Plymouth Lines. Haverhill also features.

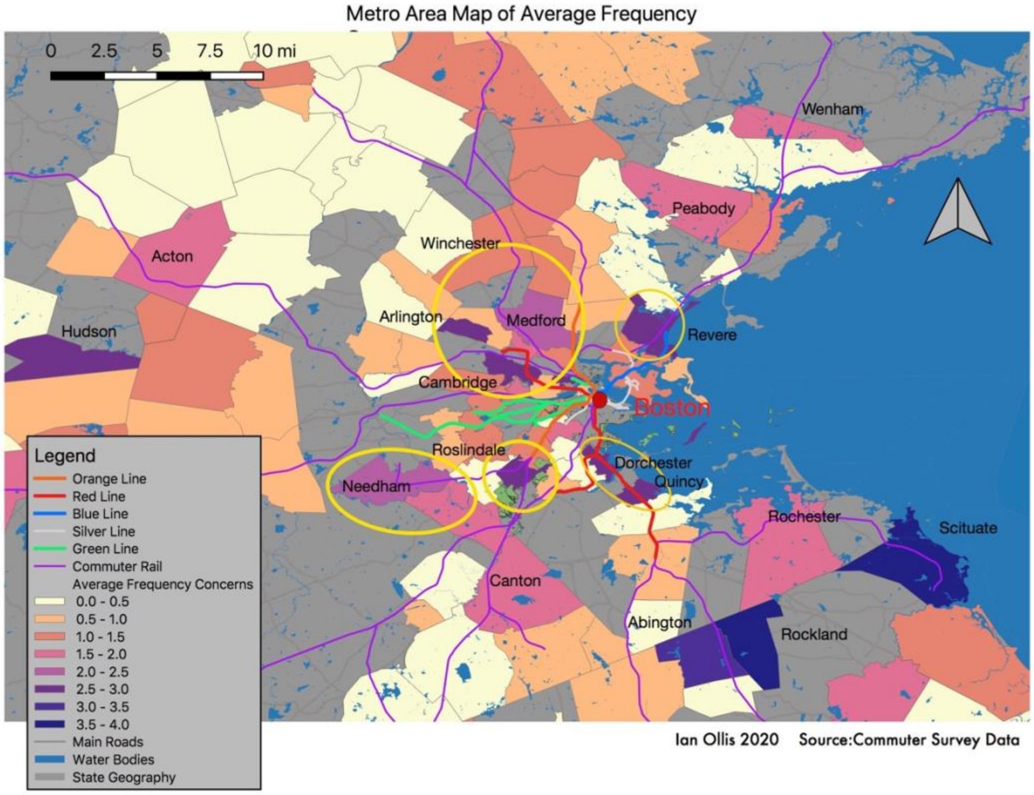


Figure 38. Boston metro area map of frequency concerns.

In the Metro area, the areas at or just beyond the ends of the subway lines have concerns but not as concentrated as those in Scituate, Rockland and Abingdon. Needham registers as an area on the shorter Commuter Rail lines.

5.3 Final GIS analysis

Free parking

The Maps illustrate that free parking is ubiquitous and spread across the two states in the study area. If people are given free parking as the standard and it is spread in most localities, this is an important area that will need attention if it encourages people to drive instead of taking transit.

Fare prices

Fare price concerns are also quite widespread. This is likely a factor influencing mode shift to a much higher degree with Commuter Rail than with subway lines or the Green Line, based on mapping of responses. People who drive on these congested roads consider Commuter Rail fares to be highly priced, but have fewer price concerns about the T subway lines.

Accessibility from home or point of origin

There seem to be three general patterns to accessibility problems that can be identified by mapping of the data. The first is in relation to getting to the existing Commuter Rail and "T" stations. It is evident that there are perceived "accessibility gaps" in the system.

The second concern seems to be that the location of stations on existing Commuter Rail lines is not sufficiently close to those surveyed in certain ZIP Codes. *A study could be done of densities, and of residents needs in catchment areas of existing Commuter Rail and subway lines termini.* For example, respondents in a number of ZIP Codes either side of the Lowell Line seem unhappy with access. Could the location of stations on that line not be best placed to serve current communities on the line? Could a bus route review improve the situation if new stations are unaffordable?

With one or two notable exceptions, the highest density of concerns about accessibility occurs in a region bounded in the South by the Worcester Line and in the East by the Lowell Line. In other words, the communities West of the Lowell Line and North of the Worcester Line. There are a few exceptions in the South *e.g.* at the end of the Greenbush Line, however future Rapid Transit extensions, whether Heavy Rail, Light Rail, or BRT *should be focused North and North West of Boston*, plus perhaps the Greenbush Line, and some rapid bus connections to the Providence Line. The Green Line extension will increase accessibility to some communities in the North but more will need to be done to the West of the Green Line Extension in future. There are also a few concerns at the end of the Worcester Line.

Parking at origin stations (Figures 28 and 29 on page 74 illustrate)

There are a significant number of parking availability concerns in a very small number of ZIP Codes where residents in Northborough, Billerica, Carlisle, Acton, Danvers Boxford, Sharon, Berkley and Pembroke consider the lack of available and reasonably priced station parking a factor in their mode choice.

Closer in towards the subway and Green Lines there are parking availability concerns in ZIP Codes that include Roslindale, Dorchester, Arlington, Cambridge, Brighton, Chestnut Hill, Newton, Chelsea, Melrose and Saugus.

Access at work or school

The following ZIP Code areas registered high average concerns regarding accessibility at work ZIP Codes: Westford, Billerica, Lawrence, northern Worcester, Foxboro, Lincoln RI, Stoneham, Lynnfield, Needham, Oak Hill, Newton, Quincy, North Weymouth, West Wood, Kendall Square.

This points to three considerations. First, there are notable ZIP Codes missing from the list above, e.g. the Seaport area. Second, some of these have a subway or Commuter Rail or Green Line station in the ZIP Code area itself, such as Newton and Worcester (the neighboring ZIP Code). What to make of this? In the case of Worcester it is a ZIP Code further away from the train station. Perhaps the local regional transit authority bus network is inadequate, or perhaps the whole journey including the train and bus for reverse commuters is lengthy because it involves multiple modes.

In Kendall the Red Line is accessible, albeit with a walk if you are working in the far reaches of the ZIP Code. Even then this result seems curious. In the case of the Newton - Oakfield ZIP Code, it is such a large area that the distance to the station might be quite far. Perhaps here too connecting within the ZIP Code by bus to the Green Line might be arduous for commuters.

Finally in ZIP Codes where there is no train station and a high degree of concerns raised, perhaps a more detailed study of the local transit and other access options needs to be undertaken.

Frequency, reliability and trip time

These are typically the metrics commuters would regard together as the “service” or sometimes “quality service”. The Worcester Line Fails on all three metrics, considering the views of these respondents. The Red Line fails on Frequency and Reliability, but does not do as badly on the travel time metric.

