

Toyota Mobility Foundation

Boston's MBTA and Transportation Network Companies: Characterizing the Dynamics

15.913 Strategies for Sustainable Business

Final Report

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1. Problem Statement

The Toyota Mobility Foundation (TMF) is committed to supporting equitable access to transportation for all people. To meet its social sustainability goals, TMF seeks to understand the dynamics between Transportation Network Companies (TNCs) and public transportation (subway, surface rail, and bus) and find a healthy balance that achieves increase in access to mobility and a sustainable transportation market. This project studies these dynamics in and around the city of Boston for the Massachusetts Bay Transportation Authority (MBTA).

Current state:

The tremendous increase in ridership for TNCs in recent years has both positive and negative implications on overall access to mobility and on the sustainability of the city’s transportation ecosystem. Ridership for TNCs has grown rapidly since 2014 with up to 96,000 rides per day in Boston in 2017 (up by 460% from 2014) [1], [2]. The increase in TNC ridership has led to the decrease in MBTA ridership (heavy rail -2%, bus -6% in past year) and revenue [3]. Thus, it is important to understand the dynamics between TNCs and MBTA and to examine the implications on the overall access to mobility and the sustainability of the city’s transportation ecosystem. The implications of the current state are summarized in Table 1.

Table 1 Positive and negative implications of increase in ridership of TNCs

Positive	Negative
Increase in access to mobility for people who do not have access to public transit	Cannibalization of ridership from conventional public transportation options → decline in revenue → undermined operations of public transportation
Decrease in congestion and pollution due to shared car rides	Increase in congestion and pollution from more TNC cars driving around
More space in the inner city from less cars parked	

However, currently the dynamics between TNCs and public transportation are not well understood. Moreover, there is a need for a more comprehensive data set that characterizes rider behavior and decisions and their implications.

Desired state:

The ultimate desired state would be to establish transportation policies that achieve the following goals:

- Increase equitable access to mobility (universal access to affordable, safe and convenient transportation) through
 - Strengthening public mass transit options
 - Sustaining public transportation (MBTA) as part of the ecosystem
 - Taking advantage of the positive aspects of TNCs
- Eliminate transportation deserts
- Alleviate traffic congestion, fuel consumption and emissions

Aim of the project:

The project aims to provide a set of tools to better understand the aforementioned dynamics: (1) develop a framework/structure (a causal loop diagram) that describes the relationship of key variables that impact the transportation ecosystem, and (2) devise a data collection methodology to understand rider behavior/decisions.

The framework may be used as the basis for policy recommendations to the city of Boston and a foundation for further analysis for the MBTA, Boston, and other cities and transit agencies operating in conjunction with TNCs. The suggested data collection methodology will enable a future focused study.

2. Why is it important to the organization?

Toyota Mobility Foundation (TMF) is a nonprofit branch of the Toyota Motor Corporation established in 2014 to help overcome all kinds barriers to mobility for all people. The Foundation combines Toyota’s extensive technology, expertise, and resources with organizations around the world to address the entire spectrum of mobility challenges, from urban transportation, congestion mitigation, to universal access and personal mobility for everyone. The following quotes exemplify TMF’s mission:

“Mobility has the power to reduce limitations, broaden horizons, and empower people to fulfill their potential, no matter where they live. We believe that everyone around the world should have the ability to grow, discover and explore.” [4]

“When people are free to move, they can broaden their horizons and fully realize their potential. Thus, we believe mobility is critical to creating societal progress and improving lives around the world.” [4]

The recent emergence and rapid growth of TNCs have changed the traditional transportation ecosystem. Hence, it has become important for TMF to learn about the impact of TNCs on access to mobility and existing transportation systems.

For this project, TMF seeks to research the dynamics between TNCs and public transportation in Boston. The effort will evaluate the conditions in which TNCs enhance the overall access and use of traditional public transit systems, and in which they can undermine public transit by cannibalizing ridership and revenue. The TMF intends to be able to replicate the study and apply the lessons learned to examine similar dynamics in other cities.

