The Potential for Using Transportation Network Companies as an Alternative to Transit Station Parking

by

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Abstract

Historically, transit agencies have prioritized sustaining existing Park and Rides (P+R) over further Transit Oriented Development (TOD), incurring high financial opportunity costs in the form of an "implicit" parking subsidy and foregoing potential ridership gains in the process. However, the widespread adoption of Transportation Network Companies (TNCs) like Uber and Lyft over the past several years presents a potential opportunity to change the tradeoff transit agencies face between P+R or TOD. This thesis explores the potential for transit agencies to utilize TNCs to reduce demand for transit station parking while decreasing transit agency subsidies and increasing ridership via a mechanism introduced as TNC and Ride or "TNC+R".

Through a case study of the North Quincy MBTA Station in the Boston Metropolitan Area, this study conducts a financial analysis to quantify the implied P+R subsidy a transit agency incurs by requiring 1:1 parking replacement in an effort to retain all existing P+R users, in lieu of additional TOD revenue and ridership. The analysis estimates that the MBTA is incurring an implicit subsidy of $20 per current parked car in lieu of another 236,700 Square Feet of TOD.

Taking the calculated parking subsidy amount, I use ridership data for North Quincy Station to model the potential financial savings of subsidizing TNC rides instead of retaining parking spaces in certain situations. The modeling considers short term rider financial indifference between P+R and TNC+R. The financial analysis estimates that the MBTA could eliminate all of the 852 existing spaces at the North Quincy TOD site and still retain existing ridership through a lower-cost TNC+R subsidy. The subsidy would convert 469 daily P+R users who travel up to 13 minutes to the station to a TNC+R alternative. The switch to a TNC+R would allow the transit agency to net another $665,000 annually without any incumbent ridership losses. The average subsidy amount decreases by over 25% to $14.50 per round-trip. Finally, the thesis concludes discussing several ways and situations to best use a TNC subsidy. Because of their significantly different cost structures, using transit station parking and TNCs in tandem is generally the best approach and the best-suited stations are those with high land values and/or with a large number of park and riders that live a short distance to the station.

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Chapter 1 Introduction

Public transit agencies, like the Massachusetts Bay Transportation Authority (MBTA) in Boston, have historically invested millions of dollars and allocated valuable real estate to provide parking for transit riders located outside of the city core. However, subsidized transit station parking and park & ride (P+R) lots in metropolitan areas present an expensive mechanism to increase transit ridership and come with a significant opportunity cost by occupying valuable land next to a station that could otherwise be used for further development. Surface lots use large amounts of valuable land and parking structures generally cost more than $30,000 per space to construct independent of land value. As a result, the land and resources used to provide transit station parking are in direct conflict with the transportation and economic benefits that communities and transit agencies can realize through denser development around stations, known as Transit Oriented Development (TOD). Even after these significant investments and large upfront costs, the “success” and usage of these parking facilities in the long term are far from guaranteed and difficult to predict until several years after construction, making many of these parking infrastructure projects quite speculative and inherently risky.

The MBTA has generally responded to station parking shortages with a call for more parking, but the rising popularity of Transportation Network Companies (TNCs), like Uber, makes it worthwhile to conduct a financial analysis to determine if they present a better alternative. Looking at a current MBTA TOD project at North Quincy Station as a case study, I first determine the “implied subsidy” or foregone net revenue that the transit agency is incurring in order to maintain P+R volumes in lieu of further TOD. With a better understanding of the implicit parking subsidy and the transit agency’s motivations, I then investigate a subsidized alternative (TNC and ride, or TNC+R) and conduct a simple financial analysis to determine if a TNC+R could better help meet the transit agency’s goals of minimizing inconvenience to existing passengers while increasing overall station ridership and agency net revenue. From this synthesis we can better understand TNCs’ potential to lower transit station parking costs through reducing demand for parking at MBTA stations and identify particular situations and station typologies where a TNC+R subsidy could be best suited.

Chapter 2 Literature Review

Park and ride (P+R) is a common transit access mode throughout US metropolitan areas. A P+R is a parking facility that aims to provide access to public transportation, generally targeted at individuals traveling to city centers who switch from a private or single occupancy vehicle and transfer to a shared mode (bus or rail). Park and ride lots generally adjoin commuter rail and light rail stations, especially outside of a city's downtown area. Unlike in dense urban environments, where transit riders are able to easily access stations by walking or taking the bus, riders residing outside of the city's core face increased distances and fewer options to access public transit, leaving driving and parking at the station a comparably easy and common option (TCRP/TRB & National Academies of Sciences, Engineering, and Medicine, 2004).

2.1 The Rationale Behind Park and Rides and Transit Station Parking

There are numerous reasons why the park and ride model has gained favor among many metropolitan areas, including Boston. The basic motivation for park and ride is that a short auto trip to and from a rail station will have fewer social costs than a longer trip to and from the final destination. Park and ride facilities can generate benefits for both end users and non-riders throughout the region. Park and ride users experience additional transportation options, cost savings and time savings. By converting standalone automobile trips to transit trips, park and ride benefits non-riders by decreasing roadway congestion throughout the region, reducing vehicular emissions, and generating additional land use opportunities by reducing the need for parking provisions in urban cores. The range of benefits from providing transit station parking include (Duncan, 2010; Nelson/Nygaard & Dyett & Bhatia, 2015; TCRP/TRB & National Academies of Sciences, Engineering, and Medicine, 2004):

- Fostering first-last mile connections by increasing the catchment area of a station by several miles, concentrating rider demand to a level that enables more frequent and reliable transit service that otherwise would not have been tenable.
- Reducing vehicle miles traveled and greenhouse gas emissions by encouraging motorists to use transit for at least part of their trip.
- Diverting additional vehicle traffic in heavily congested corridors and away from the Central Business District (CBD).
- Shifting demand for parking to outside the CBD, where it is very expensive to provide.
- Increasing transit ridership by allowing direct and easy access to the transit system.

Park and ride is one mechanism to expand the geographic access to public transit beyond the population that resides within a small radius of transit stations. This promotes additional ridership, resulting in increased fare box revenue for transit agencies. A study of BART riders originating from suburban center stations found that park and rides accounted for 90% of mode share for station access (TCRP/TRB & National Academies of Sciences, Engineering, and Medicine, 2004).

In multiple rider surveys, users have consistently identified reduced costs, faster travel time and less stress as the most important factors in their decisions to use park and ride facilities (TCRP/TRB & National Academies of Sciences, Engineering, and Medicine, 2004). With its over 44,000 station parking spaces, Greater Boston's MBTA has been able to attract approximately 30,000 riders to park on a typical weekday. One of the reasons the MBTA is able to attract commuters to use transit station parking instead of driving into downtown Boston is by offering heavily discounted parking rates. In a May 2011 survey, 28 downtown Boston parking facilities charged an average rate of $30 per day, while as of 2016 the MBTA only charged $4 for a surface lot and $7 for a garage space (MBTA, 2011).

Keeping transit station parking prices low is important in order for transit agencies to retain ridership. According to an MBTA Parking Analysis, after daily station parking rates were uniformly increased by $2 in November 2008, overall station parking use declined by 28% year over year, which highlights rider sensitivity to parking price increases. Out of the 102 MBTA stations with station parking, only one station realized increased parking usage after the price increase. The $2 price increase amounted to a 90% average increase in parking rates. As a result, the November 2008 price increase actually yielded a 23% increase in parking revenue for the MBTA, but at the cost of losing riders who previously parked to access public transit. The 28% decrease in parking usage demonstrates the importance of the transit agency's need to offer attractive parking rates and the difficult balancing act the agency must undergo: "The MBTA, especially now, relies on parking revenue more than ever. It behooves it to look closely at its parking regulations and pricing regime to ensure that the total cost of commute is competitive and delivering value for the money" (MBTA Advisory Board, 2011).

This behavior and revenue change experienced in Boston is similar to community behavior in the San Francisco metropolitan area. Studies by greater San Francisco's rail transit agency, BART, show that parking price increases had minimal ridership impacts at station parking lots that were already at least 90% utilized on average while those with utilization under 90% show a -0.33 elasticity of demand with respect to parking price changes (Levinson et al., 2012).

In addition to saving $25 a day on parking, many Boston commuters opt to park at MBTA stations to avoid congestion and even save time on their commutes. A 1971 MBTA License Plate Survey, admittedly from 50 years ago, found time savings of 23 minutes and 10 minutes by taking the Red and Blue Lines respectively over driving into the city (TCRP/TRB & National Academies of Sciences, Engineering, and Medicine, 2004). Besides potential time savings to individual users of park and ride facilities, there are also time savings opportunities for the greater region.

A benefit of relocating cars from being parked in the city's downtown to an outer area via park and rides is the elimination of those vehicles from chronically congested roadways during peak traffic hours. Removing these vehicles from these thoroughfares can free up roadway capacity for other road users.

Substituting some commuting miles via automobile with public transport can yield some environmental benefits as well through the reduction of vehicle miles traveled. However not all emissions (local pollutants and greenhouse gases) are reduced to the same extent as the miles driven by park and ride users. Because of the cold-start effect, cars release more pollutants in the first few miles of driving than subsequent miles, after the engine/catalytic converter is warmed up and operating more efficiently. Park and rides still require travelers to start their journey by their own car, such that the cold-start phase creates a relatively high share of emissions for the shorter drive to the transit station parking facilities (Burgess, 2008).

The net environmental and congestion benefits realized due to people choosing to use park and rides, instead of driving directly to their end destination, depend on what happens across the entire region, specifically due to latent demand. If other automobile users enter the market due to the gap in traffic left by commuters who now use park and rides, the initial decrease in road traffic to the city's downtown will be filled by people who previously were unwilling to make that journey on that route at that time, which may add back vehicle miles traveled and environmental emissions to the system. Plausibly, traffic could return to the same level as before and, when combined with the only partial reduction in VMT and emissions from travelers who now park and ride, could result in a net increase in vehicular travel and emissions.

One way to prevent this unintended outcome is for cities to increase the burden of parking in city centers, through reductions in parking capacity and consequential price increases. A Bay Area study highlighted that the largest factor in determining whether residents would drive or take transit was whether there was free parking available at their destination (Cervero, 1994).

P+R facilities are not without critics. While providing transit station parking can have benefits to the transit agency and the surrounding metropolitan area by capturing additional public transit riders, they pose concerns about equity and environmental justice. Because most of benefits are realized by converting automobile trips to partial transit trips, people can only benefit if they have access to a car. The costs associated with car ownership are high and a large portion are fixed, putting ownership out of reach for lower income individuals. This environmental justice consideration is more concerning since transit agencies offer heavily discounted parking rates and often operate park and ride lots at a loss. This precludes lower income individuals from benefitting to the same extent as those with access to a car.

While transit agencies may cover the operating costs of P+R, the parking revenues are unlikely to fully cover the parking construction costs (estimated to range from $5,000 per surface space and as much as $46,000 in structured parking). In a survey of 32 transit agencies, TCRP Report 122 estimated that WMATA had the most efficient parking expense-to-revenue ratio, losing only 34% of their parking investment, by having the highest annual revenue per parking space of $726. The report stated that the survey figures indicate that “most agencies heavily subsidize the cost of providing parking for their riders” and affirmed “no transit provider charges parking fees that cover the full cost of parking garages.” (Weinberger et al., 2016) The money devoted to subsidizing transit station parking reduces the budget for other regional programs that could better serve these individuals unable to afford car ownership. By providing financial incentives to car commuters, transit station parking fails to prioritize those who cannot or do not own a private automobile. In addition, transit stations with parking facilities are often located in higher income geographies compared to the metropolitan average (APTA, 2015).

Numerous researchers have questioned the efficacy of transit station parking facilities because of their high costs to transit agencies, reliance on private vehicle ownership, and forgone alternatives for better land use (Parkhurst, 1995). Even in a best-case scenario, park and rides relocate parking from a trip’s terminus – generally the city center – to a transit station located outside of the downtown area. One resulting issue is that even though the stations that have parking are located in less dense environments than the downtown, they are still located in high density areas relative to the rest of the region and have immediate and easy access to public transit. This means that the space allocated to providing transit station parking is high value and could be used for better land use opportunities such as Transit Oriented Development.

2.2 The Rationale Behind Transit Oriented Development

By using land around transit stations to provide commuter parking facilities, the transit agency impedes the station's ability to foster TOD growth. TOD provides another way for transit agencies to increase ridership through increased station area densities (concentration of trip origins and destinations). Park and ride facilities are in direct conflict with TOD and prevent the numerous benefits that TOD can bring, including (APTA, 2015) (Nelson/Nygaard & Dyett & Bhatia, 2015) (Fogarty et al., 2008):

- Higher transit ridership;
- Increased use of non-automobile modes of transportation;
- Limited car ownership;
- Reduced VMT;
- Reduced energy use and emissions; and,
- Increased land values.

