Boston Night Owl

A Framework for Introducing Overnight Bus Service That Can Close Significant Spatiotemporal Gaps in Greater Boston's Transit System

by
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S.B. Urban Science and Planning with Computer Science
Massachusetts Institute of Technology, 2023

Submitted to the Department of Urban Studies and Planning
in partial fulfillment of the requirements for the degrees of

Master in City Planning
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 2024

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Abstract

There are people traveling at every hour of the day. Cities by their nature function throughout the 24-hour day, however the same is not always true of their transit systems. Just as in the day time, overnight public transportation exists to provide mobility access to the people who need or choose to travel at night. This thesis explores the first steps in developing an overnight transit service in a region where it does not currently exist, using the Boston area as a case study. This is done through a two-step process: first, identifying where and when the service should be run, and second, learning from existing overnight systems around the world to understand how the service should operate. As part of the method, the thesis proposes a novel approach to identifying areas with acute disparity between transit supply and demand, colloquially known as "transit deserts," that involves taking into account how these factors change both spatially and temporally. The end result of this thesis is a framework that planners in cities and transit agencies can use when creating a system that can close these gaps. This is an approach that planners will find useful not just in planning night time service, but for planning service at all times of the day.

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Acknowledgments

To Jim, thank you for all your guidance over the past two years. I'm grateful to have had you join the project when it was just an idea for a senior year undergraduate thesis. This thesis could only develop the way it had through your advice and extensive expertise in the world of transit. I'm proud of the end result, and it has been a privilege to get to work with you.

To Garnette, my thesis reader, your ideas and thoughts around the city of night were immensely helpful in thinking about the topic. While writing this thesis, I've experienced more of the night than I ever had before. The night is a special time, and I'm happy to have had someone who has read and written so much about it help guide my thesis.

I'd like to give thanks to everyone who took the time to talk to me about night transit. Particularly the kind folks at TransitMatters, the Boston Transportation Department, and WMATA who humored me and my many questions.

Thank you to all of the incredible people that I met here at DUSP. Thank you to all the faculty I've learned from including Justin Steil, Amy Glasmeier, Andres Sevtsuk, and Jinhua Zhao with whom I've had the fortune of working. Thank you to all my kind and hardworking classmates for giving me role models to aspire to, most especially my fellow SB/MCP cohort with whom I made it through DUSP.

To my friends that I've made here at MIT, I can't thank you enough. Enduring the firehose was only possible having you all with me. I couldn't have asked for a more amazing group of people to spend my time at school with.

To my family: my parents, my siblings, and the whole village it took to raise me, thank you for all of your love and support over the past five years and the eighteen before that. I wouldn't have made it this far without you all in my corner.

To Emma, thank you for always being by my side, encouraging and motivating me through it all. From reading my drafts, to listening to my lectures, to riding many a midnight train and bus with me in my field research, you've been an integral part of the process. I'm beyond grateful.

This thesis is the culmination of five wonderful years at MIT and the Department of Urban Studies and Planning. I owe an immense debt to everyone, named or otherwise, who has helped me along the way.

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Introduction

For most of human history the night was defined as the time between sunset and sunrise. In a time when agriculture was the dominant industry and candles were afforded only to the elite few,[1] there was little reason to stay awake past sundown. When darkness could not be controlled, the night represented a discontinuity. It was a sharp divide between one day and the next. This pattern of human labor and activity governed by natural processes that existed since the dawn of humanity would only be broken in the modern age.

It was the industrial revolution that brought about the end of the night as a gap in time. [2] Unlike the village wheat fields, the urban steel mills, lit with artificial lights, were unencumbered by the outside darkness. The factories of 19th century Britain were where the concept of shift work first began. Two 12-hour shifts would keep the factory running through the day and night. And it was here that the 24-hour city was born. Although many lament the erosion of the day and night as another victim of industrial capitalism,[3] it is safe to say that the 24-hour city is here to stay. Cities today are hubs of activity at all times of the day. People are constantly taking trips for work and recreation. This means that travel demand around the city is constantly changing throughout the day across time and space.

One would expect public transit design and operation to match this heterogeneous nature of transit demand, with networks that bring people to all parts of the city at any time of the 24-hour cycle. However, the layout and schedule of American transit systems suggests different priorities. Transit agencies have largely oriented themselves around serving commuters. Their schedules are largely built around a long-established commuting pattern based on 9 a.m. to 5 p.m. working hours. Their network topologies follow the hub-and-spoke model. In this layout, the most frequent rail and bus lines often extend radially from the downtown jobs center to the suburbs where these urban core commuters live. This of course works well for the archetypal 9-to-5 commuter going to/from work but leaves other

[1] Ekirch, “Sleep We Have Lost.”
[2] International Labour Organization, “Origins of the Night Work Prohibition: Women as a Special Class of Factory.”
[3] Crary, *24/7*.

people at other times of the day with scant or even nonexistent service. The one time period where this lack of service is most stark is night time, when it is not uncommon for transit agencies to forgo providing service entirely.

Many cities in the US lack any form of overnight transit. Boston is a particularly notable example of a city with no night service. Once the trains reach their termini and the buses make their final runs between midnight and 1 a.m. in Boston,[4] all transit service in the city ends and does not start back up again until 5 a.m. The city has ambitious sustainability and equity plans that includes a goal that "all residents have easy and affordable access to an efficient, carbon-free transportation network."[5] Having the transit network shut down for one sixth of every day certainly makes the goal of having a completely transit-accessible city much more difficult (indeed impossible) to achieve. As it stands, the Greater Boston Area is the largest metropolitan area in the US in terms of public transit ridership that offers no overnight service.

Urbanized Area	Overnight Bus	Overnight Rail	Transit Ridership (2023)
New York	Yes	Yes (All lines)	3,260M
Los Angeles	Yes	Yes (2 lines)	402M
Chicago	Yes	No	332M
DC	Yes	No	298M
San Francisco	Yes	No	268M
Boston	No	No	244M
Philadelphia	Yes	Yes (1 line)	208M
Seattle	Yes	No	153M
Miami	Yes	No	117M
San Diego	No	No	80M

Table 1: Ten largest urbanized areas by unlinked passenger trips according to the National Transit Database (2023)

4 In this thesis, "Boston" is generally used to refer to the Greater Boston region or to the inner core of the metropolitan area as defined by the Metropolitan Area Planning Council (MAPC). When referring to the city proper, "City of Boston" will be used. See "Appendix A – Greater Boston Reference Maps"

5 City of Boston, "Green New Deal Dashboard (Beta)."

In fact, of the top ten urban areas in terms of transit ridership, only Boston and San Diego, a city with a third the transit ridership, have no form of night transit. There is nothing unique about Boston, or specifically the Massachusetts Bay Transportation Authority (MBTA) which operates public transit in the region, that would justify or explain the total absence of an overnight transit service. This thesis will show that not only is such a service feasible, but that overnight transit is a vital service that Boston, and any city hoping to reduce its car mode share and expand transit accessibility, should provide.

The purpose of this thesis is to propose a framework that decision makers in cities and transit agencies without overnight transit can use as they consider introducing overnight service. The framework covers the first steps transit agencies need to consider when designing an overnight service: where the network should cover and what the service looks like in the big picture. The first question is answered by identifying where *and when* transit deficiencies exist in the region. This is done through identifying the spatiotemporal changes in transit supply and demand in the region. Tackling the latter question involves examining what other agencies with overnight transit have done and learning from what already exists. Overnight night transit is not new, and there is a lot to be learned from peer systems around the country and world.

The principal part of this framework is a new approach to identifying “transit deserts” that takes into account not only spatial deficiencies in transit service, but the temporal deficiencies as well. Through this, night transit can be reexamined not as a disconnected, siloed service but as a seamless part of the day that has its own connectivity needs as any other time of day would. If a glaring gap existed in transit service during the day, people would expect the local transit agency or government to create and implement a plan to close the gap. That same expectation does not exist for the night, but there is no reason it should not.

Background

Night time or overnight transit is any public transportation service provided during the night time period. There are many definitions of night time transit. At its most broad, it can be defined as the period between the afternoon and morning peaks. These "peak" times are when transit service is its highest as agencies seek to provide for the 9-to-5 commuters. While it is unusual for transit agencies to not run service outside of peak times, it is not unprecedented. Some of the most extreme examples are commuter railroads which, as the name suggests, are typically focused primarily on getting commuters to and from the city center. Some salient examples are the Virginia Railway Express[6] in the Washington DC area and Metra's Heritage Corridor and North Central Service[7] in Chicago. These rail lines exclusively run into the city in the morning and out of the city in the afternoon. This outlook is not exclusive to commuter rail. In the San Francisco Bay Area, there has been discussion of ending service on the Bay Area Rapid Transit (BART) system at 9pm on weekdays and entirely on weekends amid budget shortfall brought about by the COVID-19 pandemic.[8] While these are extreme examples, particularly in the hypothetical case of BART, this shows that even in cities as "transit friendly" as Chicago, Washington DC, and San Francisco, transit agencies have historically seen the 9-to-5 commuter as central to their service and all other riders as peripheral.

This thesis however takes a more narrow view of the night with a focus on the late-night time period from 1 a.m. to 5 a.m.. Most transit agencies in metropolitan areas in the US will run their service from the beginning of the morning peak around 5 to 6 a.m. through the day and into the night, often ending around midnight to 1 a.m.. In Boston, all of the rail lines start their last run around midnight with the next scheduled departure not until 5 a.m.. The buses similarly run from 5 a.m. to 1 a.m. with a few exceptions of bus lines that start a little earlier or end a little later. Yet there is no transit service on bus or rail that runs continuously through the night in Boston.

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[6] Virginia Railway Express, "Schedules."
[7] Metra, "Maps & Schedules."
[8] Bay Area Rapid Transit, "Financial Crisis."

Night transit is a vital service that would expand transit access to thousands in the Boston region alone. There are two main groups of riders night transit would aim to serve: night shift workers and weekend leisure travelers. Providing public transit options to both of these demographic groups is important for their own distinct reasons.

The night shift (also known as late-shift or third-shift) workforce is a category that includes people who work during night time hours between 9 p.m. and 5 a.m.. These jobs often occur at night out of necessity rather than by choice. This includes nurses and other skilled healthcare professionals who have to attend to patients at all times of day, airport workers who constantly keep the airport operational for incoming and outgoing flights, or waiters and bartenders who cannot start to clean and close until the last customer leaves. The nature of these late-shift jobs means that work cannot be performed remotely, so employees in these positions have to commute to work every day.

Some industries with the highest rates of late-shift work are transportation, food services, retail, and healthcare.[9] These jobs form the backbone of many essential services in American cities. These are often the same workers who were deemed essential at the height of the pandemic and as such continued to work despite the public health crisis. Despite all that the jobs require of them, these workers often make less than their day time counterparts.[10]

[9] Zalewski et al., "Supporting Late-Shift Workers Their Transportation Needs and the Economy."
[10] Zalewski et al.

Time of Arrival to Work	Average Personal Income	Count (Millions)
Day Time (5 a.m. - 4 p.m.)	$59,927.75	115.8
Evening (4 p.m. - 9 p.m.)	$38,758.60	6.8
Night (9 p.m. - 12 a.m.)	$44,854.71	1.9
Late Night (12 a.m. - 5 a.m.)	$51,132.25	5.5

Table 2: Average income and count of workers by time of arrival to work from ACS 2022 Public Use Microdata Sample

According to the 2022 American Community Survey, workers who arrive at work between the hours of 4 p.m. and 9 p.m. make 36% less than workers who arrive at work during the day. If they work the typical 8-hour shift, workers who arrive between 4 p.m. and 9 p.m. would leave work between 12 a.m. and 5 a.m., a window of time when transit in Boston closes and ceases to run. As a result, these workers are often forced to a form of automobility if they want a reliable and quick way of getting work. Forcing low-wage workers to drive (or be driven) places an inordinate financial burden on them. According to the American Automobile Association, the average annual cost of owning a car in 2023 has risen to $12,182 per year.[11] This means that these late-shift workers are expected to spend over 30% of their income on owning a vehicle. This cost is well above the Bureau of Labor Statistics estimate to average nationwide transportation costs as a percent of income which is currently 12.2%.[12] It is possible to avoid this cost as not every single night time worker has to own a car. Some may be driven by a family member, friend, or coworker, provided they are on the same schedule. Taxis and rideshares also are available at all times of the day, although with an average per mile cost ranging anywhere from $2 to $7, the annual cost of taking a taxi to and from work every day quickly approaches and exceeds the cost of outright buying a personal vehicle depending on the commute length. In summary, owning

[11] Moye, "Annual New Car Ownership Costs Boil Over $12K."
[12] USDOT Bureau of Transportation Statistics, "Transportation Economic Trends."

a car is often the best financial choice these late-shift low-income workers can make if they want to keep their jobs, and it is a choice that imposes a heavy cost burden.

In addition to earning less, night workers are much more likely to be Black and Hispanic than their daytime counterparts.[13] This establishes the existence, or lack thereof, of overnight transit as an equity issue. The decision to not run transit at all hours of the day runs the risk of affecting a cohort of workers who do the important jobs such as nurses, store clerks, and airport workers; who are more likely to be people of color; and who on average make less money than day time workers.

The other contingent of riders that overnight transit would aim to serve is the weekend leisure crowd. These potential transit riders, often young adults in their 20s and 30s, are out at night on Friday and Saturday to go to restaurants, bars, concerts venues, clubs, or other friends' homes. These activities help keep cities economically and socially vibrant, an important concern in the post-pandemic period. In many places, a large contingent of this population is college students. Most university students, 52%, do not own a car. In schools in cities like Boston, this percentage can be as high as 98% in the case of Boston University or 97% at MIT. [14] In Massachusetts, alcohol cannot be sold after 2 a.m. so most bars will close around that time.[15] By 2 a.m., all MBTA transit service has been shut down, so both bar and restaurant patrons as well as the low-wage workers who provide the food, beverage and back-of-house services are unable to take transit home. University students are more likely to walk or cycle than the typical person.[16] However, when coming back home late at night, many often choose to take an Uber, Lyft, or taxi either due to weather, safety, or distance. While the effects of night time ride-hailing service (also known as transportation network companies or TNCs) on traffic is not very large due to generally low traffic volumes, having people use TNCs negatively impacts the environment through vehicle emissions. The high cost of TNC use is also a strong deterrent for people going out

[13] Zalewski et al., "Supporting Late-Shift Workers Their Transportation Needs and the Economy."
[14] Friedman, "Universities Where the Most Students Bring Cars to Campus."
[15] Alcoholic Beverages Control Commission, "Frequently Asked Questions Fall 2022 Update."
[16] Whalen, Páez, and Carrasco, "Mode Choice of University Students Commuting to School and the Role of Active Travel."

at night. This poses unnecessary challenges to cities like Boston hoping to stimulate the night time economy. For people who do own cars, there is a risk that they drive somewhere at night and then drive home under the influence of alcohol or other drugs, posing a danger not just to themselves but to anyone around them. [17] Since 2015, 12.9% of all road fatalities in the city of Boston occurred between the hours 1 a.m. – 5 a.m. despite the substantially lower traffic volumes. Over two-thirds of these fatalities occurred on weekend nights.[18] This is a moral case for overnight public transit which can help take both drivers and pedestrians off these incredibly dangerous night time streets.

These two groups of people, late-shift workers and the weekend leisure crowd are very different. The former needs consistent and reliable service five days a week to get them to and/or from work. The latter primarily needs service on Fridays and Saturdays and would only rely on public transit the nights they go out, which may or may not be frequent. A comprehensive overnight transit service is able to serve both of these groups. The design considerations that local governments and transit agencies need to consider when designing a system for these riders will be laid out in this thesis.

[17] Late-night public transit access has been linked to decreased arrests for DUI, bolstering the public health and safety arguments for overnight transit (Jackson and Owens, "One for the Road.")
[18] Analyze Boston, "Vision Zero Fatality Records."

Boston: The City that Always Sleeps

Boston was chosen as an initial case for this thesis as its transit system is well positioned to start an overnight service both in terms of the access and mobility needs of the people who would ride it, and as an established transit system with one of the most extensive transit networks in the US (during the day). While Boston is the focus, the framework discussed in this thesis is designed to be applicable to any city and transit system aiming to close the night time transit gap.

The Greater Boston area is home to many industries that generate night time travel demand. According to the Boston Planning and Development Agency (BPDA), the industries that employ the most night shift workers in the city of Boston were hospitals, restaurants, and schools/universities.[19] These industries are pervasive in the region. The Boston area is home to 25 hospitals, 20 community health centers,[20] around 40 colleges and universities,[21] and over 3,000 food establishments in the city alone with much more across the region.[22] The BPDA Night Time Economy study found that 10% of all trips in Suffolk County, the county in which the city of Boston is located, occur between the hours of 9 p.m. and 5 a.m.. Around 46,000 workers in Suffolk County are night shift workers accounting for 7.1% of the total workforce. This is almost twice the national rate of night shift work of 3.8%. Compared to similar cities, Suffolk County is below Chicago (8.7%) and New York (7.3%) but above Seattle (6.4%), Washington DC (5.9%), and San Francisco (4.7%). All five of those cities have some form of overnight transit.

Despite all the activity that goes on at night, there are many complaints that Boston is a "dead city" and that there is not much to do at night time. When interviewed by the Boston Globe, many college students expressed their disappointment with the night life seen in Boston. Complaints were numerous and hit all various aspect, from the monotony of going out, to its high prices, and early closing times of bars and clubs (2 a.m.). For these young

[19] Boston Planning & Development Agency, "Boston's Night Time Economy."
[20] City of Boston, "Healthcare and Life Sciences."
[21] Lima et al., "Boston by the Numbers: Colleges and Universities."
[22] Boston Inspectional Services Department, "Active Food Establishment Licenses."

adults, Boston commands a high cost of living similar to cities like New York, San Francisco, and Chicago, yet offers few of the redeeming qualities "like dollar slice pizza or happy hour."[23] One of the most common threads across the complaints was the lack of transportation options late at night. With T service ending around 12:30 a.m., a full hour and a half before most bars close, many people find themselves stuck either forced to accept the high cost of an Uber (at the same time everyone else is calling one) or brave the night and walk home. While walking is generally a recommended and sustainable form of transportation, it is not uncommon for people, especially women, to feel at risk at night even in a city widely regarded as safe.[24] Additionally, many parts of the city, like East Boston, lack pedestrian or cycling access to downtown entirely. With all of these financial, physical, and social barriers to travel, it is no wonder then that most Boston Globe readers who submitted their opinions said that the reason Boston nightlife was so boring was because of how early the T closes. As one East Boston resident put it, "It's humiliating that we call ourselves a world-class city when our transit system is closed by midnight."[25]

Aware of the complaints of Boston as "The City that Always Sleeps", Mayor Michelle Wu appointed Corean Reynolds as the Director of Nightlife Economy for Boston. The goal of the position was to bolster the city's night time economy by creating a "robust, vibrant, and family-friendly nightlife economy for all residents and visitors."[26] In interviews she has given to local media since taking office, Director Reynolds has expressed interest in expanding night time activity offerings to people of all ages, ensuring it is more than just bars and clubs. Director Reynolds has also acknowledged the need for expanded public transit access at night, not only as a cheaper alternative to taking a cab, but as a safe and reliable means for both nightlife goers and workers to get home at night.[27] Overnight transit therefore is not only a service that people are asking for, but is one that seems to be

[23] Smilgius, "'Boston Is Not a Real City': College Students Say City Nightlife Is Lacking"; "Commonwealth of Massachusetts."
[24] Brenan, "Americans Rate Dallas and Boston Safest of 16 U.S. Cities."
[25] García, "The Biggest Obstacle to a Better Night-Life in Boston?"
[26] Boston Office of Economic Opportunity and Inclusion, "Corean Reynolds Named Director of Nightlife Economy for Boston."
[27] Beland and Dearing, "Reinventing Boston after Dark."

directly in line with the city's goal of stimulating the night time economy. This begs the question: why are there no overnight public transportation options in Boston?

Late-night and Overnight transit is not a new idea to the Boston area. In the heyday of the Boston Elevated Railway Company (BERy), the predecessor to today's MBTA, there existed a quite extensive system of 24-hour streetcars, "trackless trolleys" (trolley buses), and buses.

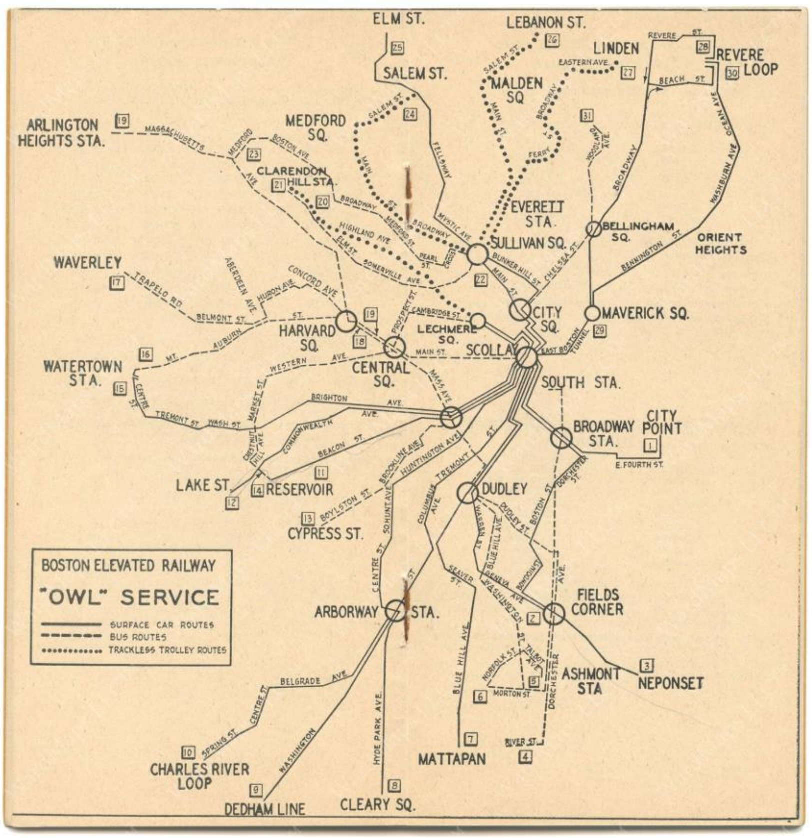

Figure 1: 1947 Map of the Boston Elevated Railway "Owl" Service from "A Brief History of MBTA Transit Maps." Most services in the system began/terminated a central hub located at Haymarket

Unfortunately, the BERy Owl Service would follow in the footsteps of so many other American transit systems of the mid-twentieth century.[28] In June 1960, the final remaining Owl bus routes would cease operation.[29] For the next four decades, the Boston streets would remain devoid of any overnight public transit service.

[28] Bloom, *The Great American Transit Disaster*.
[29] Belcher, "Changes to Transit Service in the MBTA District 1964-2023."

In 2001, the Owl service would make its long-awaited return in the form of an MBTA pilot program. This program would be the first of at least four different attempts the MBTA would make to start a new overnight service. This 2001 pilot consisted of 10 new bus routes that operated between 1 a.m. and 2:30 a.m. and which paralleled the T subway system, stopping at the same stations the T stopped at during the day.[30] This service notably only ran on Friday and Saturday evenings catering most heavily to the weekend leisure crowd.[31] This was despite efforts from advocates like Cambridge Representative Alice K. Wolf who envisioned the system as a daily service that would provide much needed access to families and late-shift workers to whom public transportation access was a "necessity not a frill." In fact, when Wolf initially presented the bill to the Massachusetts Legislature's Joint Committee on Transportation in May 2001, the proposal was to run the T until 2:30 a.m. 7 nights a week.[32] The hesitant committee members preferred a more incremental approach and opted for what would become the 2001 pilot with weekend only night owl bus service. After modest initial success, the pilot program was eventually terminated in 2005 with the MBTA citing budget issues and low ridership.[33]

A decade would pass before late-night transit was attempted again. In 2014, with a $20 million grant from the state as well as backing from corporate sponsors, the MBTA would begin a completely new late-night T pilot. The push this time came from college students and workers in the burgeoning tech industry who complained the T's schedule "did not match their late-night work ethic."[34] Attempting to avoid the failure of the prior late-night transit program, the MBTA chose to provide subway service as well as bus service, extending the operating hours of the subway to 2:30 a.m.. Then Massachusetts Transportation Secretary Richard Davey expressed confidence that train service would attract riders that buses failed to capture. Coming into March 2014, the Commonwealth

[30] Wong, "MBTA Begins New 'Night Owl' Late Night Bus Hours on Weekends."
[31] "Friday and Saturday evening" are used to refer to this period which would technically be 1 a.m. - 2 a.m. on Saturday and Sunday respectively
[32] The Crimson Staff, "A Later Bedtime for the T."
[33] Linn, "Night Owl Bus Gives Its Final Hoot."
[34] Leung, "MBTA to Start Late-Night Weekend Service in 2014."

was certain that it could transform Boston from a sleepy Puritanical town to a vibrant and bustling 24-hour city.[35]

Unfortunately, the results of the 2014 trial were not much different from the 2001 one. Problems abounded with the service. As with the 2001 pilot, ridership was not as high as expected. By February 2015, just under a year into the program, the operating hours were cut back from 2:30 a.m. to 2 a.m.. Since this program involved extended subway hours instead of buses, the largely empty trains meant substantially higher subsidies per rider. At the time, regular riders on the MBTA cost $1.43 per rider whereas during the late-night service, that figure jumped to $13.38 per ride.[36] This subsidy was even higher than the 2001 pilot which, in 2016 dollars, was $9.17 per ride.[37] Without any additional corporate sponsors in sight, the program only served to increase the projected $242 million budget shortfall facing the system. The MBTA board felt they had no choice, and in December 2015, they would vote 4-0 to end the service entirely.[38] For many, dreams of a T that never sleeps were laid to rest yet again.

However, the end of the 2014 Late-Night T program would not spell the end of night transit in the city. In March 2016, the same month late-night T trains were making their final runs, a group of advocates from TransitMatters, a local public transportation advocacy group in the Boston area, announced their initial idea for the "establishment of a robust late-night transit service on the MBTA."[39] Later that year, TransitMatters would meet with the MBTA Fiscal and Management Control Board to discuss their proposed new initiative called NightBus. The initiative would span over several years and see TransitMatters working with the MBTA and the cities of Boston and Cambridge to create an overnight transit network, in the form of buses, to bridge the service gap that had existed between the 1 a.m. and 5 a.m. hours.

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[35] Leung.
[36] Quinn, "Late-Night T Service Appears All but Dead."
[37] Linn, "Night Owl Bus Gives Its Final Hoot."
[38] Conway and Enwemeka, "MBTA Board Votes To End Late-Night Weekend Service By March 18."
[39] Ofsevit, Mendelson, and Aloisi, "Our Plan for Late-Night MBTA Service."

TransitMatters attempted to distinguish its concept from the MBTA's prior pilot program by identifying what went wrong in the old program and what would change in the proposed new one. The failed pilot of 2014-2015 notably only extended operating hours on Friday and Saturday nights. According to TransitMatters, this created a perception problem where late-night transit was seen as only for "drunk college kids" rather than for the late-night workers who would benefit from the service the most.[40] Another concern with the prior pilot was that it failed to create a comprehensive network that could get people where they needed to go across the city. Nor did it consider how transit rider makeup in the night may differ to rider makeup in the day so many low-income neighborhoods, where many night time workers would come from, were left out.

TransitMatters's NightBus sought to remedy all of these issues and do right where the old program went wrong. Instead of extending the operating hours of rail and bus a couple hours into the night on weekends, NightBus focused solely on bus lines that would be run throughout the night seven days a week. These night bus routes would be focused on providing a consistent service that would cover most of the core cities and towns of the Boston area. Through the use of timed transfers downtown, a user of these night buses would be able to get to any other location served by the network with at most one transfer.

[40] Ofsevit, Mendelson, and Aloisi.

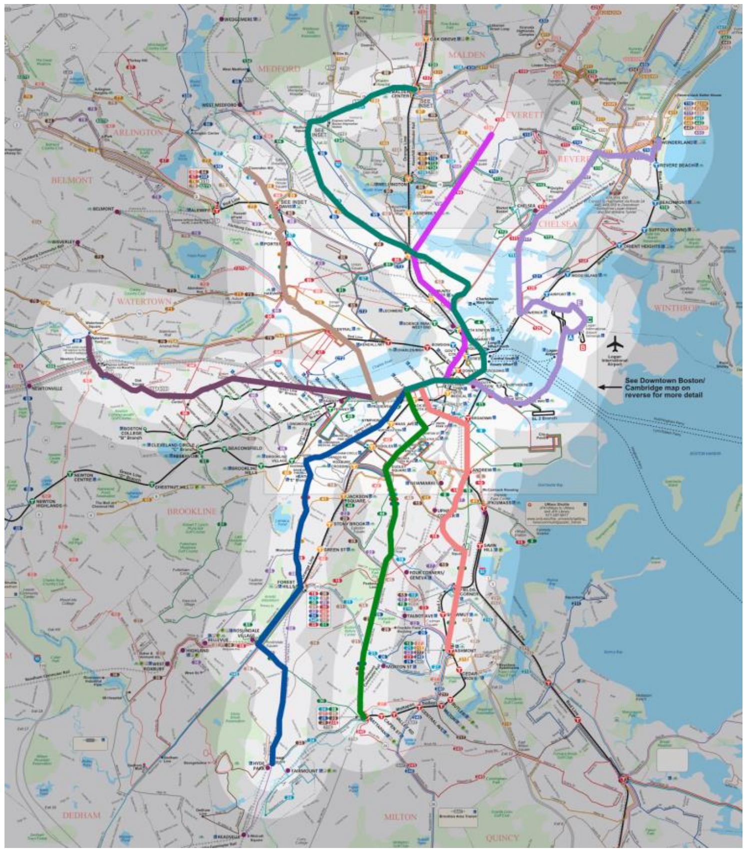

Figure 2: Initial TransitMatters NightBus proposal from 2016[41]

After months of discussion, the MBTA decided to go with a much different approach to late-night buses than the one TransitMatters had outlined. Two main parts of the T's plan related to late-night service. The first was the addition of one or two more trips to the beginning and end of the schedule on certain routes. This extended bus service to around 12:30 - 1:30 a.m. at night and around 4:30 a.m. in the morning. The second part of the MBTA's plan was the creation of a singular route that would operate between 1 a.m. and 4:15 a.m. and begin in Mattapan in the south, going north through Dorchester, Back Bay, Downtown, and then going across the harbor through East Boston, Chelsea, and finally Revere.[42] In the end, the MBTA deemed this overnight spine route too costly. However, the night transit advocates were successful in getting the later night and earlier morning trips made permanent in 2019.[43]

[41] Ofsevit, "The Amateur Planner."
[42] Dumcius, "Here's the Route of the MBTA's Free Late Night Bus."
[43] Massachusetts Bay Transportation Authority, "Early Morning and Late Night Bus Service Pilots."