Travel time

The Worcester, Fitchburg, Greenbush and Plymouth Lines are perceived as too slow, perhaps coupled with the time for the home to origin station connection. On the subways, Lexington, East Arlington and Winchester, Jamaica Plain and Revere consider travel time too high. As discussed below, access and connectivity concerns may be the problem.

Reliability

The big news here seems to be the lack of reliability concerns on the Green Line. The Red Line Reliability concerns are not surprising. Commuter Rail lines all show some degree of concern about reliability. North Attleboro on the Providence Line also raises reliability concerns. Duxbury respondents have concerns about reliability. They have to drive to join one of the two commuter lines that fall either side of their neighborhood or presumably catch a bus. Tewksbury, Melrose, and Wenham are distributed across the north

Frequency

By actual performance, the two largest Commuter Rail lines, the Worcester and Providence lines, have the frequency concerns, however the highest concentration of complaints comes from areas between the Greenbush and Plymouth Lines. Concerns regarding frequency also occur in Haverhill. In the Metro area, the areas at or just beyond the ends of the subway lines have concerns but not as concentrated as those in Scituate, Rockland and Abingdon. Needham registers as an area on the shorter Commuter Rail lines.

6. Discussion & conclusions

This final chapter highlights the findings from the study and relates them back to the research question posed at the outset. From those findings, illuminated and often reflected by the research and findings outlined in the literature review, I propose a set of measures which, taken together, are most likely to produce a mode shift at scale, perhaps in the 10 to 15% range. The insights informing these measures may also have applicability elsewhere, as they relate to the synergistic nature of interventions most likely to have this level of impact.

6.1 Key findings

Demographics and travel behavior of survey respondents:
Respondents drawn from Massachusetts and Rhode Island are geographically spread across the study area and all regularly drive to work or school in congested traffic on the 10 most congested roadways in Massachusetts.

- 61.7% of respondents almost never take a train
- 28% of those who never take the train come from 1 car households
- 81.9% of respondents almost never take a bus.
- 64.3% come from households with more than one car
- 35.6% come from households with one car.
- 306 out of 402 respondents (76%) travel alone each day.
- 71.9% of respondents have free or subsidized parking at their destination.
- 51.5% of respondents drive to work before 7:30am
- 55.5% drive home after 5pm.

The table below compares the literature review with the survey findings

Identified in literature review as inducing larger mode shift	Identified in Survey Statistics or Mapping
Opening new heavy rail lines such as metro rail, subway or commuter rail lines	Access and Network identified as 2nd most important factor for respondents in unrestrained responses (especially North West of the Metro)
Implement road pricing such as congestion pricing as has been instituted in London, Singapore	67% of respondents would consider shifting if driving cost went up 50%
Reduce free parking at work by constraining destination parking availability or making it expensive	71.9% of respondents have free or subsidized parking at work
A gas tax increase produces a response although sometimes delayed (There must be a significant increase)	67% of respondents would consider shifting if driving cost went up 50%
Open a new station on an existing rail line with land use densification	37.6% of respondents consider shifting with new station near work or 36% with new station near home
Increase train frequency, especially if the headway is higher	39% in Question 13, 34.5% in Question 11 raised train frequency as key
Increase frequency of bus connections to train stations and improve catchment area covered.	Access and Network identified as key factor, 126 respondents raise shorter time by train bus combo , 56 more frequent busses
Improve travel time for transit relative to driving a car on the same route.	31.3% raise shorter time by train bus combo, Travel time raised by 25% as reason not to take train. 45% say trains are too slow
Improve the reliability of the train service: perceived reliability apparently produces greater effects	40% (161) respondents say trains are unreliable
Implement a new light rail line or new bus Rapid Transit system with land use densification	Access and Network identified as 2nd most important factor for respondents in unrestrained responses (especially North West of the Metro)

Table15 Comparison of literature with survey responses

In summary: the literature confirms that the combinations most likely to produce higher degrees of mode shift include a method of *increasing the cost of driving*, a *reduction in free or subsidized workplace parking, extending access* to the train network, and *increased speed and frequency* of Rapid Transit (not regular buses in mixed traffic) which the public *perceive as being reliable*. Apart from densifying land use, the basket of measures most likely to produce up to 10 to 15% of mode shift targeted by this study to significantly reduce congestion generally included enhanced transit options and service *combined* with financial incentives and disincentives. Longer distance bus trips in mixed traffic don't attract car drivers.

Survey response findings

Key finding 1: The high level of free or subsidized parking provided across the study area draws Metro Boston commuters away from transit. This finding is supported by research summarized in the literature review.

Key finding 2: Respondents identify a set of principal factors keeping them from shifting to rapid transit:

- The convenience and comfort of a personal automobile
- Access & network limitations of the MBTA rail transit system
- Travel time by transit combination (including all legs of the trip) is too long
- The transit system is regarded as unreliable
- Trains are too infrequent on a number of Commuter Rail routes
- Fare prices are considered as relatively high, especially certain Commuter Rail prices

Key finding 3: 63.7% of respondents would consider shifting to Rapid Transit if the cost of driving went up substantially (50% higher cost).

Key finding 4: A full 270 out of 402 or 67% of respondents described the trains, buses and stations as crowded, dirty, unhealthy or unsafe at least once. The vast majority of survey responses were submitted prior to the Covid-19 pandemic. Post Covid-19 this issue will require closer attention.

6.2 Discussion of research question

What combination of interventions would most effectively induce mode shift away from single occupancy automobile travel to Rapid Transit at a scale that would meaningfully reduce congestion on major routes in Metropolitan Boston?

To bring this all together, there are two categories of measures that in combination might induce mode shift at the level aimed at (10 to 15%) in this study:

- incentives (including an improved transit offering, and a favorable fare price regime), and
- disincentives (such as a congestion levy or significant gas taxes, plus a reduction of free or subsidized work and school parking).

Summary of major incentives to shift:

Rebalancing fares. There is a strong belief that certain Commuter Rail fare prices are unreasonably high relative to MBTA subway fares. There is a general feeling that transit fares are high, but it is felt more acutely on Commuter Rail and perhaps not uniformly. A process of reducing and rationalizing these fares might be in order. There needs to be some value incentive to those riding commuter rail and the perception is that the fares are not uniformly appropriate across the system. *When compared with low gas prices and free parking at the office*, the balance is currently weighted against Commuter Rail.

Improving access. Concerns about access to the system are typically expressed in connection with parking availability at Commuter Rail stations, and availability of frequent bus transit to the station. These concerns are clustered around a few lines and specific stations in a specific ZIP Codes as the maps illustrate. Localized interventions are necessary to identify which areas are underserved by bus connections to the station and parking availability.