3. Sense-making

The full societal consequence of the skyrocketing popularity of Transportation Network Companies (TNCs) is quickly becoming an imperative field of study for groups interested in the sustainable well-being of population centers. In recent years, researchers have conducted studies in multiple major cities across the United States, including Boston, Denver, and Manhattan, to try to characterize how the prevalence of TNCs is affecting the overall transportation sectors in these cities. The following section gives an overview of some of these studies and the main conclusions and learnings accomplished from them.

Overall, the studies show that the rise of TNCs has been highly disruptive to traditional modes of transportation in metropolitan areas [5], [6]. They quickly took advantage of a combination of circumstances to flood the market with a highly desirable service that was largely outside the scope of regulators. The growth and demand for these services radically outpaced the ability of regulators or transportation planners to adapt or even understand their systemic impacts. In a very short time TNCs have become fundamental to cities' transportation ecosystems, and therefore any policy efforts that might hinder TNC availability risk depressing the residents' equitable access to mobility. Currently TNCs have very little incentive to share data or enter partnerships with governments and policy makers to try to holistically improve transportation ecosystems [7]. There is a significant lack of understanding of the business case to be made to incentivize cooperation among transportation mode providers or to incentivize riders to make decisions that improve transportation options for everyone.

3.1 Studies

- i) **Study:** Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the US [5]
Researcher: University of California, Davis: Institute of Transportation Studies
Metropolitan Area: Boston, Chicago, Los Angeles, New York, San Francisco Bay Area, Seattle, Washington DC

Year: 2017 (study conducted 2014-2016)

Motivation: The study was intended to support long-range transportation infrastructure decisions by collecting data on the adoption of TNCs, their impacts on travel choices, and how they affect transportation decisions and travel patterns.

Method: Researchers deployed an internet-based survey in seven major US cities, gathering demographic, travel, and residential choice data. Collected over 4,000 responses from adults evenly distributed among the targeted metropolitan areas.

Major Findings: TNC users tend to be college-educated, relatively affluent, living in urban neighborhoods, and young adults. On average, cities have experienced a 6% reduction in transit ridership with the rise of TNCs, and whether TNCs are complementing or cannibalizing transit ridership is difficult to determine and highly variable. Generally, TNCs detract from bus and light rail services, while complementing commuter rail. About 49% to 61% of TNC trips are substituting for other modes of transportation and are adding cars to the roads that would not have been there if TNC had not been an option.

Recommendations: Congestion pricing and enforced priority lanes for high-occupancy vehicles can help manage road congestion. Generate more and higher quality data on mobility service ridership, so that transportation planners and policy makers are better informed for long-term decision making, by mandating data sharing by TNCs or by executing more frequent data collection studies. Seek to understand how individuals and households make complex transportation decisions.

ii) **Study:** Fare Choices Survey of Ride-Hailing Passengers in Metro Boston [6]

Researcher: Metropolitan Area Planning Council (planning agency serving Metropolitan Boston)

Metropolitan Area: Boston, MA

Year: 2018 (study conducted October – November 2017)

Motivation: MAPC wants to understand the impacts TNCs are having on congestion and transit revenue in order to make effective policy decisions to plan for a sustainable transportation system for the future of the city. Due to restrictions barring public agencies from accessing much of the detailed usage data from TNCs, MAPC conducted the effort to collect information about TNC use directly from riders.

Method: In-vehicle intercept survey of ride-hailing passengers in a four-week period in cooperation with ten TNC drivers recruited by MAPC. Printed signs in participating vehicles asked passengers to take a survey on a tablet during the trip. MAPC collected 944 completed and valid surveys

Major Findings: Most of the respondents reported being 22 to 34 years old, college graduates, white, full- or part-time employed, and not owning a car. The distribution of reported incomes of respondents reasonably matched the income distribution of households in the region, with the largest portion of respondents reporting the lowest income range. The participants indicated a willingness to pay a substantial premium for the convenience and predictability of the TNC, and in

particular a non-shared ride. About 12% of TNC trips are substituting for transit trips, and 15% of TNC trips are adding cars to the roads during rush hour that would not have been there if TNC had not been an option. Each TNC ride represents a 35 cent loss of revenue to the public transit system.