This brings the story back to the present day. After over four years of practically no discussion, the cause of overnight transit was assumed not by the MBTA, but by the Boston City Council. On January 24, 2024, the council voted to "review the creation of a municipal bus service to provide last-mile service and late-night shuttle service for third-shift workers."[44] The text of the proposal suggests that this service will focus principally on late-night workers again avoiding what were deemed the mistakes of the 2001 and 2014 programs. The fact that it is Boston taking up responsibility of providing the service in lieu of the MBTA is noteworthy as it is a departure from all previous discussions of night transit. A timeline or any more information of the service has yet to be announced publicly. This is where this thesis picks up. Boston is a city that has tried on numerous occasions to create a functioning, useful, and cohesive overnight transit system. The question remains on what the best way is to study such a system and how can local government and transit agencies such as Boston and the MBTA make informed decisions so that they do not end up with yet another failed pilot.

[44] Gaffin, "If the MBTA Won't Provide Late-Night Bus Service, Maybe Boston Can, Councilors Say"; "Order for a Hearing to Review the Creation of A Municipal Bus Service to Provide Last-Mile Service and Late Night Shuttle Service for Third-Shift Workers."

Literature Review

To understand how a city designs an overnight transit system, it is important to look at how the topic of night transit has been studied. Night time transit is a historically understudied topic compared to the focus afforded to other areas in the transportation field. Much of the literature on night transit was published within the past 10 years. This trend is likely to continue as transit agencies contend with the post-pandemic reality that they cannot depend solely on the weekday peak rider. Even as the 9-5 workers come back to the office, they are not doing as the frequency they once used to. Fall 2022 bus ridership from the MBTA show that of the nine weekday time periods used in their classification, the AM Peak (7 a.m. – 9 a.m.) and PM Peak (4 p.m. – 6:30 p.m.) had the 1st and 3rd lowest of rates of ridership recovery. This is in contrast to Late Evening (6:30 p.m. - 10 p.m.) and Night (12 a.m. – 3 a.m.) had the 1st and 3rd highest rates of recovery.[45] As transit agencies look to provide a more holistic service that is able to meet transit demand in the off-peaks as well as the peaks, it is important to know what studies have been done that can be applied to night transit.

Workers at Night

Night time workers are the lynchpin to any successful overnight transit system. While public transit does not exist exclusively to serve commuting trips, they do comprise a consistent ridership base for overnight services. This is particularly true on weekday nights when there are fewer recreational activities occurring. As mentioned earlier, the BPDA performed a study on Boston's Night Time Economy in December 2023. At this time, TransitMatters was already informed of the city council's desire to get the conversation around night transit started again.[46] This BPDA report, while not directly addressing the issue, would help contextualize the dynamics of night time work in the city to the council. The general demographic trends of late-shift workers in Boston mirror those seen in other

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[45] MassDOT, "MBTA Bus Ridership by Time Period, Season, Route/Line and Stop - Fall."
[46] Jarred Johnson, Personal Communication (2023)

cities. For example, night shift workers in Boston are more likely to be Black or Hispanic than they are to be White or Asian.[47]

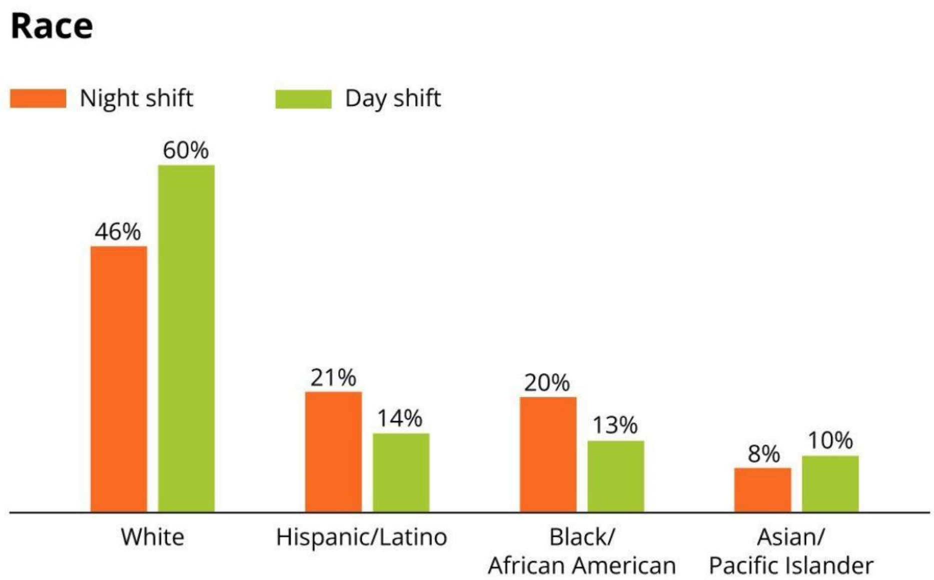

Figure 3: BPDA graph of race/ethnicity of day and night workers in Suffolk County using data from 2017-2021 ACS

In addition to racial disparities, these potential transit riders are much more likely to speak a language other than English at home (43% at night vs. 32% during the day), much less likely to have a college degree (34% vs. 60%) and are more likely to be working a part time job (43% vs. 23%). Further compounding these disparities is the significant income difference between night and day workers: the median night shift worker in Suffolk County makes $37,000 a year whereas the median day shift worker makes $61,000.[48]

The BPDA report has mapped where these night time jobs and activities are occurring, and developed graphs on transit ridership showing that while ridership on MBTA rail does generally drop after 5 p.m., there is consistent ridership until the system closes. And while not highlighted as a result, the MBTA figures included by BPDA show late-night transit ridership as having much higher rates of ridership recovery post pandemic than the peak times and most other times during the day.

[47] Boston Planning & Development Agency, "Boston's Night Time Economy."
[48] Boston Planning & Development Agency.

Figure 4: MBTA rail ridership by hour from the BPDA report

Generally, though, the BPDA report strays away from making any direct policy recommendations, choosing to largely remain descriptive when talking about the state of the night in Boston. This is in contrast to other reports of night shift workers which have taken a more activist approach to telling the story of night workers.

One example of a report written to influence and inform policy is "The Other 9-to-5" published by the San Francisco Late-Night Transportation Working Group in February 2015. This report examines the existing conditions of San Francisco's overnight transit service and how it impacts the workers, residents, and visitors who use (or do not use) the system, with a primary focus on night shift workers (people working between 9 p.m. and 5 a.m.). The researchers studied the transportation needs of night time travelers by dividing the research into five key areas: 1) availability and coverage; 2) speed and reliability; 3) safety and security; 4) awareness and comfort; and 5) cost and equity. The report delved into each of these five areas, explaining their findings and making recommendations for each. The report has detailed data on what modes people choose to travel at night, what MUNI's (the local transit agency) ridership across time looks like, and what people's opinion of the night system are. For a city without existing overnight transit like Boston, it would be difficult to replicate a study such as this. What is useful for cities like Boston is how the study frames overnight transit as an issue of equity and safety. The demographic of night time workers in San Francisco fits the mold of night time workers across the country: a group of low-income people who are unduly burdened by having to travel at a time when options are limited, and costs are higher. From a safety point of view, higher rates of vehicle collisions, bicycle theft, and intimidating conditions for pedestrians at night make ample access to public transit all the more important. None of this data is predicated on having a running overnight system but is useful to justify its existence.

In September 2019, the American Public Transportation Association (APTA) commissioned a similar report explaining how public transportation can support night time workers, and by extension the economy as a whole. The APTA report was done on a nationwide scale and therefore is not focused just on areas with existing overnight transit systems. One focus area of the report was the difficulty of the commute for late-shift workers in cities without overnight transit service.[49] The lack of transit options forces many night workers to either carpool or buy a car themselves. At their current cost, a night time worker could expect to spend well over 30% of their income just to own a car. This is over twice as large a percentage of income as what the average American spends on transportation, for a cohort that already has little income to spare. The result is high turnover among late-shift workers. This poses problems not only for the workers themselves who literally cannot afford to reach their job, but also for the employers who find it more difficult to fill these third-shift positions.

Beyond just presenting these figures, which make a compelling case for night transit in their own right, the report provides numerous case studies of cities and employers describing how both access or the lack of access to transit has affected late-shift workers. Las Vegas for example was highlighted as a success story. It is one of the few cities where transit mode share is higher at night than in the day as many low-income workers staff the casinos late at night. In contrast, Michigan's Fort Custer industrial park, the largest in that state, struggles with high turnover rates among late-shift employees as no good public

[49] Zalewski et al., "Supporting Late-Shift Workers Their Transportation Needs and the Economy."

transit access exists for the 30% of workers who work the second and third shifts. Case studies like these can help cities determine how overnight transit can help workers and the economy with tangible examples. In addition, by looking at places where overnight transit already exists, cities can compile a list of best practices and learn from the successes and failures of other cities which have led the way in 24-hour service. Even with the need for overnight transit to help night shift workers established, the question of which specific areas of the city the service should cover remains.

Transit Propensity

Transit Propensity is a measure of how likely a certain group of people is to ride public transportation. When doing service planning, one way that transit agencies can estimate how many more riders will be attracted to a new line or by increased levels of service is by creating a transportation propensity index (TPI). This usually involves aggregating demographic, workplace, or other geographic characteristics that would attract transit use. The Transit Cooperative Research Program (TCRP) Report 28 outlined certain population attributes that correlate with higher transit usage. This included Black, Hispanic, and Asian people; lower income people; immigrants; those who do not own cars; and those with mobility or work limitations.[50] Even though the report used data from over 30 years ago, many of the same trends hold to this day. Since its publication researchers and transit planners have built upon this work, particularly expanding upon the limitations of the 1998 report. One such limitation was Report 28's focus primarily on home-to-work trips and reliance on data mostly from the home end.[51] In addition to the demographic metrics described, cities have also factored in location characteristics such as job density (with emphasis on low wage and retail jobs), residential density, walkability, and overall activity density which includes jobs and residences but also shopping and recreation.[52] Population

[50] Rosenbloom, "TCRP Report 28."
[51] Bush, "Using Census Data to Identify Areas of High-Transit Propensity."
[52] Thomas Jefferson Planning District Commission, "Transit Propensity."

density in general seems to be one of the most significant determinants of which areas are likely to see higher transit demand.[53]

There are fewer applications of transit propensity as it relates to night time travel demand. One paper with an explicit focus on night transit studied ridership on the Muni's Owl all night service. The researchers created a transit propensity index meant specifically to predict night time transit demand. Only three indicator variables were used: density of night transit workers, density of low-income households, and density of zero vehicle households. Since Muni already runs night service and thus has ridership data available, the researchers were able to validate the index and found that it was a reasonable predictor of ridership on the owl network.[54] A master's thesis from the University of Washington built upon this work from the San Francisco study, incorporating these metrics, as well as additional demographic data, to create a night TPI for the city of Seattle.[55] Instead of using the index to predict overnight transit ridership, the Thesis used the TPI to spatially evaluate how well the existing King County Metro Night Owl service covered the areas deemed to have the highest night time demand.

Night Transit Propensity in Boston

In my undergraduate thesis, I applied a night time transit propensity methodology to the Boston area which drew inspiration from past research on night time transit demand done by Dentel-Post et al. and Margetic. Unlike in prior research on night transit TPIs, this undergraduate thesis examined a region that did not already have an overnight transit service. This meant that instead of creating a TPI that could be validated using existing transit ridership or overnight route choices, the thesis would work the other way around. The thesis developed a night time TPI that could be used in Boston to identify areas of the city that have the highest need for an overnight transit service. The index was designed specifically to quantify transit propensity among late-shift workers as that was the demographic identified as the core constituent of overnight transit riders. Eight different

[53] Bush, "Using Census Data to Identify Areas of High-Transit Propensity."
[54] Dentel-Post et al., "Getting People Around After the Trains Stop Running."
[55] Margetic, "Night Riders: Accessibility, Land Use, and Late-Night Transit."

variables were chosen to model night time TPI including standard demographic variables like race, income, and education as well as variables related specifically to worker characteristics such as time leaving for work and industry of employment, with a focus on night time commuters in industries with higher rates of late-shift workers.

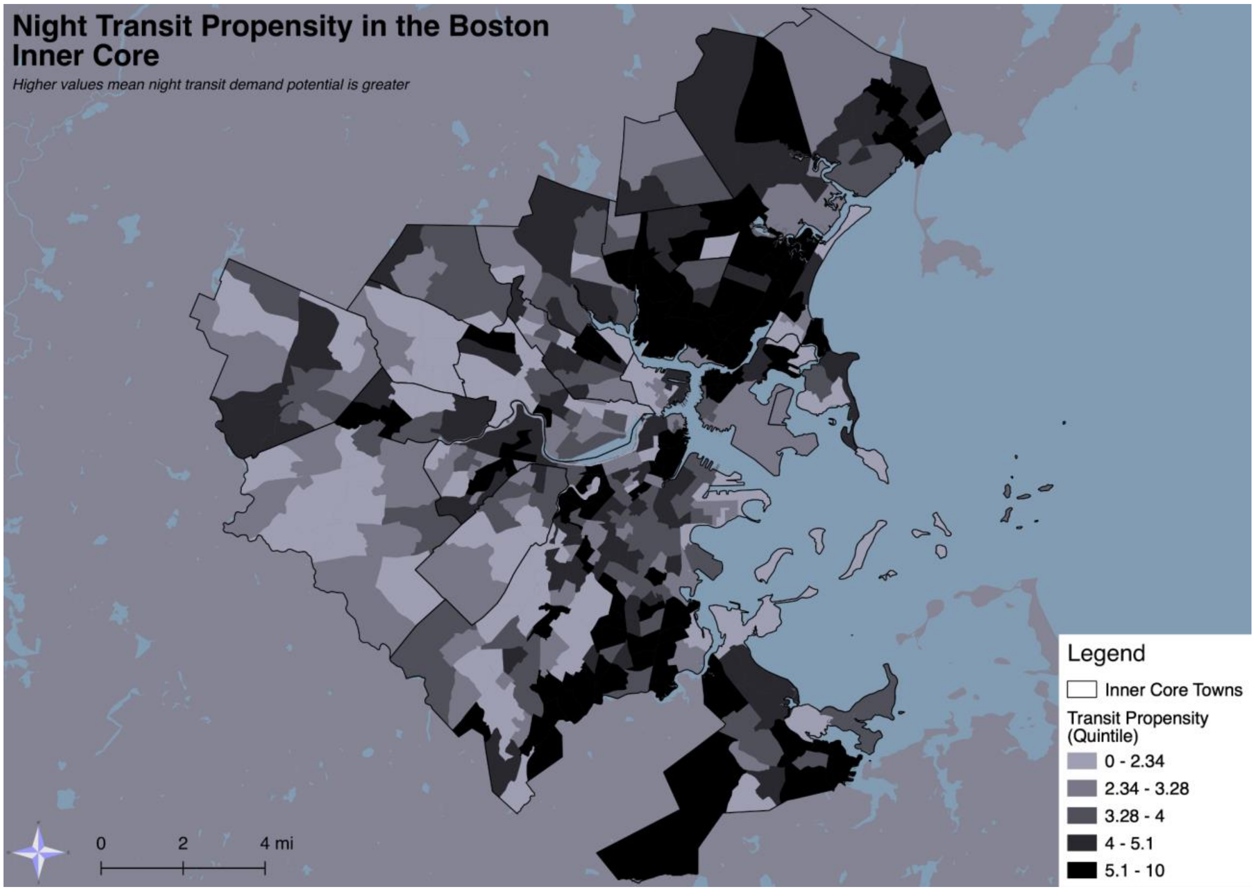

Figure 5: Map from my undergraduate thesis on night time transit propensity

The areas of the region identified as having high night time transit propensity included Dorchester, Mattapan, and Hyde Park in the southern part of the city of Boston; Downtown Boston, Fenway, and Allston in the Northern part of the city; and East Boston, Chelsea, Revere, Everett, and Malden across the Boston Harbor.[56] Using this TPI it was possible to evaluate the past and present proposals for late-night service in the region, including the old pilot programs of extended T service as well as the TransitMatters NightBus proposal.

[56] Neighborhoods and towns of greater Boston will be referred to repeatedly in this thesis. For a maps of where these towns and neighborhoods are, refer to "Appendix A – Greater Boston Reference Maps."

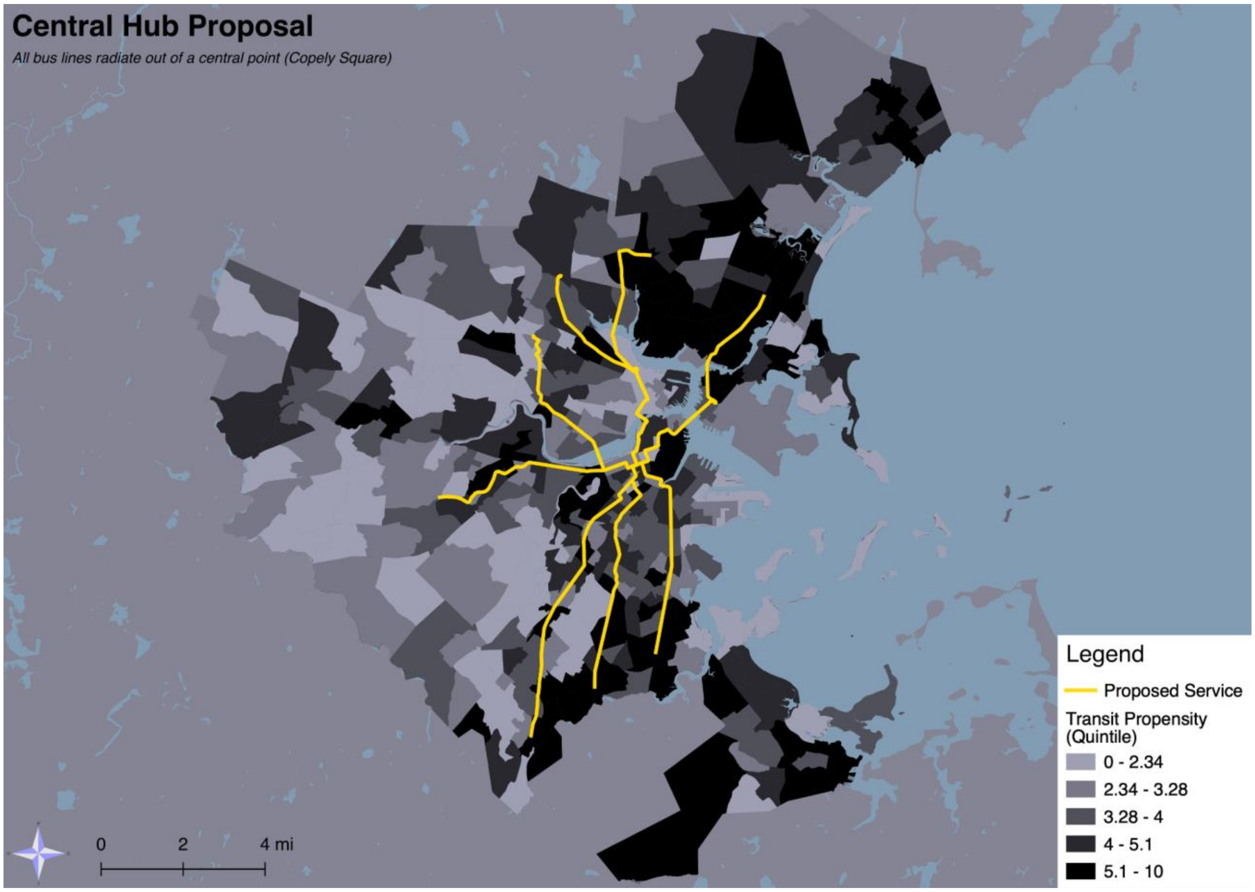

Figure 6: Map with TransitMatters NightBus proposal overlayed on night-time TPI

One of the principal arguments of the thesis was that the old MBTA late-night transit pilots failed because they followed existing day-time transit routes without consideration of how travel patterns might change at night. Using the TPI, it could be seen that none of the past proposed late-night services targeted night time workers as well as the TransitMatters NightBus network would.

My master's thesis expands upon my undergraduate work in a few ways. The TPI outlined in the undergraduate thesis is tailor-made to represent demand among night time transit workers. First, while the point of the earlier thesis was to center the system design on workers, this of course ignores the sizable contingent of night time transit riders who would not be commuting, such as weekend recreational travelers. Second, the night time TPI used perpetuates the idea that night time transit has to be considered a completely separate and distinct idea from day time transit. This master's thesis challenges this notion and portrays night time transit as a continuum, a transit service that is no different than transit at any other time of the day. For a seamless and continuous model of public transportation to work, it is important that there be a way to measure transit propensity and need for public transit in a city across time.

Transit Deserts

The term "transit desert" originated from a paper by Jiao and Dillivan. Using the same language as food deserts, transit deserts are described in this 2013 paper as "areas that lack adequate public transit service given areas containing populations that are deemed transit-dependent."[57] The paper's goal was to create a clear method which could be used to identify areas of cities that had large gaps between transit supply and demand using GIS.

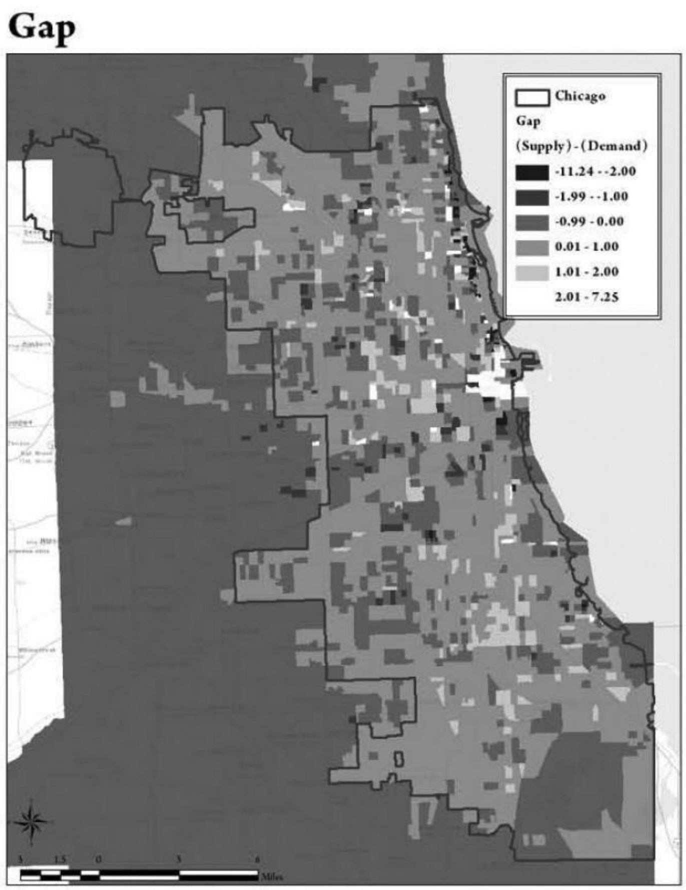

Figure 7: Chicago transit deserts map from Jiao and Dillivan (2013)

[57] Jiao and Dillivan, "Transit Deserts."

In the original paper, transit supply for each census block group was quantified by looking at four different factors: number of bus and rail stops, frequency of weekday service, number of routes, and length of bike routes and sidewalks. Transit demand was calculated by determining the “transit dependent population” of a block group using a methodology originally described in a 2006 US Department of Transportation report.[58] The method applied a simple interpretation of transit dependency by looking at populations who do not have access to a vehicle such as people in zero car households, those too young to have a license, and households with more driving aged people than vehicles available.

Later studies would expand on the definitions of transit supply and transit demand, adding new variables to the original ones from the 2013 paper. In particular, methods of quantifying transit demand have seen large shifts. Where the original 2006 methodology aimed to limit its scope to just populations that need transit, more recent methods have modeled transit demand by examining variables that are correlated with higher transit ridership. This includes demographic variables such as race, car ownership, education, and income. In a somewhat circular manner, some studies have even included existing transit ridership as an indicator of transit demand. This means that generally, the method of quantifying transit demand has shifted away from trying to identify the exact number of transit dependent people towards a definition that resembles transit propensity.

One thing that is notably lacking from the majority of methods for calculating transit supply and demand is a temporal component. For transit supply, indicator variables are usually aspects that are unchanging throughout the day like number of stops present or miles of sidewalks. Even for time-dependent variables like number of transit trips, it is not uncommon for researchers to sum the total number of transit trips over a specific time period such as only peak trips,[59] all trips in a weekday,[60] or all trips over the course of the week.[61] For the most part traditional transit desert studies take transit supply and demand

[58] Steiss, “CTPP 2000 Status Report.”
[59] Aman and Smith-Colin, “Transit Deserts.”
[60] Jiao and Dillivan, “Transit Deserts.”
[61] Center for Neighborhood Technology, “AllTransit Methods.”

to be a static variable throughout the day. What is lost is the variation that comes with changing levels of transit service and transit demand throughout the day. It is possible that some place that is considered a transit oasis at one time of the day, could be considered a transit desert at another.

Temporal Variability of Transit

Transit service is constantly changing throughout the day. What is easily accessible via public transit at 8 a.m. may be more difficult to reach at 1 p.m. and impossible to each at 3 a.m.. While traditional transit desert methodologies do not focus too heavily on this aspect, the temporal variability of transit access generally and how that affects city residents is something that has been explored in the literature.

In a return to the progenitor of transit desserts, Farber et al. (2014) examines how food deserts in Cincinnati shift over time. The term "food desert" has existed since the 1990s and has typically been defined as areas of a city that lack access to sources of affordable healthy food. Farber et al. took issue with the fact that traditional analyses of food deserts used simple Euclidean distance or road network distance to identify food deserts. The reality is that many people rely on public transportation to get to supermarkets and grocery stores. Old metrics such as Euclidean distance do not accurately represent the access transit dependent populations have to these locations. Instead, the researchers identify food deserts not based on distance to supermarkets but on public transit travel time to supermarkets. They used schedule data from the two largest transit agencies in the Cincinnati metro area to quantify how far each census tract in the city was from a super market at different times of day.[62] In the end, the researchers were able to derive information such as what percent of the day a certain area had easy access to supermarket (within 10 or 20 minutes on transit) and what the average travel time to the nearest supermarket was across the city. This paper is useful because it shows how adding a

[62] Farber, Morang, and Widener, "Temporal Variability in Transit-Based Accessibility to Supermarkets."

temporal component can change what areas are defined as having "good" transit access. It is not just enough for physical infrastructure to be nearby; it all depends on what the service looks like when it's needed.

Other more recent studies have also looked into analyzing the temporal variability of transit using language from Jiao and Dillivan's original 2013 Transit Desert paper. One such example is Kaeoruean et al. (2020) which analyzed public transit supply-demand gaps in Calgary.[63] This paper quantifies transit supply and demand in Calgary and how it changes across time although critically only in the morning period from 5 a.m. to 9 a.m.. This paper describes a way to quantify how transit supply can change over time by looking at the number of trips in a given area on an hourly basis. The researchers also tried to quantify transit demand over across time in this morning period, although their method involved looking at existing transit passenger numbers. This limits its usefulness in identifying true transit deserts as these areas are likely to see suppressed transit ridership due to inadequate transit supply. This method would also completely break down at night in cities like Boston when there are no transit riders whatsoever. Nonetheless, this paper does show that researchers are thinking about how a temporal dimension can be added to traditional analyses and provides a useful way to factor total transit trips into a transit supply index. This thesis will build upon these studies into the temporal accessibility of transit to create a comprehensive transit supply-demand gap methodology that can work at any hour of the day whether transit service is present or not.

[63] Kaeoruean et al., "Analysis of Demand–Supply Gaps in Public Transit Systems Based on Census and GTFS Data."

Methodology

Knowing where transit demand outstrips transit supply is important in deciding where new transit service should go. However, the biggest issue with how transit deserts are currently identified is that they are typically static and unchanging. Maps of transit accessibility frequently show cities divided between the blue/green area transit oases and the deep red transit deserts. However, this only paints a partial picture. Levels of transit service are not static nor are people's travel patterns. While night is often the most notable time in which these transit supply-demand gaps occur, transit deficient areas can appear at any time. A dynamic map of the transit supply-demand gap would be able to give governments and transit agencies a better idea of where they should focus service delivery at night as well as during the day.

Data

There were two principal data sources used to identify spatial-temporal gaps in MBTA transit service: the American Community Survey and GTFS. Both were chosen for their ease of access, consistency across geographies, and ubiquity. While this thesis is specific to the Boston case, the methodology described is applicable to any US city whether it has 24-hour transit or not. Hence all of the data used was provided either by the census or is common to most American cities.

For calculating transit supply provided by the MBTA, all of the indicator variables can be derived from the MBTA GTFS feed. GTFS, short for General Transit Feed Specification, is an open standard that transit agencies across the world use to report schedules on their system. The standard was originally developed by Google in 2005 in collaboration with Portland's TriMet to be able to integrate transit trip planning into Google Maps.[64] It has since grown to encompass more than just schedules including information like real time location of buses, station exits, fares, and soon demand response services.[65] In addition to the GTFS feed, some data from MassGIS, the open data portal for spatial data for

[64] McHugh, "Pioneering Open Data Standards: The GTFS Story."
[65] MobilityData, "General Transit Feed Specification."

Massachusetts, was used. However, any data from MassGIS could be replaced or recreated with GTFS data. With the Federal Transit Administration now requiring all transit agencies "create and maintain public domain GTFS dataset,"[66] there should be no issue applying these methods in other cities, even ones with much smaller transit networks than Boston.

The main data source used to model transit demand was the 2018-2022 American Community Survey (ACS) from the US Census Bureau. This is the most recent ACS data at the time of writing. The benefits of using census data are the fact that this data is readily available and consistent for all geographies across the country. It is also released on an annual basis so transit agencies can regularly reapply this methodology not only as transit schedules change but as populations do as well. All demographic data was collected at the census tract level.