There are a number of respondents who live in the vast areas between the Worcester and Fitchburg lines and between the Fitchburg and Lowell lines who do not perceive the rail network as accessible to them. This means that they will continue to drive unless better access is provided, even if the cost of driving goes up. Areas such as Carlisle, Tyngsboro, Dracut, Stoneham, Waltham and Arlington between Lowell and Fitchburg Lines, and areas like Northborough, Sterling, Framingham, and Stoneham, between the Worcester and Fitchburg Lines have network accessibility concerns. (See recommendation below). In the case of Framingham, this may be that the other end of the trip (work) is inaccessible for those in Framingham closer to the Worcester Line. Other accessibility concerns were raised in Scituate and Marshfield at or past the end of the Greenbush Line.

Improving transit reliability. The literature review suggests that the perception of reliability matters more than actual reliability. Reliability in the minds of respondents is a crucial discouragement from shifting to transit. Those living close to the extremities of the Red Line feel that the system is unreliable. This is unsurprising given recent derailments and underperformance of this line.

With specific regard to Commuter Rail there are a geographically distributed number of concerns about reliability. In places like Natick, it is easy to link this to the Worcester Line. The Worcester Line does appear to engender reliability concerns from commuters. Areas like Hudson, are also in this vicinity.

Reducing trip duration on identified routes. Many travel time concerns on the rails are clustered around the Worcester and Fitchburg lines and perhaps the Greenbush and Lowell lines. Revere and Jamaica Plain also have these concerns.

Frequency. Frequency concerns seem to cluster at the termini of the Greenbush Line, Worcester line, Providence Line and Haverhill Line as well as Rockland and Abington on the Plymouth Line. On the Subways, this is also apparent at the ends of the Red, Orange and Blue lines.

Summary of the major dis-incentives to promote shift:

Parking. Prior research demonstrates that ample free or subsidized parking at workplaces encourages single occupancy vehicle driving to work or school. The survey shows that this is a prolific resource in Metro Boston available to over 70 percent of those who are driving these congested roads regularly. The GIS mapping shows that it is not concentrated in certain areas, and for all the efforts in Boston, Cambridge and beyond following environmental agreements etc., there appears to be plenty of parking made available to employees. While this perk is currently not costed and factored into most motorist's mode choice decision, it will reduce the apparent cost of driving. There is in fact a real cost to constructing and maintaining workplace parking but this is not passed on to the motorist. Federal and state tax policy have a role to play here. Transit is competing with a powerful hidden subsidy incentive to drive. There is a cost to inducing driving also, including the costs of adding additional roads and highways, negative impacts on health and the environment etc. The Parking incentive will need to be removed if improved transit is to attract sufficient motorists to shift.

Driving costs. The research indicates that increasing the cost of driving will be essential in addition to improved Rapid Transit options in order to achieve higher levels of mode shift targeted by this study. Congestion Pricing and toll fees have been shown to be an effective method. Gas taxes would also work, but if gas prices are relatively low (as currently experienced in the US), the gas tax will need to be substantial in order to achieve mode shift. Such a high increase may be more difficult to achieve politically than a congestion levy. Using these funds to pay for significant improvements to the Rapid Transit network, rolling stock and service of course solves many problems simultaneously.

6.3 Policy recommendations

The combination of measures needed to achieve a ~10 to 15% mode shift from auto to Rapid Transit in Massachusetts and of application elsewhere should include:

1. At least one form of increasing the cost of driving such as road/congestion pricing or gas or carbon taxes.
2. A measure to reduce the abundant availability of free or subsidized parking at the end point of drivers' regular commute. (The survey would indicate that in order to shift large numbers of drivers, points one and two should shift the cost of driving.)
3. The improvement of access to Rapid Transit in neighborhoods that feel cut off from the network, including *more frequent feeder buses,* parking and select extensions to the network to bring in communities left out, particularly North and West of the inner Metro area.

4. Improving the Rapid Transit offering by addressing a number of specific interventions including increasing frequency on certain Commuter Rail lines and improving reliability of the subway lines.
5. Adjusting fare pricing of Commuter Rail (A nuanced approach but in a number of cases this will mean a reduction in certain commuter fare prices by location.)

1. **Suggested interventions by the Legislature**
   The direct disincentive measures that induce mode shift will require regulation or decisions at the state level to implement. A congestion charge, or gas tax, and a limitation on free or subsidized parking at work locations will be crucial for mode shift *large enough to reduce congestion.* Whether a gas tax or the proposed Transportation Climate Initiative ("TCI") or a congestion charge is instituted, the level that it is pegged will significantly affect the outcome. A very small levy or tax will produce virtually no mode shift to transit. Dealing with the effective free parking subsidy for automobile travel has implications for federal and state tax policies which need to be addressed. (See 2014 study of Washington D.C. (Hamre & Buehler, 2014)).

2. **Suggested interventions by Municipalities**
   The parking reduction or taxation will likely require municipal intervention in terms of land use and availability, parking requirements, zoning strategies and so on. Boston Mayor Martin Walsh announced a measure in his 2019 Environment and Transportation Legislative Agenda that he supports "An act to allow parking assessments for infrastructure investment: Would allow cities and towns to add an assessment to spaces in private parking garages, to be used to build and maintain roads and bridges as well as bicycle and pedestrian infrastructure." (*2019 Environment and Transportation Legislative Agenda Announced*, 2019). Another approach might be to require employers to provide subsidized monthly transit pass provision to their employees as an alternative to free or subsidized parking by offered by employers. Parking freeze regulations have been tried before and may be continued in future. On its own the approach of capping the total amount of parking that may be built has been insufficient to cause mode shift in large numbers. Dealing with the free workplace parking is the most complex item to regulate.

   While not a focus of this thesis, municipalities will also have to play a large role in any efforts to improve multi-modal access via long-term measures to densify land around rail lines and stations.

3. **Suggested interventions by the Fiscal and Management Control Board (FMCB)**
   One incentive measure - a reduction in Commuter Rail fare prices - will require FMCB intervention. The MBTA should revisit the Commuter Rail fare prices and not increase the subway fare prices until reliability improves and another round of maintenance is completed.

4. **Suggested interventions by the MBTA**
   The MBTA needs to consider and respond to the three metrics of transit that respondents have highlighted if it wishes to induce mode shift or increase its ridership: average travel time improvements, reliability improvements and increased frequency of the trains *and the feeder buses* (Buses that connect to Commuter Rail stations and subway stations should have increased frequency). This is not an alternative to the financial incentives indicated above. These measures need to work in concert if a 10 to 15% mode shift target is to be remotely achievable. A set of localized studies should be performed in areas that have higher than average concerns about travel time, reliability or frequency to establish what the specifics are in each case. Commuter Rail frequency is mentioned, but also total travel time. The travel time includes the feeder buses that connect to each Commuter Rail train station. This means working with the regional transportation authorities running bus networks connecting to the Commuter Rail stations as well as the buses run by the MBTA that connect to subway and Commuter Rail stations. It may also mean having the Commuter Rail operator provide a "first/last mile" shuttle service to select stations.
   The recent approval by the Fiscal and Management Control Board of the MBTA of phase 1 of the Regional Rail Vision is a step in the right direction. Electrification improves the average speed of trains, which improves the travel time metric. The GIS maps in this study suggest that this should urgently be expanded to electrify the Worcester Line. When combined with newer electrified trains, this will improve both the total travel time and in all likelihood the reliability of the Worcester line.