Recommendations: Riders are increasingly accustomed to TNC mobility, but roadways can't accommodate further growth in vehicle travel. The city must provide a reliable and effective transit system that is competitive and complementary to TNCs. Regulations should establish a transportation fee structure proportional to the impact of each ride on the transportation system (congestion-based pricing, for example) such that these fees would fund the public transit system.

iii) **Study:** Impacts of Ridesourcing – Lyft and Uber – on Transportation [8]

Researcher: Alejandro Henao (Doctoral thesis for the University of Colorado Civil Engineering)

Metropolitan Area: Denver, CO

Year: 2017 (study conducted in Fall 2016)

Motivation: The researcher sought to understand how TNCs compete and interact with traditional transportation, and how they impact transportation systems, society, and the environment. There is a dearth of data available to understand and measure the impacts. TNCs are very unwilling to share their usage data.

Method: The researcher conducted in-vehicle intercept surveys of passengers while driving as an independent contractor for both Uber and Lyft. Collected data on 416 rides and collected 311 valid passenger surveys.

Major Findings: About 22% of TNC trips are replacing trips that riders would have otherwise taken on public transit, and 34% of TNC trips are adding vehicles to the roadways. On average, a TNC driver spends almost 40% of time traveled without a passenger. Riders are willing to pay a premium for TNC rides because public transportation is unavailable or undesirable. 12% of TNCs are trips that otherwise would have not been realized. The ratio of passenger miles traveled to vehicle miles traveled in Denver has decreased from 112.3% to 60.8% due to the increase in TNC rides.

Recommendations: TNCs are insufficient to meet a city's transportation needs. Cities must focus resources on protecting public transportation in the face of the rise of TNC popularity.

iv) **Study:** Empty Seats, Full Streets *Fixing Manhattan's Traffic Problem* [9]

Researcher: Schaller Consulting with cooperation from the Taxi and Limousine Commission and NYC Department of Transportation

Metropolitan Area: New York City, NY

Year: 2017

Motivation: Examine the impact of TNC growth on traffic conditions in the Manhattan Central Business District (CBD), in particular to assess anti-congestion plans being developed by city and state governments.

Method: Researchers compiled available trip data obtained from the New York City Taxi and Limousine Commission, the New York City Department of Transportation, and Uber (through Freedom of Information Law requests) from 2013 and 2017. Researchers analyzed datasets for over 30 million trip records beginning and/or ending in the Manhattan Central Business District, focusing on key metrics: trip volume, time spent with and without passengers, vehicle speeds, and vehicle mileage.

Major Findings: Taxi and TNC trips increased by 15% from 2013 to 2017, while the number of these vehicles increased by 59%, average vehicle speed declined by 15% (due to congestion), and unoccupied vehicle time increased by 81%. The growth in TNCs has dramatically increased traffic congestion.

Recommendations: The study shows that policies need to disincentivize driving around in the CBD. Recommendations to consider include levying a \$2 to \$5 surcharge on rides in the CBD to fund the public transit system. Methods to reduce the amount of time drivers spend on the roads without passengers include penalizing drivers for excessive unoccupied time between trips and more effectively matching drivers dropping off passengers with nearby passengers needing to be picked up.

Some of the common results from the studies show that about 12%-22% of TNC trips are replacing trips that otherwise would have been taken on public transit, which has resulted in a decrease in ridership and revenues of the public transit (each TNC ride represents a loss of 35 cents for the public transit system). It is also found that around 15%-34% of TNC trips are adding vehicles to the roadways. These changes in the shares of modes of transportation has led to a decrease in efficiencies of vehicle transportation: one study shows that the unoccupied vehicle time has increased by 81%, while other shows that PMT/VMT efficiency (passenger miles traveled / vehicle miles traveled) has decreased from 112.3% to 60.8% due to the increase in TNC rides [5], [6], [8], [9].

On the positive side, the studies show that the TNCs may be increasing overall access to transportation, as 12% of TNCs trips are trips that otherwise would have not been realized [8].