Transit Supply

Following precedents set in prior studies on transit deserts, the transit supply component was determined using three criteria that are static and one new criterion that is dynamic across time. The four are as follows:

VARIABLE	DEFINITION	TEMPORALITY	DATA SOURCE
TRANSIT STOP DENSITY	The number of heavy rail, light rail, and bus stops within a census tract normalized by the area	Static across time	MassGIS Data Portal or stops.txt in GTFS
BUS ROUTE LENGTH DENSITY	The length of all bus routes that go through a tract in kilometers divided by the total area of the tract in square kilometers	Static across time	MassGIS Data Portal or shapes.txt in GTFS
TRANSIT COVERAGE	The percentage of a tract's land area that is within 400m of a bus stop or 800m of a rail stop	Static across time	MassGIS Data Portal or stops.txt in GTFS

[66] Federal Transit Administration, National Transit Database Reporting Changes and Clarifications.

NUMBER OF TRANIST TRIPS	The number of total transit trips, on both bus and rail, that occur within 200m of a census tract in an hour	Aggregated hourly	GTFS

Table 3: Transit supply variables

Table 3 outlines the four indicator variables used in calculating transit supply. The first three variables are all standard are often included in traditional transit desert studies. Transit stop density is the most straight forward: more stops in a given the area means people have to travel less distance to access transit. Bus route length density was added to take into consideration connectivity the rest of network following precedent set by Aman and Smith-Colin (2021). Being near more unique bus lines means transit riders have more options of places to go. The final static measure is transit coverage which quantifies what portion of a census tract is transit accessible. People are usually only willing to walk a certain distance to transit stops. The area within this walking distance is known as a stop's catchment areas or walksheds. The convention in transportation planning is to have walksheds of 400m radii (~1/4 miles) for bus stops and 800m radii (~1/2 miles) for rail stops in recognition that people are often willing to walk further to ride the train.[67][68]

The temporal component of transit supply is captured through the fourth variable. The number of transit trips is calculated first by determining the number of trips each stop gets in a given hour h which can be derived from the GTFS schedule. Then stops are matched to census tracts based on which census tract(s) they fall in or near. For the purposes of trip allocation, bus stops are matched to any tract within 200 meters of the stop. This was done as many bus stops are on roads which serve as boundaries for census tracts. Without this buffered joining, the method would yield edge cases where one tract has a large number of trips while a neighboring tract had none simply because all the stops along a road/boundary belonged to the first tract.

[67] Daniels and Mulley, "Explaining Walking Distance to Public Transport."
[68] Walksheds in this study are calculated as perfect circles with radii of 400 and 800m irrespective of the existing street network. There are concerns that this over estimates how much area is truly reachable by foot from transit, and that network walking distance, or even perceived walking distance would be a better metric. see: https://boston.transit-access.com/

These variables were then all standardized into a z-score. The z-score standardization for the three static variables was simple:

$$Z_{t,i} = \frac{v_{i,t} - \mu_i}{\sigma_i} \tag{1}$$

Where $Z_{i,t}$ is the z-score of indicator variable i, for tract t,
$v_{i,t}$ is the absolute value of indicator variable i, for tract t,
μ_i is the mean value of indicator variable i across all tracts, and
σ_i is the standard deviation of indicator variable i across all tracts.

This equation however breaks down for the number of transit trips supply indicator variable 4, number of trips. Tracts should not get a positive z-score if the transit service is very low. This would happen if z-scores were standardized to a time when service is low like at midnight. The standardization completely breaks down during hours where there is no service across all tracks since the standard deviation of the number of trips across tracts would be 0. As such, transit trips are all normalized using the mean and standard deviation of tracts during the 2 p.m. hour. Consequently, the z-score standardization for supply indicator variable 4 is calculated with the following equation:

$$Z_{4,t,h} = \frac{v_{t,h} - \mu_{14}}{\sigma_{14}} \tag{2}$$

Where $Z_{4,t,h}$ is the z-score of indicator variable 4 (number of transit trips), for tract t at hour h,
$v_{t,h}$ is the absolute number of transit trips tract t sees at hour h,
μ_{14} is the mean number of transit trips across all tracts at hour 14 (2 p.m.), and
σ_{14} is the standard deviation of transit trips across all tracts at hour 14 (2 p.m.)

In the end, every tract will have 24 different composite transit supply scores for each hour in the day. The equation for calculating the transit supply score of a tract t at hour h is given by the following equation:

$$S_{t,h} = \frac{Z_{1,t} + Z_{2,t} + Z_{3,t} + 2 \cdot Z_{4,t,h}}{5} \tag{3}$$

Where $S_{t,h}$ is the overall transit supply score at hour h for tract t,
$Z_{i,t}$ is the z-score of the indicator variable i for tract t, and
$Z_{4,t,h}$ is the z-score of total transit trips for tract t at hour h.

Note that total transit trips per tract is weighted twice as much as the other variables. This is to put more emphasis on the transit level of service as this is a critical component of transit access. Living near a trainstation is not very useful if there are no trains running.

Transit Demand

The process for estimating transit demand attempts to blend the methods of finding transit demand in typical transit desert studies with methods used to estimate transit propensity, particularly building off of work from my prior thesis. Unlike in the original 2013 transit desert study by Jiao and Dillivan, the purpose of the transit demand score is not only to capture "transit-dependent" populations, but also to identify areas where transit demand generally is likely to be higher. Eight indicator variables were chosen to estimate transit demand:

VARIABLE	DEFINITION	TEMPORALITY	DATA SOURCE
LOW INCOME HOUSHEOLDS	The number of households earning less than $80,000 per year per square kilometer	Static Across time	American Community Survey 2018-2022
ZERO CAR HOUSEHOLDS	The number of households reporting no vehicles owned per square kilometer	Static across time	American Community Survey 2018-2022

PEOPLE OF COLOR	The number of people who do not identify as non-Hispanic White alone per square kilometer	Static across time	American Community Survey 2018-2022
YOUTH POPULATION	The number of people aged 10 to 17 per square kilometer	Weighted more heavily in the day time (6 a.m. to 6 p.m.)	American Community Survey 2018-2022
YOUNG ADULT POPULATION	The number of people aged 18 to 29 per square kilometer	Weighted more heavily at night (6 p.m. to 6 a.m.)	American Community Survey 2018-2022
ELDER POPULATION	The number of people aged 65 and older per square kilometer	Weighted more heavily in the day time (6 a.m. to 6 p.m.)	American Community Survey 2018-2022
NIGHT INDUSTRY WORKERS	The number of workers employed in the following industries per square kilometer: • Retail Trade • Educational Services, and Health Care and Social Assistance • Arts, Entertainment, and Recreation, and Accommodation and Food Services • Transportation and Warehousing, and Utilities	Weighted more heavily at night (6 p.m. to 6 a.m.)	American Community Survey 2018-2022
NUMBER OF WORKERS LEAVING FOR WORK	The number of people leaving for work at a given time per square kilometer	Aggregated hourly	American Community Survey 2018-2022

Table 4: Transit demand variables

The first three variables selected to model transit demand are density of low-income households, density of zero-vehicle households, and density of people of color. These three factors are consistent indicators of transit propensity at all times of the day. The link between transit ridership and zero-vehicle households is self-evident: households that lack a car for personal use are more likely to use non-car modes to travel. This is true for transit as well. Over 90% of zero-vehicle households in major metropolitan areas are in areas with access to some form of transit.[69] Income level and race have also long been correlated with ridership dating back to at least the 1998 TCRP Report 28.[70] This has been made even more acute after the pandemic. In Boston, from 2015-2017, people from households with incomes below $56,000 accounted for 29% of all MBTA riders. Non-White riders made up 34% of the system's ridership. By 2022, the relative portion of low-income riders was up to 48% and the relative portion of riders of color was 58%.[71]

Four of the variables included in transit demand are weighted differently based on time of day. During the day time more emphasis is placed on the youth and elderly populations. The youth population is transit dependent owing to the fact that most of them are not yet old enough to have a license. Even among youth eligible to get a license, 75.7% of 16-year-olds and 57.6% of 17-year-olds remain unlicensed.[72] Elderly people have similarly been found to be more transit dependent compared to the general population.[73] While the majority of people 65 and older are licensed, they may find it more difficult to drive as they age as visual and mobility impairments become increasingly common.[74]

At night time, young adults are weighted more heavily as well as workers from specific "night industries." Regarding young adults, the BPDA found that night time workers are more likely to be between the ages of 20 and 24 than day time ones are.[75] A study on Washington, DC metropolitan area similarly found the age group most overrepresented in late-night travel (midnight to 4 a.m.) were 25–29-year-olds.[76] In addition to working late-night jobs, this demographic is also the most likely to go out at night for leisure activities.[77] The industries classified as "night industries" for the transit demand score were the ones

[69] Tomer, "Transit Access and Zero- Vehicle Households."
[70] Rosenbloom, "TCRP Report 28."
[71] Mohl, "Survey Indicates Dramatic Demographic Shift among T Riders."
[72] Federal Highway Administration, "Table DL-20 - Highway Statistics 2022."
[73] Rosenbloom, "TCRP Report 28."
[74] Al-Namaeh, "Common Causes of Visual Impairment in the Elderly"; US Census Bureau, "Mobility Is Most Common Disability Among Older Americans, Census Bureau Reports."
[75] Boston Planning & Development Agency, "Boston's Night Time Economy."
[76] National Capital Region Transportation Planning Board, "2017/2018 Regional Travel Survey In-Depth Analysis Late-Night Travel: Characteristics of Travelers and Trips."
[77] American Nightlife Association, "Market Overview."

identified by the APTA report as having high rates of late-shift work.[78] These industries include transportation, food services, retail, healthcare, and entertainment. These are often jobs that cannot be worked remotely, so presence of workers in these industries can also be an indicator of daytime transit demand.

The final component of transit demand is number of workers leaving for work by census tract. This is data from ACS table B08302 which has data on the time people leave for work throughout the day. The only issue with this source is that from 12 p.m. to 5 a.m., data is not reported in granular enough time increments to report the true hourly number. As an approximation, this method assumes constant commuting numbers across the hours in these three time categories: "12:00 P.M. To 3:59 P.M.", "4:00 P.M. To 11:59 P.M.", "12:00 A.M. To 4:59 A.M.." For example, if a census tract reported 160 people leaving for work between 4 p.m. and 11:59 p.m., then its commuting volume at 6 p.m. is assumed to be 20. Similar to the transit trips variable in the transit supply score, this variable is weighted more than the other variables to capture more strongly the temporal changes in transit demand throughout the day.

For the transit demand indicator variables 1-7, the z-score is calculated the same as it was for the first three transit supply indicator variables (refer to equation 1). However, unlike for supply indicator variable 4, demand indicator variable 8 is standardized hourly and not with respect to 2 p.m. or any other baseline. The Z-score calculation for indicator variable 8 is shown below:

$$Z_{8,t,h} = \frac{v_{t,h} - \mu_h}{\sigma_h} \quad (4)$$

Where $Z_{8,t,h}$ is the z-score of indicator variable 8 (density of people leaving for work at a given time), for tract t at hour h,

$v_{t,h}$ is the absolute density of people leaving for work at tract t sees at hour h,

[78]Late shift work is defined in the report as shifts that start between 4 p.m. and 6 a.m. (Zalewski et al., "Supporting Late-Shift Workers Their Transportation Needs and the Economy.")

μ_h is the mean density of people leaving for work at hour h across all tracts t, and σ_h is the standard deviation of density of people leaving for work at hour h across all tracts t.

Aggregating the demand indicator variables is a similar process as was done when calculating transit supply. However, for transit demand, some variables are weighted differently based on time of day. The transit demand score of a tract t at hour h is given by using the following equation:

$$D_{t,h} = \frac{Z_{1,t} + Z_{2,t} + Z_{3,t} + w_1 \cdot Z_{4,t} + w_2 \cdot Z_{5,t} + w_1 \cdot Z_{6,t} + w_2 \cdot Z_{7,t} + w_3 \cdot Z_{8,t,h}}{9} \tag{5}$$

Where $D_{t,h}$ is the overall transit demand score at hour h for tract t,
$Z_{i,t}$ is the z-score of the indicator variable i for tract t,
w_1 is the weight of the day time variables (youth and elder populations). This takes on value of 1.5 if h is in range [6, 18) and 0.5 otherwise,
w_2 is the weight of the night time variables (young adults and night job populations). This takes on value of 0.5 if h is in range [6, 18) and 1.5 otherwise,
w_3 is the weight for indicator variable 8 and always takes value 2 regardless of hour, and
$Z_{8,t,h}$ is the z-score of density of workers leaving home for tract t at hour h.

Transit Supply-Demand Gap

The transit supply-demand gap (transit gap) is a measure of whether the level of transit service is able to adequately meet the demand. With this methodology, this transit gap varies across both space (different tracts) and time (different hours of the day). The transit supply-demand gap for a tract t at hour h his calculated with the following equation:

$$G_{t,h} = S_{t,h} - D_{t,h} \tag{6}$$

The result will be 24 different transit gap values across all the tracts in the data set.

Let σ_h be the standard deviation of the transit supply gap across all tracts at in a given hour h. When $G_{t,h}$ is between -σ_h and σ_h, the transit supply sufficiently meets the transit demand. If $G_{t,h}$ is less than -σ_h, then transit supply does not adequately meet transit demand and the tract is deemed a "transit desert." If $G_{t,h}$ is greater than σ_h, then transit supply exceeds transit demand, and the tract is said to be a "transit oasis." Being able to identify these locations will help transit agencies know where to target service expansions across geographies and times.

Results

The transit supply and demand scores across time were calculated for every tract in the inner core cities and towns of the Greater Boston Area.[79] Across all times, the areas where transit supply was consistently the highest were downtown Boston, Lower Roxbury, and Fenway Kendall. These areas are all served by at least one rail line and a handful of frequent bus lines.

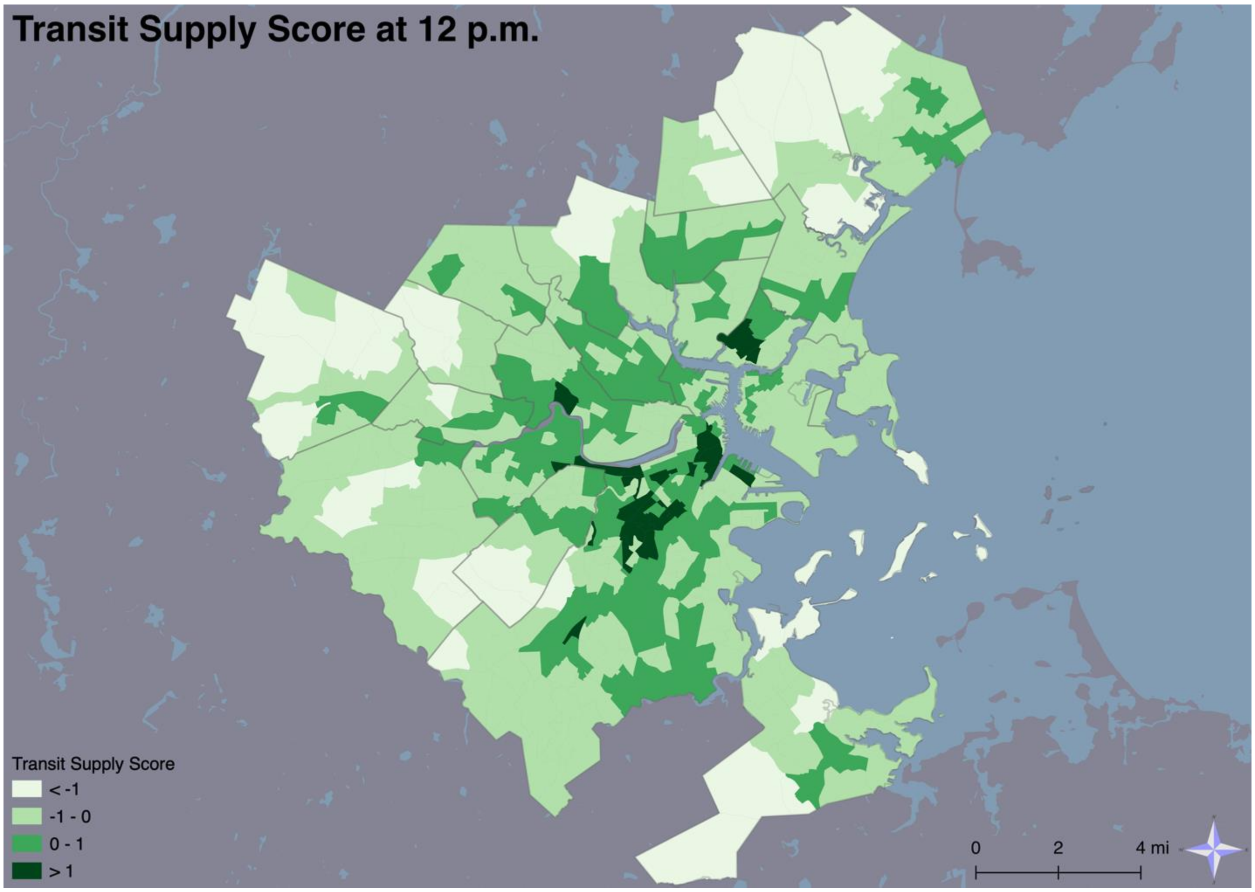

Figure 8: Map of transit supply at 12 p.m.

These same neighborhoods also exhibited a high degree of transit demand in addition to areas in Back Bay, East Boston, and Dorchester.

[79] See “Appendix B – Hourly Transit Supply Scores” and “Appendix C – Hourly Transit Demand Scores” for maps of transit supply and transit demand by hour.

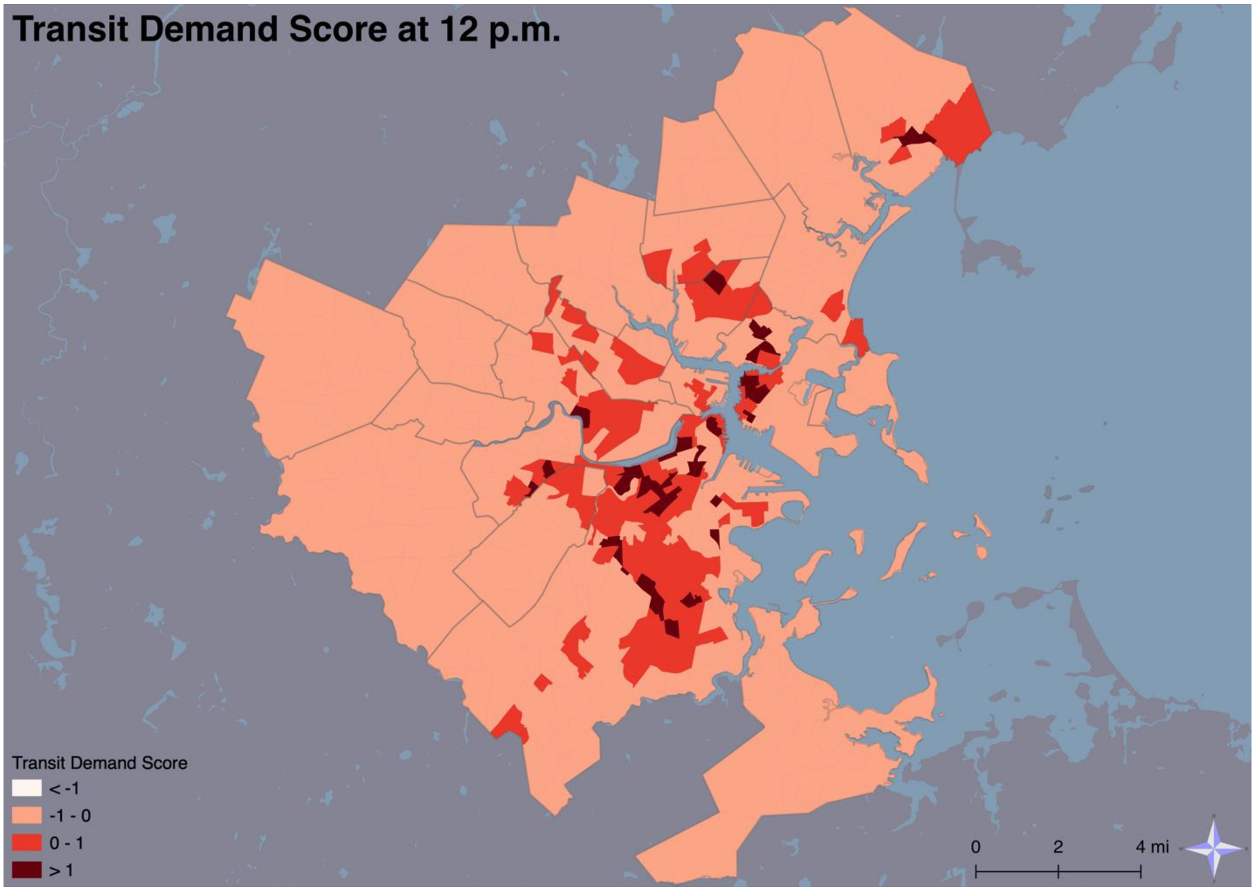

Figure 9: Map of Transit demand at 12 p.m.

Combining the two examples shown, a map of the mid-day transit supply-demand gap can be made, highlighting the areas where transit is oversupplied and undersupplied.

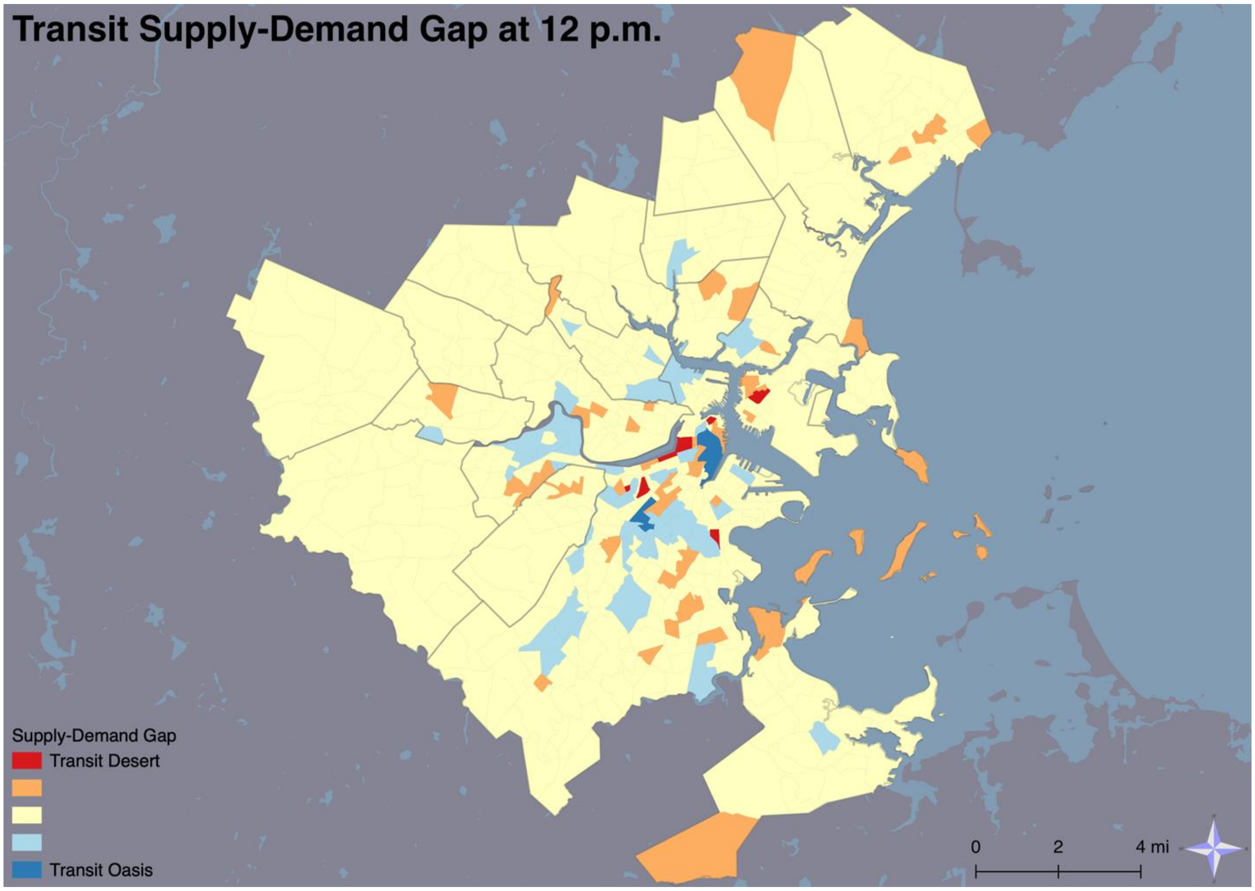

Figure 10: Map of transit supply-demand gap at 12 p.m.

Figure 10 shows a city that for the most part is decently served by public transportation. Areas in yellow on the map are places where supply just about meets demand. Areas in blue are the transit oases where residents, workers, and visitors have ample access to transit. The transit deserts, where transit service is outstripped by demand, are highlighted in orange/red. Some notable parts of the region with transit desert clusters are include part of the Dorchester neighborhood, which has a high Black and low-income population; Allston to the west which has a large number of students and zero vehicle households, and East Boston across the harbor which has a high number of Hispanic and low-income residents.

One result shown in Figure 10 that people familiar with Boston may be surprised about is the classification of census tracts in Beacon Hill and Back Bay as transit deserts. These neighborhoods consistently rank among the most walkable neighborhoods in the region[80] with a dense urban fabric that has seemingly managed to avoid heavy automobile centric development. It is important to note however that an area can be underserved by transit while still being walkable. These tracts, while within walking distance of MBTA rail stations, lack the high degree of bus connections that other similarly urban census tracts have. It should therefore come as no surprise that walking, not transit, is the primary mode of transportation to work among residents of these areas. In fact, in Beacon Hill and the eastern half Back Bay, cars have a higher commute mode share than public transit.[81]

[80] Stefanescu, "These Are Boston's Most Walkable Neighborhoods."
[81] American Community Survey 2018-2022

The major benefit of this spatiotemporal method for assessing transit service gaps over prior work in this field is the ability to examine different times of day. There is a noticeable change in which areas are identified as transit deserts/oases as the day progresses.

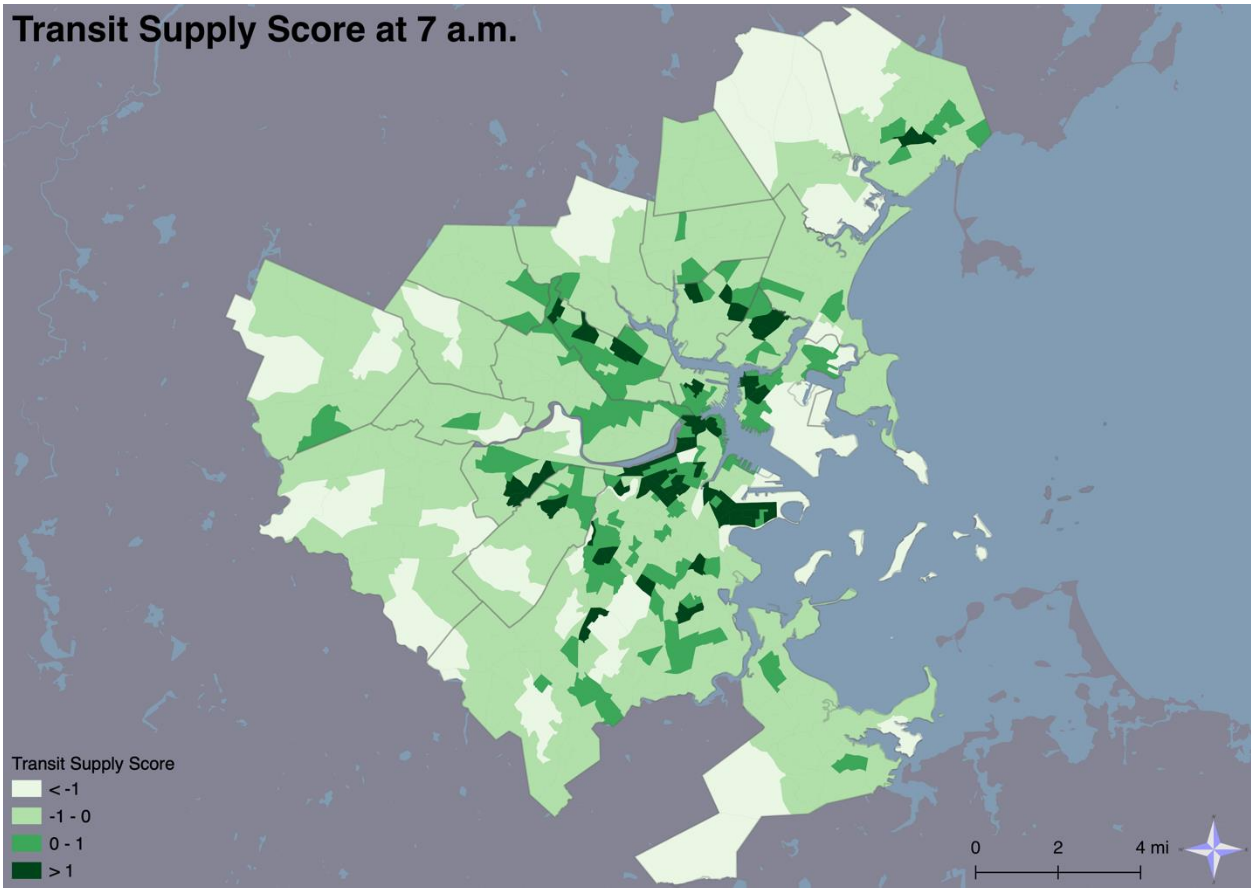

Figure 11: Map of transit supply at 7 a.m.