5. **Suggested interventions by the MassDOT and MBTA jointly**
   A study should be conducted into the possibilities of extending the rail network beyond the current GLX project, the proposed West Station and the South Coast Rail connection. Concerns about the network limitations are more pronounced North and North West of Boston than they are in the South or in neighborhoods around Boston. In some cases a new station on the Fitchburg, Lowell or Worcester lines connected to a new bus service may bring a new set of customers to the MBTA network from these areas. Bus services could be improved by changes in the route network or speed increased with a dedicated lane or two. It may be that a discussion about an extension to the Red Line past the 128 highway should be re-opened, or it may be that a new cross-rail, Light Rail or Bus Rapid Transit route connecting existing rail lines similar to the new purple line in Maryland will be the answer to the connectivity issues in the North West. This is a matter for further research.

6.4 Areas for further research

- Online surveys provide a useful platform for gathering data quickly by means of stated preference and revealed preference surveys and should be used more often by transit agencies. The tools used have some limitations and the quality of responses need to be filtered.
- The stated preference survey and GIS mapping approach could be used to the benefit of other Metro Rail systems.

- Further survey work to cover additional Zip codes would add further to the mapping results.
- Use of CTPS data to yield further insights as a result of matching of the origins and destinations of trips made by drivers on Massachusetts roads and how these relate to the current rail transportation network. Geographically, concerns about reliability, which are there in the literature, are almost entirely absent along zip codes associated with the Green Line in the survey for example. With the Green Line having lost the most ridership of all "T" lines, and having suffered a number of derailments over the past year, this low level of concerns about it from respondents seems highly unusual.
- The MBTA should commission a more granular study and action plan dealing with accessibility issues in neighborhoods highlighted in this thesis.
- A study of the mode choice in areas with current toll pricing versus routes with no tolls would add to the knowledge of the subject

More use could be made in future of the survey data of the CTPS staff at the Massachusetts Department of Transportation by matching of the origins and destinations of trips made by drivers on Massachusetts roads and how these relate to the current rail transportation network. Linking the origin and destinations of commuters helps inform how the current rail system is not serving modern commuting patterns and adds to this research by looking for both opportunities and weaknesses in the network. Understanding the route, gives more meaning to comments in surveys and mapping done in this research with location specific data.

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Appendix 1. Survey Instrument: Boston Commuter Congestion Survey 01

Q1
On which of the following Massachusetts roads or highways do you travel during your daily weekday commute? (Select whichever roads on the list are applicable & click the submit arrow below):

- I-93 North of the Boston central
- I-93 South of the Boston central
- Route 2 (Between I-95 and Alewife)
- Route 28
- I-95 between Peabody and Route 2 (Lexington)
- Route 9 (Between Boston and Worcester)
- US Route 3 (Between Burlington & Chelmsford)
- I-90 between Worcester and Boston
- Route 1A between Revere/Lynne and Boston (Including the Ted Williams Tunnel)
- Route 1 between Revere and Boston
- × None of the above

Q2
What is the ZIP Code of your origin (where you usually begin your commute or journey?)

Q3
At what time do you usually leave to travel this route (Pick the closest option)

- Before 6am
- 6 to 6:30am
- 6:30 to 7am
- 7 to 7:30am
- 7:30am to 8am
- 8 to 8:30am
- 8:30 to 9am
- After 9am

Q4
What is the ZIP Code of your destination (where you usually end your usual daily commute or journey?)

Q5
At what time do you usually leave to travel back to your daily point of origin (pick the closest option)

- Before 3:30pm
- 3:30 to 4pm
- 4 to 4:30pm
- 4:30 to 5pm
- 5 to 5:30pm
- 5:30 to 6pm
- 6 to 6:30pm
- 6:30 to 7pm
- After 7pm

Q6
On a typical day, how many people are in your car, including you?

- 1
- 2

- 3
- 4
- more than 4

Q7
Do you ever take the train (The T, Commuter Rail, Subway, Green line) instead of your car?
- More than once a week
- Once a week
- Once or twice a month
- Once or twice a year
- Never

Q8
Do you ever take a bus instead of your car?
- More than once a week
- Once a week
- Once or twice a month
- Once or twice a year
- Never

Q9
Do you have subsidized parking or free parking at work?
- Yes
- No

Q10
Why do you drive instead of taking a train (MBTA Commuter Rail, subway or Green Line)?

Q11
Why do you drive instead of taking a train (Commuter Rail, MBTA Subway or Green Line)?
Please rank the top five (5) of the following options in order of first choice (1) (main reason) to 5th reason (5)
- The trip by transit is too long - Too many connections required
- The trip by transit is too long - Trains too slow
- The trains are infrequent and don't run at times of day when I need them
- Trip by transit is inconvenient: no route from home to my destination & back
- There is no station or stop near my point of origin
- I struggle to find parking at the station or stop
- There are insufficient bike or scooter lock up facilities at my station or stop
- It is difficult to purchase tickets at my station or stop
- There is inadequate or no disability access at my station or stop
- There is no universal ticket/card to use all modes that I need to get to my destination
- Trains are unreliable or unpredictable: they break down or are delayed too much
- Bus connections are unreliable or unpredictable: break down/are delayed too much
- Trains or stations are too crowded
- Trains or stations are dirty and poorly maintained
- Connecting buses are too crowded
- Trains are too expensive for me
- Using my car is less expensive than taking my public transportation choices
- The train is inconvenient because I often have to reach multiple destinations

- Train-bus combo is inconvenient because I often have to reach multiple destinations

Q12
Complete the following sentence: “The change to the train or transit system that would cause me to switch to using public transit for my daily or regular commute would be…..”

Q13
Which five (5) of the following changes to the transit system would cause you to switch to using public transit for your daily or regular commute (pick the five (5) most likely to influence your decision? Please rank 1 (most important reason) to 5 (least important reason)
- Reduced number of connections on my regular commute
- Shorter journey time by train
- Shorter journey time by train – bus combination
- More frequent trains
- More frequent buses
- A new station, stop or train line near my home or point of origin
- A new station near my destination (work, school etc.)
- Sufficient additional parking for cars at the station/stop to guarantee me a parking spot
- More bike or scooter lock up facilities at my station or stop
- More ticket machines or methods of payment at my station or stop
- Improved disability access at my station or stop
- One universal ticket to use on all modes that I need to get to my destination
- More reliable trains that don’t break down or get delayed as often
- More reliable bus connections
- Less crowded trains
- Less crowded buses
- Less crowded stations or stops
- Cleaner or better maintained trains or stations
- Less expensive public transportation fares
- A fare ticket which allows multiple stops on my route
- If the cost of driving my car went up substantially
- Nothing would ever cause me to travel by train or subway

Q14
Does your household have more than 1 car?
yes no

Q15
If the cost of driving your car went up by 50% through the introduction of a gas tax, congestion pricing or a new or raised toll fee, or new fees on parking, how likely are you switch to taking transit for your daily commute?
(Don't forget to click the 'submit' arrow at the end of the page)
- Extremely likely
- Somewhat likely
- Somewhat unlikely
- Extremely unlikely

Q16
If you answered unlikely or very unlikely for the previous question, what is the main reason for your answer?