4. What hasn't been addressed already? What's getting in the way?

As mentioned in the previous sections, there is a significant lack of understanding of the role that TNCs play in the transportation dynamics and what are its implications in different outcomes like transportation sustainability or accessibility. Some studies have attempted to measure some of the final outcomes that have been observed because of the rise of the TNCs, but no root cause and systemic understanding have been achieved.

With the purpose of bridging this existing gap, the team took a series of steps to propose the best set of tools that would help the understanding of the transportation dynamics. The first step was to synthesize the insights, findings and conclusions from the literature review. With this information, we identified the key variables that affected the transportation ecosystem and designed a first draft of the causal structure model. This model was then iterated with system dynamics and transportation experts both in TMF and in the MIT System Dynamics Group to achieve a more refined version of this model. The next step was to propose a data collection methodology that would provide enough data to feed the causal structure model and help make sense out of it. Leveraging our team members' experience with conjoint survey analysis and customer focused in-depth interviews, we designed a model for a conjoint analysis survey and a guide and questionnaire for in-depth interviews. In the following sections we give a detailed explanation of the results of this process.

iv.1 Causal Structure

Determining and implementing meaningful solutions to this problem require all key players, from policy makers to TNC executives to individual riders, to take a long view to making decisions that support long-term transportation system sustainability. The problem is that a lack of understanding of the full system causal structure means that long-term planning is very difficult and the business case for choosing sustainable behaviors is impossible to make.

In the multiple surveys and studies available on this topic, researchers primarily focused on the types of trips people were making and the transportations decisions people of various demographics were making. There seemed to be a lack of analysis on what the real motivations were behind riders' transportation decisions. Because of this perceived gap, we based the construction of our causal diagram on the idea of how a rider chooses between public transit and a TNC for any given ride, assuming that both options are equally accessible. In other words, what makes one option more attractive and the other less attractive.

The other consideration that is underrepresented in existing studies is an understanding of the causal interrelationships between TNCs and public transit that potentially create competition or mutual benefit between the modes. We therefore built the causal loop diagram (CLD) with the objective of illustrating these interactions. The structure is anchored around the variable of "TNC Attractiveness." For the purposes of this discussion we refer to bus and rail transportation offered by the MBTA in the Boston area as the "T" as it is commonly known. The full CLD, describing the most compelling causal dynamics at play in ridership between TNCs and the T, is depicted in Figure 1.

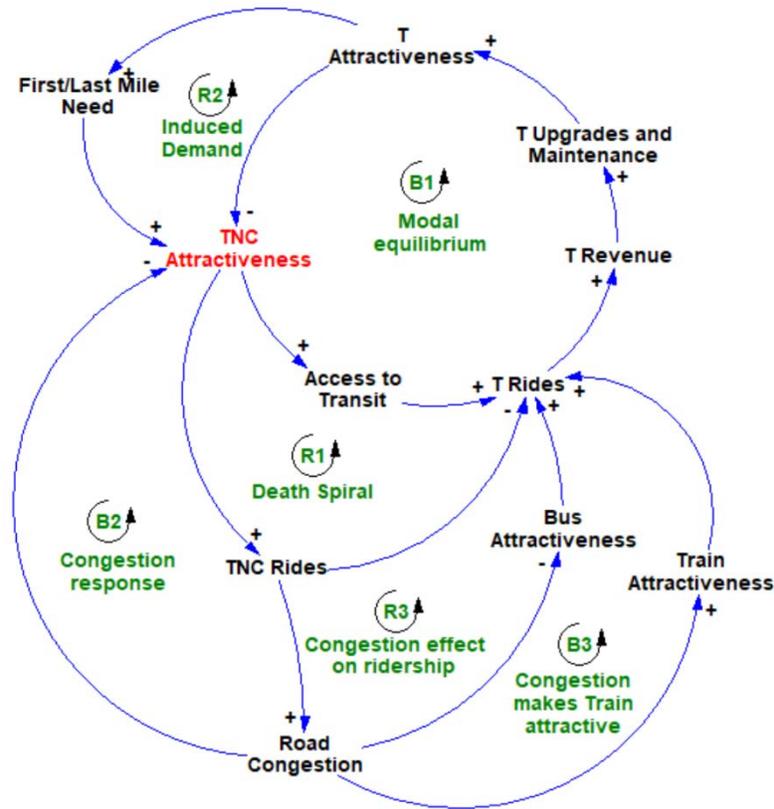


Figure 1: Causal loop diagram illustrating the ridership dynamics between TNCs and the T