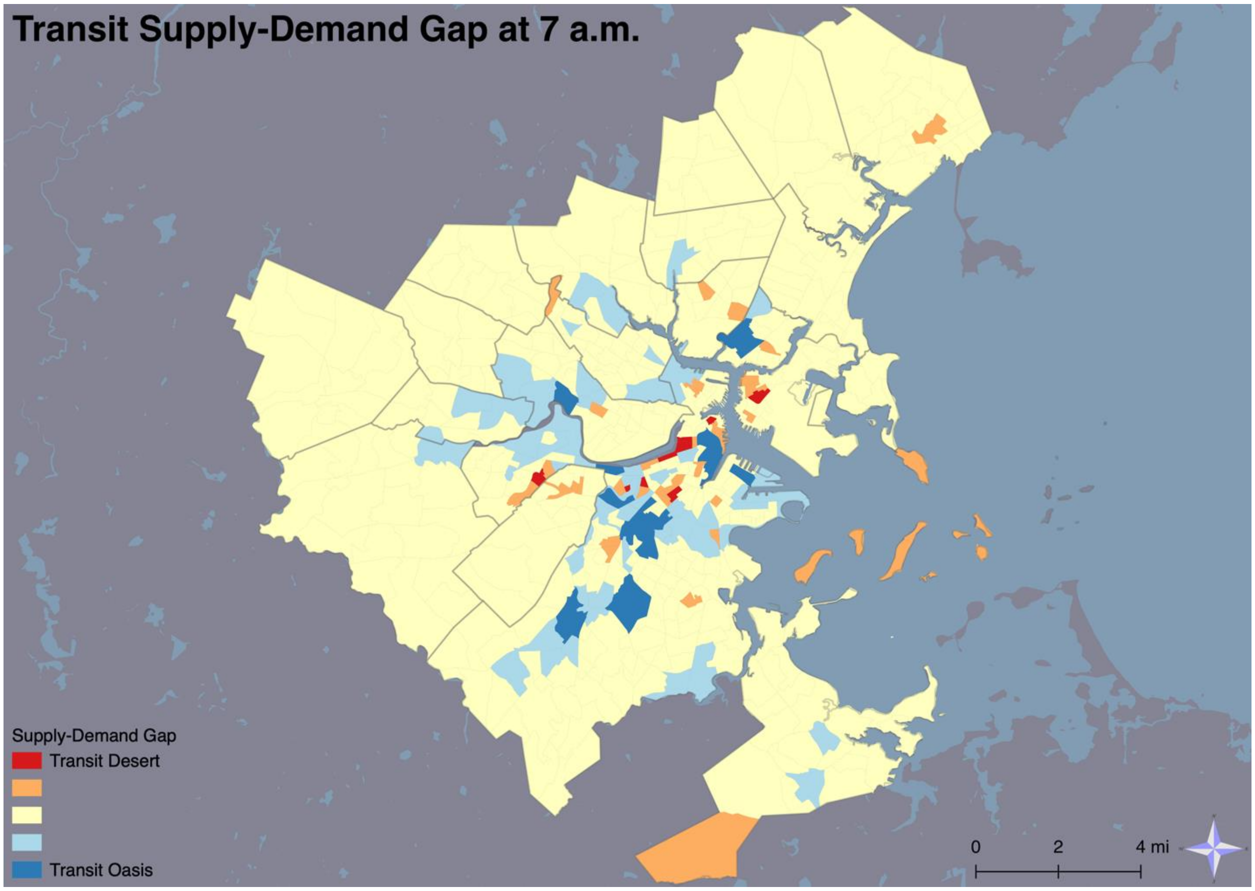

Figure 12: Map of transit supply-demand gap at 7 a.m.

7 a.m. is when transit service is at its highest in the Boston region. Because the method used the 2 p.m. service level as the baseline, any hours with more total service are likely to see more transit oases and any hours with less service are likely to see more transit deserts. The 7 a.m. time period leaves sizable transit deserts in Allston/Brighton, the aforementioned Back Bay/Beacon Hill area, the South End, and East Boston.

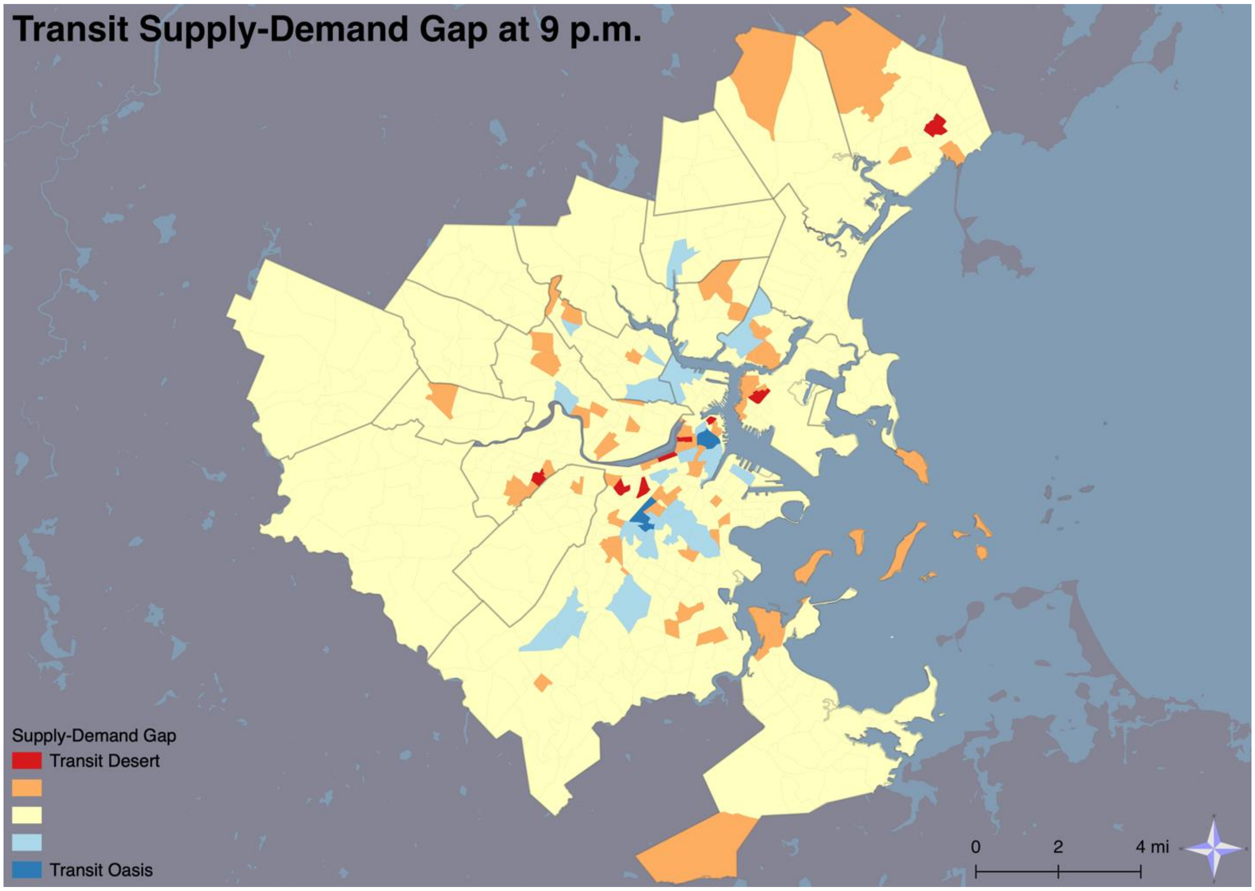

Figure 13: Map of transit supply-demand gap at 9 p.m.

By 9 p.m., well after the evening peak, transit service is cut in half. The formerly transit-rich Allston in the western panhandle of the city is back to adequate levels of service to meet the demand. New transit deserts are starting to appear along the Beacon Street corridor from Brighton to Back Bay as well as across the river in Cambridge around MIT and Harvard Square.

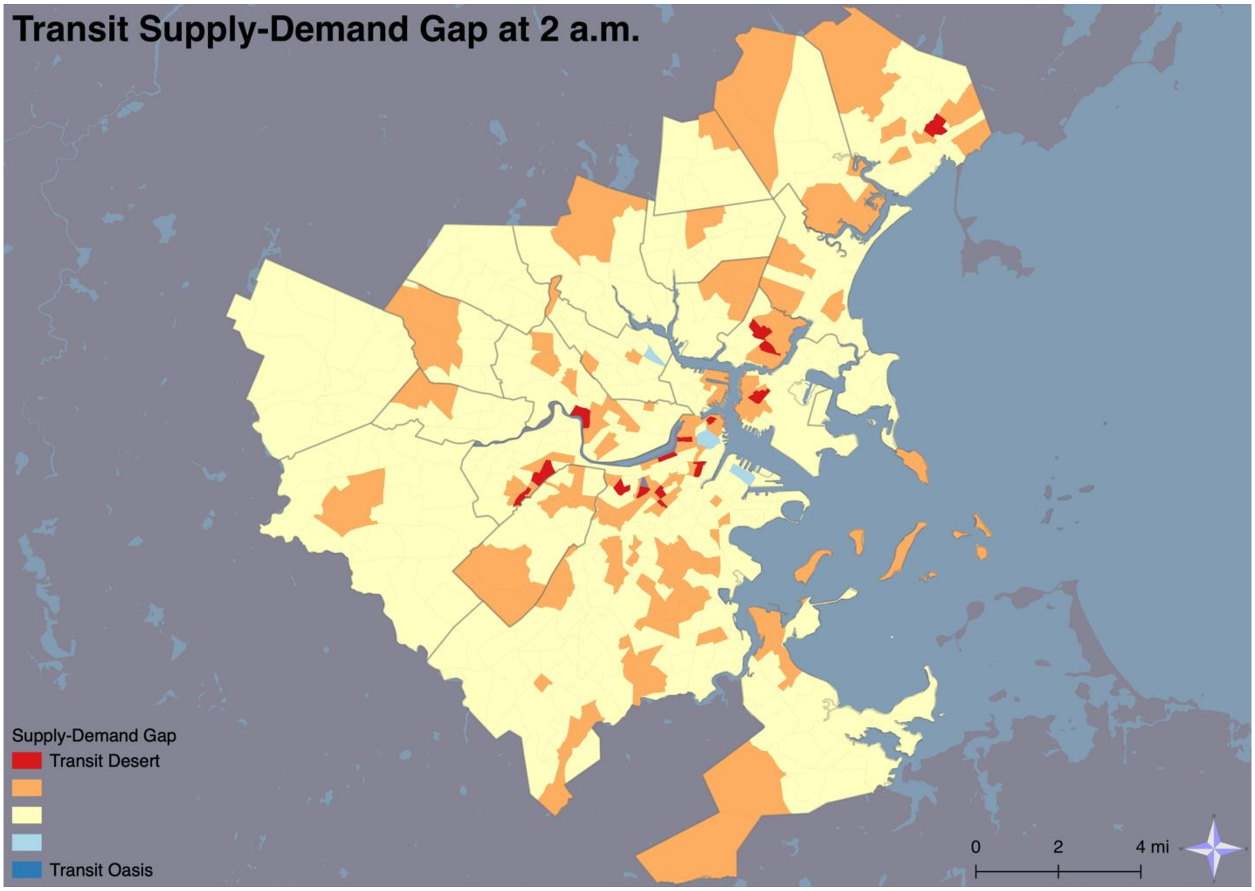

Figure 14: Map of transit supply-demand gap at 2 a.m.

By 2 a.m., all transit service in the region has stopped. The transit deserts are extensive covering wide swathes of the inner core of Greater Boston. The map now is starting to resemble the Night Transit Propensity Index of Boston from last year's thesis. Some of the most notable areas of large transit supply-demand gap are the string of tracts stretching from Beacon hill to Allston; Dorchester, Mattapan, and Hyde Park in the South; Harvard Square; and tracts from East Boston up through Chelsea and Revere. These deserts persist until the 5 a.m. hour when MBTA service starts back up.

Seeing the maps in sequence, it is possible to get a sense of how transit service ebbs and flows in the region. Despite all upheaval in the way we think about public transportation post pandemic, the leveling of the demand curve away from the peaks, and push among transit agencies towards off peak use to make transit more than just a commuting service, schedules, at least for the MBTA, are still built around the 9-to-5. It is at the peaks where the MBTA is best able to meet the needs of the region's residents.[82]

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[82] To see how the transit supply-demand gap changes over time see Appendix D – Hourly Transit Gap Scores. To see an animated version visit https://gbarrett101.github.io/documents/thesis/transit-gap.webp

Application to Boston

As of May 2024, Boston is still in the very early stages of planning. The only aspect of overnight transit that is set is the commitment by the city council to study the topic. No operators have been found, no vehicles have been determined, and there are not even any confirmed routes yet. However, the city has been working with advocates from TransitMatters to get ideas on what their city service might look like. Since 2016, the TransitMatters's NightBus proposal has undergone some revision. Were the city to follow the TransitMatters plans exactly, then the system would look something like this:

Figure 15: Revised TransitMatters NightBus Proposal. Line names are based on termini with numbers picked to be similar to the existing daytime routes they follow[83]

The network consists of just eighth lines extending radially out from a central hub at Copley Square. This system would operate on a pulse schedule. In such a system, bus schedules are coordinated on intervals to facilitate transfers at a central location. In the

[83] Levy, "Boston NightBus."

case of the NightBus proposal, buses would leave on an hourly basis from Copley. All routes would arrive around 25-28 minutes after the hour and depart around 32-35 minutes after the hour. This would allow for guaranteed transfers for all riders and maximize schedule legibility as all buses would leave at consistent hourly times. The topology of the system allows users to get anywhere the lines reach with at most a single transfer. The network was designed to be minimal yet able to cover most of the key areas of the Boston region that an overnight system should serve. This meant it was built around serving night time workers, a repudiation of the defunct late-night T program which were seen as transit for "drunk college kids."[84]

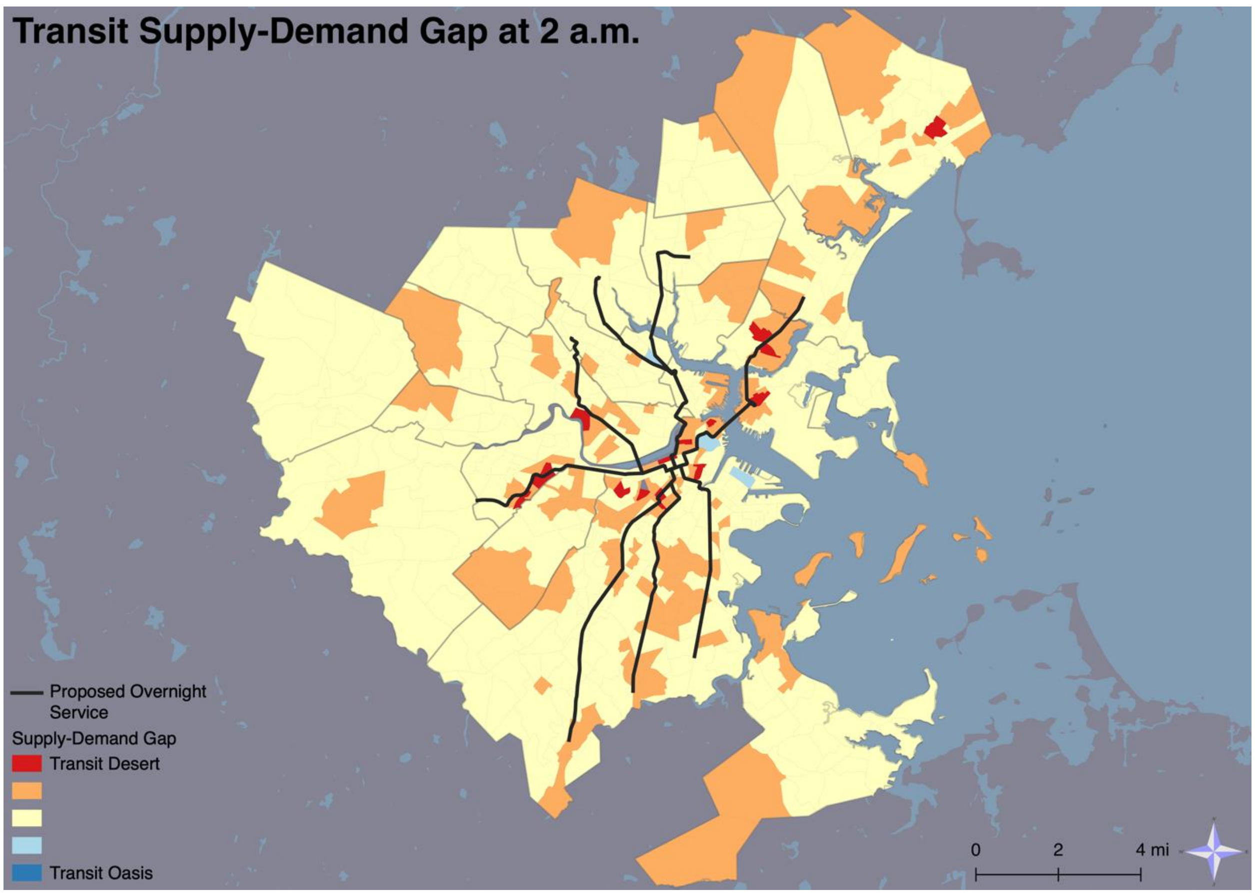

Figure 16: Map of transit supply-demand gap at 2 a.m. with NightBus proposal overlayed

Overlaying the TransitMatters plan on top of the transit supply-demand gap map for 2 a.m. reveals the network's efficacy in covering areas deemed in need of night transit. Considering that the routes need to be short enough for the bus to be able to complete a

[84] Ofsevit, Mendelson, and Aloisi, "Our Plan for Late-Night MBTA Service."

whole round trip in one hour, the lines are very successful in covering all of the transit deserts within the 30 min radius. The only lines that appear to be extraneous under this evaluation are the N101 and N92 that go to Medford and Malden respectively. Those areas were not identified as having particularly high transit demand at night time. This does not mean that these areas will not generate riders at night time. In last year's night time TPI, Malden was highlighted as an area with a high night time TPI. However, if the city of Boston (rather than the MBTA) is funding and running this service, these routes would likely should be the first to go. This would likely work out for the city anyway as these two lines spend much of their runs outside of the city limits., although this arbitrary categorization of lines toby what does and does not land within the city limits is generally not an advisable way to determine which routes should be cut. This is exemplified by the lines that go through Cambridge and Chelsea that also spend much of their run outside of Boston but hit major night time transit desert in both cities.

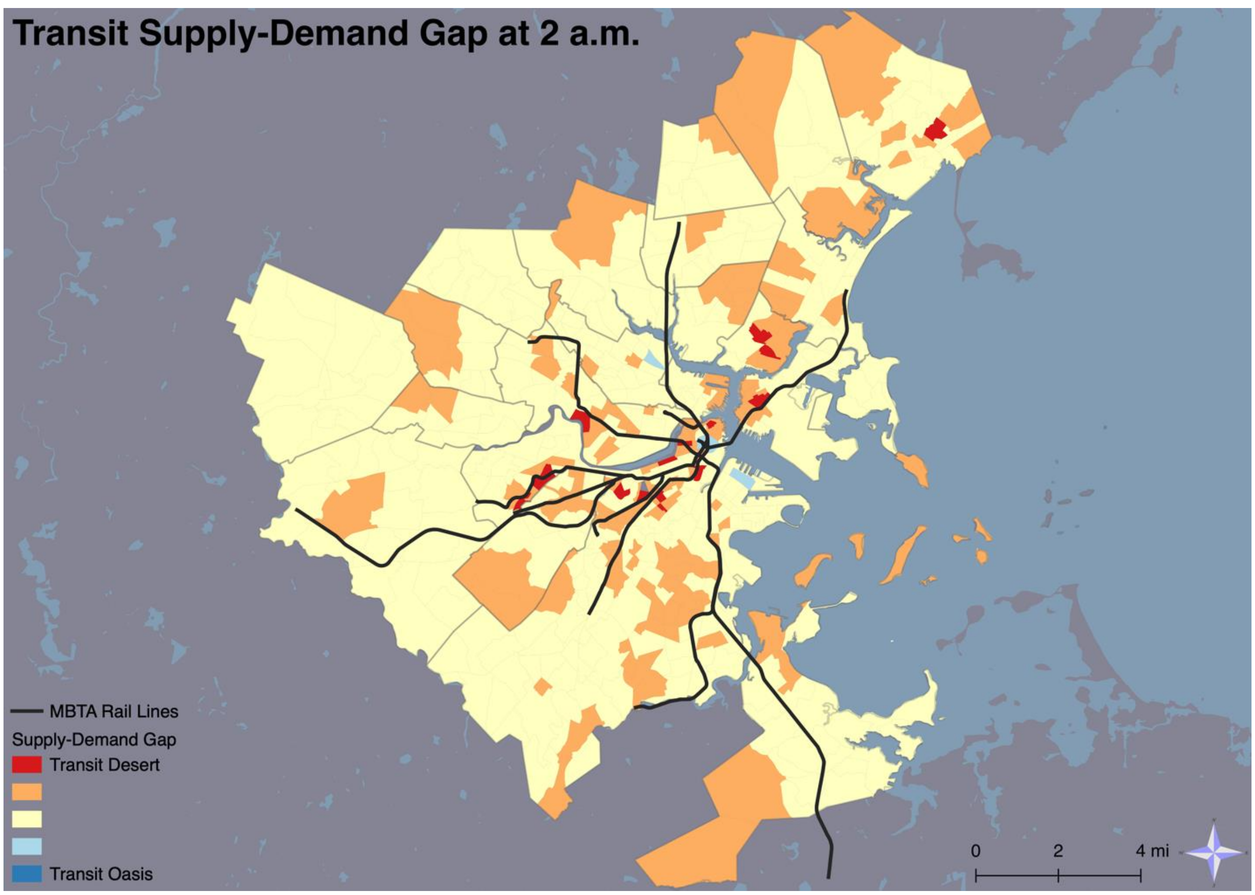

Figure 17: Map of transit supply-demand gap at 2 a.m. with MBTA rail lines overlayed

Overlaying the MBTA rail lines on the map reveals one reason why the pilots of 2001-2005 and 2014-2016 might have seen less success. While the existing rail lines do well to cover some transit deserts like the ones that span from Allston to Beacon Hill, they just miss others or spend a lot of time in areas that do not have high night transit demand at all. Examples of this include the Northern end of the Orange Line, the D Branch of the Green Line, and the Braintree Branch of the Red Line. Meanwhile, areas with high night time transit demand such as Dorchester and Chelsea are left unserved.

While this methodology is being applied in the context of overnight transit, the results are not exclusively useful at night. A transit desert at 1 a.m. suffers the same issues that a transit desert at 1 p.m. does: that the amount of transit supplied is inadequate to meet the demand. With the understanding that transit as a public service that is meant to provide travel access to those who need it, it is imperative that transit agencies know where transit deserts exist across both time and space so that they can work to remedy them. It just so happens that the largest transit deserts in the Boston region exist at night, as that is when there is no transit at all. However, transit deserts are always present. This spatiotemporal method of analysis reveals that across time, transit deserts can shrink, grow, and move but they never completely disappear. Even at its nadir, almost 1 in 10 Boston area residents live in transit deserts. While at its worst, over 1 in 4 residents live in transit deserts.

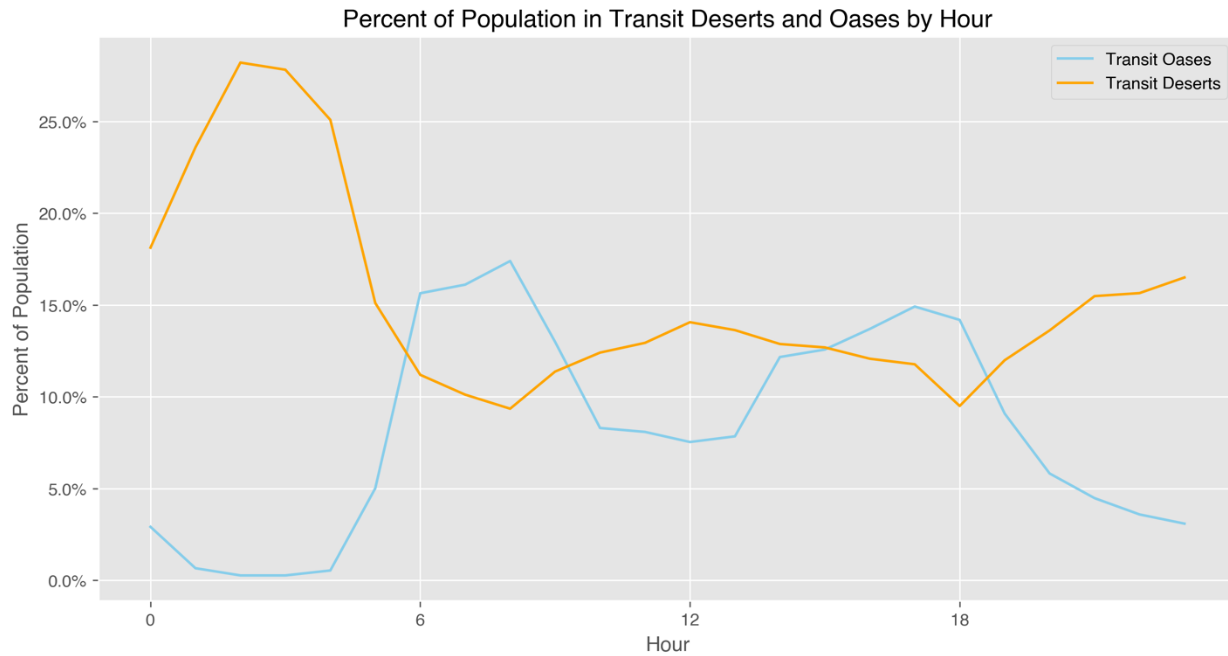

Figure 18: Graph of percent of people living in transit deserts and transit oases in the Boston region overtime

What this methodology provides to Boston is a single tool to identify transit deficiencies in the region. It presents the issue of the lack of night transit as an access issue like any other. The problem is that night time travelers lack transit access. This is the same problem that many in the day face as well. Local government and transit agencies already work to try to close transit access gaps. This thinking and these access solutions can guide how night transit is approached as well. This is what is happening in the city of Boston. The city council order on night transit also mentions the expansion of last mile transit. [85,86] And in interviews, city councilors have likened night transit to services like the Mission Hill Link, a shuttle whose main purpose is to fill existing transit gaps.[87] Using this method, the city of Boston and the MBTA can easily see how shuttle services like the Mission Hill Link that

[85] The last-mile problem transit is a term from transportation and logistics. It details the difficulty of getting someone to or from public transit in the first or final legs of their journey. Examples of last mile trips are driving to a park-and-ride train station from home or walking from where the bus drops off to work. (Boarnet et al., "First/Last Mile Transit Access as an Equity Planning Issue.")
[86] "Order for a Hearing to Review the Creation of A Municipal Bus Service to Provide Last-Mile Service and Late Night Shuttle Service for Third-Shift Workers."
[87] Mission Hill Link, "About Us."

operate in transit deserts in the day time could transition to filling transit deserts at night as travel patterns and needs shift.

Overall, this method of identifying spatiotemporal transit deserts will help Boston hone in on areas that are most important to serve at night time. Picking the routes however is just the first step in panning a transit service. Another important determiner of a transit network's success is how it is implemented. The following section details the second part of the framework which involves examining other overnight transit services from around the world and seeing transit agencies looking implement night transit can draw inspiration from these examples.

Designing for the Night

Vehicle Choice

One of the most common questions that comes up when discussing night transit, at least in the Boston case, is "why can't the trains be run all night?".[88] This question is so pervasive, that Bay Area Rapid Transit (BART) has "Why doesn't BART run 24/7" at the top of the list of its frequently asked questions.[89] These are often followed up by "they do it in New York, why not here?". As the far and away most extensive and highest ridership[90] transit system, the New York City Subway, operated by the Metropolitan Transportation Authority (MTA), is often looked up to as an aspirational model of an American subway that can compete with the other great transit systems of the world in Asia and Europe. The city is of course famous as the "city that never sleeps" supported by its subway which runs all 25 lines 24 hours a day, 7 days a week.[91] However, the New York City Subway is rather unique in its around-the-clock service schedule. Copenhagen is the only other city in the world, where every single metro line runs 24/7.[92,93] Where night transit does exist, it is often on buses. One of, if not the, biggest reason for this lack of 24-hour rail service is the need to do maintenance.

The overnight period is a consistent time in which transit agencies are able to perform regular maintenance.[94] This includes everything from cleaning the stations to inspecting and repairing tracks and signaling systems. For example, the MBTA has about four hours between the last train at 1 a.m. and the first train at 5 a.m. to perform subway maintenance work. However, only around two hours of this time is usable working or "wrench" time as

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[88] García, "The Biggest Obstacle to a Better Night-Life in Boston?"
[89] Bay Area Rapid Transit, "Frequently Asked Questions (FAQs) | Bay Area Rapid Transit."
[90] Federal Transit Administration, "March 2024 Raw Monthly Ridership (No Adjustments or Estimates)."
[91] MTA, "Riding the Subway."
[92] Copenhagen Metro, "The Metro's Timetable – on the Minute."
[93] Chicago's CTA Red and the Blue Line as well as Philadelphia's PATCO high speed line also run 24/7 operation but all other rapid transit lines in the city do shut down at night. (PATCO, "PATCO Timetable"; Chicago Transit Authority, "Night Owl Service.")
[94] Levy, "Overnight Public Transit."

tracks need to be cleared and de-energized[95] and crews need to be moved to where maintenance needs to be done.[96] The inverse of course needs to happen at the end of the maintenance period. This limited wrench time alone is what makes the proposition of running the T just an hour later challenging as that would eliminate half the maintenance time. New York has been able to get around this problem through the distinctive design of the network that involves heavy interlining and express tracks.[97] However, New York is not free from the issues that 24/7 rail service comes with.

Figure 19: Graphic showing hypothetical overnight maintenance window under a normal schedule (top) and a one hour extended schedule (bottom) showing total wrench time is cut in half.

In lieu of complete overnight maintenance, the MTA does more targeted work on stations and tracks through weekend and late-night service changes. These service changes, where subway lines are rerouted or completely shut down, are a common fixture of the New York City subway. The MTA publishes service changes every week on their website which can often be confusing to locals and visitors alike.[98] In their 2018 report, the Regional Plan Association (RPA) had suggested ending overnight subway entirely service on weekday nights and replacing it with buses. The RPA argued that this would expedite the MTA's signal modernization efforts as well as generally improve rider experience through safer and cleaner stations and platforms. This was justified by noting that only 1.5% of riders rode the system from 12:30 a.m. to 5 a.m. and that these riders could be potentially better

[95] De-energizing is the process of cutting electricity to the third rail and catenary systems of a system making sure it is safe for people to work on them.
[96] *Inside the T - Maintenance of Way*.
[97] Levy, "Overnight Public Transit."
[98] MTA, "Planned Weekend Work."

served by buses which could operate at higher frequencies on the empty night time streets.[99] Despite only being mentioned once in the 400 page report, this suggestion was met with enormous backlash.[100] Both the mayor and MTA chairman at the time had to give statements confirming their commitment to overnight service.[101] While New York does not seem poised to end 24/7 rail operation anytime soon, this example both shows why overnight bus is a preferable alternative to overnight rail and how buses operating at night can actually help improve daytime transit operations.