In contrast to park and rides, Transit Oriented Development focuses on the area in close proximity to transit stations to improve transit accessibility and decrease automobile usage and dependence within a metropolitan region. Many researchers and planning and engineering firms focus on the ½ mile radius surrounding a transit station when thinking about TOD, based on the notion that Americans are generally not willing to walk more than a ½ mile or 10 minutes to access transit. The exact radius to a station that TOD is effective is more complicated and can be increased by addressing factors like pedestrian safety and comfort (Guerra et al., 2012).

Transit Oriented Development is guided by the three tenets of Density, Diversity and Design. While every realization of Transit Oriented Development varies based on the needs and characteristics of a given station, all TOD projects seek to implement higher density of people and places, through mixed-use developments with urban designs that promote walkability within the community and transit use for trips terminating elsewhere in the region (Cervero, 2001).

The land surrounding transit stations tends to be more valuable, at least in part because public transit provides a convenient and low-cost transportation option and this "value" gets capitalized into land prices. By increasing density and promoting a combination of residential, commercial and retail land uses through TOD, more people are able to live or work (ideally both) close to transit access. Because of the close proximity to public transit, fewer trips are dependent on automobiles and through a virtuous cycle allows for even greater density by freeing up additional space for TOD that would have previously been used for parking (Salat & Ollivier, 2017; Suzuki et al., 2013).

Unsurprisingly, in the USA a larger portion of commute trips originating or terminating within a ½ mile of a transit station were completed by public transit compared to the metropolitan area at large as seen in Table 2-1 below. This is particularly true for home-to-work trips, showcasing the importance and effectiveness of increasing both residential and employment density and locating more jobs near transit stations. Data compiled for the Center for Transit Oriented Development shows this to be true across US cities of varying sizes as seen in Table 2-1 (Dorn, 2004).

2000 Transit Share for Commute Trips		
Area	Within ½ Mile of Station	Metro Area At-Large
Chicago	25%	11%
Washington D.C.	30%	9%
Memphis	6%	2%
Cleveland	13%	4%
Denver	12%	5%
Charlotte	4%	1%
Los Angeles	16%	5%

Table 2-1 2000 Transit Share for Commute Trips (Dorn, 2004)

Station areas with Transit Oriented Development characteristics tend to have lower vehicle ownership rates for households located closer to transit. A 2005 Bay Area study found that the average number of vehicles per capita was 0.50 for residents within ¼ mile of a transit station, 0.54 for ¼ - ½ mile, 0.61 for ½ - 1 mile and 0.75 for residents living more than 1 mile from a transit station. The same study also found that 70% of car-less households were located within one mile of a Bay Area public transit station (Gossen, 2005). Similar trends were found throughout multiple US metropolitan areas. For example, in Arlington County, VA, researchers found that TOD households had an average of 0.9 cars vs 1.6 cars for non-TOD households (Renne, 2005).

The mixed-use development emblematic of Transit Oriented Development can lead to an overall reduction in the need to make intra-region journeys outside of the station area by capturing more trips internally to the station area. Having a combination of residential, commercial and retail offerings within the same neighborhood increases local accessibility by allowing an individual to work close to where they live and complete many other travel journey types like running errands and eating out much more conveniently. Highlighting the relationship between land-use and transportation demand, these trips that would have previously ended outside of the station area and been completed by automobile or motorized public transit can be replaced with much shorter trips that can be done by pedestrians or cyclists.

This shows the importance of diversity of land use. Even if a station's surrounding area has high development density, but only of one type, it would still require significant transportation infrastructure for individuals to access it. For example, if a station area only has office space, but no housing stock, workers would not be able to live close to their places of work and would need to commute in by vehicle or public transit. This also creates a spike of inbound traffic during the morning commute and a similar spike of outbound traffic in the evening. The large surges increase congestion and would require significant investments to add additional capacity. The expensive capacity increases would only be useful during the large spike in commuting hour demand and would sit unutilized the rest of the time, particularly during the weekend. Even if you realize minimal reductions in longer intra-region trips between station areas, the Transit Oriented Development mixed use areas help balance inbound and outbound peak flows since some residents work outside of the station area, while some workers reside outside of the station area (Cervero & Kockelman, 1997).

A combination of housing and commercial options in the same station also helps the business viability of restaurants and retailers. For example, a restaurant can serve business and residential demand throughout the whole day in a mixed-use neighborhood, compared to one that only caters to corporate business. Even if they have the same number of daily customers because both are in equally dense areas, similar to the large spike in transportation demand, the office park restaurant would need to be larger since most patrons would come for lunch, instead of spreading demand across the lunch, dinner and weekend crowds.

Development density and diversity of land use helps generate increased and more stable transportation demand throughout the day and week. Transit Oriented Development's emphasis on well-designed communities is essential in order to fully benefit from the first two TOD tenets of density and diversity. Transit Oriented Development design prioritizes non-motorized forms of transport and walkability.

Because of the relative scarcity of land in urban areas, a large part of land use planning is an exercise in efficiency and prioritization. While density increases the total number of trips, when combined with mixed-use development TOD increases accessibility and can lower average trip lengths because more potential activities are located more conveniently and closer to each other. The shorter trip length reduces the likelihood these trips need to be completed via automobile and instead can be done by walking or biking. TOD station areas that emphasize walkable design and pedestrian access can further convert automobile mode share to non-motorized forms by making these modes more enjoyable and safer.

Compared to motor vehicle traffic, pedestrian and cycling traffic is a more efficient allocation of public space since it requires less area per user, promotes regular exercise and does not consume large amounts of fossil fuels. By converting automobile trips to walking and biking, TOD design can create a positive feedback loop into density by freeing up space for development that would have previously been used for vehicle parking and roadway usage.

2.3 Transit Oriented Development and Park and Rides in the Boston Metro Area

The Massachusetts Department of Transportation (MassDOT), the MBTA and the Metropolitan Area Planning Council (MAPC) – the Boston area's regional land planning organization – all generally use TOD guidelines to cover the area within a half-mile radius around any MBTA rail transit, bus rapid transit or commuter rail station, with a particular emphasis on the land within the quarter-mile radius core of these stations (MassDOT & MBTA, 2017). In the metropolitan Boston area, the half-mile buffer areas around stations account for only 5% of the region's land, but as of 2012 represented 25% of housing units and 37% of total employment. The housing and employment numbers demonstrate the importance Transit Oriented Development plays in the region and continued role it will play to unlock sustainable growth in the future (MAPC, 2012).

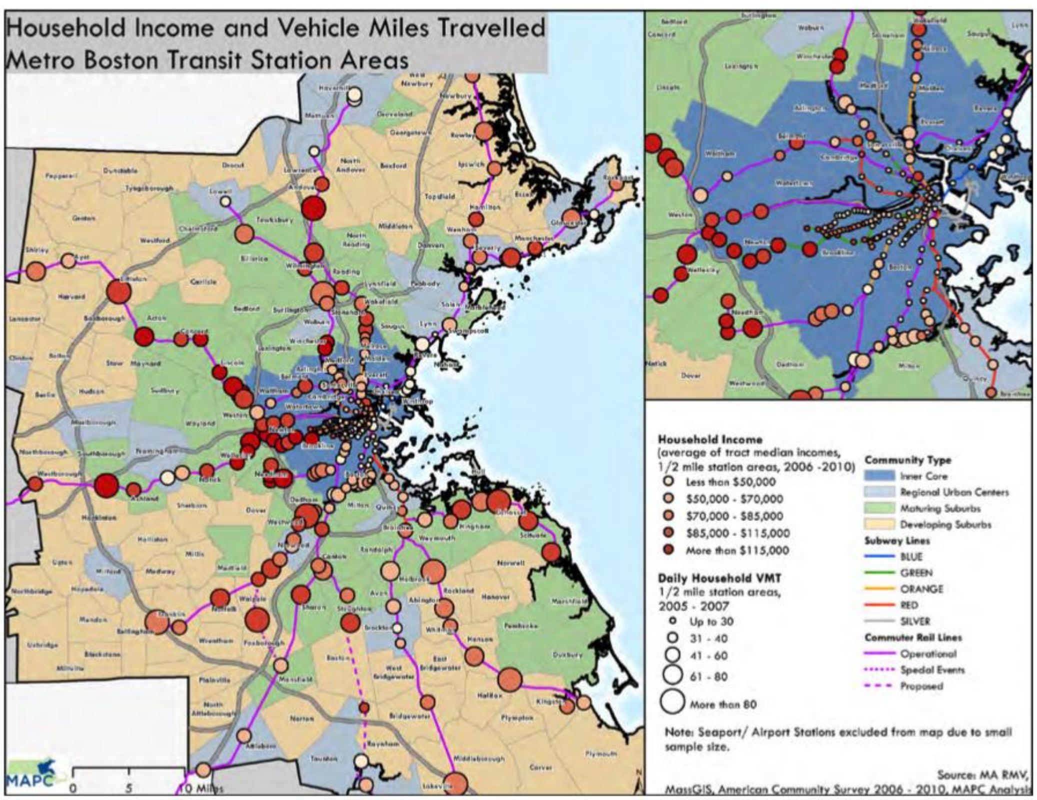


Figure 2-1 Household Income and VMT by MBTA Station Area (MAPC, 2012)

Data for the Boston metropolitan area shows the familiar inverse relationship between density and transportation demand. Regionwide, the average daily Vehicle Miles Traveled per household is 49 miles, while the station areas with the lowest VMT – less than 20 miles per day – are all found in areas with a combined residential and employment density greater than 35 persons per developed acre. Conversely, above-average VMT occurs in the 80 station areas with development density of less than 25 persons per developed acre. When comparing between station area typologies, similar TOD-favorable trends emerge. Stations areas that have higher daily household VMT capture lower transit commute mode shares, while station areas with higher WalkScores also have a higher share of transit commuters (MAPC, 2012).

Proximity to transit stations does not ensure higher transit use and lower reliance on automobiles on its own. The 2012 MAPC TOD Report determined that in Trolley Suburbs and Undeveloped Station area types, "the travel behavior of new residents and employees is likely to be only marginally better than non-transit areas, due to the low density of land uses, the lack of destinations and high vehicle ownership." Highlighting the importance of TOD principles, the report stated that "only with very intensive efforts to build at significantly higher densities, add additional destinations and promote low auto ownership will TOD in these station areas result in more sustainable transportation patterns." (MAPC, 2012)

Station Typology	Surface Parking Share of Station Area Land	Acres of Surface Parking within 1/2 Mile of Station	Employment + Residential Density per Acre
Commerce Park	17%	83.4	15.5
Metro Core	11%	49.9	161.4
Neighborhood Subway	8%	39.0	43.5
Seaport / Airport	27%	80.1	33.3
Suburban Transformation	11%	50.6	6.3
Town & Village	7%	33.9	14.7
Transformational Subway	19%	81.3	36.9
Trolley Suburb	4%	18.2	18.3
Undeveloped	4%	20.3	7.0
Urban Gateway	15%	71.3	31.0
All Stations Average	11%	46.5	46.6

Table 2-2 Parking and Density by Station Typology (MAPC, 2012)

Further data published by the MAPC shows the extent of land devoted to surface parking within a ½ mile radius of MBTA transit stations. As seen in Table 2-2, surface parking occupies an average of 47 acres or 11% of the total ½ mile radius station area. More successful TOD is possible by converting a portion of this surface parking lot land into stores, homes, offices and other uses that create more destinations for people on foot and using transit.

The MBTA has a sizeable parking footprint of over 44,000 agency-owned and operated parking spaces at their stations: 29,000 commuter rail and over 15,000 rapid transit parking spaces. For FY15, these 44,324 MBTA parking spaces averaged 21,225 paying parked vehicles per day and grossed revenue of $41.9 million (MBTA, 2015a). These parking spaces across 102 stations occupy 322 acres of land at MBTA stations, highlighting how much land is devoted to parking that could otherwise be used for TOD (MBTA Advisory Board, 2015). According to the MBTA, in the Boston metro region half of all commuter rail and 10% of rapid transit passengers start their trip by driving and parking at a transit station parking space (MBTA, 2018). As of

2016, daily parking at MBTA facilities was $4 at commuter rail stations and between $5-7 at rapid transit stations seen in Figure 2-2, generating revenue of $42.0 million for FY16.