Beginning from the key variable of TNC Attractiveness, the diagram describes several important balancing and reinforcing loops that, if well understood by policy makers, can inform regulatory decisions to improve the transportation system. The first of these is the balancing loop B1 which is at the heart of the issue of ensuring equitable access to transportation to all residents in all areas of the city, and is described in Figure 2.

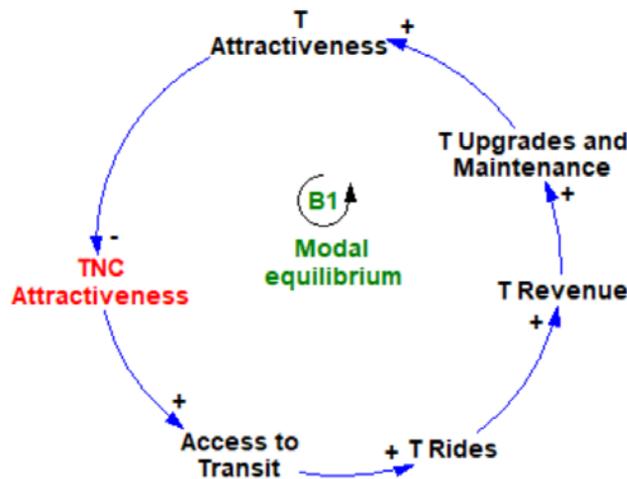


Figure 2: Modal Equilibrium balancing loop

The optimistic first order consequence of the increasing “TNC Attractiveness” in the city is an increase in citizens’ “Access to Transit.” TNCs can provide the necessary link between neighborhoods lacking reliable transit services and the bus stops or train stations they need to reach, eliminating transportation deserts. As Access to Transit increases, T Rides, T Revenue, and the capacity to do T Upgrades and Maintenance increase. This rides-to-maintenance relationship is the key to improving T Attractiveness citywide, which, in turn reduces the relative attractiveness of TNCs.

The Death Spiral loop R1, represented in Figure 3, depicts the dynamic of TNCs contributing to the demise of the public transit system. In this loop, as TNC Attractiveness increases, the TNCs cannibalize ridership from the T, causing TNC Rides to rise while T Rides fall, thus reducing revenue, upgrades and maintenance, and attractiveness for the T, further increasing TNC Attractiveness. The more attractive TNCs become, the farther the T falls behind and the more impossible it becomes for the T to meet riders’ needs.

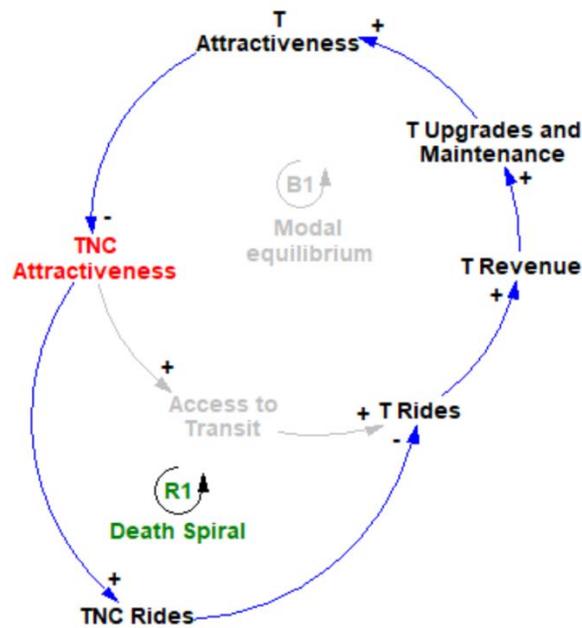


Figure 3: Death Spiral reinforcing loop

The Induced Demand reinforcing loop R2, characterized in Figure 4, presents an alternate positive linkage between T Attractiveness and TNC Attractiveness, where they drive one another’s growth. TNC Attractiveness grows, creating better Access to Transit, leading to greater T Attractiveness. More riders opting to travel by T induce a need for another means to cover the first and last miles of their trip, thus inducing more demand for TNCs and increasing TNC Attractiveness. In this loop, TNC Attractiveness boosts T Attractiveness, which further multiplies TNC attractiveness.