In the same way that extending rail service on the T would drastically cut the amount of time that is available to do overnight maintenance work, shortening the operating hours could substantially increase the amount of work that can get done. In the past few years, the MBTA has undergone extensive shutdowns and implemented numerous slow zones as a result of a backlog of maintenance that needs to be done.[102] While an overnight bus system is primarily for the period between 1 a.m. and 5 a.m., there is no reason why the hours of this could not be expanded, even if only on occasion, to extend the rail overnight maintenance period. There are some maintenance tasks that require more than just 2 hours of work. Providing ample overnight bus service in place of rail in the late night and early morning hours near closing and opening can be a strategy to open up more night time maintenance, avoiding the need for more disruptive weekend or weekday shutdowns.

Target Demographic and Weekend Service

As discussed, overnight public transportation has two primary demographics of riders: late-shift workers and weekend recreational travelers. Each of these groups have different needs. The former groups require access everyday with steady demand through the late-night period as shifts start and end at different times. The latter group has ridership that is highest on Friday and Saturday nights. The demand for late-night recreational travel depends on when venues such as bars and restaurants close. For example in Boston, all

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[99] Cooper, "Ending 24/7 Service on the Subway and Other Wild Ideas."
[100] Ahmed, "Overnight Subway Service Is Enormously Popular — Except When It Isn't."
[101] Ahmed; Nonko, "MTA Says That 24/7 Subway Service Isn't Going Anywhere."
[102] Seay, "Systemic MBTA Problems Led to Poor Track Maintenance and Slow Zones, New Reports Find."

alcohol sales must cease and entertainment venues close by 2 a.m.. This results in a strong jump in ridehailing demand immediately following closing time.[103] An overnight transit service would likely experience a similar demand surge at this time.

Generally, overnight transit systems should be built around serving the late-shift workers. Boston itself serves as a good case study of why this is important. Its two pilot programs from 2001[104] and 2014[105] both failed due to underperforming ridership. What these pilots shared in common was that they only ran on weekends and were thus not as useful to workers who would need to ride on weekdays as well as weekends. This is in contrast to the early morning and late-night bus pilots of 2018 which provided for additional bus trips to the beginning and end of operating hours every day. These two programs were immediate successes, and both made permanent within a year of their initial launches.[106] Late-shift workers serve as a core and consistent rider base for any overnight system.

This is not to say that it is not possible to also target weekend travelers or that service for them is doomed to fail. On the contrary, there are many successful systems that do run augmented weekend overnight service, although this is in addition to, rather than in lieu of, regular weekday service. From an international perspective, both London and Berlin are examples of cities with unique weekend night service. As cities that are world renowned for their nightlife,[107] it makes sense that they would have dedicated late-night transit services to meet weekend travel demand. London has the Night Tube which consists of 5 Underground and 1 Overground lines that run through the night on Fridays and Saturdays.[108] Berlin similarly operates their U-Bahn (subway) and S-Bahn (regional rail) services 24 hours on weekends.[109] On all other days in both London and Berlin rail service ends around midnight to 1 a.m..

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[103] Lunis, "City's Nightlife Director Plans on Investing in and 'reimagining' Boston."
[104] Linn, "Night Owl Bus Gives Its Final Hoot."
[105] Quinn, "Late-Night T Service Appears All but Dead."
[106] Massachusetts Bay Transportation Authority, "Early Morning and Late Night Bus Service Pilots."
[107] Bell, "25 Cities With the Best Nightlife in the World."
[108] Transport for London, "The Night Tube."
[109] "Night Buses & Public Transport at Night."

In London in particular, the decision was made to add Night Tube in 2016 even though the city already had an existing system of night buses. Transport for London (TfL), the local transit agency, had argued that the addition of the weekend Night Tube would have numerous benefits. These included quantifiable impacts such as new jobs to run the service, travel time savings for workers who mode shifted away from bus, and a general economic benefit of £2.70 for every £1 spent. In addition, TfL also noted many unquantifiable benefits like the reduction in demand for illegal taxi services and improvement of nightlife in the city by encouraging more people to go out and allowing business to stay open longer. Since its implementation, this program has been fairly successful operating continuously since 2016 with only a brief pause at the height of the Pandemic in 2020 and 2021.[110]

These weekend night transit services in London and Berlin also show that it is feasible to run 24-hour rail. The drawbacks are not as stark as 24/7 rail because the week night periods are still available to perform maintenance.[111] The benefits are potentially increased ridership on weekend nights on top of the baseline bus ridership. It is well documented that people prefer riding trains to buses.[112] In Boston, when people have complained about lack of night time transit service, they explicitly mention the T rather than pointing out that bus service also stops around the same time.[113] The aforementioned proposal by the RPA to end overnight rail in New York notably did not include Thursday, Friday, or Saturday nights.[114] While buses may theoretically serve all areas where rail would go, there will always be a contingent of people who would only be convinced to ride transit if it is on rail rather than bus. For example, in 2015 before London implemented the Night Tube, the city's night buses carried 42 million passengers every year.[115] Whereas in the following year from 2016-2017, TfL reported 7.8 million passengers on the Night Tube[116] and 37.4

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[110] Transport for London, "Full Night Tube Service Restored for the First Time since the Start of the Pandemic."
[111] Transport for London, "The Night Tube."
[112] Scherer and Dziekan, "Bus or Rail."
[113] García, "The Biggest Obstacle to a Better Night-Life in Boston?"
[114] Cooper, "Ending 24/7 Service on the Subway and Other Wild Ideas."
[115] Transport for London, "Consultation Launched on Night Bus Services."
[116] Transport for London, "Night Tube Is Even Bigger Success than Predicted, New Figures Show."

million on night buses.[117] This is a growth of over 3 million people riding public transit at night. Over this same time frame, TfL's overall transit ridership only increased by 1 million meaning night transit gained riders while the rest of the day time system was losing them.

A transit agency's ability to run rail 24 hours on weekends may vary based on the unique conditions of the city. In the MBTA's case, the long backlog of necessary maintenance projects makes the prospect of running overnight rail unlikely (and perhaps not the recommended use of resources given the circumstances). However, the London example was given to show that 24-hour rail operation is possible in a way that does not completely sacrifice the overnight maintenance window. Although this is only done successfully in cities that already have an existing overnight transit service that runs every day.

Frequency and Network Design

Ridership at night is, by definition, going to be lower than in the day time. Even in cities like New York and London, cities known for their nightlife activities, late-night transit ridership ranges from 1.5% to 3% of daily transit ridership.[118] While overnight transit is a vital service for those who do travel at night, it can understandably be difficult for a transit agency to justify a high level of service for relatively low ridership. As a result, it is not uncommon for late-night service schedules to have much longer headways (the time between vehicle arrivals) than exist in the day time. For example, in San Francisco, many lines like the 38 Geary or the N Judah which run at 8–10-minute frequencies during the day only run every half hour night.[119]

However, frequencies are extremely important in transit service planning. Total travel time has consistently been found to be in an important determiner of mode choice[120] Frequencies naturally play a significant role in travel time, particularly when they are long

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[117] London City Hall, "Night Bus Usage."
[118] Cooper, "Ending 24/7 Service on the Subway and Other Wild Ideas"; Transport for London, "Latest TfL Figures Show the Tube Reaching 4 Million Journeys per Day."
[119] SFMTA, "Weekday Frequency Guide"; SFMTA, "Muni Owl All-Nighter Service."
[120] Frank et al., "Urban Form, Travel Time, and Cost Relationships with Tour Complexity and Mode Choice"; Cervero, "Built Environments and Mode Choice."

like the 20- and 30-minute headways often seen on night transit. This is compounded by the fact that riders perceive time waiting for transit to be longer than the amount of time they actually waited for.[121] Every transfer increases the amount of time a passenger can expect to wait. With just two or more transfer, commuters can be as much as 24% more likely to drive than take transit.[122] Travelling at night comes with its own concerns about safety that affects certain groups like women in particular.[123] This creates a conundrum when planning for night transit where planners need to try to minimize wait times as much as possible with the understanding that service frequencies will not exceed certain levels.

Infrastructure improvements are one way to reduce perceived travel time, although these can often be time-consuming and expensive to implement.[124] Planners have much more control over the schedule and network design of systems and are able to make improvements that can reduce travel times without additional infrastructure or vehicles. For night systems, and any bus network with low frequencies, timed transfers, and pulse points can help ensure passengers experience as little wait times as possible.

Timed transfers occur when multiple transit vehicle's runs are scheduled to meet at regular intervals to facilitate the transfer of passenger. A simple example is when a bus is held at a train station to allow passengers from the train to board the bus. When this is expanded to include many or even all routes in a system, this is what is known as pulse scheduling.[125] Under pulse scheduling, all buses may meet at a central location at the same time, wait five minutes for passengers to alight and transfer as needed, and then depart on their respective routes. The effect is that even if each of the buses only operates at half hour frequencies, a person transferring between them will only wait 5 minutes between rides. This is already done in many smaller transit agencies. An example is Brockton Area Transit

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121 Fan, Guthrie, and Levinson, "Waiting Time Perceptions at Transit Stops and Stations."
122 Ha, Lee, and Ko, "Unraveling the Impact of Travel Time, Cost, and Transit Burdens on Commute Mode Choice for Different Income and Age Groups."
123 Chowdhury and van Wee, "Examining Women's Perception of Safety during Waiting Times at Public Transport Terminals."
124 For example, amenities like bus shelters and real time departure clock have been found to significantly reduce perceived wait times at bus stops according to Fan et al. (2016)
125 Nelson, Brand, and Mandel, "Use and Consequences of Timed Transfers on U.S. Transit Properties."

(BAT), a regional transit agency in Massachusetts. Their daytime system operates on a pulse-based schedule out of the BAT Center allowing for easy transfers between their ~15 lines.

Vancouver TransLink's NightBus, while not as strict with their timed transfers, does have a central transfer point that is characteristic of pulse networks.

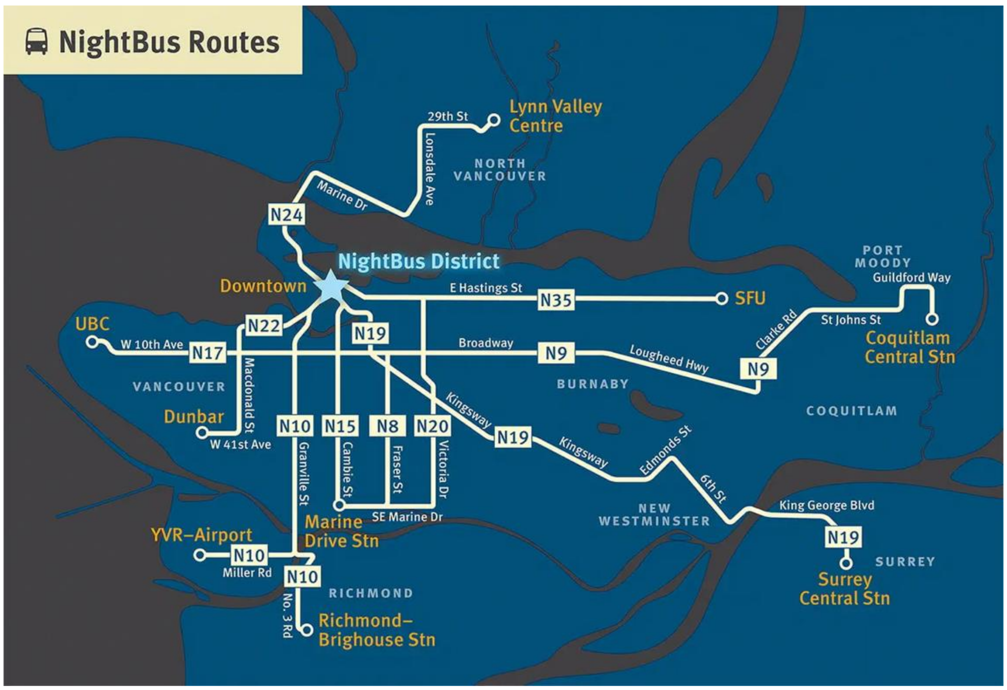

Figure 20: Vancouver NightBus system map highlighting NightBus District

All NightBus routes meet downtown at a night bus district. The benefits are twofold. First, all night transit riders are able to get from one part of the system to any other part of the system with just a single transfer downtown. Second, by concentrating all transfers in the NightBus District, the city can help assuage concerns people might have with waiting for a bus at night. This can happen though direct interventions such as installation of lighting and placing staff in the district. TransLink itself advertises the district as a "well lit, patrolled environment."[126] Riders are also made to feel safer indirectly through the concept

[126] TransLink, *Introducing the NightBus District*.

of "eyes on the street." This idea, originally coined by Jane Jacobs, says that the presence of people on the street helps keep crime down and create a more welcoming environment. [127]

Following these principles, it is possible to create a night time transit system that not only minimizes passenger travel time but does so with an efficient use of vehicles and operators.

[127] Jacobs, *The Death and Life of Great American Cities*.

Conclusion

The purpose of this thesis was to establish a framework US transportation planners can use as they consider introducing a new overnight transit service. When performing the initial planning for night transit, there are two main questions that need to be answered. The first question is where will the service go and who is it serving? This is really the core question for any transit service. Public transportation exists to bring people where they need to go, when they want to. So long as there is a strong need for travel, public transit should be there to fill the gap. The second question is directed at operation and design: what should the system look like broadly and how should it be run? Picking the routes is one thing, but as seen with the failed late-night pilots in Boston, if the implementation is poor then the system will struggle to be viable.

To address the first question, the thesis laid out a novel methodology for assessing transit supply and demand gaps that looks not just at spatial but also temporal disparities. This meant redefining "transit deserts" to be areas where transit supply is inadequate compared the existing demand across both time and space. This new spatiotemporal lens with which to examine transit deserts can help planners target transit routes which can best fill these supply-demand gaps. While this spatiotemporal transit desert methodology was created with night transit in mind, it is able to model supply and demand at all times of the day. There is no distinction between a transit desert at day and one at night. A transit agency that is committed to expanding transit access to everyone should be trying to close transit gaps that exist at all times. While they are often most prominent at night, they exist in the day as well. This spatiotemporal approach can help agencies identify these deficiencies and work to fix them.

Addressing the second question about system operation involved taking best practices from existing overnight transit systems. Night transit, while not universally adopted, is also not new. Taking inspiration and best practices from existing systems can help transit agencies ensure that overnight transit is implemented in a way that fits the needs of night time travelers. This means creating a service that is targeted to support night time workers.

This thesis used Boston and its transit provider, the MBTA, as a case study which leaves the question of what do the prospects of night transit look like in the Boston region? When work for this thesis started in Fall 2022, night transit had not been in the conversation since 2019 when the select late-night bus routes had been made permanent. Since then, however, the conversation around night transit in Boston has only grown. This started with the mayor's appointment of a Director of Nightlife economy showing a commitment to trying to revitalize the night and has culminated both with grants to promote night time activities in Boston[128] and a commitment from the city council to review the creation of a "late night shuttle service."[129] While it could be argued that the city of Boston should not be spearheading the effort in place of the MBTA, er leadership is good news for the eventual implementation of overnight transit. This thesis can serve as a guide for how the city of Boston, and potentially the MBTA, can study overnight transit.

When the clock hits midnight, none of the roads ever disappear. Cars still drive on the streets. People are still walking the sidewalks. In many cites however, public transit is nowhere to be seen. There are few discussions on how cities can establish a "night time highway system". There is little analysis on what the subsidy per driver of the roads at night are. There is no automobile equivalent to night owl transit because night time driving is just driving. There is no temporal distinction on driving like there is for transit.

This thesis exists because so many transit agencies see night transit as a luxury that a city like New York may be able to provide but is just "not feasible here." However, in the same way that night driving is just driving, night transit is just transit. The goal of transit is to provide everyone with an affordable, reliable, and sustainable means of transportation. Any transit agency's goal should be to provide access to all residents and close any gaps where they exist. When framed this way, having lengthy periods of time when the entire city is inaccessible by public transit seems unacceptable. Yet this is the reality of most

[128] "Wake Up the Night Grant Pilot Program."
[129] Gaffin, "If the MBTA Won't Provide Late-Night Bus Service, Maybe Boston Can, Councilors Say."

American cities. If state and city officials are serious about reaching their climate goals,[130] keeping true to their equity commitments,[131] achieving their vision zero plans,[132] then overnight transit is a must. It is important that transportation planners be thinking about this service now as cities like Boston realize how vital to workers and residents this overnight transit connection is. It is only a matter of time.

[130] Boston has committed to reducing their carbon output to 50% of 2005 levels by 2030 and to be fully net-zero by 2050 (Eshel et al., "City of Boston Greenhouse Gas Emissions Inventory 2005-2021"; City of Boston, "Climate Action Plan 2019 Update.")

[131] In February 2021, the Boston City Council adopted a resolution in support of transit equity acknowledging the historic neglect groups such as people of color, low income people, and those with disabilities have had when to comes to public transportation access (City of Boston, "City Council Adopts Resolution in Support of Transit Equity.")

[132] Boston plans to "eliminate fatal and sever traffic crashes in the city by 2030" (City of Boston, "Vision Zero."). Recall that since 2015, 12.9% of all traffic fatalities in Boston happen between 1 a.m. and 5 a.m. despite the substantially lower traffic volumes (Analyze Boston, "Vision Zero Fatality Records.")

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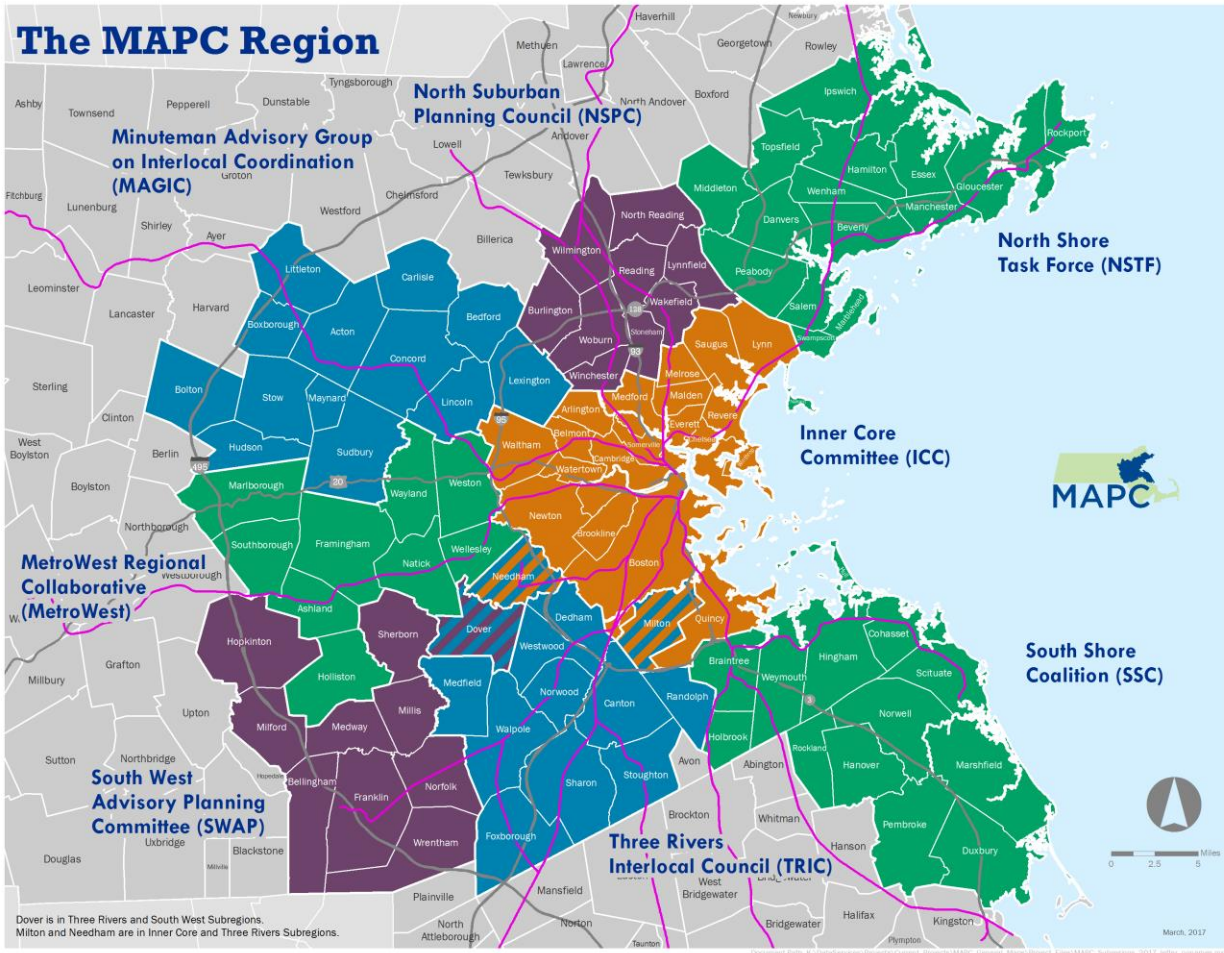
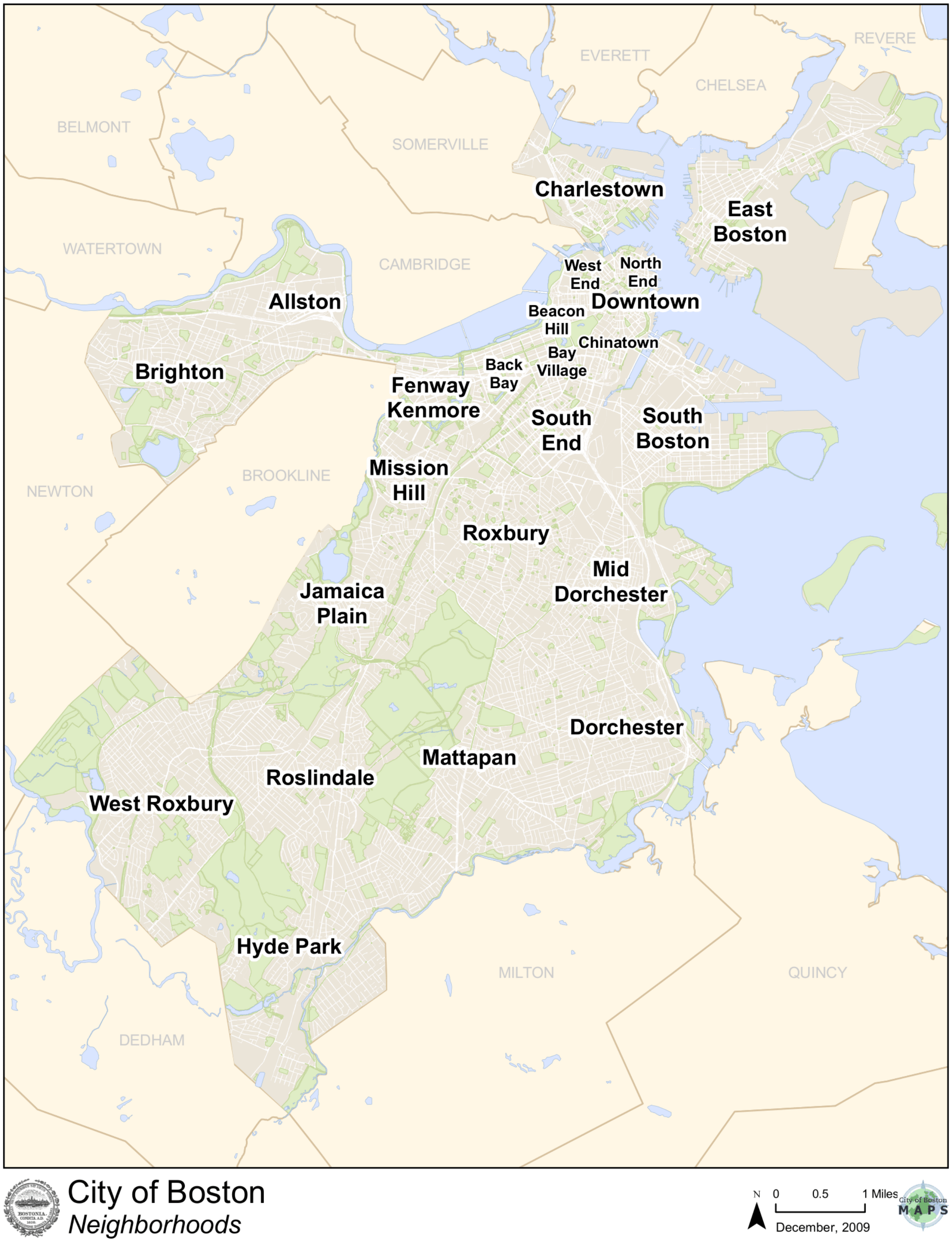
Appendix A – Greater Boston Reference Maps



Map of all towns and cities in the MAPC area. This thesis focuses on the ones in the Inner Core Committee (marked in orange)[133]

[133] Metropolitan Area Planning Council, "Subregions."

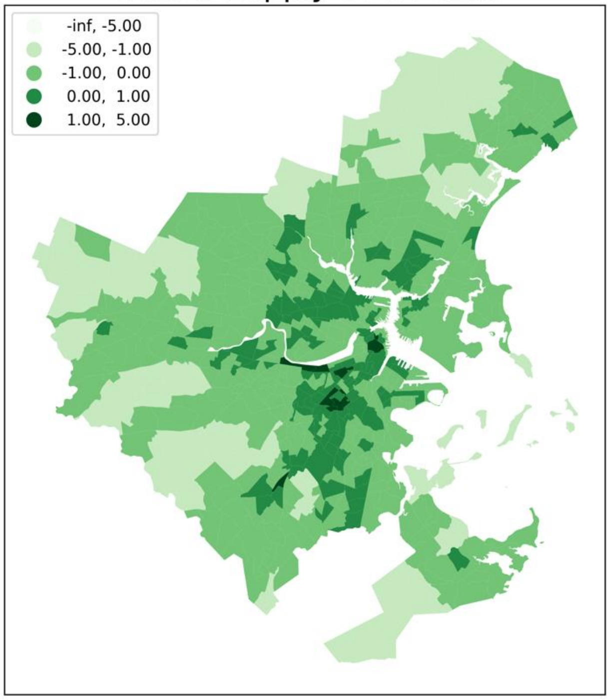


City of Boston Neighborhood Map[134]

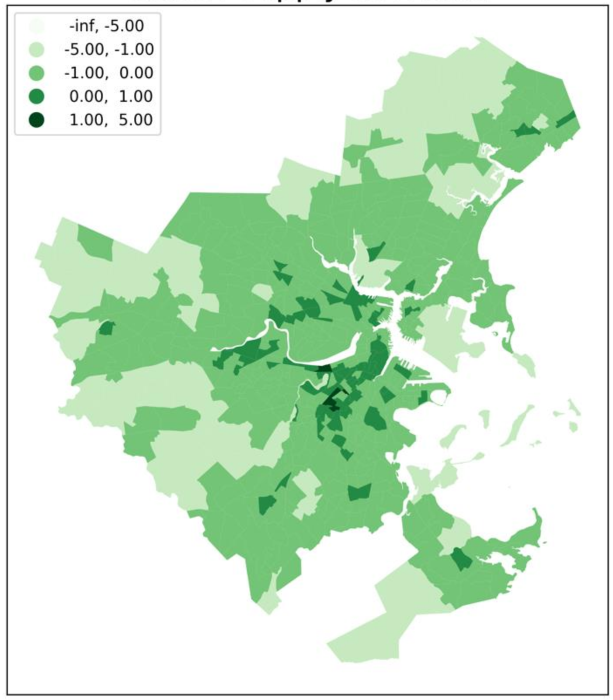
[134] City of Boston, "Neighborhoods."

Appendix B – Hourly Transit Supply Scores

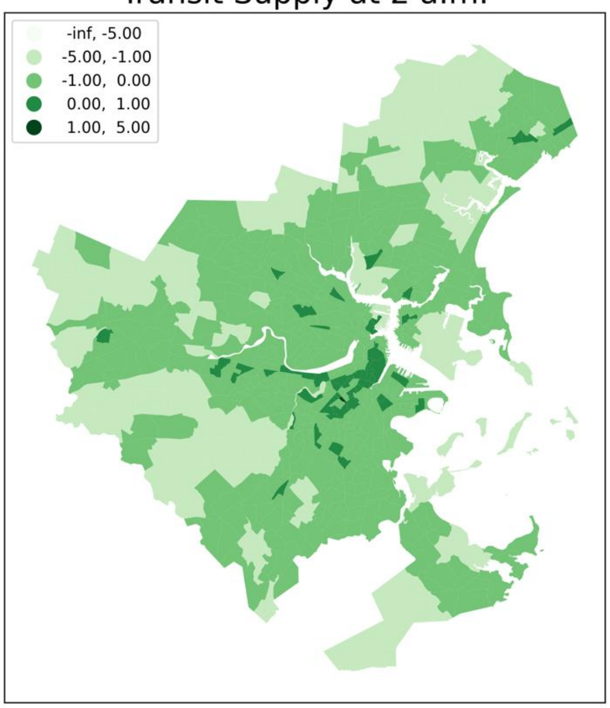
Transit Supply at 12 a.m.



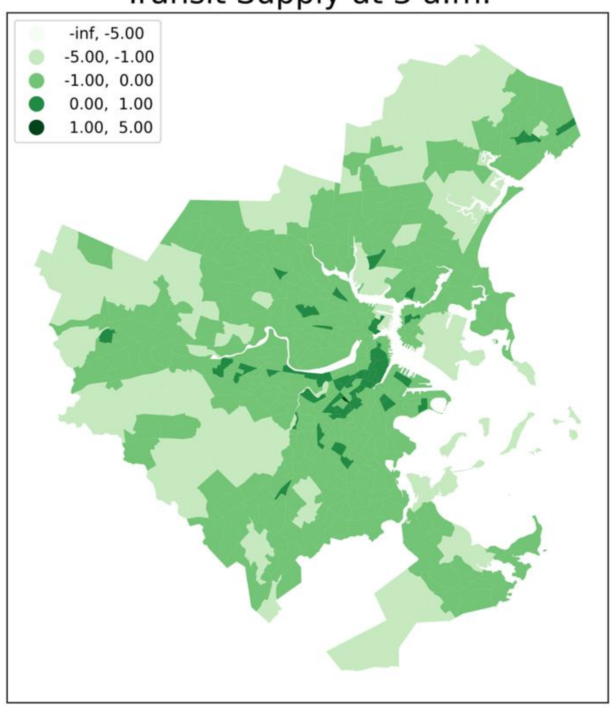
Transit Supply at 1 a.m.