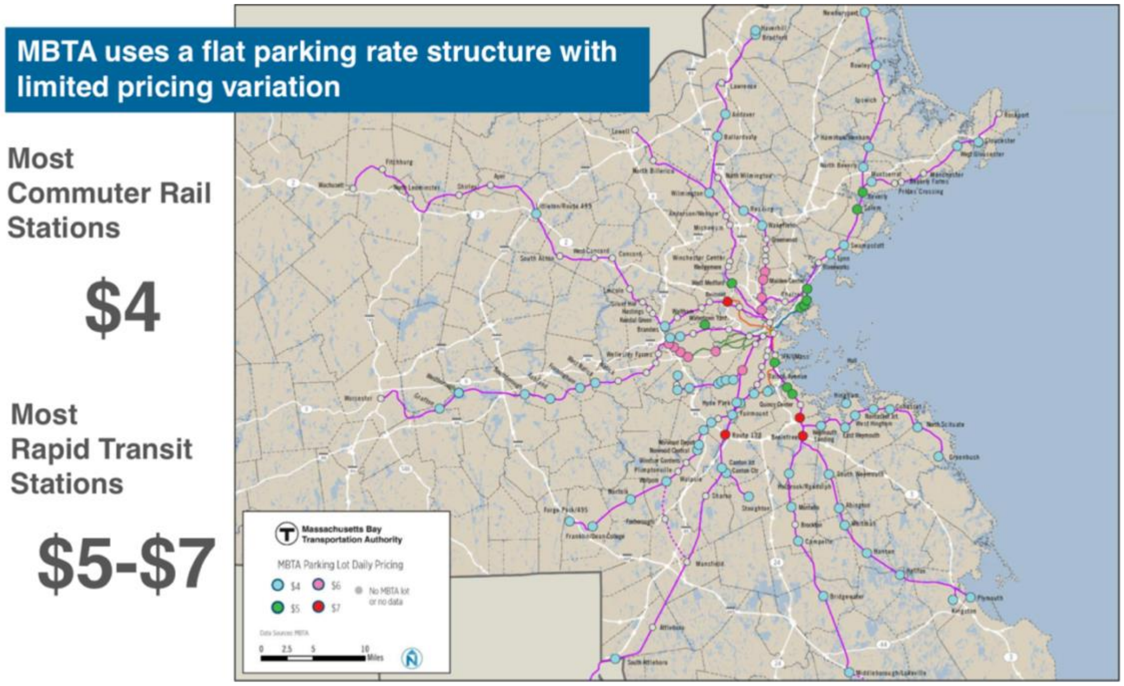
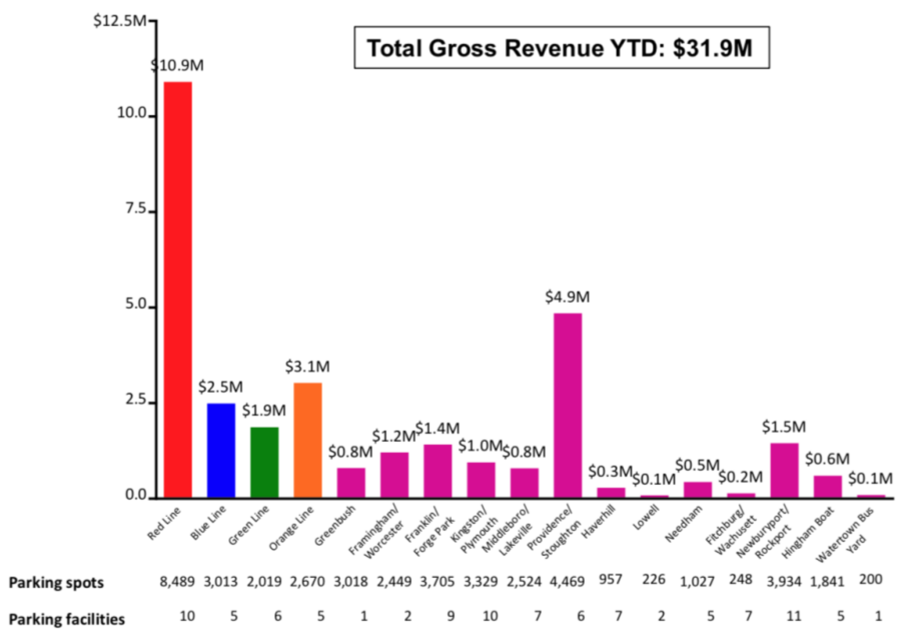


Figure 2-2 MBTA Parking Lot Daily Pricing (MBTA & Nelson/Nygaard, 2018)



Source: MBTA internal data. 9 months FY16 YTD (Mar16).

Figure 2-3 MBTA Parking Revenue by Route (MassDOT FMCB, 2016)

For the first 9 months of that fiscal year, the 8,500 parking spaces at 10 Red Line rapid transit stations accounted for over one-third of the total MBTA parking revenues as seen in Figure 2-3. The daily rates the MBTA charges for transit station parking is in line with peer transit agencies seen in Figure 2-4 and shows the potential wider applicability of this thesis' later findings and the common dilemma that transit agencies face between providing park and ride facilities or Transit Oriented Development.

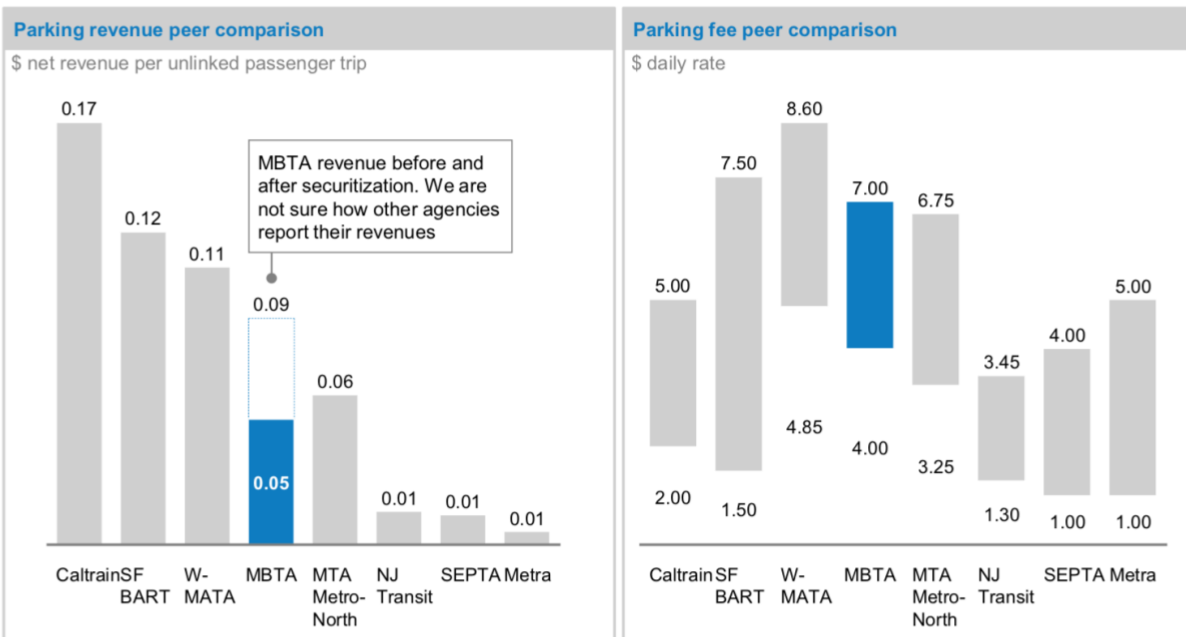


Figure 2-4 MBTA Parking Comparison to Peer Transit Agencies (MBTA Advisory Board, 2015)

2.4 The Tradeoffs between TOD and Park and Rides

Because of the clear conflict between providing surface parking and TOD, many agencies have turned to consolidating surface lots into parking structures and garages with a 1:1 replacement ratio. By building parking vertically instead of horizontally, transit agencies can reduce the amount of land dedicated to parking and allow for higher density development around the station. Additionally, centralized parking right next to the station can reduce the amount of spillover rush hour congestion and parking into adjacent residential neighborhoods.

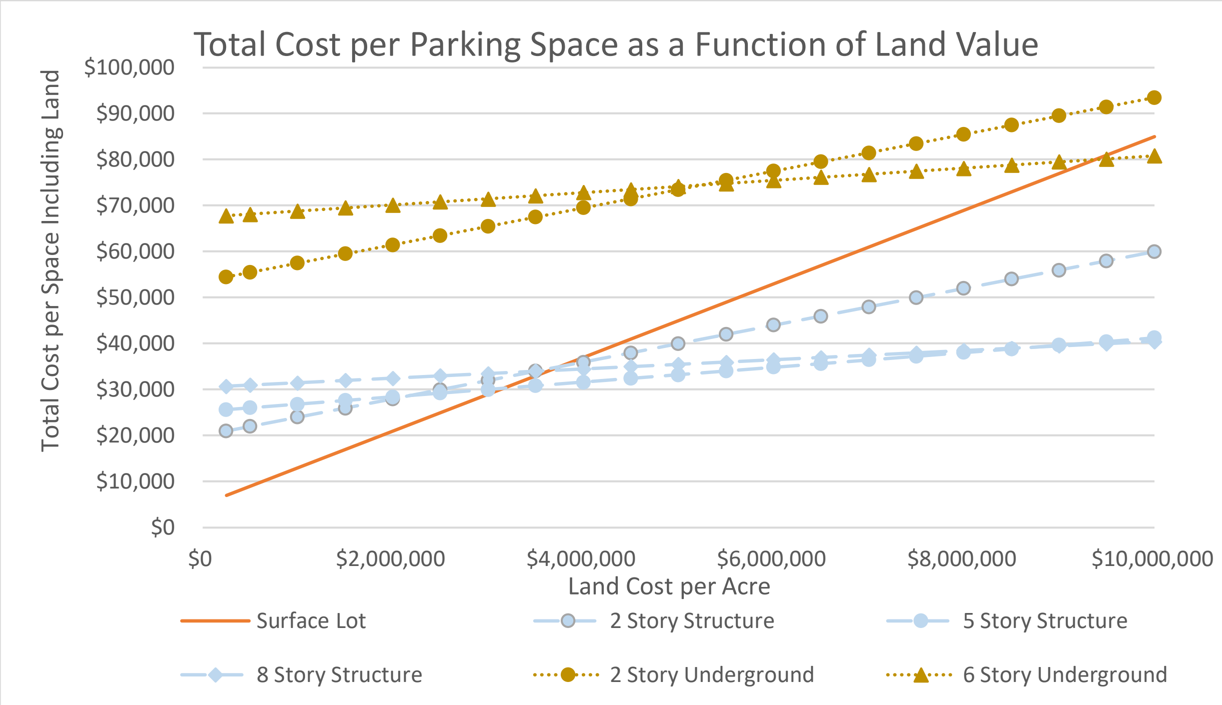


Figure 2-5 Total Cost per Parking Space as a Function of Land Value (Martin & Hurrell, 2012)

As seen in Figure 2-5 above, as land value increases, surface parking becomes more costly than parking structures. The intersection point between parking structures and surface lots varies based on local factors like construction and labor costs but happens around land values per acre of $2.5-4 million. This is because even though construction costs are much lower for surface spaces, the opportunity cost in the form of land value is so large that it becomes cheaper to spend an additional $30,000 per space to construct a parking structure than buying more land for surface spaces for station areas with land values above $2.5 million per acre (Martin & Hurrell, 2012).

Even as transit agencies consider converting existing surface lots to parking structures in station areas with high land value, the parking facility still occupies valuable land in the walkable zone around the station area and displaces other higher density land uses that are more in line with Transit Oriented Development. For example, a surface parking lot can accommodate 120 parked vehicles per acre, which directly translates into transit trips. However, according to APTA Transit Parking Recommended Practices, a medium-density apartment complex at 40 units per acre would likely yield the same number of daily station boardings as the surface lot (APTA, 2015). The exact development density needed to yield the same number of transit trips as a surface parking lot depends on the parking utilization rate and residential transit capture percentage but means that net transit boardings can be maintained even without very dense, high-rise apartments.

Operating on a net neutral ridership framework, the California and Bay Area Metropolitan Transportation Commissions have developed a tool to determine the number of replacement parking spaces. Their findings have shown that in suburban areas, where land value is around $1-2 million per acre, you only need to have 0.74-0.82 spaces for each displaced parking space to keep ridership levels the same (Nelson/Nygaard & Dyett & Bhatia, 2015). Furthermore, transit agencies are increasingly considering alternatives to park and ride lots because of their high cost. The California MTC analysis found that stations with recently completed parking structures generally cost the agency $7.65 per trip in a transit parking subsidy (Urgo & MTC, 2012). In contrast, if the agencies decided to build residential units instead of parking spaces, the project would still generate transit riders and be cash flow positive. However, the development density would need to be high enough to maintain the same ridership levels of a fully utilized station parking lot. Ignoring the economic benefits of the additional housing development, another MTC analysis determined that a residential development would need to be 4-5 floors before being able to offset the ridership generated by a BART surface parking lot (Wilbur Smith Associates & Huynh, 2011).