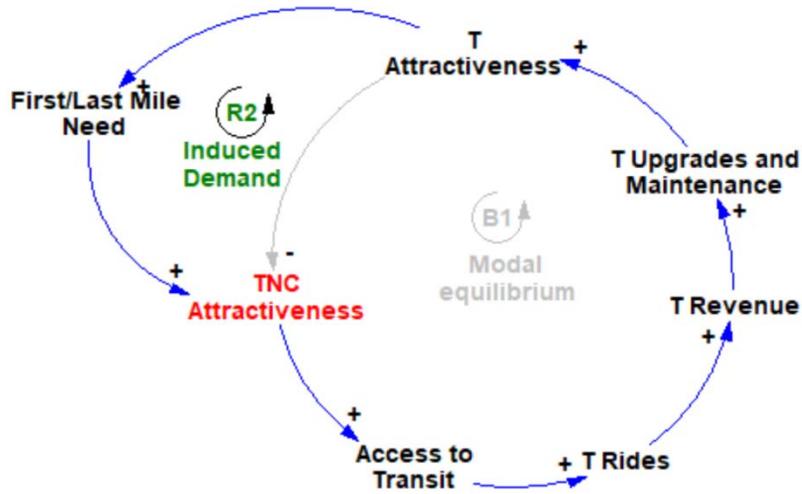


Figure 4: Induced Demand reinforcing loop

In the final step, represented in Figure 5, the model incorporates Road Congestion, which affects TNCs and the T in different ways. Further, the Road Congestion effect on the T is different for the rail system and the bus system. Simply, increasing TNC Attractiveness leads to increased Road Congestion, which reduces TNC Attractiveness (B2) and Bus Attractiveness, but enhances Train Attractiveness. These dynamics create a reinforcing loop (R3) further increasing TNC Attractiveness through the Bus Attractiveness variable, but the effect of congestion increasing Train Attractiveness is a balancing loop (B3) increasing T Attractiveness.

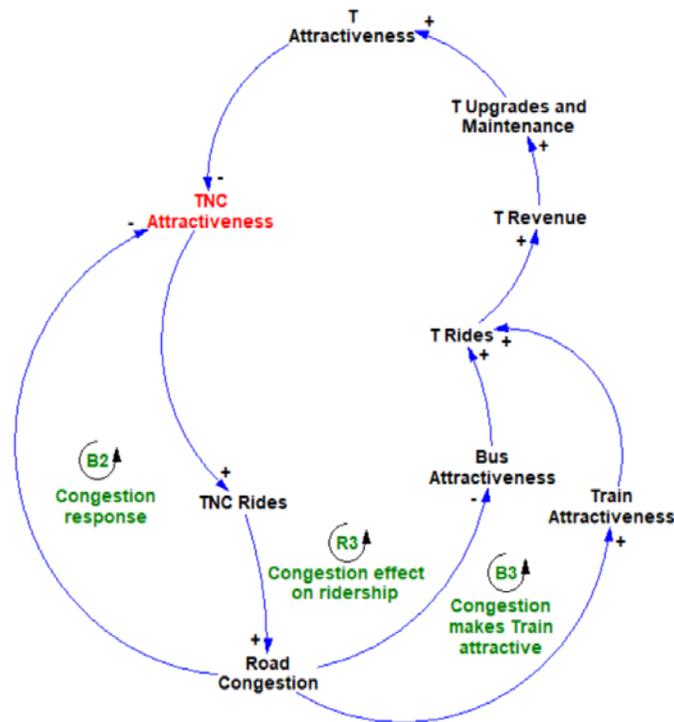


Figure 5: Road Congestion effects

These loops are clearly simplifications of very complex relationships, but they offer insight into the access points that policy makers can utilize to promote a healthy, harmonious transportation system. To get a better sense of the magnitude and reasoning behind the different interactions and relationships displayed in this causal structure model, we propose a data collection methodology, explained in the next section.