Appendix 2 Home ZIP Codes of Respondents (HomeZip)

VALUE	FREQUENCY	TOTAL PERCENT	VALID PERCENT	Neighborhood
1109	11	2.70%	2.70%	Springfield
1801	10	2.50%	2.50%	Woburn
1844	8	2.00%	2.00%	Methuen
1970	7	1.70%	1.70%	Salem
2148	7	1.70%	1.70%	Malden
1605	6	1.50%	1.50%	Worcester
1776	6	1.50%	1.50%	Sudbury
1867	6	1.50%	1.50%	Reading
1960	6	1.50%	1.50%	Peabody
2351	6	1.50%	1.50%	Abington
2474	6	1.50%	1.50%	Arlington
1754	5	1.20%	1.20%	Maynard
1864	5	1.20%	1.20%	North Reading
2144	5	1.20%	1.20%	Somerville
2766	5	1.20%	1.20%	Norton
2860	5	1.20%	1.20%	Pawtucket RI
1852	4	1.00%	1.00%	Lowell
2048	4	1.00%	1.00%	Mansfield
2114	4	1.00%	1.00%	Boston(West End)
2128	4	1.00%	1.00%	East Boston
2135	4	1.00%	1.00%	Brighton
2138	4	1.00%	1.00%	Cambridge
2150	4	1.00%	1.00%	Chelsea
2169	4	1.00%	1.00%	Quincy
2180	4	1.00%	1.00%	Stoneham
2360	4	1.00%	1.00%	Plymouth
2472	4	1.00%	1.00%	Watertown
1507	3	0.70%	0.70%	Charlton
1527	3	0.70%	0.70%	Milbury
1581	3	0.70%	0.70%	Westborough
1601	3	0.70%	0.70%	Worcester
1603	3	0.70%	0.70%	Worcester
1609	3	0.70%	0.70%	Worcester
1752	3	0.70%	0.70%	Marlborough
1757	3	0.70%	0.70%	Milford
1803	3	0.70%	0.70%	Burlington
1826	3	0.70%	0.70%	Dracut
1862	3	0.70%	0.70%	North Billerica
1906	3	0.70%	0.70%	Saugus
2101	3	0.70%	0.70%	Beacon Hill (Boston)
2119	3	0.70%	0.70%	Roxbury
2124	3	0.70%	0.70%	Dorchester

2155	3	0.70%	0.70%	Medford
2184	3	0.70%	0.70%	Braintree
2302	3	0.70%	0.70%	Brockton
2370	3	0.70%	0.70%	Rockland
2536	3	0.70%	0.70%	East Falmouth
2717	3	0.70%	0.70%	East Freetown
1104	2	0.50%	0.50%	Springfield
1106	2	0.50%	0.50%	Longmeadow
1118	2	0.50%	0.50%	Springfield
1460	2	0.50%	0.50%	Littleton
1468	2	0.50%	0.50%	Templeton
1518	2	0.50%	0.50%	Fiskdale
1519	2	0.50%	0.50%	Grafton
1520	2	0.50%	0.50%	Holden
1570	2	0.50%	0.50%	Webster
1583	2	0.50%	0.50%	West Boylston
1602	2	0.50%	0.50%	Worcester
1740	2	0.50%	0.50%	Bolton
1772	2	0.50%	0.50%	SouthBorough
1810	2	0.50%	0.50%	Andover
1824	2	0.50%	0.50%	Chelmsford
1834	2	0.50%	0.50%	Groveland
1845	2	0.50%	0.50%	North Andover
1851	2	0.50%	0.50%	Lowell
1854	2	0.50%	0.50%	Lowell
1880	2	0.50%	0.50%	Wakefield
1886	2	0.50%	0.50%	Westford
1902	2	0.50%	0.50%	Lynn
1915	2	0.50%	0.50%	Beverly
2035	2	0.50%	0.50%	Foxboro
2043	2	0.50%	0.50%	Hingham
2050	2	0.50%	0.50%	Marshfield
2062	2	0.50%	0.50%	Norwood
2067	2	0.50%	0.50%	Sharon
2072	2	0.50%	0.50%	Stoughton
2115	2	0.50%	0.50%	WestFens/Kenmore
2121	2	0.50%	0.50%	Dorchester
2130	2	0.50%	0.50%	Jamaica Plain
2131	2	0.50%	0.50%	Roslindale
2132	2	0.50%	0.50%	West Roxbury
2141	2	0.50%	0.50%	Cambridge
2145	2	0.50%	0.50%	Somerville
2151	2	0.50%	0.50%	Revere
2152	2	0.50%	0.50%	Revere
2176	2	0.50%	0.50%	Quincy

2215	2	0.50%	0.50%	WestFens/Kenmore
2322	2	0.50%	0.50%	Avon
2332	2	0.50%	0.50%	Duxbury
2359	2	0.50%	0.50%	Pembroke
2420	2	0.50%	0.50%	Lexington
2467	2	0.50%	0.50%	Chestnut Hill
2492	2	0.50%	0.50%	Needham
2532	2	0.50%	0.50%	Buzzards Bay
2657	2	0.50%	0.50%	Provincetown
2771	2	0.50%	0.50%	Seekonk
2780	2	0.50%	0.50%	Taunton
2895	2	0.50%	0.50%	Woonsocket, RI
2908	2	0.50%	0.50%	Providence, RI
2919	2	0.50%	0.50%	Johnston, RI
1001	1	0.20%	0.20%	Agawam
1002	1	0.20%	0.20%	Amherst
1020	1	0.20%	0.20%	Chicopee
1056	1	0.20%	0.20%	Ludlow
1083	1	0.20%	0.20%	Warren
1085	1	0.20%	0.20%	Westfield
1096	1	0.20%	0.20%	Williamsburg
1220	1	0.20%	0.20%	Adams
1453	1	0.20%	0.20%	Leominster
1516	1	0.20%	0.20%	Douglas
1532	1	0.20%	0.20%	Northborough
1542	1	0.20%	0.20%	Rochdale
1543	1	0.20%	0.20%	Rutland
1545	1	0.20%	0.20%	Shrewsbury
1562	1	0.20%	0.20%	Spencer
1564	1	0.20%	0.20%	Sterling
1588	1	0.20%	0.20%	Whitinsville
1608	1	0.20%	0.20%	Worcester
1701	1	0.20%	0.20%	Framingham
1702	1	0.20%	0.20%	Framingham
1719	1	0.20%	0.20%	Boxborough
1720	1	0.20%	0.20%	Acton
1741	1	0.20%	0.20%	Carlisle
1742	1	0.20%	0.20%	Concord
1749	1	0.20%	0.20%	Hudson
1760	1	0.20%	0.20%	Natick
1778	1	0.20%	0.20%	Wayland
1821	1	0.20%	0.20%	Billerica
1833	1	0.20%	0.20%	Georgetown
1835	1	0.20%	0.20%	Haverhill
1843	1	0.20%	0.20%	Lawrence