While transit station parking can be quite effective at generating transit trips per developed square foot (as much as 35 round trips per 10,000 SF), it still occupies a significant amount of space adjacent to a transit station that is exclusively used by one parked car, unlike other modes of station access. Additionally, in areas of high land value, it quickly becomes financially unviable for transit agencies to subsidize parking facilities to generate transit ridership. Ultimately, transit station parking is not a scalable solution as stations with parking facilities provide less ridership compared with stations that focus on pedestrian access and transit connections. Of the 43 BART stations, 27 have parking facilities but stations without parking facilities account for two-thirds of total boardings and none of the top 10 stations by volume provide any parking facilities. Instead, these stations have dense urban development that Transit Oriented Development embodies and highlights the inherent conflict between park and rides and TOD and the opportunity cost of continuing to provide transit parking at stations with high land values and TOD potential (APTA, 2015).

Even though parking spaces take up significant amounts of valuable space, transit agencies see merit in keeping some transit parking spaces to minimize disruption to existing passengers who access the station via vehicle. While the research into Transportation Network Companies is still nascent and many questions remain regarding their net societal impact, their ability to provide flexible and infrastructure-less vehicular access to transit stations presents an opportunity to lessen the tradeoff that exists between transit station parking and TOD.

2.5 TNCs: Background

Transportation Network Companies (TNCs) have garnered widespread adoption and attention over the past several years. Uber, for example, operates in hundreds of cities and regions throughout the world and has been operating in the Boston metropolitan area since 2011. Similar to a taxi or traditional livery car services, TNCs match riders with a driver who drives their passenger to their desired destination. However, there are several key differences between a TNC like Uber and traditional taxi services, which have allowed the former to grow in popularity.

Rides completed through TNCs are digitally facilitated through smartphone apps or websites and cannot be physically hailed on the street, which make up the majority of city taxi trips. In the USA, TNCs like Uber and Lyft have reached sufficient network density to the point where many riders find it more convenient to use TNCs over taxis because riders can be picked up quickly at a specific address without needing to be at a major downtown avenue, where taxis are most easily flagged down.

Contrary to taxis, TNCs do not have a medallion-like system (government-fixed number of vehicles) and do not operate at a relatively fixed supply throughout all hours of the day. This allows TNC drivers to operate more dynamically and enables the number of drivers online to vary throughout the day and be more responsive to changes in demand for trips. Uber and other TNCs have chosen to implement dynamic pricing that varies rider and driver fares based on real-time conditions, like an imbalance between supply and demand. Dynamic pricing systems like “surge” or “prime time” pricing promote more consistent driver availability and low wait times during times of peak demand at the expense of fluctuating prices. Taxis are structured the opposite, typically offering uniform pricing and fixed supply independent of demand, leading to oversupply during demand troughs and scarcity during peak hours.

Additionally, Uber and Lyft operate at the regional or state levels, allowing drivers to complete trips throughout different municipalities while taxis are mostly regulated at the city level – there are 9 distinct taxi regulators in the Metro Boston area as seen in Figure 2-6. Oftentimes a taxi medallion only allows a taxi to pick up street hails in one specific municipality. For example, Boston taxis are not able to pick up street-hail riders across the Charles River in Cambridge, which is regulated by its own taxi authority, even though the MBTA provides public transit service throughout the two neighboring cities in the Boston metropolitan area (MAPC, 2017).

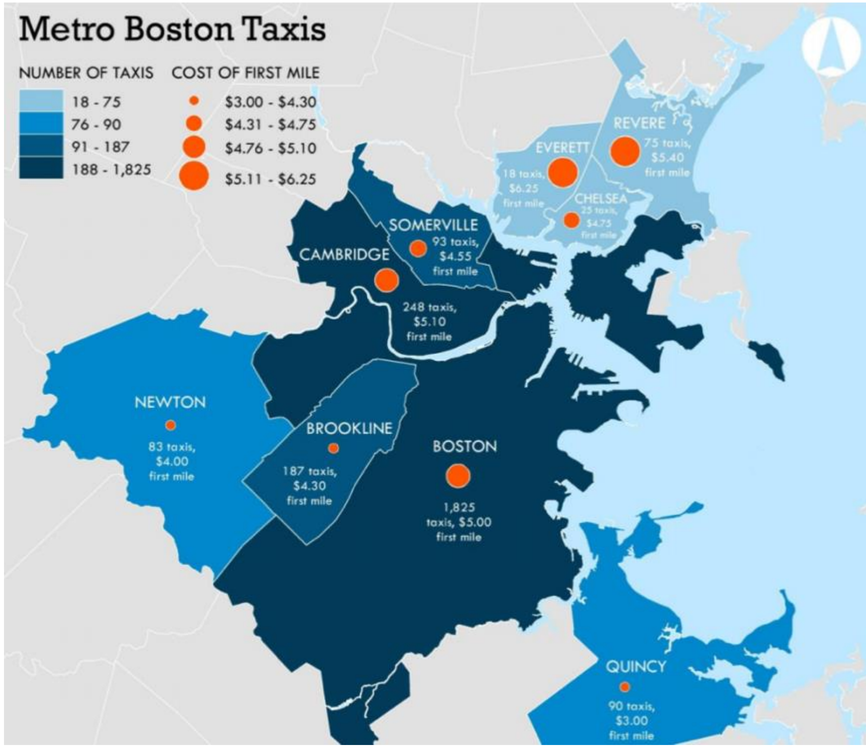


Figure 2-6 Map of Nine Distinct Taxi Regulations in Boston Metro Area (MAPC, 2017)

In comparison to the relatively fractured nature of the taxi supply and regulation across a metropolitan area, TNCs operate a single platform, with a region-wide reach which spans a public transit agency's footprint and could allow for a simpler station access system than coordinating and developing technical solutions with taxi operators in each municipality throughout a region. In addition, TNC's greater service reliability – especially outside the downtown corridor – during peak hours offers an advantage over taxis for the commuter base that runs on tight schedules.

The price of a TNC trip is primarily a function of distance traveled whereas someone who decides to park pays the same price regardless of how many miles away they live from the station. In the case of Uber[1], the cost of an individual trip is a function of a booking fee, base fare, trip distance, trip duration and a fare multiplier:

$$price = (base\ fare + \beta D * miles + \beta T * minutes) * (fare\ multiple) + booking\ fee$$

Equation 2-1 Generalized Uber Fare Structure

where: base fare, βD, βT, and booking fee are constants that are fixed within a given territory; and, the fare multiple reflects real-time differences between supply and demand and varies by time and location. Fares are generally subject to a minimum fare within a given territory.

In this paper I focus on Uber as an example TNC for my analysis for the sake of simplicity given Uber's global market position and unique opportunities available to me.[2] However, other TNCs, like Lyft have the same key attributes and capabilities as Uber and the findings of this thesis should be broadly applicable to them.

2.6 Methodological Roadmap

This paper explores this potential for transit agencies to continue to provide vehicular station access for existing park and ride passengers without the need to displace significant space that could be better served as Transit Oriented Development. I will also discuss how subsidized TNC station access could best be structured for this specific use case and be

[1] Lyft also has the same fare structure.
[2] When I started work on this thesis, I was already working for Uber as an intern, which helped facilitate the analysis for this thesis.

leveraged by transit agencies to more efficiently and effectively increase public transit usage by minimizing the tradeoff between TOD and vehicular access types to transit, like P+R facilities.

In order to unlock TOD, one of the most common strategies available to transit agencies is to convert surface P+R lots into TOD leases (Suzuki et al., 2015). Historically, transit agencies have required a 1:1 parking replacement when converting existing P+R surface lots into TOD. This means that private developers were required to replace all P+R spaces to ensure that incumbent riders were not lost because of a reduction of commuter parking. However, this full parking replacement practice has some shortcomings. Besides focusing on and prioritizing only one access mode (P+R users), the high cost of parking construction – in excess of $30,000 per structured parking space – creates a financial impediment to joint development projects. The developer's construction costs to build the mandated replacement parking is subtracted from their cash TOD lease payments to the transit agency. Sometimes, the developer's projected revenues cannot even offset their replacement parking costs, which besides negating the transit agency's residual land value prevents otherwise worthwhile TOD projects from being implemented (MBTA Advisory Board, 2015). In addition to the construction costs of replacement parking, the physical space that the parking occupies limits the TOD project's footprint and density and ensuing lease value (Transportation Research Board & National Academies of Sciences, 2014).

TCRP 224's Guide to Joint Development for Public Transit Agencies discussed whether transit agencies prefer to have the private developer build the replacement parking as opposed to the transit agency using the proceeds from the TOD lease to build it itself. A third option was having the transit agency fund the replacement parking itself but contract the developer to design and build it. The report states "replacement garages are very expensive, and while there are alternative approaches for where to place this cost in the transaction structure and how to "count" it, transit agencies understand that at the end of the day, this cost will have to be absorbed, directly or indirectly, in the value they realize from the land. It may be absorbed directly in a lower land price or indirectly in the agency's use of its sale or lease proceeds to fund the garage." (Board et al., 2021) While the agency's net financial outcome remains the same given a fixed amount of replacement parking, the "transaction structure" of who explicitly pays for the design/build of the replacement parking impacts the terminology this thesis subsequently uses when discussing the net cost the transit agency is incurring by continuing to provide P+R station access. For a simple example, if a transit agency converts a 200-space surface parking lot into TOD with replacement parking while collecting PV $10 million in lease payments from the developer and then separately pays the developer $6 million to construct the garage, the transit agency is explicitly subsidizing the 200 replacement spaces by directly paying the $6 million construction costs in a separate transaction. Alternatively, if the agency bundled the replacement parking with the TOD lease payments and had the developer pay $6 million for the replacement parking and only $4 million in lease payments, the transit agency is implicitly subsidizing the 200 replacement spaces by foregoing $6 million in additional lease revenue to have the developer pay for the replacement parking construction costs.

Transit agencies have historically implemented the 1:1 replacement parking practice to ensure that existing passengers were not lost because of reductions in P+R spaces. However, if a surface lot is chronically underutilized, it is obvious that 100% replacement parking is unnecessary to maintain ridership and diminishes the transit agency's financial return from the

TOD lease. The tradeoff is more complex when the P+R lot is heavily used and the decision involves not only P+R revenue and ridership, but the ridership and revenue generated by different TOD scenarios, the value of the TOD lease and the cost of the replacement structure.

Chapter 3 of this thesis puts a financial price tag on the tradeoff between P+R lots and TOD using the North Quincy MBTA rapid transit station as a case study. The approach used is a simplified version of BART's "Replacement Parking for Joint Development" Policy (Willson et al., 2005), which has been in use by the Bay Area's transit agency since 2005. The BART methodology removed the requirement of a 1:1 parking space replacement when converting an existing P+R lot to TOD and instead evaluates various parking replacement scenarios to better understand the financial and ridership impacts. BART adopted the policy after it became clear that their previous 1:1 replacement parking policy was negatively impacting the transit agency's ability to lease out its valuable land assets for TOD (Weinberger et al., 2016). BART's four step methodology takes a broader approach to station access in contrast to a strict 1:1 replacement policy and aligns with the principles of supporting ridership and improving the agency's fiscal health while accounting for access mode split, system capacity and support of broader agency and regional goals. The four steps are 1) Summarize key policy and context issues, 2) Build TOD scenarios at different amounts of replacement parking, 3) Evaluate ridership and financial impacts of the scenarios and 4) Select preferred strategy (Willson, 2005).

Chapter 3 of this thesis uses a simplified BART framework and quantifies the MBTA's foregone net revenue (implicit subsidy) by requiring a 100% replacement of their 852 P+R spaces at North Quincy Station as a condition of their TOD lease. The methodology takes the selected TOD bid with 100% replacement parking and considers an alternative TOD scenario with the same private development density and total footprint but without any replacement parking. It compares each scenario's financial impact to the existing conditions by considering revenue/cost changes in parking revenue and operating costs, parking replacement capital costs and TOD ground rent. Unlike BART's implementation, the simplified methodology this thesis adopts does not quantify net ridership changes by incorporating ridership gains from TOD and instead only focuses on the impact to existing P+R ridership. By comparing the net revenue and P+R ridership differences of these two scenarios, this thesis quantifies the "implicit parking subsidy" (or foregone revenue) the MBTA is incurring by requiring 100% replacement parking as part of their TOD project at North Quincy Station.

After quantifying the transit agency's implicit parking subsidy to retain existing P+Rers at North Quincy Station, Chapter 4 considers additional scenarios that the MBTA could consider to better address the (often competing) dual goals of increasing net revenues (reducing the implicit subsidy) and minimizing ridership losses from existing P+Rers (or alternatively increasing net ridership). The chapter primarily focuses on the alternative scenario of using TNCs to provide subsidized station access (TNC+R) to a portion of incumbent P+R users in lieu of replacement parking spaces. The thesis considers a TNC subsidy where a P+R user is financially indifferent between the two modes of station access, using only short-term costs (i.e., ignoring factors like cost of vehicle ownership) and thus set at the rider's daily parking price. A TNC trip fare is predominately determined by the trip's duration and any fare in excess of the P+Rer's parking fee would require subsidization by the transit agency. From this, we determine how long a TNC trip to the station can be before the required transit agency subsidization exceeds the implied parking subsidy from Chapter 3. Under these trip conditions, the transit agency could retain incumbent P+Rers by providing them a subsidized TNC+R alternative, at a lower implied cost (higher net revenue) to the transit agency. P+R travel time data to North Quincy Station from an MBTA survey allows us to calculate the total number of P+Rers that could be diverted to TNC+R at a lower agency cost, thus reducing the number of replacement parking spaces while retaining existing P+R passengers and collecting more net revenue from the TOD project.