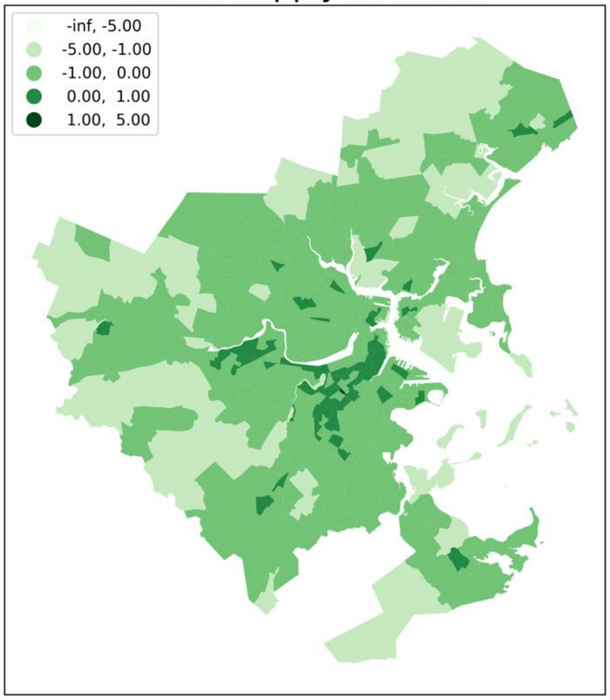
Transit Supply at 2 a.m.



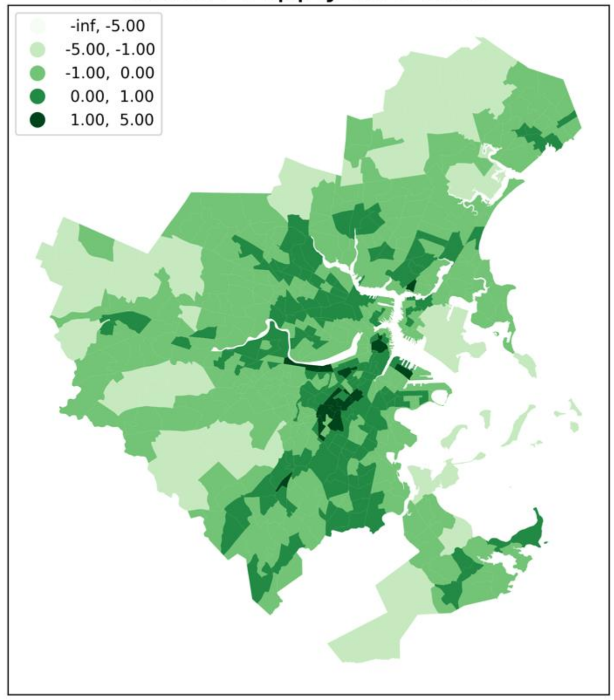
Transit Supply at 3 a.m.



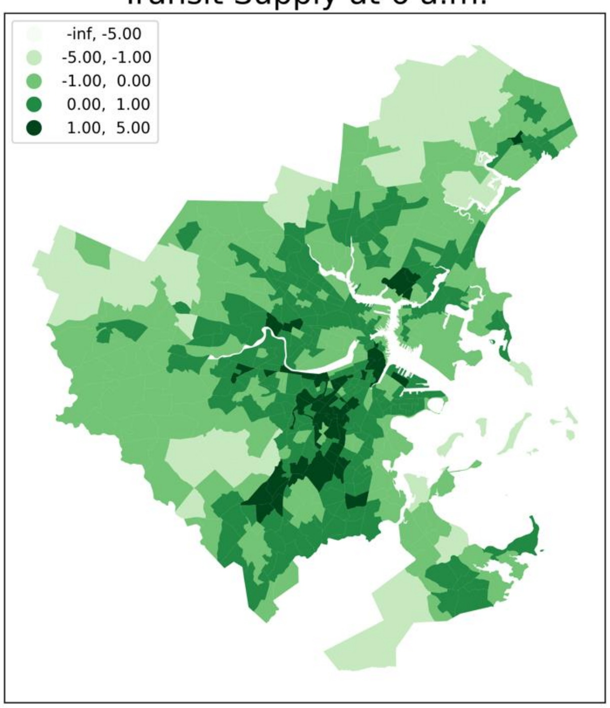
Transit Supply at 4 a.m.



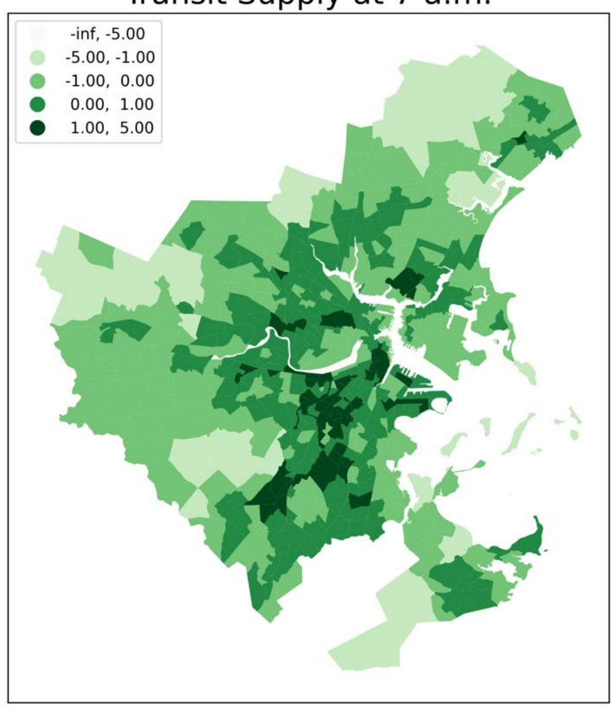
Transit Supply at 5 a.m.



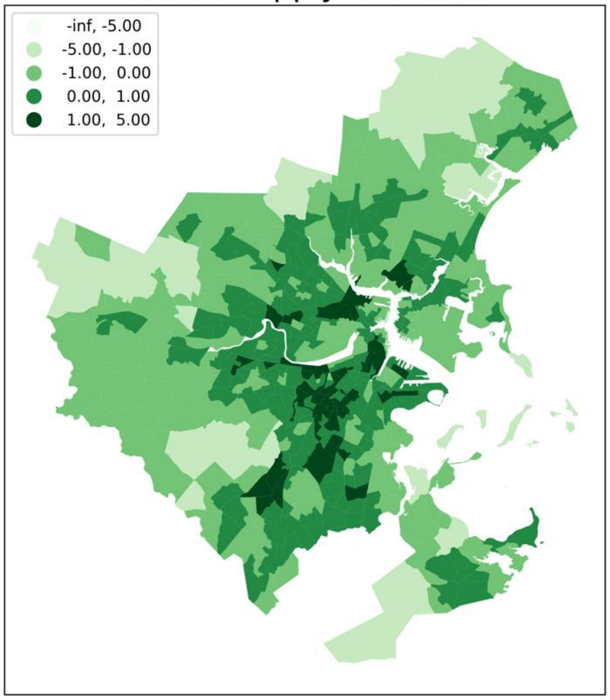
Transit Supply at 6 a.m.



Transit Supply at 7 a.m.



Transit Supply at 8 a.m.



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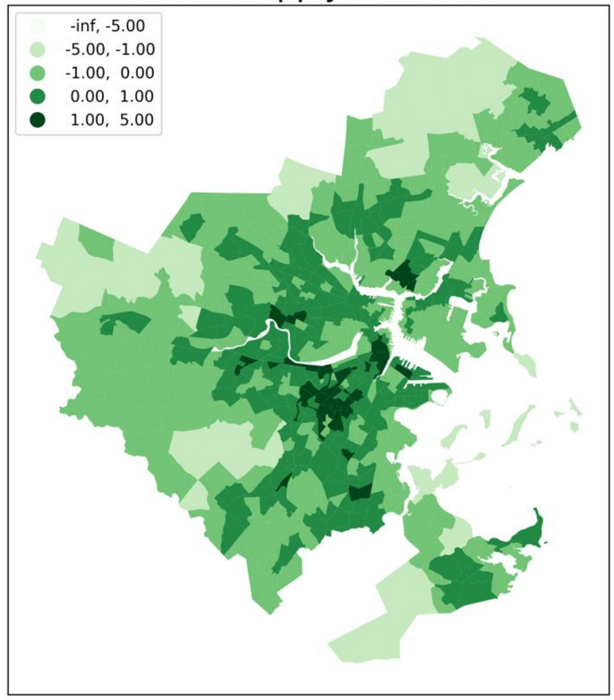
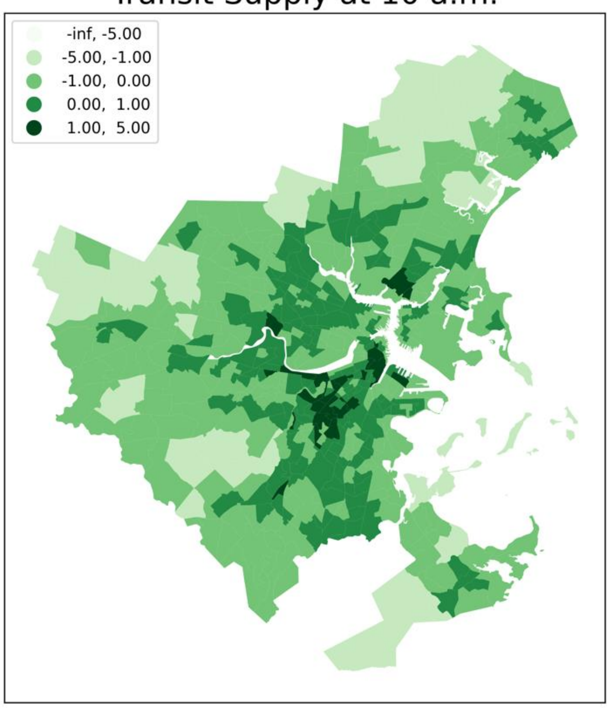
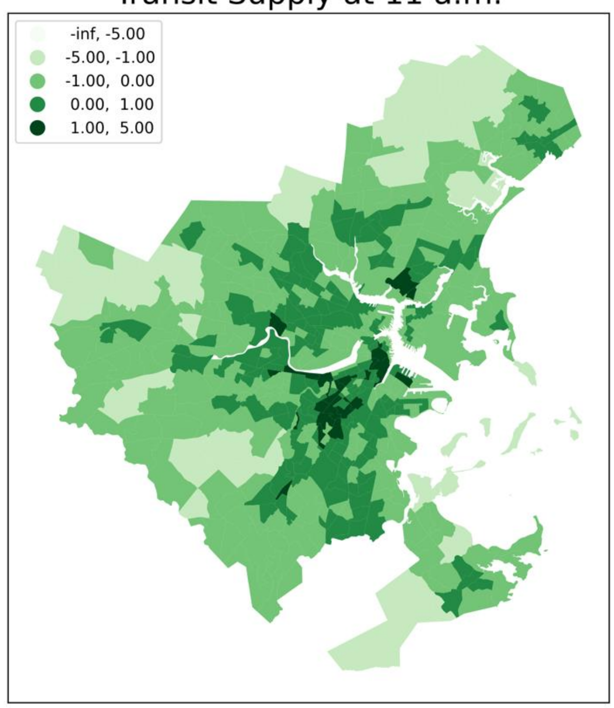
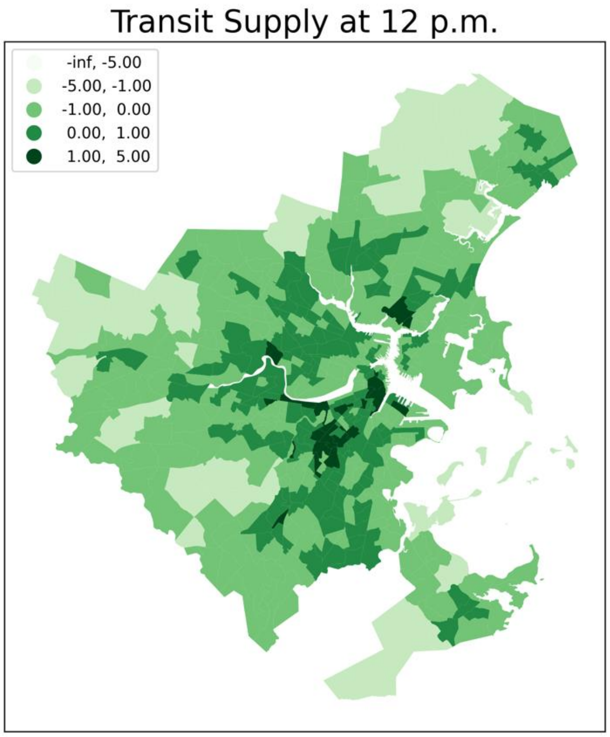


Transit Supply at 10 a.m.



Transit Supply at 11 a.m.

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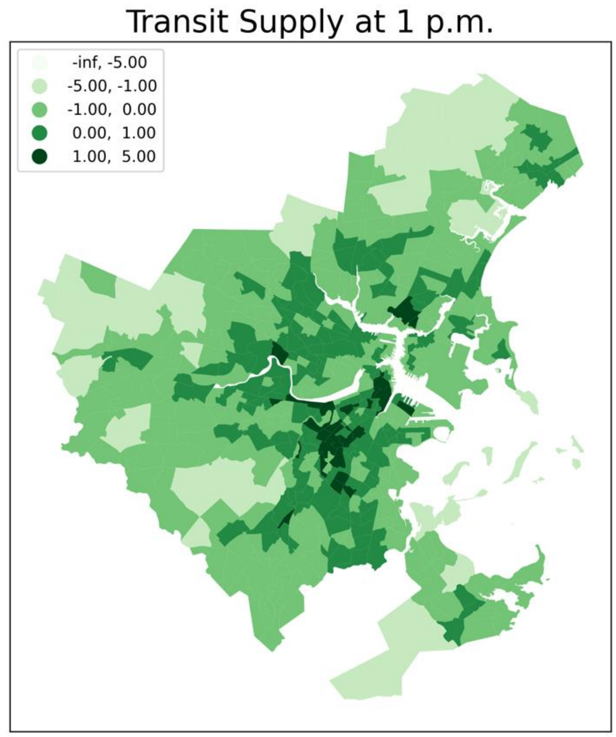
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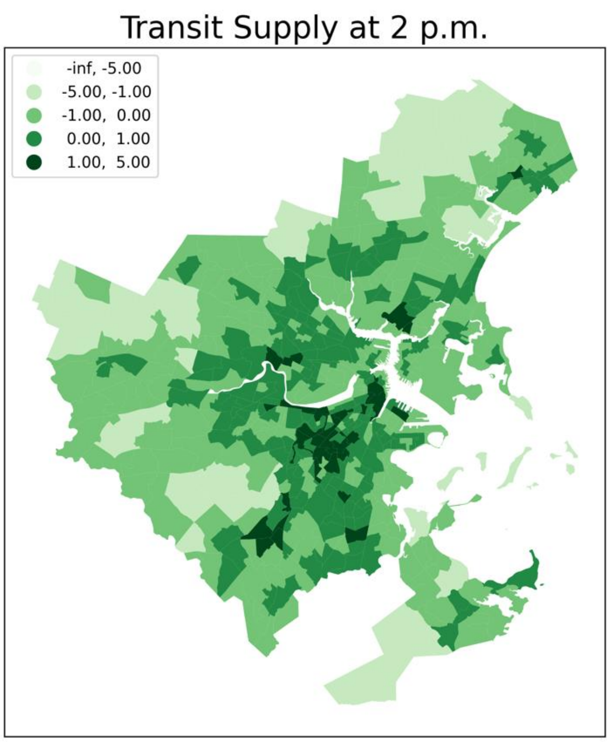
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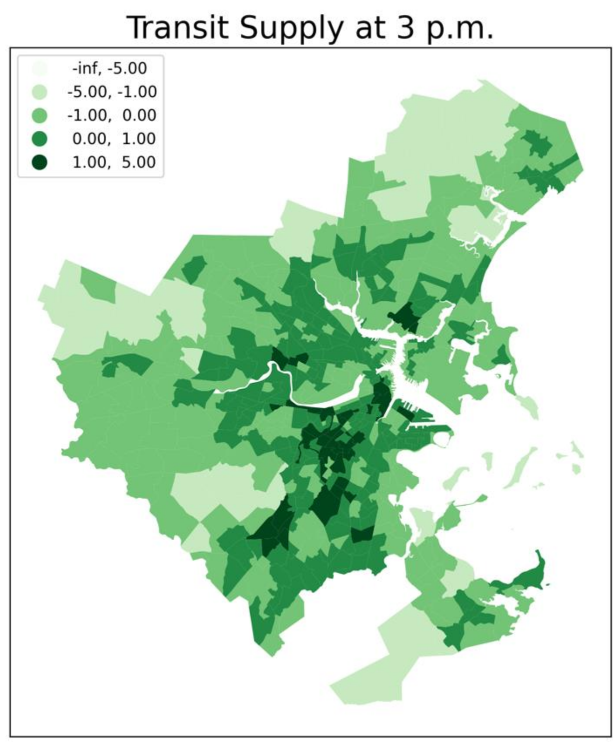
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0.00, 1.00
1.00, 5.00

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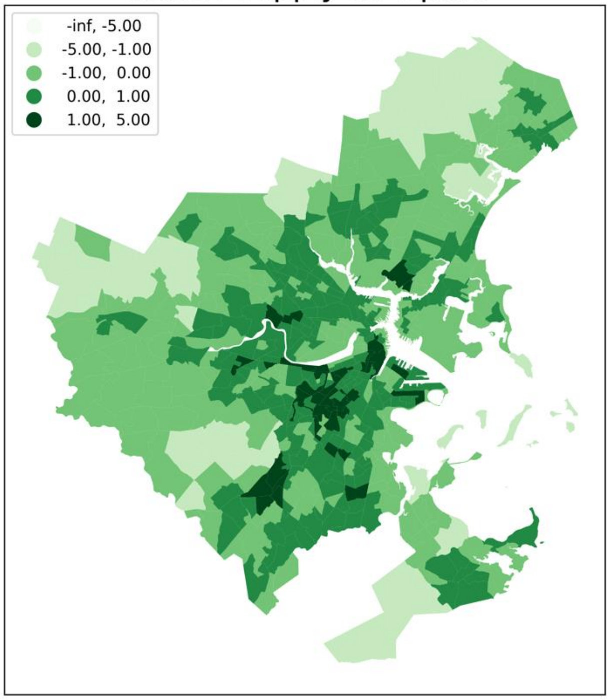

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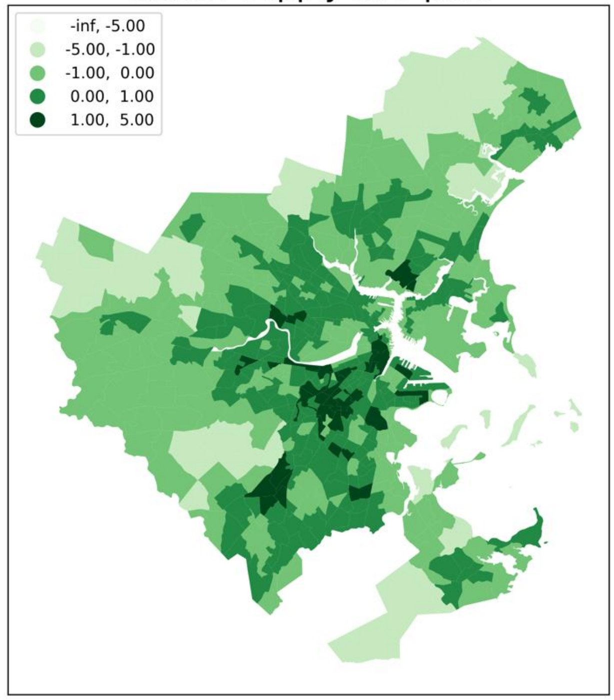

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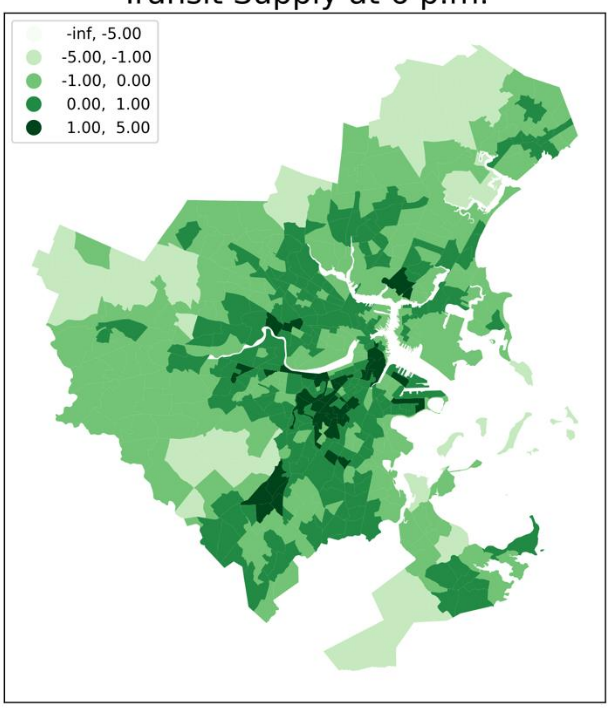

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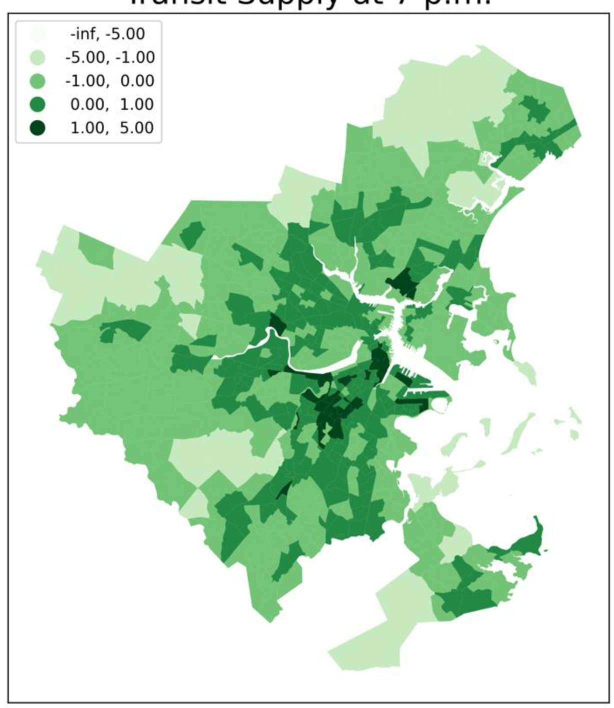

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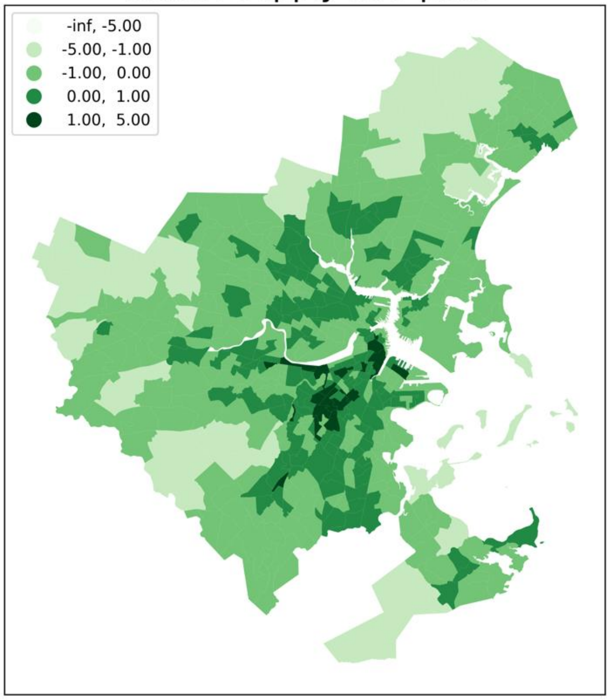

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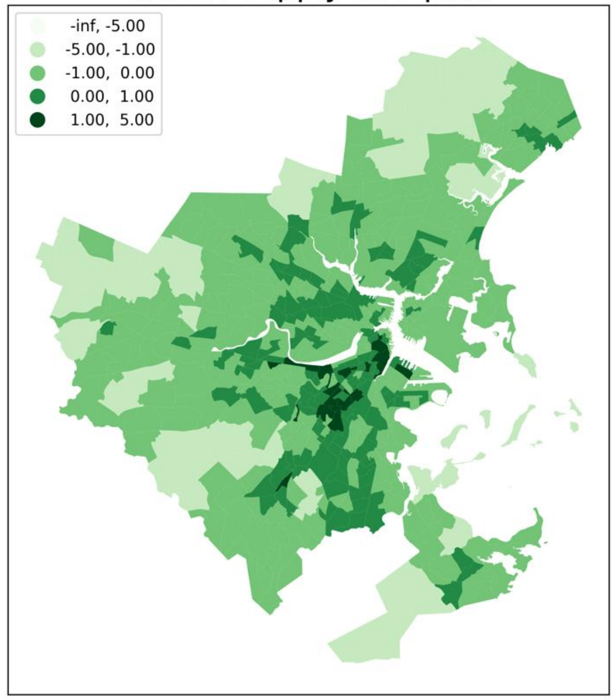

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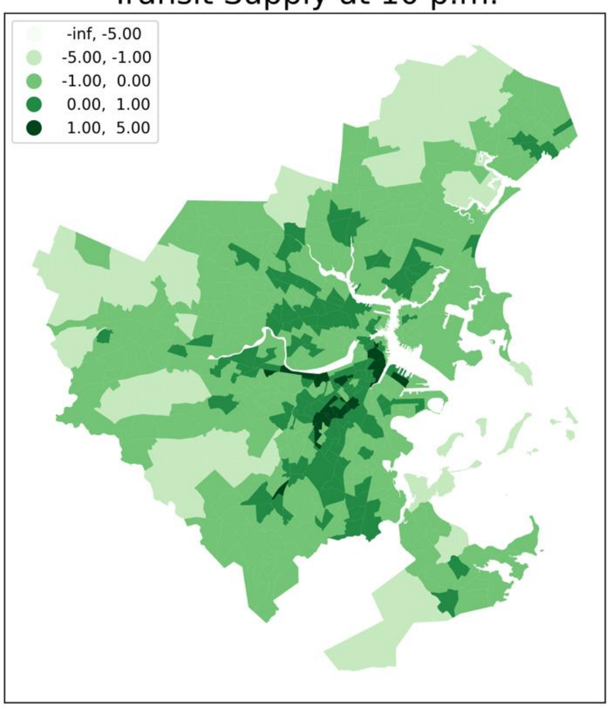

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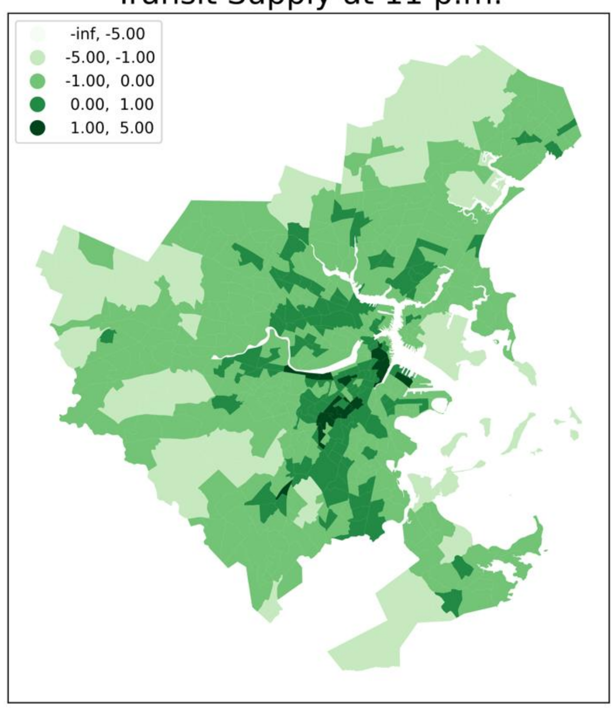
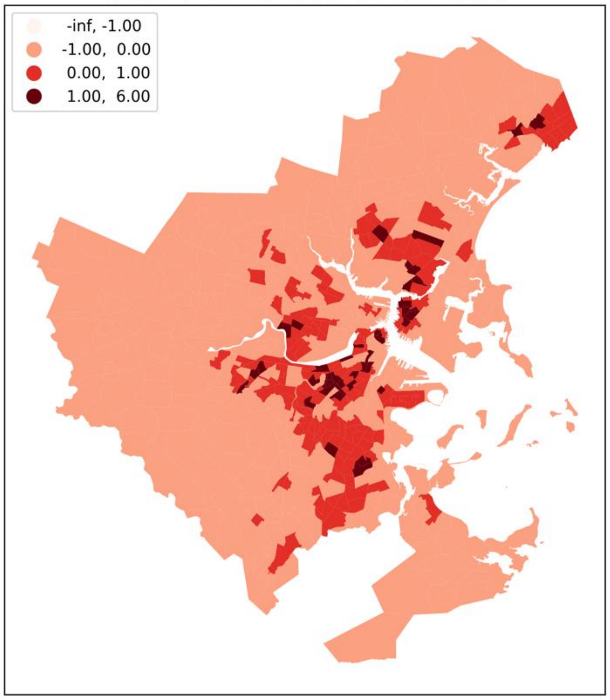
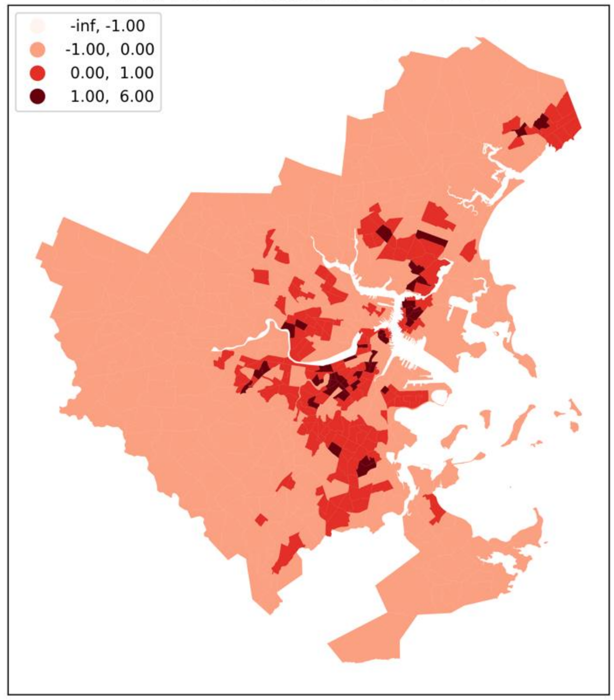


Appendix C – Hourly Transit Demand Scores

Transit Demand at 12 a.m.