1850	1	0.20%	0.20%	Lowell
1876	1	0.20%	0.20%	Tewksbury
1879	1	0.20%	0.20%	Tyngsboro
1921	1	0.20%	0.20%	Boxford
1923	1	0.20%	0.20%	Danvers
1940	1	0.20%	0.20%	Lynnfield
1961	1	0.20%	0.20%	Peabody
1984	1	0.20%	0.20%	Wenham
2019	1	0.20%	0.20%	Bellingham
2021	1	0.20%	0.20%	Canton
2026	1	0.20%	0.20%	Dedham
2032	1	0.20%	0.20%	East Walpole
2066	1	0.20%	0.20%	Scituate
2108	1	0.20%	0.20%	Beacon Hill (Boston)
2120	1	0.20%	0.20%	Roxbury Crossing
2122	1	0.20%	0.20%	Dorchester
2126	1	0.20%	0.20%	Mattapan
2134	1	0.20%	0.20%	Allston
2139	1	0.20%	0.20%	Cambridge
2170	1	0.20%	0.20%	Quincy
2301	1	0.20%	0.20%	Brockton
2324	1	0.20%	0.20%	Bridgewater
2343	1	0.20%	0.20%	Holbrook
2346	1	0.20%	0.20%	Middleboro
2375	1	0.20%	0.20%	South Easton
2382	1	0.20%	0.20%	Whitman
2421	1	0.20%	0.20%	Lexington
2451	1	0.20%	0.20%	Waltham
2452	1	0.20%	0.20%	Waltham
2453	1	0.20%	0.20%	Waltham
2459	1	0.20%	0.20%	Newton
2476	1	0.20%	0.20%	Arlington
2632	1	0.20%	0.20%	Centerville
2673	1	0.20%	0.20%	West Yarmouth
2703	1	0.20%	0.20%	Attleboro
2715	1	0.20%	0.20%	Dighton
2718	1	0.20%	0.20%	East Taunton
2724	1	0.20%	0.20%	Fall River
2739	1	0.20%	0.20%	Mattapoisett
2740	1	0.20%	0.20%	New Bedford
2743	1	0.20%	0.20%	Acushnet
2747	1	0.20%	0.20%	North Dartmouth
2760	1	0.20%	0.20%	North Attleboro
2770	1	0.20%	0.20%	Rochester
2779	1	0.20%	0.20%	Berkley

2818	1	0.20%	0.20%	East Greenwich, RI
2852	1	0.20%	0.20%	North Kingston, RI
2861	1	0.20%	0.20%	Pawtucket, RI
2871	1	0.20%	0.20%	Portsmouth, RI
2893	1	0.20%	0.20%	West Warwick, RI
2904	1	0.20%	0.20%	Providence, RI
2907	1	0.20%	0.20%	Providence, RI
2910	1	0.20%	0.20%	Cranston, RI
2912	1	0.20%	0.20%	Providence, RI
TOTAL	**402**	**95%**	**95%**	

Appendix 3 Work ZIP Codes of Respondents (WorkZip)

VALUE	FREQUENCY	TOTAL PERCENT	VALID PERCENT	Neighborhoods
2101	19	4.70%	4.70%	Beacon Hill (Boston)
2210	18	4.50%	4.50%	West Broadway/SouthBoston
2116	16	3.70%	3.70%	Backbay
2114	14	3.50%	3.50%	Boston(West End)
1801	10	2.50%	2.50%	Woburn
2108	10	2.50%	2.50%	Beacon Hill (Boston)
2451	10	2.50%	2.50%	Waltham
2109	9	2.20%	2.20%	North End (Boston)
2115	8	2.00%	2.00%	WestFens/Kenmore
2138	8	2.00%	2.00%	Cambridge
2155	8	2.00%	2.00%	Medford
1701	7	1.50%	1.50%	Framingham
1760	7	1.70%	1.70%	Natick
1887	7	1.70%	1.70%	Wilmongton
2111	7	1.70%	1.70%	Chinatown(Boston)
2125	7	1.70%	1.70%	Dorchester
1731	6	1.50%	1.50%	Lincoln
1810	6	1.20%	1.20%	Andover
2128	6	1.50%	1.50%	East Boston
1803	5	1.00%	1.00%	Burlington
1821	5	1.20%	1.20%	Billerica
1601	4	1.00%	1.00%	Worcester
1730	4	1.00%	1.00%	Bedford
2110	4	1.00%	1.00%	Financial District (Boston)
2118	4	1.00%	1.00%	South End (Boston)
2121	4	1.00%	1.00%	Dorchester
1545	3	0.70%	0.70%	Shrewsbury
1581	3	0.70%	0.70%	Westborough
1742	3	0.70%	0.70%	Concord
1757	3	0.70%	0.70%	Milford
1844	3	0.70%	0.70%	Methuen
1863	3	0.50%	0.50%	North Chelmsford
1915	3	0.70%	0.70%	Beverly
2113	3	0.70%	0.70%	North End (Boston)
2119	3	0.70%	0.70%	Roxbury
2120	3	0.70%	0.70%	Roxbury Crossing
2122	3	0.70%	0.70%	Dorchester
2124	3	0.70%	0.70%	Dorchester
2129	3	0.70%	0.70%	Charlestown
2134	3	0.70%	0.70%	Allston
2135	3	0.70%	0.70%	Brighton
2148	3	0.70%	0.70%	Malden