Chapter 3 Implicit P+R Subsidy

Transit agencies have historically implemented the 1:1 replacement parking practice to ensure that existing passengers were not lost because of reductions in P+R spaces. This chapter seeks to better understand the financial impact of mandating 100% replacement parking and quantify the foregone financial value ("implicit subsidy") that a transit agency chooses to incur. I use a current MBTA TOD project at North Quincy Station as a case study.

3.1 North Quincy Station Case Study

The case study is a project currently being developed at North Quincy Station, which will convert an existing P+R surface lot into a TOD lease with 100% replacement parking. The financial analysis will ultimately consider the cost per existing P+R user, quantifying the cost to continue to provide parking spaces for current users of the MBTA station and the resulting foregone revenue or "implicit subsidy" to maintain the transit station parking status quo in lieu of no replacement parking and additional TOD benefits.

3.1.1 North Quincy Station Background and Profile

North Quincy Station serves over four Boston area communities including South Boston and Quincy. In addition to being a stop on the Red Line, the station is served by 8 MBTA bus routes. In 2014, an average of 6,975 riders entered the Red Line station each weekday (MBTA, 2014b). The primary mode of access to the station is by walking and the second is via automobile, accounting for over 30% of riders in the 2008-2009 CTPS Passenger Survey (MBTA, 2010). The same survey determined that 75% of North Quincy Station boardings were for home-based work trips and the top four reasons for using North Quincy Station were: 1) avoid driving/traffic; 2) avoid parking at destination; 3) convenience, 4) less expensive.

3.1.2 North Quincy Station Parking Current Condition

North Quincy Station has two MBTA parking lots that total 1,206 P+R spaces. The North Quincy TOD project site currently consists of the 852-space MBTA surface parking lot on Hancock St and has an area of 7.2 acres, which adjoins the Red Line station (Epsilon Associates, 2017). The MBTA's second surface parking lot at North Quincy Station is located on Newport Avenue and provides another 354 parking spaces (MBTA, 2015a), which will remain unaffected by the North Quincy TOD project. In FY15, the two combined MBTA surface parking lots brought in around $1 million in parking revenue to the MBTA, accounting for just under 200,000 vehicles paying the $5/day MBTA parking fee. For FY15, the 852 space Hancock St parking lot had a weekday utilization of 55% and grossed $600,000 in revenue across 122,000 parked vehicles.

2015 North Quincy MBTA Parking Data			
	Hancock St Lot	Newport Ave Lot	Combined Lots
Available Spaces	852	354	1,206
Weekday Average	469	255	724
Weekday Utilization	55%	72%	60%
Total Revenue	$613,734	$332,246	$945,980

Table 3-1 North Quincy Station Parking Utilization (MBTA, 2015)

3.1.3 North Quincy Station Transit Oriented Development Project

In July of 2015, continuing with the strategy of encouraging TOD and increasing annual recurring revenue through real estate leases (MBTA Advisory Board, 2015), the MBTA issued an

Invitation to Bid (ITB) for a 99-year ground lease on the existing 852-space MBTA parking lot at North Quincy Station. According to the MBTA, the ITB "is intended to free up as much of the square footage for private development as possible" and "the rent payment will be structured to maximize economic return to the MBTA." (MBTA, 2015b)

The ITB also required the successful bidder to replace all of the 852 surface parking spaces in a new on-site MBTA-owned structured parking garage at the private developer's sole expense. The ITB mandated that "the MBTA will only consider proposals that include a full replacement parking solution for the MBTA" on the parcel (MBTA, 2015b). In FY15, the surface lot averaged 143 cars parked per space for an average weekday utilization of 55%. After evaluating the submitted bids, the MBTA and FMCB finalized a 99-year ground lease that had the highest net present value (MBTA Advisory Board, 2016).

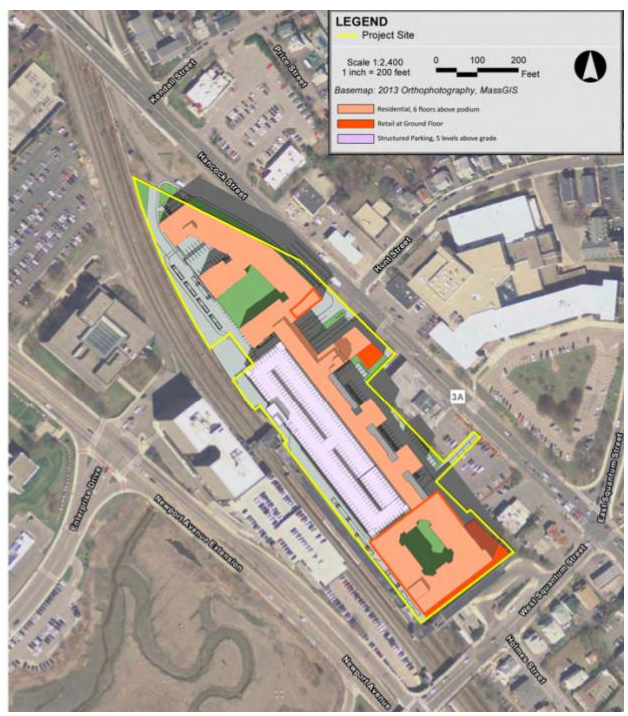


Figure 3-1 North Quincy Station Hancock St Surface Parking Lot (left) and planned TOD development (right) (Epsilon Associates, 2016)

Table 3-2 below illustrates the anticipated use of the existing parking lot land: 608,000 square feet devoted to 579 residential units, 42,000 square feet devoted to retail space, and the remaining space for the planned 1,307 parking garage spaces – 852 of which will be used for MBTA parking. Redevelopment will total 1,013,125 gross square feet that will occupy 95,000 square feet of land or approximately 7 acres. The net present value (NPV) calculated by the MBTA for the 99-year lease term was $20,079,227. A 5% interest rate was used by the MBTA to calculate the NPV of the lease. The MBTA estimated in addition to the $20 million in net present value, that the town of Quincy, where the parking lot is located, would realize $1.6 million in new tax revenue per year. This is because MBTA parking lots do not generate any property or sales taxes for the local municipalities.

	Bozutto/Atlantic Developer
GSF Residential	608,000
GSF Retail	42,000
GSF Parking	363,125
Total GSF per project	1,013,125
Residential Units	579
Private Parking Spaces	455
MBTA Spaces	852
Total Parking Spaces	1,307
Total Payments over 99-Year Lease	$230,617,279
NPV of Payment over Lease Term	$20,079,227
Annual City Tax Revenue	$1,600,000

Table 3-2 Final Bid Proposal of Winning TOD Developer (MBTA Advisory Board, 2016)

3.1.4 North Quincy Hancock St Replacement Parking Scenario Analysis

I compare the selected bid ("Scenario A") to the existing surface parking lot status quo and further consider an alternative TOD scenario without any replacement parking ("Scenario

B") using a simplified framework from BART's Replacement Parking for Joint Development Access Policy Methodology, first discussed in Chapter 2.

The BART methodology involves building a series of development and replacement parking scenarios, which are subsequently evaluated. Scenario B takes the same TOD proposal from Scenario A but replaces the square footage occupied by the 852 replacement MBTA parking spaces with TOD. This Scenario (B), thus allows us to estimate the MBTA's foregone financial benefits due to its mandating a 1:1 parking replacement.

	Existing Condition	Scenario A: TOD with 100% Replacement Parking	Scenario B: TOD with 0% Replacement Parking
Total Gross Square Feet*	236,712*	1,013,125	1,013,125
GSF Residential	0	608,000	793,366
GSF Retail	0	42,000	54,805
GSF Private Parking	0	126,413	164,954
GSF MBTA Parking	236,712	236,712	0

Note: *for simplicity, the SF of the existing surface parking spaces is included in the "Gross Square Feet" row

Table 3-3 Development Scenarios for Hancock St Lot

Table 3-3 shows the land uses under: the existing conditions, 852 MBTA surface parking; Scenario A (current plans) and Scenario B. Scenario B has the same total gross square footage of Scenario A, but reallocates the 237k GSF for MBTA Parking to private TOD using the same GSF Residential/Retail/Private Parking proportions as the private TOD in Scenario A. Next, we evaluate the different scenarios by comparing the revenue and cost impacts under the alternatives. Table 3-4 below shows a schematic diagram of the financial differences between the scenarios.

	Existing Condition	Scenario A - TOD w/ 100% Parking Replacement	Scenario B - TOD w/ No Parking Replacement
Parking Revenue	*Continued parking revenue from the existing 852 surface MBTA parking spaces*	*Continued parking revenue from the 852 replacement parking spaces provided to the MBTA by the developer*	*N/A*
Lease Revenue	*N/A*	*Lease revenue paid by the developer for the use/benefit of 776k SF of developable space*	*Lease revenue from the 776k SF from Scenario A and additional revenues from the 236k SF of developable space that would otherwise be occupied by the 852 spaces of MBTA parking and the construction costs associated with them*
Parking Operating Costs	*Annual O&M associated with MBTA parking for the existing 852 surface spaces*	*Annual O&M associated with MBTA parking for the 852 replacement spaces*	*N/A*

Table 3-4 Schematic of Financial Evaluation of Scenarios at N. Quincy

Next, Table 3-5 details the specific conditions of the North Quincy Hancock St parking lot to calculate the revenue and cost impacts of the two scenarios.

Revenues and Costs	Existing Condition		Scenario A		Scenario B	
Parking Revenue	Variables	Present Value	Variables	Present Value	Variables	Present Value
Number of MBTA Spaces	852		852		-	
Annual Cars parked per MBTA space	143		143		-	
Daily parking price	$5		$5		N/A	
MBTA Parking Revenue		$12,690,633		$12,690,633		$0****
Lease Revenue						
Lease Value per Developer SF*	$75.69		$75.69		$75.69	
Developer TOD Square Feet	0		776,413		1,013,125	
Lease Value	0		$58,764,710		$76,680,828	
Replacement Capital cost per space**	0		$35,000		$35,000	
Garage lifespan before major capital investment***	30 years		30 years		30 years	
Number of MBTA Spaces Replaced	0		852		0	
Cost of Replacement Parking over 99 Year Lease***			$38,685,483		0	
Lease Value after replacement parking costs		0		$20,079,227		$76,680,828
Costs						
Parking O&M Yearly Costs per Space	$240		$240		N/A	
MBTA Operating Costs		$4,259,793		$4,259,793		$0
Net Present Value* **		**$8,430,840**		**$28,510,067**		**$76,680,828**
Notes:						
*This is calculated from the NPV the developer is paying the MBTA (including construction costs of the replacement parking) to benefit from their 776k SF of private TOD						
**Based on construction costs per parking space for other MBTA garages, including Wonderland ($36,500), Beverly ($68,200) and Salem ($54,500)						
***This includes the upfront construction costs and based on a 30 year useful life, the cost of replacing the garage every 30 years over the course of the 99 year lease term						
****To replicate the MBTA's ITB decision, 99 year period and 5% discount rate were used						
*****Assumes that all revenue from existing parkers is lost and no additional vehicles choose to park at the other MBTA North Quincy surface parking lot						

Table 3-5 Detailed Financial Evaluation of Scenarios (MBTA Advisory Board, 2016; Rocheleau, 2012; Rosenberg, 2014)

Finally, Table 3-6 summarizes the financial impact of the various scenarios.

Relative to Existing Conditions	Scenario A: TOD with 100% Replacement Parking	Scenario B: TOD with 0% Replacement Parking
Change in MBTA Parking Revenue	$0	-$12,690,633
Change in TOD ground rent	$20,079,227	$76,680,828
Change in O&M Parking Costs	$0	-$4,259,793
Change in Net Present Value	$20,079,227	$68,249,987
Annualized Worth	$1,012,042	$3,439,967
Annual Parked Vehicles	0	-121,940

Table 3-6 Summary of Scenarios A and B Relative to Existing Conditions

Looking at the differences between Scenario A and B, Table 3-6 shows that the MBTA will forego $48.2 million (NPV) over the economic life of the project, in order to retain the 122,000 annual parked vehicles at the 852 spaces. This translates to an annualized worth of approximately $2.4 million, or approximately $20 per parked vehicle. It is clear that the transit agency is sacrificing significant financial value in order to not displace incumbent riders. In the next chapter, this thesis will investigate if a TNC+R alternative might allow the transit agency to retain existing ridership at a lower “subsidy” to the agency.