Transit Demand at 1 a.m.



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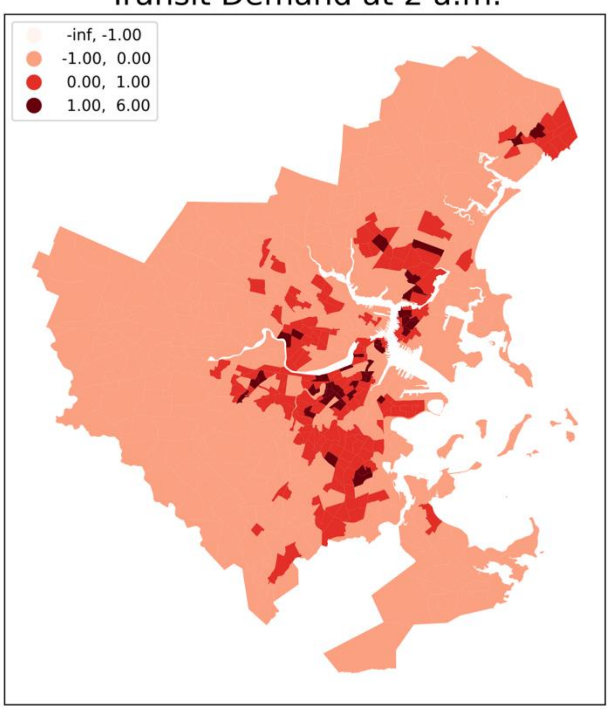

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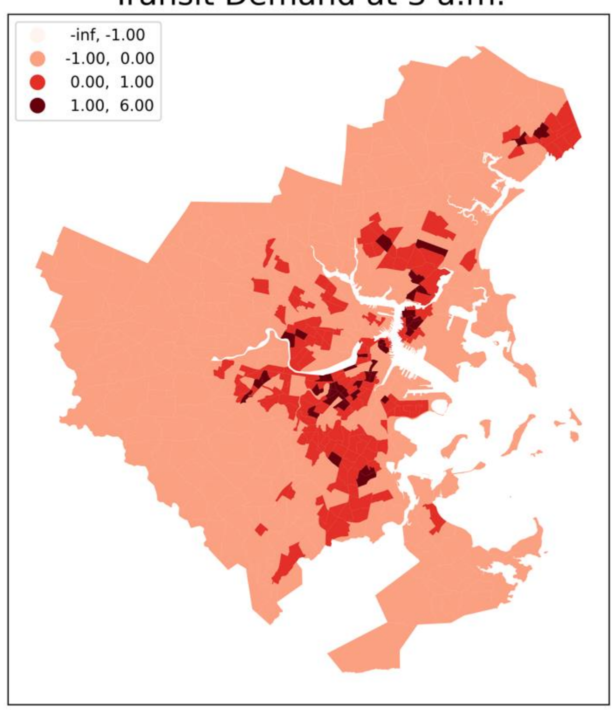

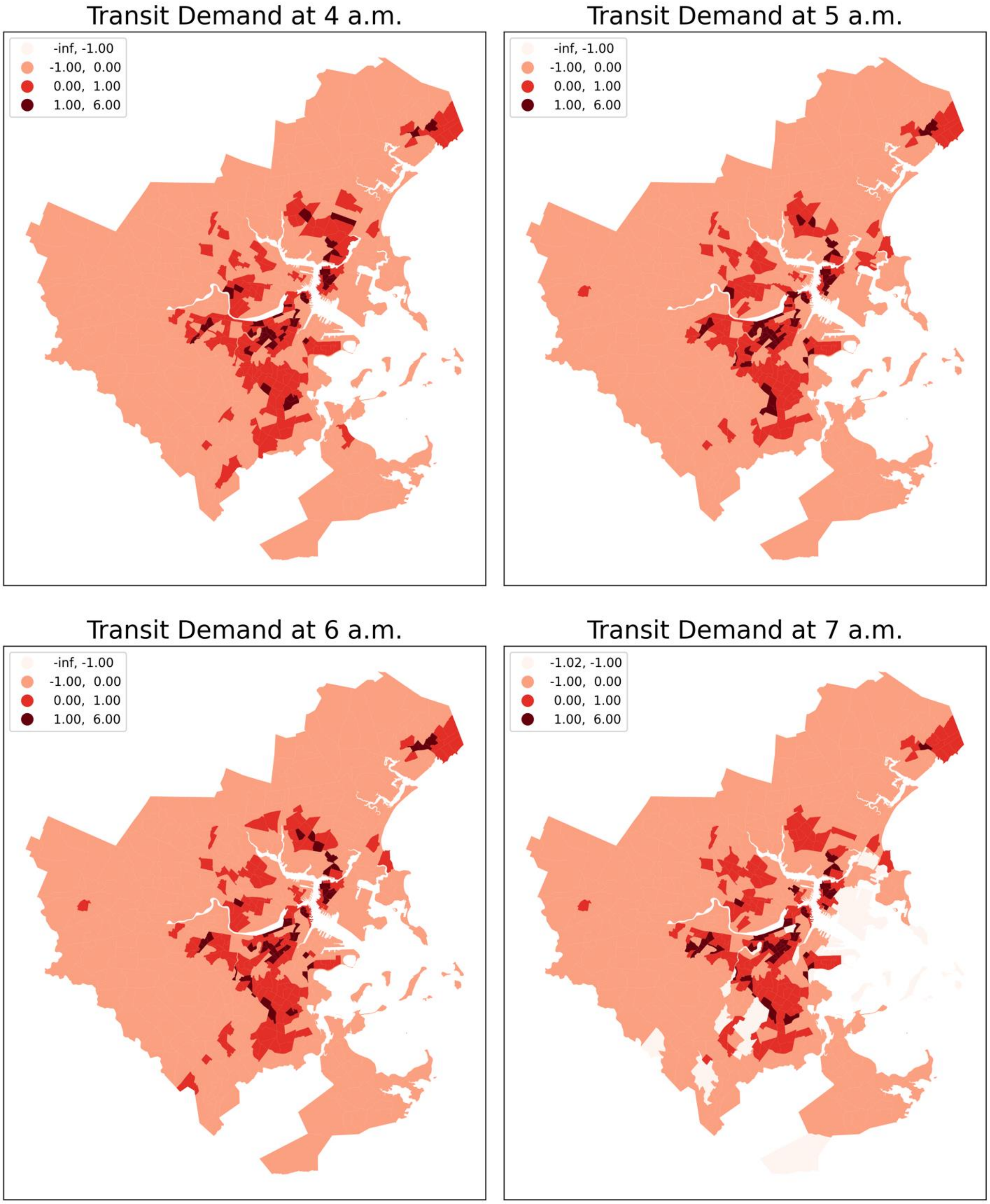
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1.00, 6.00
Transit Demand at 5 a.m.
-inf, -1.00
-1.00, 0.00
0.00, 1.00
1.00, 6.00
Transit Demand at 6 a.m.
-inf, -1.00
-1.00, 0.00
0.00, 1.00
1.00, 6.00
Transit Demand at 7 a.m.
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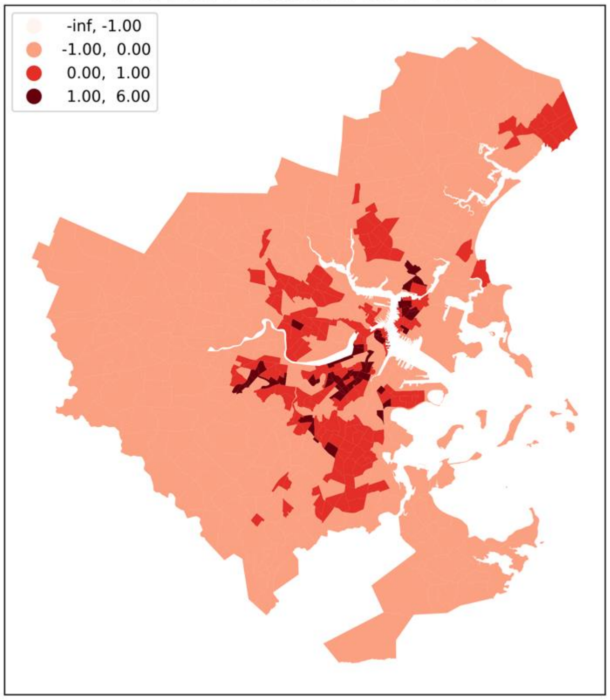
1.00, 6.00

Transit Demand at 8 a.m.



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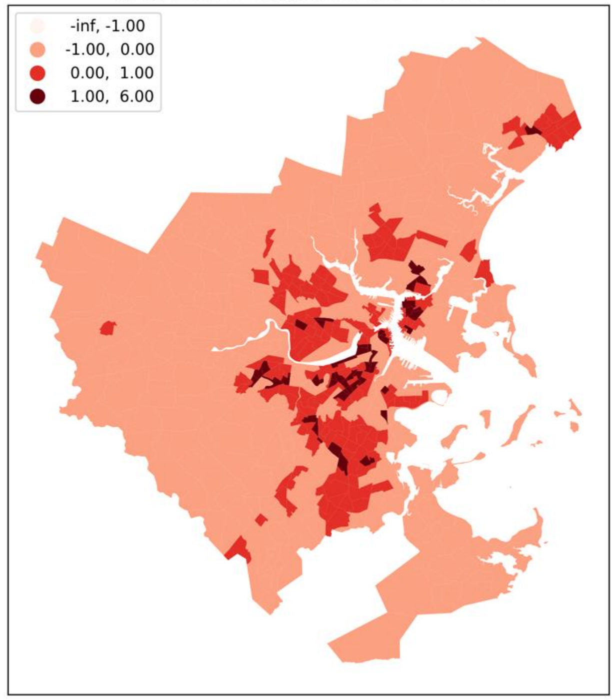

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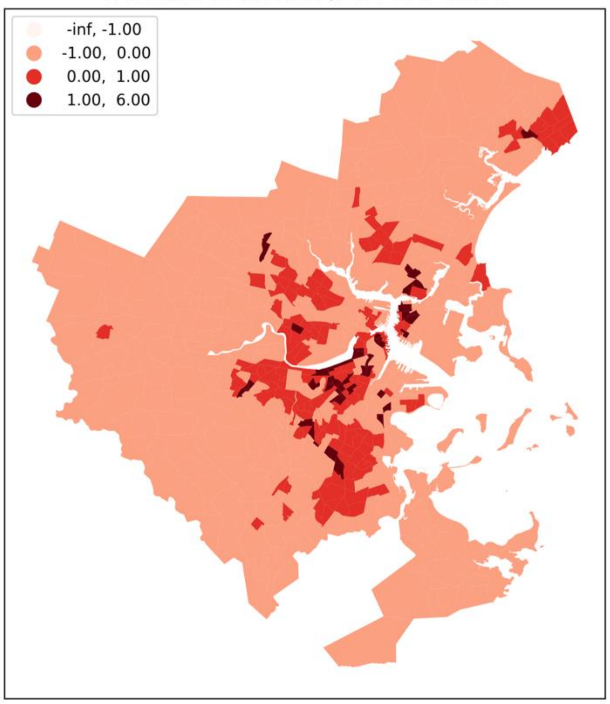

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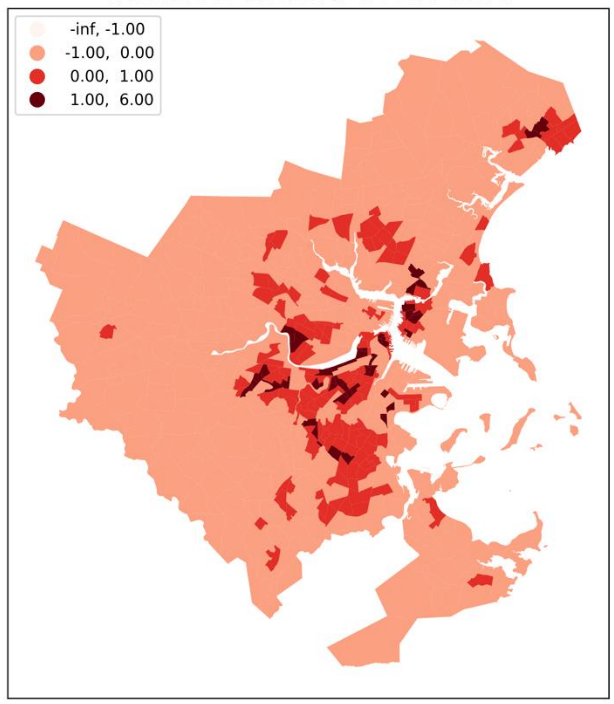

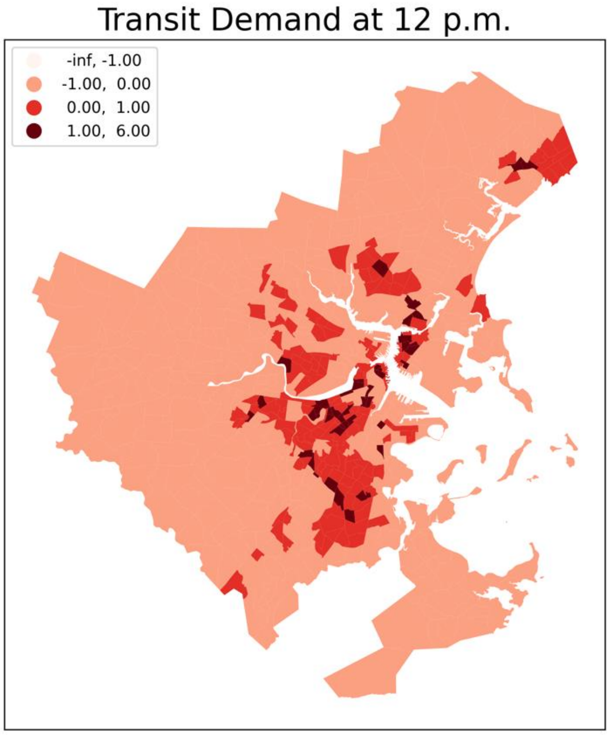
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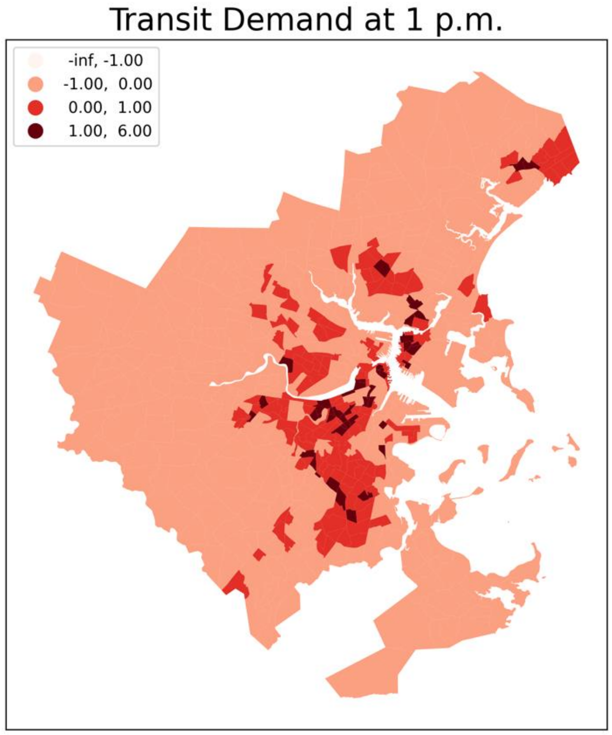
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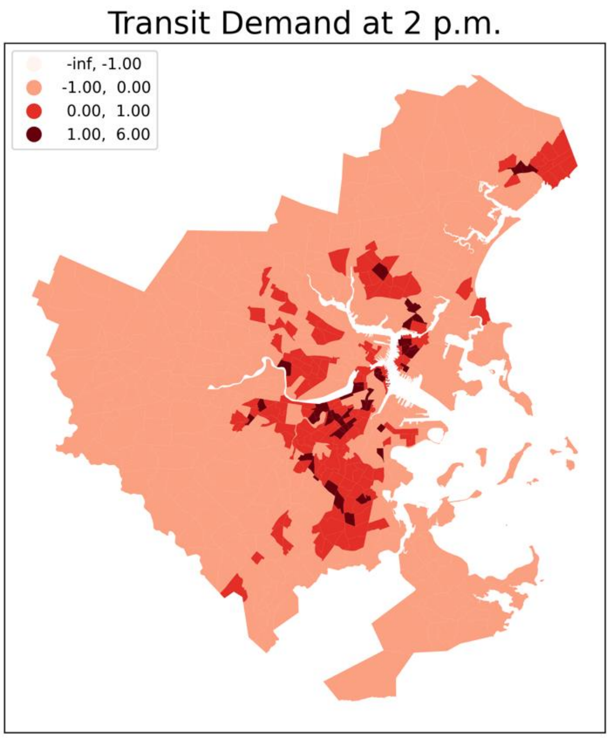
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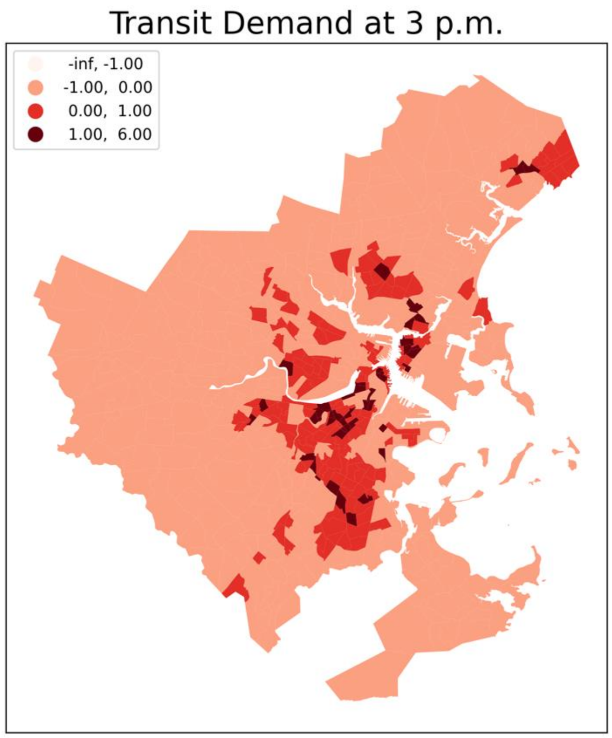
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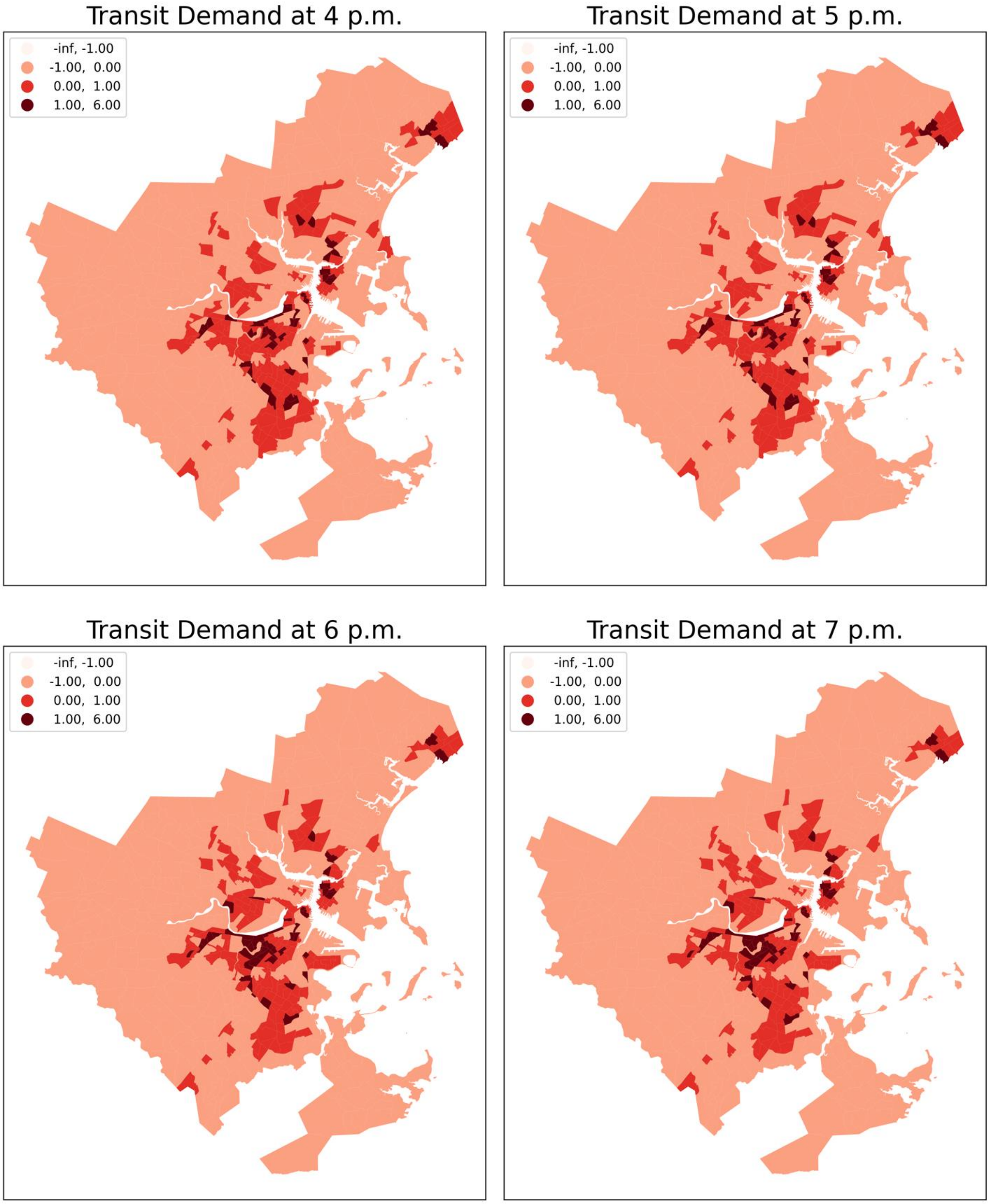
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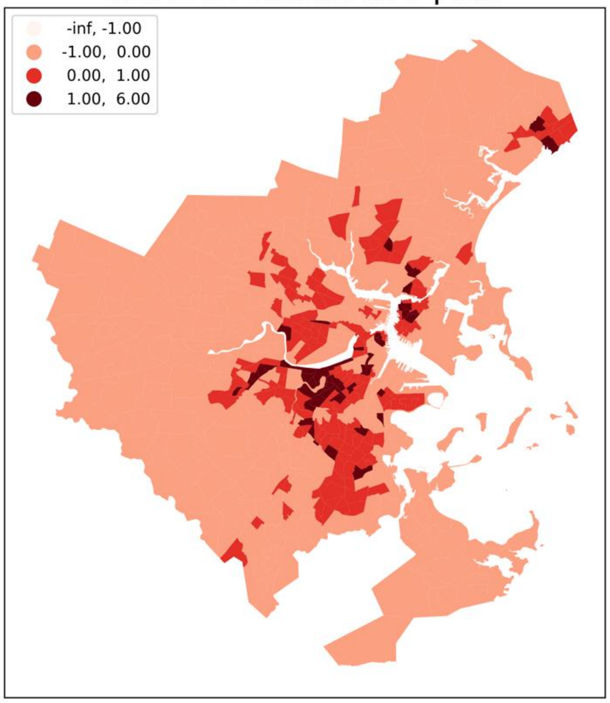
Transit Demand at 8 p.m.



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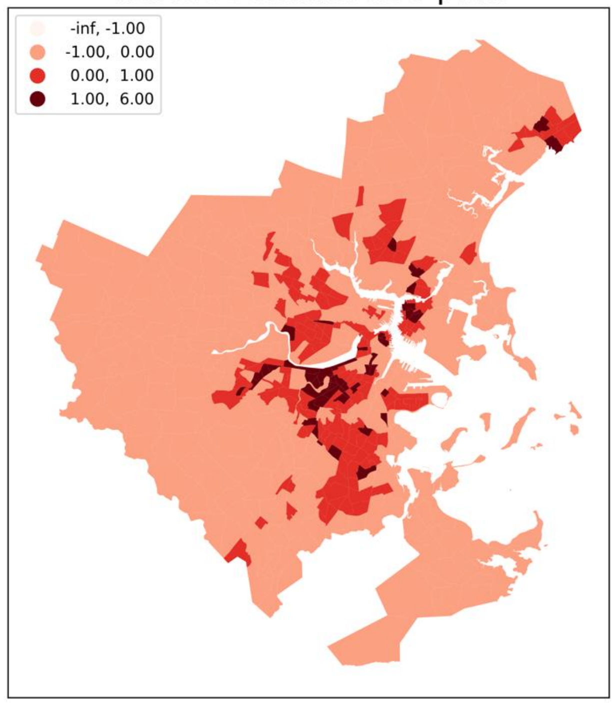

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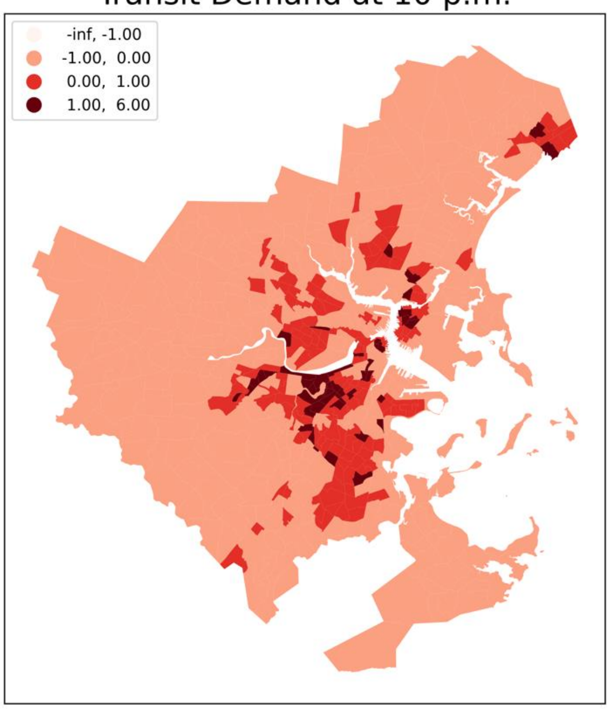
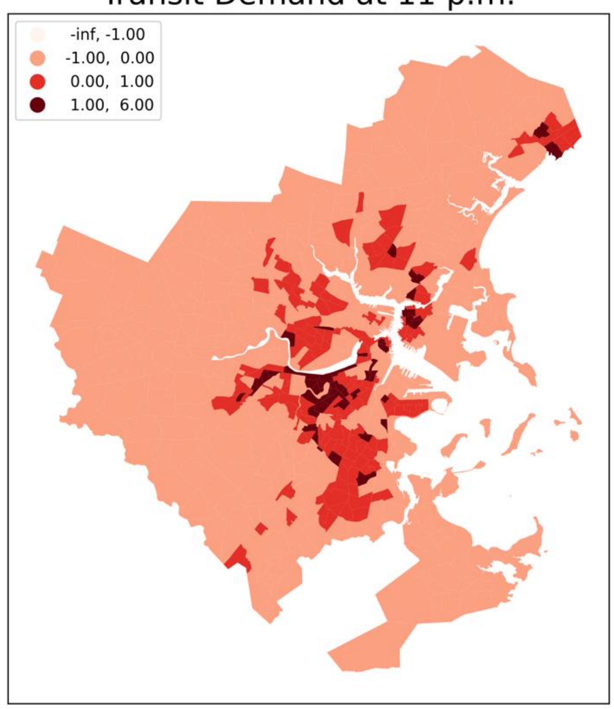
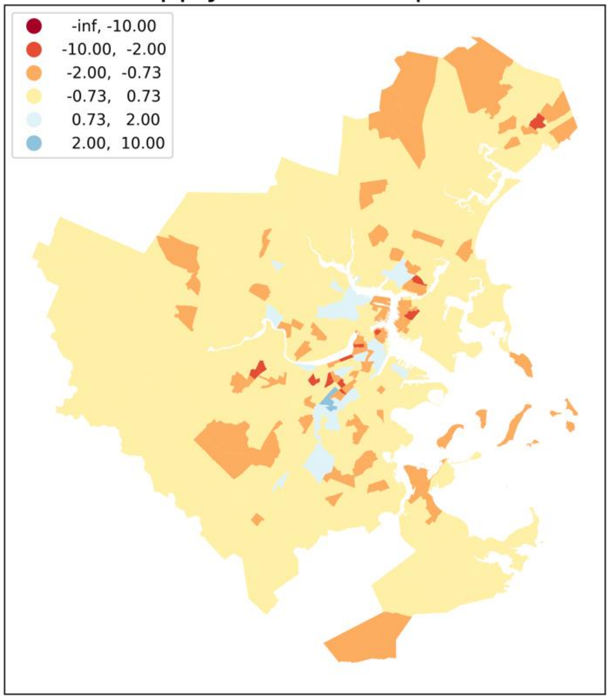


Transit Demand at 11 p.m.