2150	3	0.70%	0.70%	Chelsea
2171	3	0.70%	0.70%	Quincy
2199	3	0.70%	0.70%	Prudential District (Boston)
2215	3	0.70%	0.70%	WestFens/Kenmore
2453	3	0.70%	0.70%	Waltham
2454	3	0.70%	0.70%	Waltham
2459	3	0.70%	0.70%	Newton
2467	3	0.70%	0.70%	Chestnut Hill
2537	3	0.70%	0.70%	East Sandwich
1003	2	0.50%	0.50%	Amherst
1104	2	0.50%	0.50%	Springfield
1532	2	0.50%	0.50%	Northborough
1654	2	0.50%	0.50%	Worcester
1703	2	0.50%	0.50%	Framingham
1845	2	0.50%	0.50%	North Andover
1923	2	0.50%	0.50%	Danvers
1960	2	0.50%	0.50%	Peabody
2062	2	0.50%	0.50%	Norwood
2072	2	0.50%	0.50%	Stoughton
2126	2	0.50%	0.50%	Mattapan
2127	2	0.50%	0.50%	Telgraph Hill/South Boston
2130	2	0.50%	0.50%	Jamaica Plain
2139	2	0.50%	0.50%	Cambridge
2140	2	0.50%	0.50%	Cambridge
2141	2	0.50%	0.50%	Cambridge
2151	2	0.50%	0.50%	Revere
2169	2	0.50%	0.50%	Quincy
2322	2	0.50%	0.50%	Avon
2452	2	0.50%	0.50%	Waltham
2478	2	0.50%	0.50%	Belmont
2481	2	0.50%	0.50%	Wellesley Hills
2532	2	0.50%	0.50%	Buzzards Bay
2601	2	0.50%	0.50%	Hyannis
1020	1	0.20%	0.20%	Chicopee
1331	1	0.20%	0.20%	Athol
1432	1	0.20%	0.20%	Ayer
1451	1	0.20%	0.20%	Harvard
1460	1	0.20%	0.20%	Littleton
1516	1	0.20%	0.20%	Douglas
1536	1	0.20%	0.20%	North Grafton
1541	1	0.20%	0.20%	Princeton
1585	1	0.20%	0.20%	West Brookfield
1603	1	0.20%	0.20%	Worcester
1608	1	0.20%	0.20%	Worcester
1609	1	0.20%	0.20%	Worcester

1752	1	0.20%	0.20%	Marlborough
1773	1	0.20%	0.20%	Lincoln
1805	1	0.20%	0.20%	Burlington
1826	1	0.20%	0.20%	Dracut
1832	1	0.20%	0.20%	Haverhill
1843	1	0.20%	0.20%	Lawrence
1850	1	0.20%	0.20%	Lowell
1854	1	0.20%	0.20%	Lowell
1867	1	0.20%	0.20%	Reading
1886	1	0.20%	0.20%	Westford
1906	1	0.20%	0.20%	Saugus
1940	1	0.20%	0.20%	Lynnfield
2035	1	0.20%	0.20%	Foxboro
2043	1	0.20%	0.20%	Hingham
2090	1	0.20%	0.20%	Westwood
2117	1	0.20%	0.20%	Financial District (Boston)
2132	1	0.20%	0.20%	West Roxbury
2136	1	0.20%	0.20%	Hyde Park
2142	1	0.20%	0.20%	Cambridge (Kendall)
2144	1	0.20%	0.20%	Somerville
2153	1	0.20%	0.20%	Medford
2176	1	0.20%	0.20%	Quincy
2180	1	0.20%	0.20%	Stoneham
2191	1	0.20%	0.20%	North Weymouth
2201	1	0.20%	0.20%	Boston Government Center
2241	1	0.20%	0.20%	Financial District (Boston)
2251	1	0.20%	0.20%	Westwood
2301	1	0.20%	0.20%	Brockton
2302	1	0.20%	0.20%	Brockton
2325	1	0.20%	0.20%	Bridgewater
2421	1	0.20%	0.20%	Lexington
2456	1	0.20%	0.20%	New Town
2464	1	0.20%	0.20%	Newton
2472	1	0.20%	0.20%	Watertown
2482	1	0.20%	0.20%	Wellesley Hills
2493	1	0.20%	0.20%	Weston
2494	1	0.20%	0.20%	Needham Heights
2540	1	0.20%	0.20%	Falmouth
2664	1	0.20%	0.20%	South Yarmouth
2717	1	0.20%	0.20%	East Freetown
2718	1	0.20%	0.20%	East Taunton
2722	1	0.20%	0.20%	Fall River
2760	1	0.20%	0.20%	North Attleboro
2766	1	0.20%	0.20%	Norton
2767	1	0.20%	0.20%	Raynham

2769	1	0.20%	0.20%	Rehoboth
2861	1	0.20%	0.20%	Pawtucket, RI
2865	1	0.20%	0.20%	Lincoln, RI
2904	1	0.20%	0.20%	Providence, RI
2910	1	0.20%	0.20%	Cranston, RI
3060	1	0.20%	0.20%	Nashua, NH
3801	1	0.20%	0.20%	Portsmouth, NH
4005	1	0.20%	0.20%	Biddeford, ME
5402	1	0.20%	0.20%	Burlington VT
TOTAL	**402**	**94%**	**94%**	

Appendix 4: Coding of long form responses.

The phrases used in long form in the answers to the long form questions were grouped into the heading and coded in the QDA software accordingly:

Convenience

CONVENIENCE, FREEDOM TO LEAVE, FREEDOM TO ARRIVE, FLEXIBLE, OWN TIMING, FLEXIBILITY, OWN TERMS, LEAVE WHENEVER I WANT, INFLEXIBLE DESTINATION TIMES, OWN TIMELINE, ODD HOURS, CONTROL OF TIME, INCONVENIENT

Access and Network

NO STATIONS, NO TRAIN, UNAVAILABLE, DOES NOT GO TO MY AREA, TO MY WORK, ACCESS, FAR, WORK DESTINATION, CHANGE TRAINS, DESTINATION TO WORK, LIMITED PUBLIC TRANSPORTATION, NOT ACCESSIBLE, NO TRAINS, NOT A GOOD ROUTE, NO SIMPLE COMMUTER OPTIONS, NOT A REALLY GOOD WAY, UNAVAILABLE, NO INFRASTRUCTURE, TO MY PLACE OF EMPLOYMENT, NO COMMUTER RAIL, OUT OF THE WAY, NO STOPS CLOSE ENOUGH, NO MBTA, COMMUTER RAIL IS TOO FAR, MUST CHANGE 2 TRAINS, BUSES DON'T REACH, TOO MANY CONNECTIONS, CLOSE TO MY STARTING POINT

Need Car Tools Locations

TRAVEL AWAY FROM WORK, TOOLS, NEED CAR FOR WORK, SEVERAL LOCATIONS, UBER DRIVER, VARIOUS LOCATIONS, TRAVEL DURING THE WORKDAY, MATERIALS, MULTIPLE LOCATIONS, EQUIPMENT HOME, DRIVING AROUND THE CITY, HAULING STUFF, MULTIPLE PLACES.