Chapter 4 TNCs as an Alternative to Transit Station Parking

As shown in the North Quincy analysis, the MBTA stands to gain some $48 million in NPV over the life of the project or roughly $2.4 million in annualized worth, if it did not replace the 852 P+R spots. This means that the MBTA is willing to sacrifice an additional $2.4 million in annual net revenue in order to retain the ridership associated with 122,000 parked vehicles (P+Rers) per year (or 469 each weekday), resulting in an implicit P+R subsidy of $20 per existing rider. A critical question is whether the MBTA could spend less than $20 to retain that incumbent P+R user through an alternative means of station access, without the need of a P+R space. One way to provide such equivalent access would be to incentivize former P+Rers to use TNCs for station access , which this paper refers to as "TNC+R".

4.1 Proposed TNC+R Subsidy Alternative

In the case of North Quincy Station, the daily price of parking that the MBTA charges is $5. To the former P+Rer, a $2.50 one-way Uber fare to get to or from the station would be financially equivalent. But, for most P+R users, an Uber fare would be much more than the $2.50 each way, so the question becomes – could the revenues obtained from the additional TOD adequately cover the costs of substituting P+R for TNC+R?

Such a subsidy could be structured to give a percentage discount off of the ride or a fixed dollar discount, e.g., $5 off the total fare, for each trip to or from the station. I focus on the proposed rider flat fare of $2.50 per Uber trip to or from North Quincy Station, which is financially equivalent from the rider's short-term perspective and, thus, should make the rider financially indifferent. At this point of rider financial indifference, we can simulate the financial cost of the MBTA subsidizing Uber rides to and from North Quincy Station and compare it to the total implied parking subsidy at North Quincy Station, as calculated as the difference between Scenarios A and B presented in Chapter 3.

Given that the MBTA preferred Scenario A because it retained 122,000 annual P+R generated trips to North Quincy in lieu of Scenario B's additional $48 million NPV in TOD lease payments, I now consider a third alternative. "Scenario C" introduces a TNC+R component to help retain incumbent ridership while reducing the number of replacement parking spaces to allow for more TOD. Based on the MBTA's dual goals, Scenario C should be the preferred option if it can maintain station access for existing users of P+R and generate higher net revenues via increased TOD. This would happen if there are situations in which the additional TOD lease revenue generated from a decrease in the number of replacement parking spaces was greater than the subsidy required to convert an existing P+R user to TNC+R.

Besides requiring no permanent physical space, a key difference between providing Uber rides versus P+R parking is their cost functions. In the case of Boston in 2016, the formula for calculating the cost of an UberX trip is (Uber.com, 2016):

$$price = (\$2.00 + \$1.24 * miles + \$0.20 * minutes) * (fare\ multiple) + \$1.15$$

Equation 4-1 Uber fare formula in Boston 2016

The trip duration can be converted into the trip distance (and vice versa) if we assume the average vehicle speed does not fluctuate significantly for trips to a particular station. For TNC trips originating in Quincy in 2017, the average speed was 21 miles per hour (Mass.gov, 2017). This allows us to approximate the cost of an Uber trip to North Quincy Station without needing to know both the trip distance and the duration (in-vehicle travel time). Each additional minute someone lives from the station would add $0.63 to the cost of taking an Uber to North Quincy Station. Thus, the price of an Uber trip to North Quincy Station as a function of duration becomes:

$$price = (\$2.00 + \$0.63 * minutes) * (fare\ multiple) + \$1.15$$

Equation 4-2 Uber fare formula as a function of trip duration

With this we can forecast the cost of subsidizing Uber to North Quincy Station for the current P+Rers from the 2008-2009 CTPS MBTA Passenger Survey, which provides travel times in passenger cohorts by each station access mode (including P+R) for each individual MBTA station. First mentioned in Chapter 3, this systemwide survey was conducted for the MBTA by the CTPS. Paper surveys were handed out by CTPS at every MBTA station in sufficient volumes and times to be able to represent and capture insight into at least 85% of trip characteristics. At MBTA Rapid Transit Stations, 23,000 surveys were completed, representing an estimated 8% survey response rate. The stated purpose of the survey is to gather data that are not easily obtained through any other means. Data from this survey are "used to update the regional travel-demand model that is routinely used by the Boston Region Metropolitan Planning Organization (MPO)." Table 4-1 shows the distribution of travel times for MBTA P+Rers at North Quincy Station, who accounted for just over 30% of station riders in the 2008-2009 survey. P+R users have the highest average trip time to North Quincy station across all other access types at 12.7 minutes. For comparison, riders who walk to the station have an average travel time of 8.4 minutes and account for 52.5% of all station riders (MBTA, 2010).

Travel Time to North Quincy Station for MBTA P+R riders				
Trip time to Station (minutes)*	Upper Bound Imputed Distance (miles)**	% of P+Rers	Number of Current Parkers** *	One-way Uber fare****
0-5	1.8	17.3	125.2	$6.95
6-10	3.7	44.1	319.1	$10.49
11-15	5.5	16.7	120.8	$14.04
16-20	7.4	13.9	100.6	$17.59
21-30	11.1	4.9	35.5	$24.68
31-45	16.6	2.3	16.6	$35.32
Over 45		0.8	5.8	

*Average is 12.7 min according to CTPS Survey
**Imputed using the 21mph average speed for TNC trips in Quincy
***Calculated by taking the FY15 724 weekday average number of parked cars at the two MBTA North Quincy parking lots (combined capacity of 1206 spaces) and multiplying by the "% or P+Rers" column
****Calculated from Equation 4-2 and assuming an average fare multiple between 1.1-1.2 to allow for a buffer for "surge" trips

Table 4-1 Travel Time to North Quincy Station for MBTA Drive/Parkers (Mass.gov, 2017; MBTA, 2010, 2015a)

Table 4-1 shows the Uber fares corresponding to a range of survey-reported N. Quincy Station-access times. The table also shows the estimated number of riders by access time cohort based on the combined MBTA station parking volumes at the two P+R lots (the 852 space TOD site and the unchanged 354 spaces on Newport Ave) for 2015 – the most recent year's available data prior to the MBTA soliciting the TOD lease. As first introduced in Chapter 3, in 2015 the combined North Quincy P+R lots averaged 724 parked vehicles per weekday across the available 1,206 spaces, for a weekday utilization of 60%. The 852-space Hancock St lot averaged 469 weekday vehicles and the 354-space lot on Newport Ave averaged 255 parked cars.

4.1.1 TNC+R versus P+R Financial Analysis: Only Considering Riders' Short-Term Costs

A P+R user pays $5 (the daily price of parking) in short-term, immediate costs to access North Quincy Station. If we only consider the rider's immediate, short-term costs, a rider would be financially indifferent between P+R and TNC+R by continuing to pay $5 a day or $2.50 per one-way trip. Any TNC fare in excess of $2.50, would need to be subsidized by the transit agency to maintain a rider's financial indifference.

Because the TNC+R and P+R options are not mutually exclusive and are influenced differently by trip duration, it makes financial sense for the transit agency to support TNC+R access for trips within a certain travel time of the station while continuing to provide P+R for riders traveling from further away. In the case of North Quincy Station, given the previously calculated implied parking subsidy per one-way trip of $10, this breakeven trip duration is 12.8 minutes, or 4.5 miles. At this trip length, the one-way TNC+R fare to North Quincy Station would total $12.50.

A financially indifferent rider would cover $2.50 of the one-way fare (to mirror the $5 daily parking fee) and the MBTA would need to provide a $10 subsidy for the remaining fare, which matches the amount of the transit agency's implicit subsidy determined in Chapter 3 to retain existing P+R users. As seen in Figure 4-1 below, a TNC trip shorter than this breakeven duration would require a smaller subsidy, while the implicit parking subsidy remains unchanged since it is independent of travel time. For example, a 5-minute trip to North Quincy Station would have an average total Uber fare of $7, requiring an MBTA subsidy of $4.50, while the implicit P+R subsidy remains at $10/one-way trip. Thus, for any trips shorter than 13 minutes, the MBTA would be financially better off by subsidizing TNC+R trips in lieu of providing P+R; for station-access trips beyond 13 minutes, it would be cheaper for the MBTA to continue providing parking.

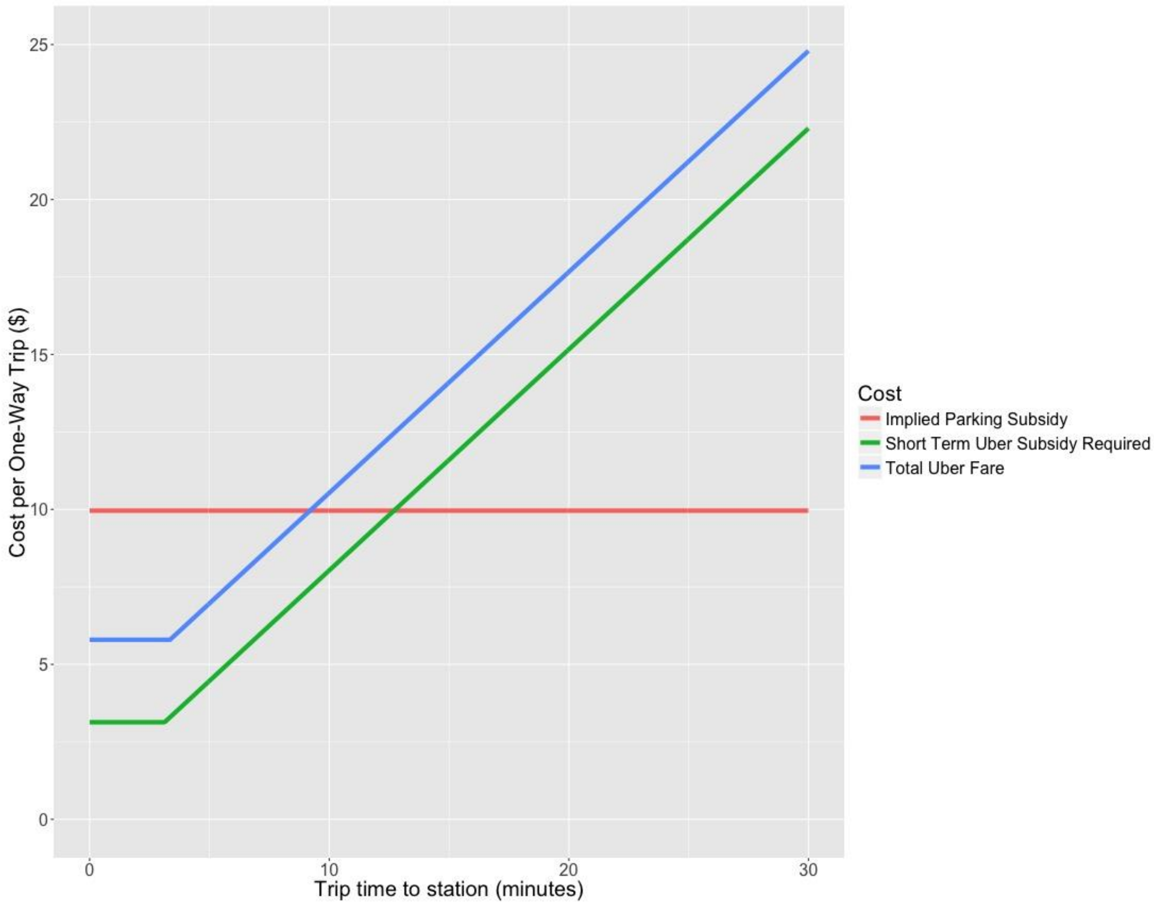


Figure 4-1 TNC vs P+R Costs as a Function of Trip Duration

The critical questions become: based on the $20/round trip implicit P+R subsidy the MBTA is incurring to retain the 852 parking spaces used by an average of 469 weekday riders, how many existing North Quincy P+R users could be retained by TNC+R at a lower marginal MBTA subsidy (increasing the MBTA's net revenue) and consequently how many of the planned 852 replacement parking spaces could be eliminated without sacrificing the daily passengers from 469 parked cars.

The specific North Quincy case allows us to consider parking volumes across both MBTA P+R lots – the 852 space TOD site and the unchanged 352 spaces on Newport Ave – to determine if 469 P+R users could be converted to TNC+R and yield a better financial outcome to the transit agency. By considering the combined parking volumes, the MBTA can unlock greater financial benefit by relocating any Hancock St P+Rers that live further than 13 minutes away to the Newport Ave lot and “trade” them with riders from the Newport Ave lot who travel for less than 13 minutes to North Quincy Station. Additionally, because not all of the 1,206 P+R spaces are being replaced as part of the TOD project – only the 852 parking spaces on Hancock St can unlock the $2.4 million in annualized worth – we assume that the MBTA gains zero financial value by converting any ridership in excess of the 469 weekday passengers that the 852 parking spaces currently generate. Thus, for the specific North Quincy case, we will only consider converting up to 469 riders from P+R to TNC+R – which the MBTA implicitly values at $2.4 million in annualized worth – even if there are still additional P+R users below the 13 minute breakeven point.