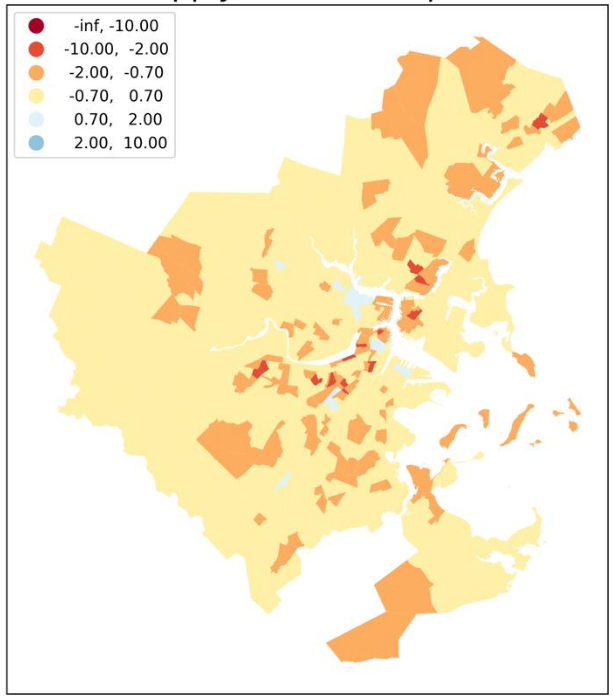


Appendix D – Hourly Transit Gap Scores

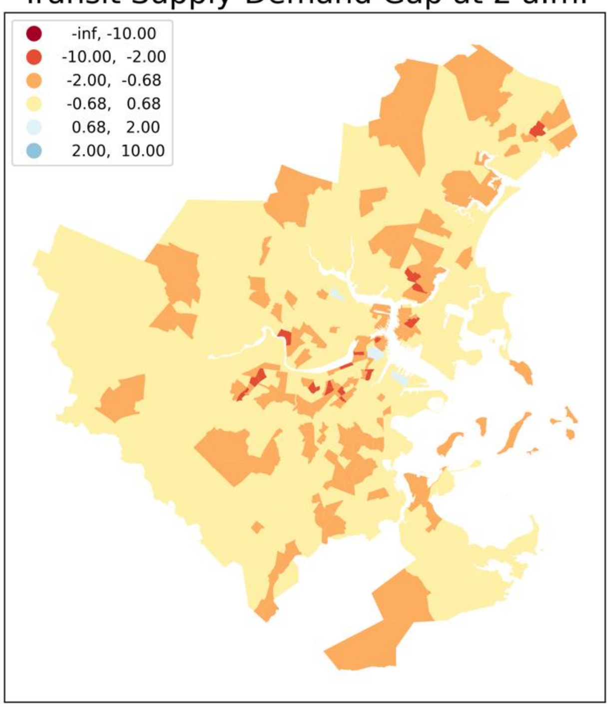
Transit Supply-Demand Gap at 12 a.m.



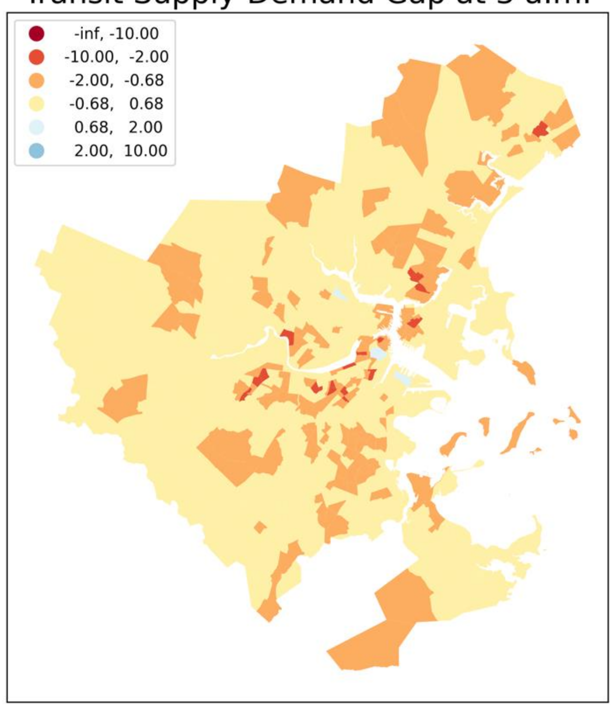
Transit Supply-Demand Gap at 1 a.m.



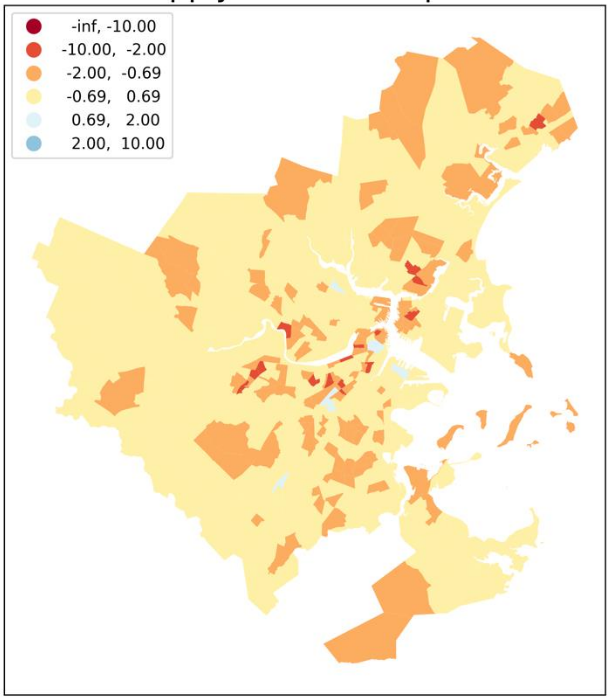
Transit Supply-Demand Gap at 2 a.m.



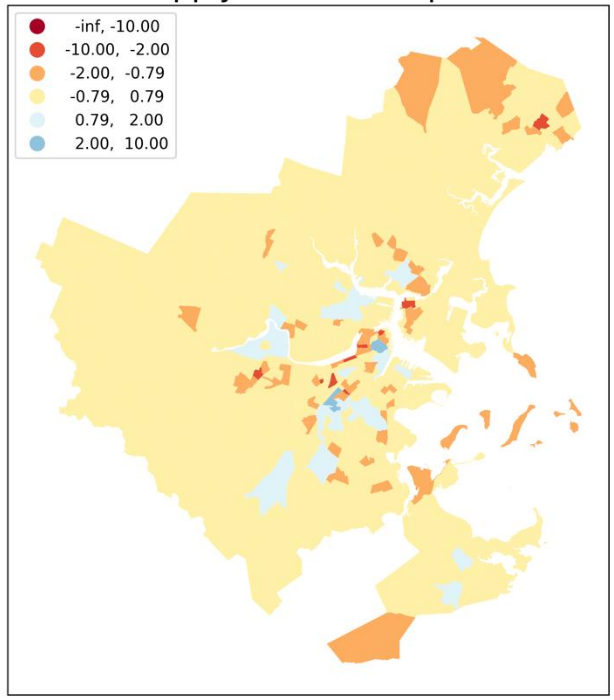
Transit Supply-Demand Gap at 3 a.m.



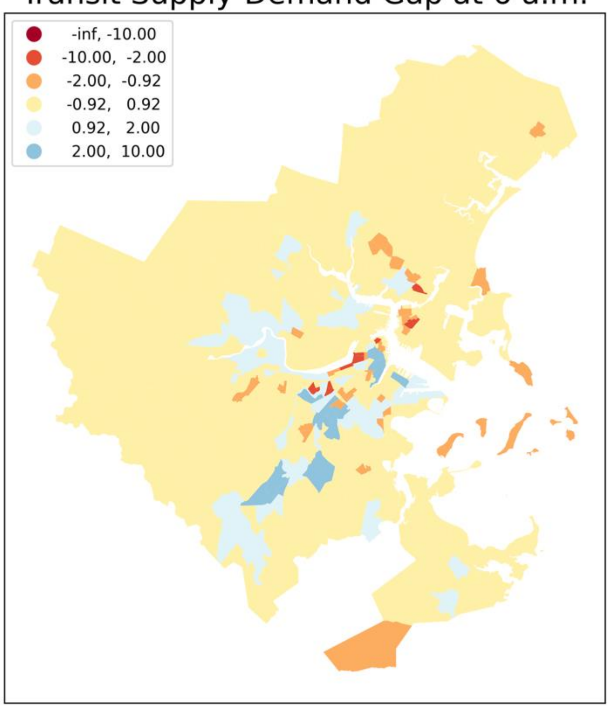
Transit Supply-Demand Gap at 4 a.m.



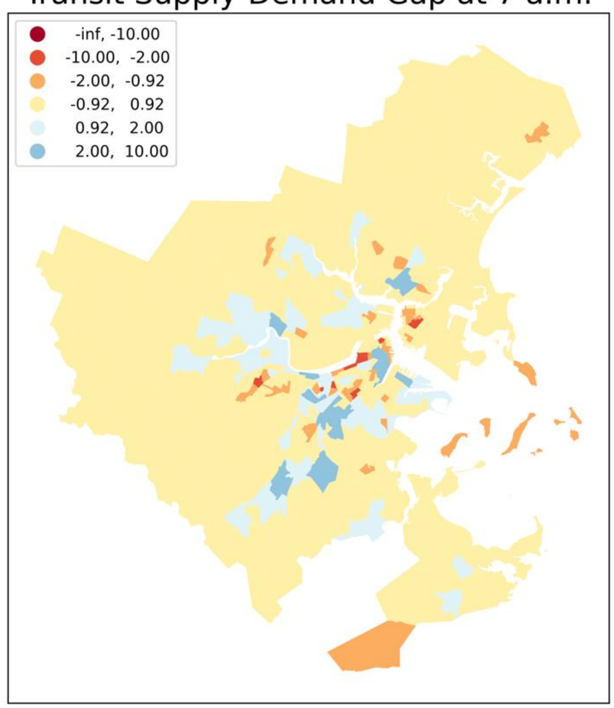
Transit Supply-Demand Gap at 5 a.m.



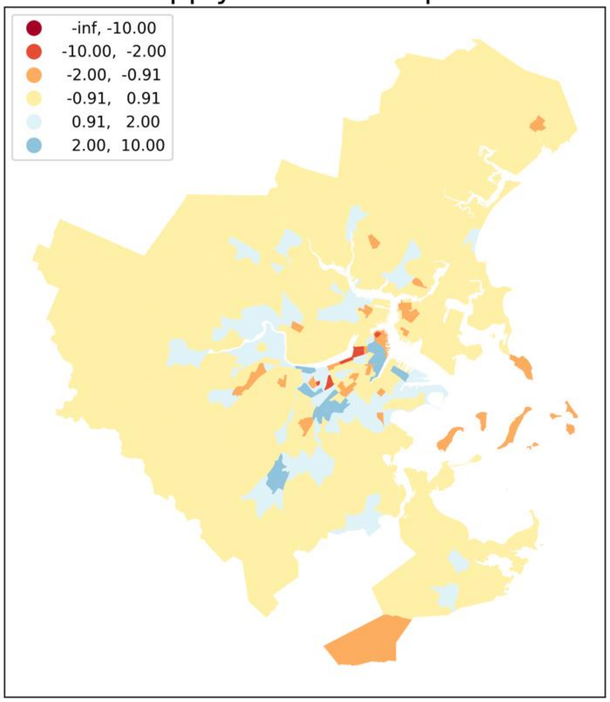
Transit Supply-Demand Gap at 6 a.m.



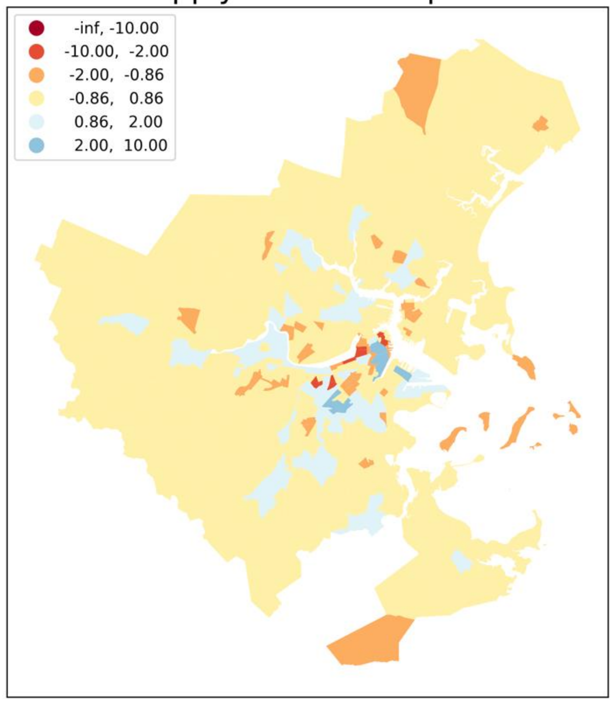
Transit Supply-Demand Gap at 7 a.m.



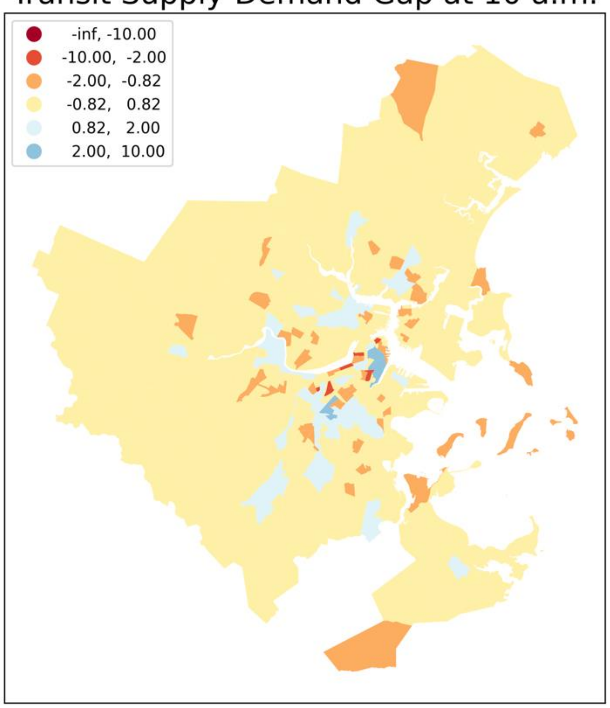
Transit Supply-Demand Gap at 8 a.m.



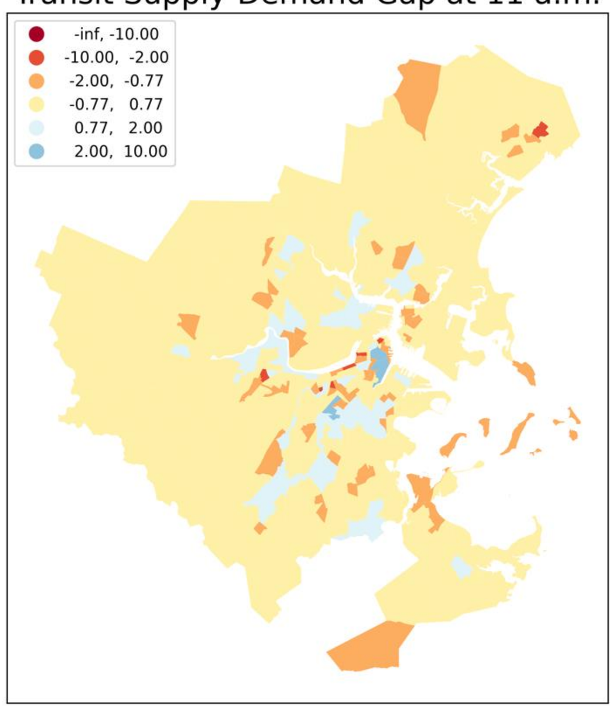
Transit Supply-Demand Gap at 9 a.m.



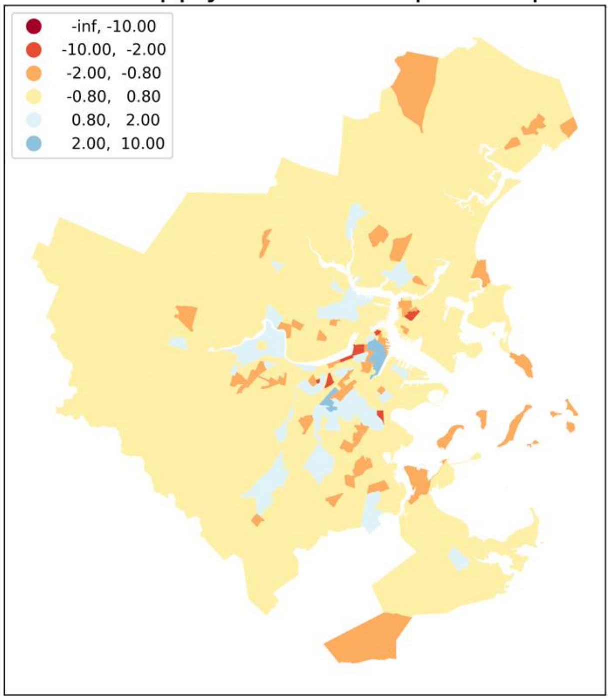
Transit Supply-Demand Gap at 10 a.m.



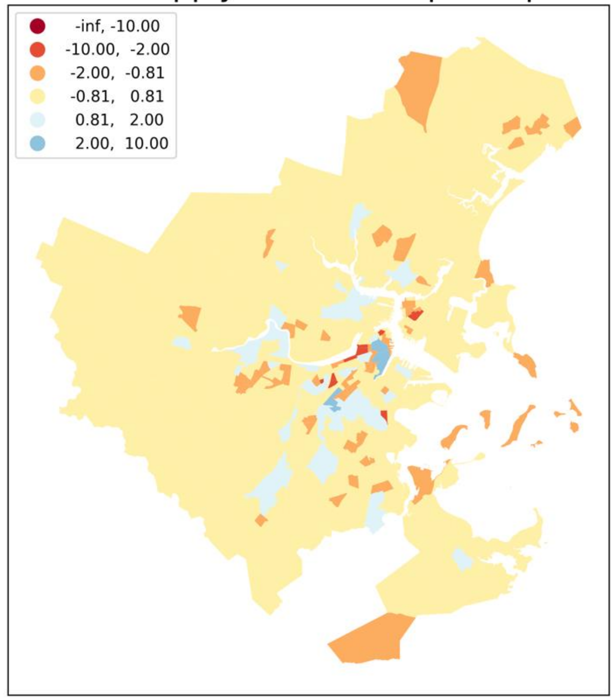
Transit Supply-Demand Gap at 11 a.m.



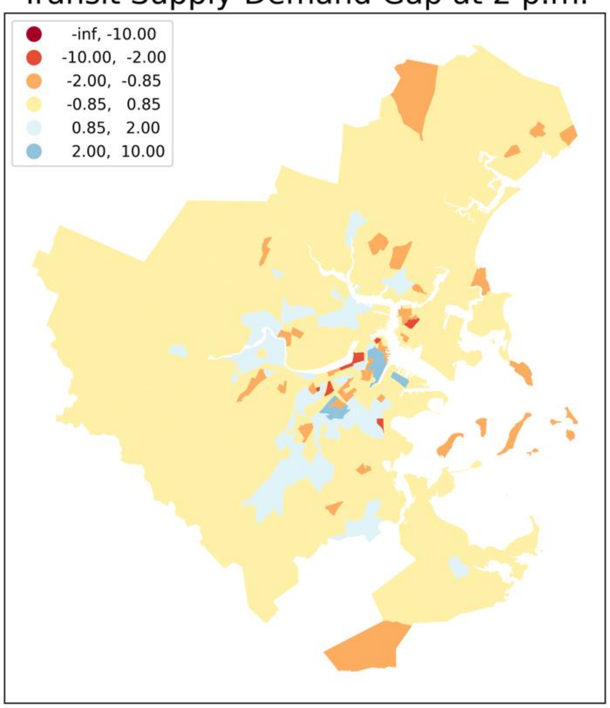
Transit Supply-Demand Gap at 12 p.m.



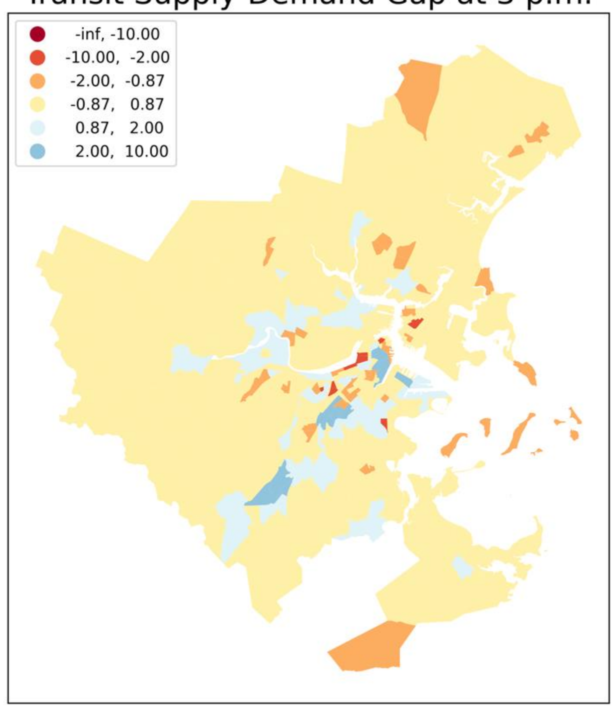
Transit Supply-Demand Gap at 1 p.m.



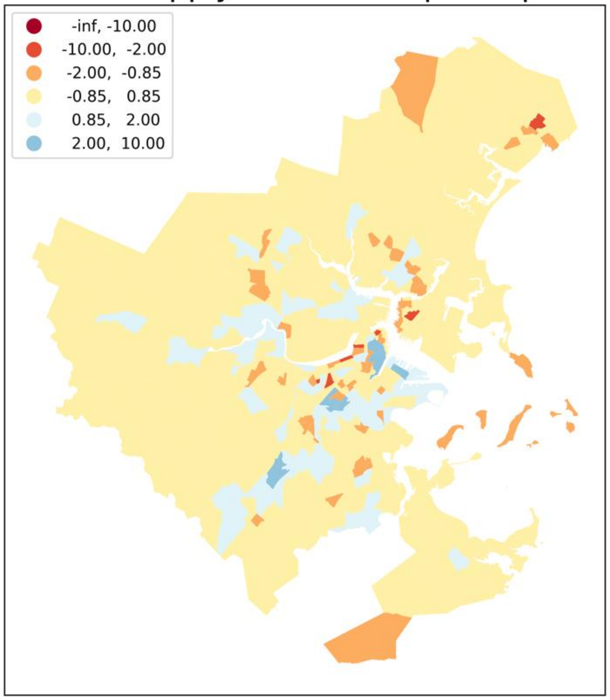
Transit Supply-Demand Gap at 2 p.m.



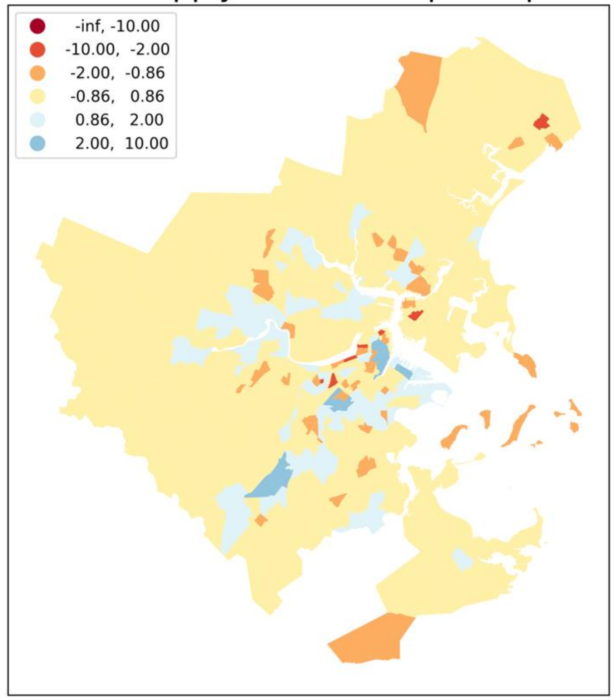
Transit Supply-Demand Gap at 3 p.m.



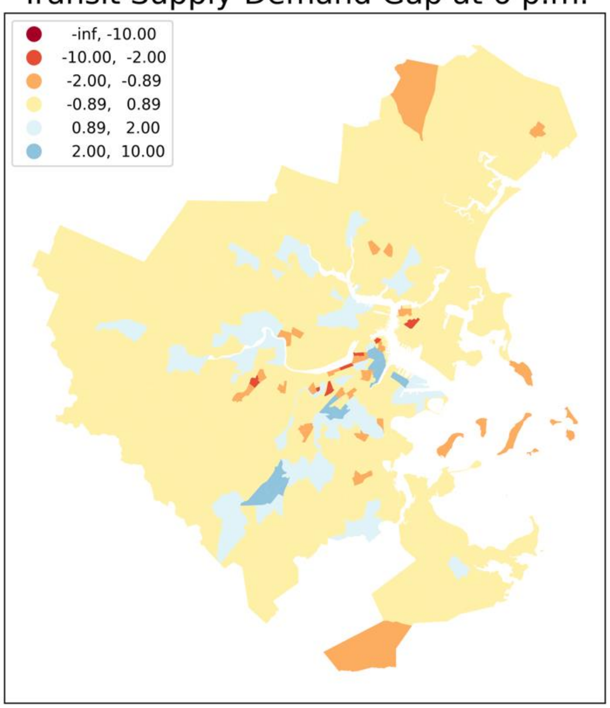
Transit Supply-Demand Gap at 4 p.m.



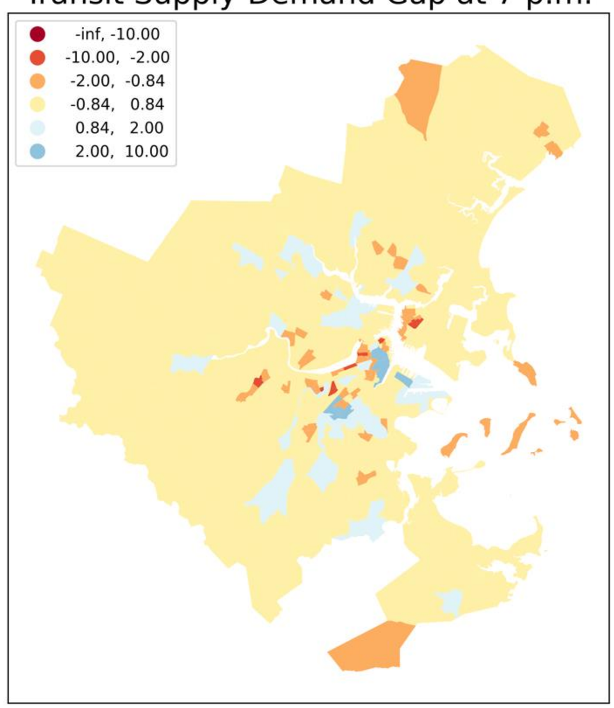
Transit Supply-Demand Gap at 5 p.m.



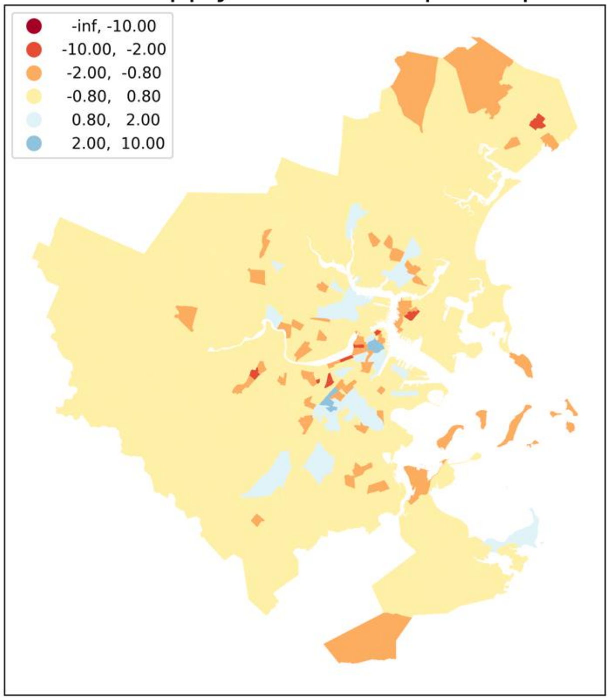
Transit Supply-Demand Gap at 6 p.m.



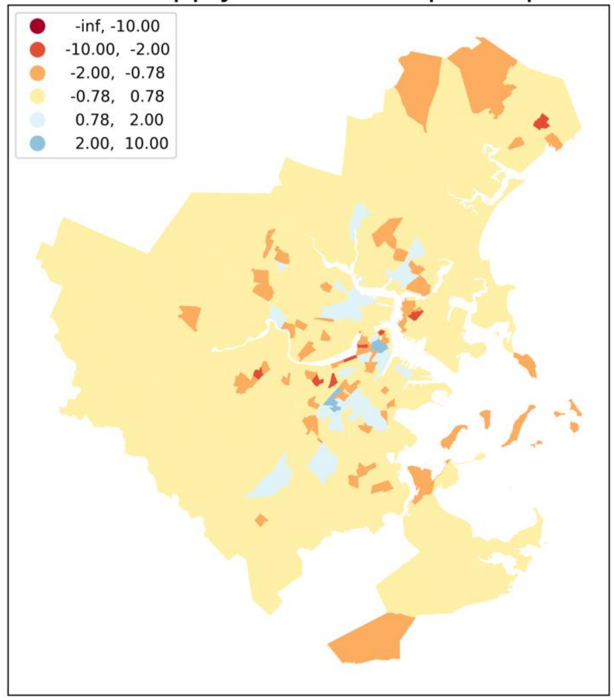
Transit Supply-Demand Gap at 7 p.m.



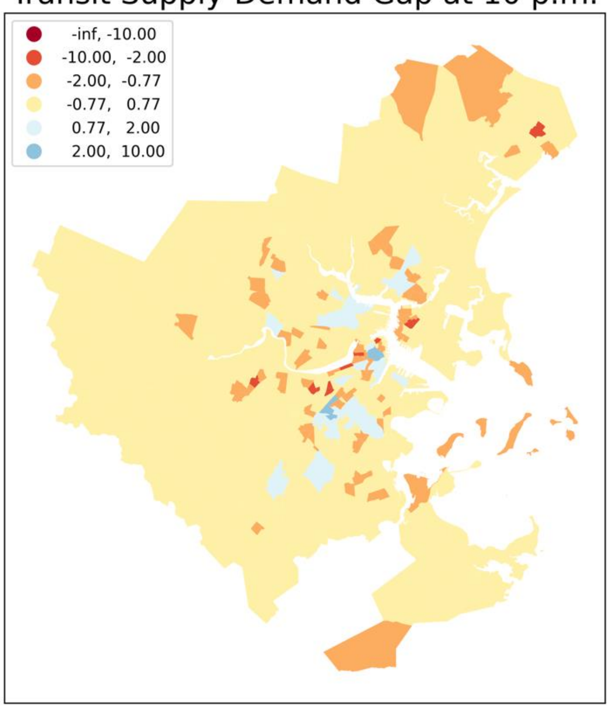
Transit Supply-Demand Gap at 8 p.m.



Transit Supply-Demand Gap at 9 p.m.



Transit Supply-Demand Gap at 10 p.m.



Transit Supply-Demand Gap at 11 p.m.