Time Speed

QUICKER, FASTER, FASTEST, TIME, TIME-EFFICIENT, LONGER, HOURS, SPEED, BETTER TIMING, LONG, SLOW, COMMUTE WOULD BE TOO LENGTHY, ADDS TIME, MORE EFFICIENTLY

Cost Fares

CHEAPER, COST IS TOO MUCH, MORE EXPENSIVE, COST MORE, COST, TOO EXPENSIVE, TRAIN CHARGES, SO IS THE PASS, SAVINGS ARE NOT WORTH IT

Reliability

BROKE DOWN, SERVICE IS ERRATIC, UNRELIABLE, ALWAYS BREAKING DOWN, LATE, RELIABILITY, BREAKS DOWN, UNPREDICTABILITY OF PUBLIC TRANSPORTATION, FREQUENT BREAK DOWNS, UNPREDICTABLE TRAIN SCHEDULES, ALWAYS LATE, DELAYS, THEY BREAK DOWN, CAN'T DEPEND ON THE MBTA, SPOTTY AT BEST, TRUST, ALWAYS BREAKING DOWN, GETTING TO WORK ON TIME, INCOMPETENT MBTA, CONSTANT DELAYS, NOT AT ALL DEPENDABLE, DELAY TOO MUCH, BREAKS DOWN, CANCELLATIONS, I CAN CONTROL

Frequency Schedule

NOT ENOUGH TRAINS, LEAVE AS SOON AS I CAN, HAVING TO WAIT, SPECIFIC TIMES I NEED, RELY ON TRAIN SCHEDULES, AT THE TIME I NEED THEM, NOT ENOUGH FREQUENCY, TIME OF TRAIN, NOT ALIGNED, NOT ENOUGH TRAINS, LACK OF TRAINS, FOR THE TIMES I NEED, NO REGULAR TRAIN SERVICE, MIDDLE OF THE DAY,

LEAVE AT MY OWN TIME, TRAINS ARE SCARCE, TRAINS DON'T RUN, DURING THAT TIME, ONCE AN HOUR, WORK VERY LATE, WORK OVERTIME, WORK VARY TOO MUCH, TRAINS DO NOT RUN ENOUGH, AREN'T ENOUGH TRAINS, FOR THE TIME I NEED THEM

Free/Subsidized Parking

BECAUSE OF THE PARKING, THERE IS FREE PARKING, FREE PARKING AT WORK, BECAUSE I HAVE FREE PARKING, FREE PARKING, I CAN PARK DIRECTLY IN MY BUILDING, THE COST OF A PARKING PERMIT

No/Expensive Parking (At Stations)

PARKING IS EXPENSIVE, CAN NEVER FIND PARKING AT THE STATION, DIFFICULT TO PARK, HAVE TO FIND PARKING

Car-Love Comfort Privacy

I HAVE A CAR, OWN VEHICLE, ENJOYMENT OF CAR, MORE FREEDOM, CAR IS EASIER AND SIMPLER, TIME ALONE, PERSONAL CHOICE, I PREFER DRIVING MY OWN CAR, I WANT THE PRIVACY OF MY VEHICLE, I ENJOY DRIVING, BECAUSE I'M IN CONTROL, PREFER TO BE ALONE, COMFORT IN CAR, USING MY CAR, MORE FREEDOM, LIKE MY PRIVACY, PERSONAL PREFERENCE, I OWN A CAR, MY OWN SPACE, I PREFER TO HAVE CONTROL, PREFER MY CAR, MORE COMFORTABLE DRIVING, HAVE A CAR, COMFORT, WOULD LIKE TO DRIVE IN A SINGLE MANNER

Advertising Info Wayfind
NOT AWARE OF TRAIN, THE TRANSPORTATION IS CONFUSING, FIGURING OUT WHICH SUBWAY

Health Safety Crowding
IT'S MORE PEACEFUL, OVERCROWDED, LESS CROWDS AND SMELLS, DRAMA AND STRESS, GET YOU SICK, DON'T LIKE TRAINS, NOT BE BOTHERED BY OTHER PEOPLE, NEGATIVE EXPERIENCES, I DO NOT LIKE SHARING, SAFETY ISSUES, UNCOMFORTABLE TRAVELLING ON PUBLIC TRANSPORTATION, ANNOYANCE, SURROUNDED BY A TON OF PEOPLE, VOLUME OF PEOPLE, I FEEL SAFER DRIVING, STATIONS AND TRAINS ARE OLD AND DIRTY, GETTING A COMMON COLD ON THE TRAIN, SMELLS ON THE TRAIN, TERRIFIED OF TRAINS, DIRTY, FILLED WITH STRANGE PEOPLE, AVOID HARASSMENT, CROWDED TRAIN CARS, HOMELESS PEOPLE, TOO CROWDED, CORONAVIRUS, MBTA UNSANITARY, HATE PACKED TRAINS, CRAMMED INTO, UNCOMFORTABLE TRAIN, HAVE A DISABILITY, CROWDED, I HATE PEOPLE, GERMS

Carpool HOV
CARPOOL WITH MY PARTNER, WE DRIVE THERE TOGETHER, CARPOOLING, PICK THEM UP FOR WORK, HOV LANE.

Daycare Multiple Stops
DOING SOMETHING AFTER WORK, PLACES ON THE WAY BACK, DROP OFF KIDS AT DAYCARE, DROP OFF FOR SCHOOL, RUN ERRANDS AFTER WORK, DROP MY DAUGHTER TO DAYCARE, I NEED TO GO MULTIPLE PLACES, STOP IN DIFFERENT PLACES, STOP AT THE GROCERY STORE, MORE THAN 1 STOP

Appendix 5. Couhes Exemption

The proposed research activities outlined in Exempt ID: E-1922: Boston Congestion Commuter Survey **have been determined to be exempt**.
No further actions in COUHES Connect are required.

As the Principal Investigator or Faculty Sponsor, you must adhere to the policies within the Investigator Responsibilities for Exempt Research and ensure that all members of the research team comply with these policies.

Your study may proceed as long as all research procedures correspond with responses within the Exempt Evaluation. If the scope or procedures of the research undergo significant alterations, you must submit a new Exempt Evaluation.

Any deviation or violation of the Investigator Responsibilities for Exempt Research or alterations from the study as described in the Exempt Evaluation must be reported to the COUHES office for further review.

E-1922, Boston Congestion Commuter Survey.

Principal Investigator: Ollis, Ian Michael
Faculty Sponsor: Aloisi, James
Start Date: FEB-05-2020
End Date: APR-30-2020

Determination(s): Exempt

Exempt Category 3 - Benign Behavioral Intervention

Research involving benign behavioral interventions where the study activities are limited to adults only and disclosure of the subjects' responses outside the research could not reasonably place the subjects at risk for criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation. Research does not involve deception or participants prospectively agree to the deception. 45 CFR 46.104(d)(3)

Exempt Category 2 - Educational Testing, Surveys, Interviews or Observation

Research involving surveys, interviews, educational tests or observation of public behavior with adults or children and disclosure of the subjects' responses outside the research could not reasonably place the subjects at risk for criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation. Research activities with children must be limited to educational tests or observation of public behavior and cannot include direct intervention by the investigator. 45 CFR 46.104(d)(2)

If you have questions, please contact COUHES directly:

email: couhes@mit.edu | phone: 617-253-6787 | website: couhes.mit.edu | online: COUHES Connect
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Massachusetts Institute of Technology
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