Trip time to Station (minutes)	Avg Weekday P+R Users	One way Uber fare*	Uber Subsidy per One Way Fare*	Annual Uber Subsidy per Rider per Cohort	Cumulative Annual Uber Subsidy Required	Cumulative Weekday P+R Users
0-5	125	$6.95	$4.45	$2,312	$289,449	125
6-10	319	$10.49	$7.99	$4,156	$1,615,796	444
11-15	121	$14.04	$11.54	$6,001	$2,340,920	565
16-20	101	$17.59	$15.09	$7,845	$3,129,958	666
21-30	35	$24.68	$22.18	$11,533	$3,538,887	701
31-45**	17	$35.32	$32.82	$17,066	$3,822,911	718**

Notes:
*This is an upper bound of the average Uber fare or subsidy per cohort since it calculates the fare using the max trip time in the range. (E.g., in the 6-10 minute bucket, only a 10 minute Uber trip would cost on average $10.49, while a 6 minute trip would be closer to $7)
**There are an estimated 6 additional riders that drive more than 45 minutes, which are not included in this table

Table 4-2 Short Term Costs - Uber vs Parking Subsidy Comparison by Trip Time

Table 4-2 highlights (in shaded cells) instances where a user could be converted from a P+R to a TNC+R at a lower agency net cost. The table estimates that providing a TNC+R for the 444 existing P+R users that drive for less than 10 minutes would require a $1.6 million annual subsidy. This only leaves room to convert up to 25 additional weekday riders before reaching a total of 469 converted riders. I make the assumption that at least 25 of the 121 riders in the 11- to 15-minute cohort travel less than the 13-minute breakeven trip time and can be converted to TNC+R at a lower subsidy to the MBTA. For simplicity, I assume it still costs the MBTA $11.54 per one-way trip for these 25 riders even though it should theoretically require a subsidy of less than $10. These 25 additional riders each require $6,000 in annual TNC+R subsidies, adding $150,000 to the cumulative annual subsidy amount. At this point, the MBTA can convert an estimated 469 P+R users (or 122,000 annual trips) to TNC+R at a total annual subsidy of $1.8 million. Because the TNC+R is able to convert all of the trips that the 852 parking spaces previously facilitated, all of the Hancock St parking spaces can be eliminated and the MBTA's financial return would be an additional $48 million (in PV), due to increased lease payments for the TOD. After using a portion of the TOD lease payments to fund the TNC+R subsidy, the MBTA is able to increase their net present value by over $13 million (or $665,000 in annualized worth) by decreasing their "subsidy" more than 25% to $14.50 per retained round trip.

	P+R	TNC+R	TNC+R vs P+R Difference
Parking Spaces Eliminated	0	852	852
Avg Weekday Riders	469	469	0
Annual Trips Retained	121,940	121,940	0
Avg "Subsidy" per Round Trip	$19.93	$14.48	($5.45)
Annual "Subsidy" Required	$2,430,264	$1,765,812	($664,452)
PV of Subsidy over 99 Year Lease	($48,217,185)	($35,034,249)	$13,182,935

Table 4-3 Comparison of P+R and TNC+R

4.1.2 TNC+R versus P+R: The Longer Term

The above analysis assumes P+R users only consider the most salient costs when making the station access choice: the $5 parking fee paid to the MBTA (or $2.50 per one-way trip). Users might also consider other financial and longer-term costs in their decisions, including vehicle ownership, insurance and maintenance costs, and how they are impacted by driving. For example, if a user actually factored in the estimated full $0.17 in operating & maintenance expenses per mile driven (AAA, 2015), the amount they might be willing to pay for TNC access would go up and thus the subsidy required from the MBTA would go down and the trip distances for which a TNC subsidy would be attractive to the MBTA would increase. Better understanding these possibilities, however, would require more detailed analyses of consumer behavior and choices vis-à-vis car ownership, use, and perceptions of costs.

4.2 TNC+R vs P+R Subsidy: Potential Benefits and Drawbacks

One concern about the feasibility of subsidizing access to North Quincy Station via a TNC like Uber is the potential to cannibalize riders from other modes of access besides driving and parking. This is important for the MBTA to realize the greatest gains because most other modes of station access, particularly at North Quincy Station require minimal subsidization to draw riders to the station. In fact, at North Quincy Station, based on the CTPS MBTA Passenger Survey (MBTA, 2010), more than half (53%) of daily riders walk to the station, while 32% used P+R, and another 9% were dropped off at the station. To use P+R, the individual must "belong" to the auto ownership "club" – at an average cost of vehicle ownership is $8,700 each year according to AAA (AAA, 2015). An implied P+R subsidy is, thus, likely inequitable in terms of favoring wealthier users. Indeed, MBTA customer parking demographic data shows that while their age and employment status are similar to non-P+Rers, P+Rers tend to be wealthier than those who do not use MBTA transit station parking facilities (MBTA & Nelson/Nygaard, 2018). To use TNC+R, a user only needs a smartphone and a form of digital payment, which could be a credit card or Uber gift card. Considered thusly, subsidizing TNC+R versus P+R could allow the MBTA to make the subsidy more equitable if the transit agency so desires.

That said, the lower barrier of using TNC+R compared to P+R poses an operational and financial threat to the MBTA. Namely, how to ensure equitable distribution of a TNC+R subsidy and/or ensure that the total amount of subsidy does not exceed the implied subsidy of providing parking facilities? The proposed TNC+R subsidy is structured so that the rider is financially indifferent between TNC+R and P+R; the end user would still need to pay a minimum of $5.00 to benefit from it. MBTA P+R users are the only substantial subset that must pay "more" to access the transit station. For a TNC subsidy to cannibalize from station access modes other than P+R, riders would have to be willing to pay money out of pocket – which they currently avoid – to benefit from the subsidy. A TNC subsidy would still require a rider payment to access the transit station ($5.00 day) – in contrast to all other modes.

According to the 2008-09 user survey (MBTA 2010), only 38% of North Quincy respondents did not have access to a vehicle to get to the station and only 13% were part of a household that had no vehicles. In other words, 62% of riders had the vehicle means for P+R but just half of them, or 32% of total riders, were willing to pay the $5.00 daily P+R fee. This suggests that a TNC+R subsidy would only modestly cannibalize other station access modes, although clearly this requires more detailed data and analysis.

In any case, the approach could be designed such that the MBTA could have strong controls over a TNC+R subsidy and could structure the program to target riders and trip types that best meet the agency's goals. For example, the MBTA could structure a TNC+R subsidy so that a rider pays the first $25 (i.e., the equivalent of parking five days per week) in total trips to or from North Quincy Station each week with the rest of the trips to the station for that week covered by the subsidy. The time frame could be changed to monthly or yearly depending on agency goals, as could the amount the rider must pay upfront to get the TNC+R subsidy. This approach would allow the MBTA to target frequent station riders (e.g., weekday commuters who access the station five times a week); increasing the time interval also encourages the rider to factor in longer term costs like vehicle ownership into their transportation decision, which could lower the required amount the MBTA needs to subsidize to make the rider financially indifferent. The structure also lets the MBTA incur TNC+R subsidies only if a given rider takes a certain number of trips to the station in a given time frame. Compare this to the current North Quincy Station implied P+R subsidy: $20 for each parked car, regardless of whether it is for a daily commuter or one-off tourist on the weekend.

A TNC+R subsidy could also be limited to trips beginning or ending in particular geofences and time-gated to certain hours of the week. This could be one method to cap the amount the MBTA subsidizes for a given trip and would allow for additional targeting of who benefits from the subsidy to align with agency goals. For example, it could be limited to peak commuting hours or time periods where station parking facilities are above their 85% target utilization to attract potential North Quincy Station riders who would otherwise be dissuaded by the prospective parking congestion. For a station that already has parking facilities, it would make sense for the MBTA to subsidize a TNC trip during periods of high parking occupancy and less so when there is ample parking available – generally all non-commuting hours and weekends – where parking spaces are otherwise sitting empty instead of being occupied by another MBTA passenger. Tailoring a TNC subsidy by geofence could also allow the MBTA to achieve greater equity by targeting higher subsidies to specific neighborhoods or census tracts that have lower household incomes.

A significant drawback of providing station parking facilities is the lack of flexibility and challenge of predicting future conditions and demand over such a long, multiple-decade time horizon. Like any major capital investment – yet unlike the TNC+R alternative – most of the P+R costs are upfront, and high, incurred well before revenues are realized. That said, the proposed TNC+R subsidy faces its own lack of control; specifically, the MBTA has little ability to control the cost structure of TNCs, in the short and long terms. As mentioned above, the MBTA could structure subsidized TNC+R access to cap their own costs, both on an individual trip or aggregate basis. For example, the transit agency could implement a fare structure so that the rider pays the first $2.50 of a TNC fare, the MBTA subsidizes up to the next $10, and the rider pays any fare amount in excess of $12.50 per trip. At an aggregate level, the MBTA could choose to stop subsidizing TNC+R trips to North Quincy Station for a given year once they have exhausted their annual $1.8 million planned subsidy budget. While this approach would allow the MBTA to control their own total cost, the brunt of it would be borne by riders, limiting the number of riders who could benefit from the TNC subsidy and/or forcing riders to have to cover any cost overruns.

This situation would commonly arise when TNCs employ dynamic pricing, mainly increasing fares during peak times when an area is undersupplied. If TNC+R generated more demand than supply, in the short term, a TNC would implement surge pricing, forcing a rider to pay for all of the increased fare if the MBTA capped their per trip subsidy at $10. Over the long term, if TNCs increased their fares at a rate greater than overall inflation the MBTA would either have to increase the total amount they spent on TNC+R subsidies or decrease the total number of trips and riders that could benefit from the subsidy. However, even if Uber's base fares almost doubled in price after adjusting for inflation, it would still be cost competitive to provide TNC+R for the 17% of overall P+R users that travel up to 5 minutes to access North Quincy Station. In contrast to being locked into a 99 year lease period, a transit agency contract for TNC+R would have a much shorter length – perhaps annually – and any unforeseen cost issues could be addressed quite promptly and reflected in the renewal evaluation process.

Even in a future reality where TNCs are more expensive than a parking subsidy across any trip length, it would only be a relatively short-term problem because the MBTA, at least in the North Quincy case, could still choose to construct parking facilities. For example, the MBTA retains some “option value” by keeping the current 354-space parking lot on Newport Avenue. If the cost of TNC+R subsidy exceeded the TOD revenues from the 852 replaced parking spaces, they could redirect the TNC subsidy to construct additional parking spaces at the Newport Avenue lot by converting the surface spaces to a multi-story parking structure.

Chapter 5 Situations for TNC Subsidy Consideration

Using North Quincy Station as a case study, we see some financial potential for the MBTA to use subsidized TNC services as a substitute for P+R. Because of the much different cost structures of TNCs and P+R facilities, it most likely makes the most sense to use the two mechanisms of station access in combination instead of in isolation. By using TNCs in select scenarios, similar to how park and ride facilities are only offered at a certain subset of MBTA transit stations, the MBTA could be better able to meet its goals by reducing implied parking subsidies while increasing net ridership at these public transit stations (MBTA & Nelson/Nygaard, 2018). Drawing from our modeling of a TNC subsidy (using Uber as the reference case) at North Quincy Station, I conclude by examining different scenarios to determine what situations and station characteristics would benefit from subsidized TNC station access. This will primarily be informed by understanding the primary cost components of the two alternatives and how different station characteristics and time periods influence them in order to identify situations where one station access mode outperforms the other.

In contrast to TNCs, the main determinant of the transit station parking subsidy amount is the land value next to the station, where the parking facilities are located. The value of the land determines if the spaces should be a surface lot or structured garage; the more expensive the land, the greater the incentive to build up (multi-story parking structure) than out (surface lot). Building up, of course, incurs much higher investment costs and once a parking garage is constructed, these “sunk” costs cannot be easily recouped. The land value is also the main component of the opportunity cost (implied subsidy) associated with transit station parking –

the value the land could fetch for alternative development. The land value is also impacted by the existing allowable zoning densities (e.g., floor-to-area ratios) and land use types. If recent trends of increased mixed-use development density around station areas continue, the value of that land will likely increase as more units or uses can be situated on the same amount of land (Dain, 2019).