iv.2 Data Collection Methodology

The causal structure model presented in the last section contemplates several relationships and interactions that occur in the urban transportation ecosystem and is an important tool that helps understand the dynamics from a conceptual point of view. However, in order to enable this tool as a functioning system dynamics model, it is necessary to get a deeper understanding of how these interactions occur through quantitative and qualitative data.

In this section we propose a two-part data collection methodology. The first part is related to quantitative data collection, and the second part is related to qualitative data collection.

4.2.1 Quantitative Data Collection – Conjoint Survey

T attractiveness and *TNC attractiveness* are two variables involved in the causal model introduced in the previous section. These variables are key to the model because they drive the decision of the users to choose the mode of transportation of their preference for each trip. However, this “attractiveness” is an ambiguous term that depends on many different factors that people weigh when considering the different modes of transportation (e.g. time, price, comfort, etc.).

It is necessary to have information about the way users make their transportation decisions to understand this attractiveness. In Boston, different surveys of different types have been performed with different purposes (e.g. determine the share of each mode or learn characteristics of T users) but no survey has attempted to make a robust analysis on how riders make decisions. In order to fill this gap, we propose the implementation of a conjoint analysis.

Conjoint analysis is a survey-based, statistical technique used to understand the decision-making process of people by measuring how they value each of the different attributes of a product. It is based on the concept of a utility function, which captures the utility that people get from a product as a function of different attributes. In the specific case of the transportation mode choice, a utility function would tell the utility that a specific mode of transportation would provide the rider, given some attributes like riding time, walking time, wait time, price, comfort, etc. In the survey, respondents are

asked to choose between different options which include different variations of the attributes to be tested. The results are then used to make a statistical analysis and determine the weight that people give to each of the attributes to determine their total utility.

For this work, we designed a model conjoint survey that could be used as a reference in a future implementation. We used a survey software (Sawtooth Discover [10]) that is specialized in conjoint analysis to create the survey, which has two main sections, a general information section and the conjoint questions section. The general section includes questions to understand some general demographic characteristics and transportation habits of the respondents, like age, occupation, income, neighborhood of residence, preferred mode of transportation, frequency of use of each mode, and the number of cars in household. Figure 6 shows an example of one of the questions made on this general information section.

A survey about your transportation preferences

Please rate the following transportation modes in terms of how desirable they are.

	Undesirable	Somewhat Desirable	Very Desirable	No Opinion
Own Car	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public bus	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Subway	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lyft, Uber, etc.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Back Next

0% 100%

Figure 6: Sample question from survey - general information section

The second section of the survey, the conjoint questions section, was constructed under the consideration of having a balance between asking about different variables and not overwhelming the audience/model with details and questions. For this reason, we decided to limit the amount of decision variables, or attributes, to four. To each of these attributes, we assigned a number of levels, or options, from which respondents could choose. The attributes and levels are described in Table 2.

Table 2: Attributes and levels used in the design of the conjoint survey

Attribute	Levels
Transportation mode	Own car, public bus, subway, Lyft/Uber
Total time	7-9 minutes, 10-12 minutes, 13-15 minutes, 16-18 minutes, 19-22 minutes, 23-25 minutes, >25 minutes
Walking distance (each way)	Less than 2 city blocks (<500ft), less than a quarter mile, less than half a mile, greater than half a mile
Price per ride	<\$5, \$5-\$9, \$10-\$14, \$15-\$19, \$20-\$24, \$25-\$29, >\$30

With this information of attributes and levels, the survey software generated automatically the conjoint questions, by creating different combinations of the different attributes and levels to each respondent. An example of one of these questions is shown in Figure 7.

A survey about your transportation preferences

All else being equal, which of the following transportation modes would you select to travel for an appointment?