In general, within a given metropolitan area, land value is higher in areas of greater density, especially those in close proximity to public transit stations (APTA & NAR, 2018). In essence, this means that in station areas of higher land value and development density, P+R facilities imply a higher parking subsidy compared to other geographies in the region. This contrasts with TNCs, for which baseline pricing is uniform across the entire metropolitan region and is not really influenced by the land value of a specific station area. This simply means that a 10 minute, 2.5 mile Uber trip will cost the same amount of money, regardless of whether it is to Back Bay or Mattapan Station, even though the two station areas have significantly different land values.

Because of the vastly different upfront capital costs between garage versus lot P+R facilities, the two types of parking impact the moment in the parking facility's lifecycle when a TNC+R subsidy alternative should be seriously evaluated. Even without including land costs, the capital costs per parking space in a structure (garage) is around $35,000 and the MBTA generally expects structures to have a state of good repair for 20 years before any other major infrastructure investment is required. In other words, for structured parking, the window to consider the TNC+R option is open only once every 20 years, at the moment of deciding of deciding to build (or re-build due to end of economic life) a station-area parking garage.

Stations with surface parking spaces, on the other hand, could be evaluated for a TNC+R alternative on a more frequent basis because the spaces require significantly less sunk, upfront costs (“only” $5,000 per space). That said, stations with surface parking likely have lower land value; such that the implied subsidy (the foregone revenues from developing TOD) would likely be lower. This would decrease the likelihood of subsidized TNC+R access being financially worthwhile because the TNC fares are largely independent of land value within a region. As a result, the most likely case where an existing surface parking lot would benefit from the TNC+R subsidy is a station area that has undergone an increase in land value such that it now makes more financial sense to have a parking structure than surface spaces: building parking up instead of out. We see this manifest in the surface lot to parking structure consolidations at North Quincy and Wonderland Stations.

Parking utilization at existing station facilities and reciprocal parking revenue will most likely not impact the decision to pursue a TNC+R subsidy approach or change the time frame of that decision. Instead, it would only influence changes at the margin and would primarily be used in determining the exact travel times to the station that could benefit from the TNC+R subsidy. This is because parking revenues are insignificant compared to the capital and land opportunity costs, particularly for stations with parking structures. As mentioned in the literature review, offering transit station parking at below cost is by design in order to attract commuters to take public transit into the city center, where private parking facilities need to charge much higher prices just to breakeven (TCRP/TRB & National Academies of Sciences, Engineering, and Medicine, 2005). Because of this, parking utilization and revenue alone will not change the time frame under which a TNC+R subsidy should be evaluated or implemented except in the extreme scenarios.

Two extreme parking utilization scenarios come to mind. The first is when a station parking lot is deemed too full to effectively operate – particularly during weekday mornings – which would dissuade prospective riders from using public transit at all. A subset of stations that would fall into this bucket would be those operating at greater than 85% weekday parking utilization (MBTA Advisory Board, 2015). If the agency determined that more parking was the preferred remedy to the P+R overutilization, the transit agency could consider a TNC+R subsidy, either as a stop-gap measure (while the additional parking is being constructed) or for sustained long-term use.

The second extreme parking utilization scenario is when the existing station parking facilities are dramatically underutilized, such that revenues do not cover the estimated $240 in baseline annual operating and maintenance costs. This negative cash flow at these parking facilities means it would make sense for the agency to evaluate a switch to a TNC+R subsidy in the immediate term. Some MBTA stations that could fall under this scenario are Mattapan and Greenbush, which only brought in FY15 annual revenue of $221 and $209 per space respectively (MBTA, 2015a).

Certain public transit station typologies and characteristics would be more favorable to deploying a TNC+R subsidy. We now can see that TNC+R becomes more financially attractive compared to P+R as land value increases because of the underlying difference in cost structures. However, like park and ride facilities, TNC+R access still puts a vehicle on the road and contributes to the region's VMT. Thus, the rationale behind exploring a TNC+R subsidy is to substitute or complement existing station parking facilities and should be limited to stations with parking lots. In the literature review section, we learned that P+R facilities are provided to encourage commuters to take public transit to the city center instead of driving there directly and that park and ride facilities are located in many different station types, except for in the downtown core.

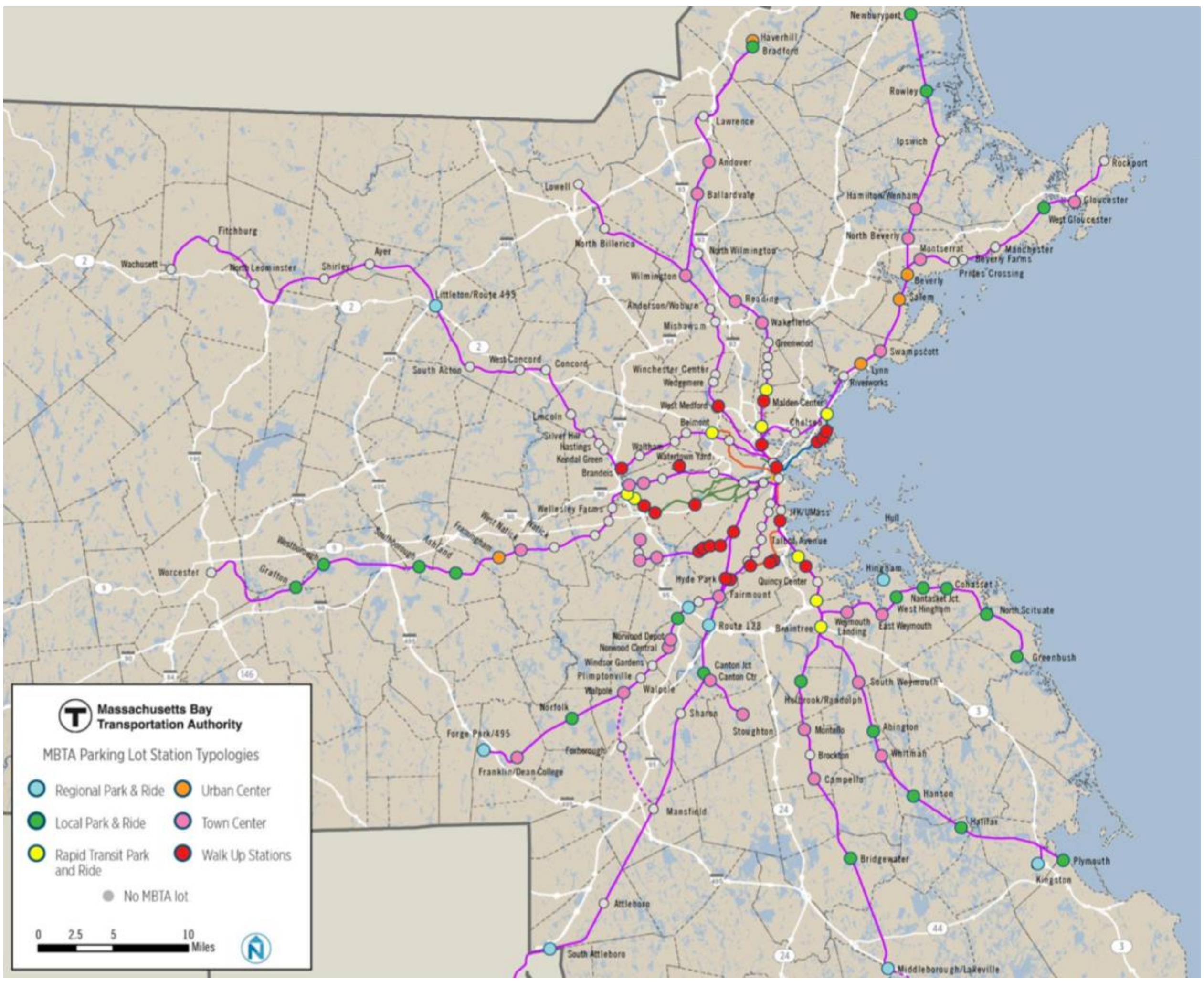


Figure 5-1 MBTA Parking Lot Station Typologies (MBTA & Nelson/Nygaard, 2018)

Transit stations with parking located closer to the city center would most likely be the best candidates for a subsidized TNC+R alternative to P+R. Based on CTPS/MAPC nomenclature, station types that fall under this umbrella include metro core, transformational subway, neighborhood subway and some urban gateway stations (indicated as "Rapid Transit Park and Ride" or "Walk Up Stations" in Figure 5-1 above). These station types generally offer rapid transit access and commonly have higher transit commute mode share, density, and WalkScores and lower daily household VMT and household transportation costs than station types with parking facilities located further on the outskirts of a region. Stations like these, that already have a higher share of walk and bike access, would have a smaller proportion of transit riders impacted by a possible switch to TNC+R. These station areas are already designed for and accommodate livelihoods where a vehicle is not requisite (MAPC, 2012).

These station types, which are located closer to the city center, will also have greater TNC reliability than station areas on the outskirts of a metropolitan area. Because of the primarily distance-based cost structure of TNCs, stations that have a larger share of existing P+Rers that live close to the station would be more favorable to an TNC+R subsidy. While the average driving time to the station would be a good proxy, looking at the actual distribution of driving times would help more precisely estimate the number of riders that would require a lower subsidy to access the public transit station.

The stations most likely to benefit from subsidized TNC+R access – either as a substitute or complement to parking – are those with existing parking facilities located closest to the city core. In addition, TNC's flexibility (infrastructure-less model) and minimal start up time and upfront costs allow them to be used to address specific station situations and potentially serve as both a short-term and longer-term option. For example, in the recent cases of the North Quincy and Wonderland MBTA Stations, the construction of the parking garages led to yearlong disruptions of existing parking operations (MBTA, 2019). Even if the financials favored implicitly subsidized P+R over TNC+R, the MBTA could subsidize TNC+R access during the time period that the new parking facilities are under construction. Such a scenario would allow the agency to pilot the TNC+R alternative and help the MBTA determine how it could best operationalize a TNC+R for future scenarios.

Chapter 6 Conclusion

As we learned in the Literature Review, we know there is a tradeoff between P+R and Transit Oriented Development. In Chapter 3, we performed a financial analysis to look at the MBTA's decision to require 100% replacement parking as part of a TOD lease at North Quincy Station. We compared the MBTA's chosen scenario of TOD with 100% replacement parking to an alternative scenario without any parking replacement and determined that the MBTA was foregoing $48 million (NPV) in order to maintain station access for these 470 average weekday riders. On a per trip basis, this thesis estimated that the MBTA was incurring an "implicit parking subsidy" of $20 per parked car, in lieu of additional TOD.

Chapter 4 explored whether a subsidized TNC+R alternative could maintain existing P+R ridership with less replacement parking spaces and at a lower net cost to the MBTA. We focused on a TNC subsidy structured so that existing P+Rers would be financially indifferent considering only short-term costs. Using the North Quincy Station case study, I determined that a TNC+R subsidy for incumbent P+Rers who live within 13 minutes of the station could allow the MBTA to net an additional $13 million (NPV) from the TOD project while allowing additional TOD density without displacing any incumbent riders.

The simple financial analysis framework that this thesis utilizes certainly leaves a multitude of opportunities and questions for future research that were not addressed. Unlike BART's Replacement Parking Methodology, Chapter 3 did not consider the net ridership impacts between the replacement parking scenarios, which would also estimate transit trips generated from TOD (which would not need any station access subsidization) instead of solely focusing on changes in trips from P+R users. In Chapter 4, the analysis assumed riders would be agnostic between P+R and TNC+R as long as they paid the same price, which only considered the immediate rider expenditures. Future work could further investigate a user's actual willingness to pay for a TNC+R, which would better inform the required subsidy to switch a P+R to TNC+R. It would also shed light on whether users preferred driving vs. being driven, if they would consider longer term costs like vehicle expenses into their decision or be open to a shared TNC+R option like uberPool and lyftLine. A similar follow-up to survey non-P+R users would help estimate the risk of cannibalizing users from other modes of station access and help the transit agency decide how to best operationalize a TNC+R subsidy. Further quantification and sensitivity analysis of different scenarios would inform how differences between projections vs. future realities might change the optimal outcome. Additionally, future research could be done to investigate the best practices of governmental partnerships with TNCs and work with outside legal counsel to draft model contracts to address any contingencies and concerns associated with TNC+R. Further analysis could also be done to investigate if TNCs have the ability, in terms of supply of drivers, to accommodate any proposed increase in TNC trips to the station. Further work could better account for the political feasibility and sentiment of different proposals instead of narrowly focusing on the financial outcomes.

The analysis in this thesis indicates an interesting opportunity to address some of the shortcomings that come with P+R. It may actually make the most sense to use P+R and TNC+R in tandem to best realize the transit agency's objectives. Just as P+R plays an intermediate solution between high- and low-density areas, TNC+R is probably best situated at station typologies with existing parking facilities that have the highest land value and are closest to the city core. The lack of infrastructure required for a TNC subsidy allow TNCs to offer solutions of many shapes, timespans and sizes and if properly harnessed, present a new opportunity available to transit agencies that should be seriously considered.

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