1 / 10

Transportation Mode	Own Car	Lyft, Uber, etc.	Public bus	Public bus	Subway
Total Time	10-12 minutes	16-18 minutes	10-12 minutes	16-18 minutes	13-15 minutes
Walking Distance (each way)	less than a quarter mile	greater than a half mile	less than a quarter mile	greater than a half mile	less than a half mile
Price per ride	\$20-\$24	\$5-\$9	\$15-\$19	<\$5	\$10-\$14
	Select	Select	Select	Select	Select

None, I wouldn't choose any of these.

Select

Back
Next

Figure 7: Sample question from survey - conjoint analysis section

In order to test the functionalities of the survey, we conducted a trial run with 23 Boston residents that responded to the survey. Figure 8 shows a summary of the results.

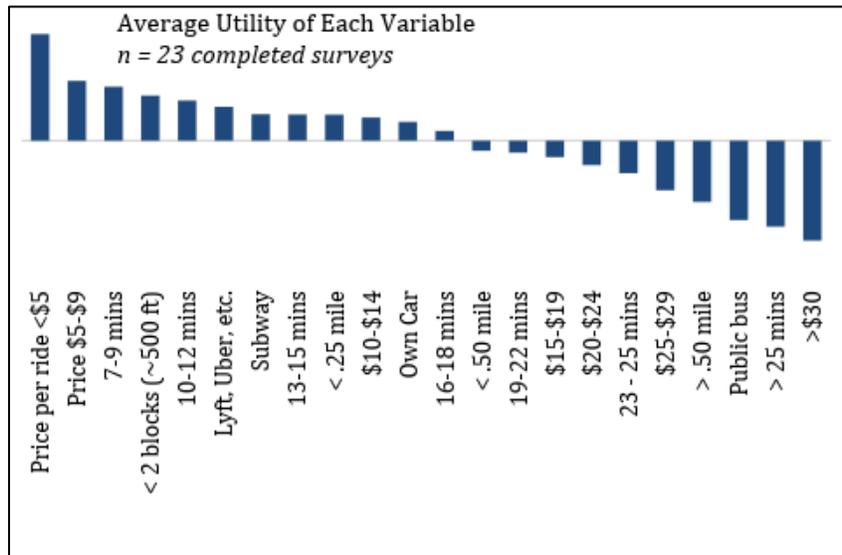


Figure 8: Summary of results – Conjoint survey test

What the graph tells is the average utility generated from each of the attributes. For example, in the far left we have the price per ride <\$5, which generates the highest utility. This means that the respondents would prioritize the fact that the ride would cost less than \$5 more than any other attribute. The same logic can be applied to the far right attribute, price >\$30, which has a large negative utility.

This survey is a first approach to a choice-based conjoint analysis. With further refinement and broader distribution of the survey, high quality results could be obtained, and important conclusions and findings could be included in the causal loop diagram.

The complete model conjoint survey can be found in the Appendix of this report.

4.2.2 Qualitative Data Collection

In parallel to the conjoint survey, it is important to develop a qualitative research that helps understand better what drives citizens to use different modes of transportation. This would help to i) help to interpret the results from the conjoint analysis research and ii) refine the causal structure model and conjoint survey.

The methodology we propose to carry out this qualitative data collection is through in-depth interviews using a design thinking approach. This approach focuses on creating empathy with the user in order to

get a deep understanding of his or her motivations, needs, emotions and reasoning involved in making a decision. The Appendix includes a guide, as well as a proposal of the questionnaire, that would be helpful when conducting the in-depth interviews.

5. Proposed Improvements/Recommendations

Based on the literature review we conducted and on direct discussions we had with stakeholders like representatives of the Mayor's Office of New Urban Mechanics (MONUM) and on the causal structure model we developed, we have built a good general understanding of the transportation system and the dynamics that play in it. With this understanding we provide some general recommendations that may contribute to a more sustainable and accessible transportation system. Detailed and more specific recommendations are not given, as for that the finishing of the system dynamics model is necessary.

5.1 Characterize and Maximize T Attractiveness

A thorough conjoint study of the variables influencing riders' transportation mode choices will help policy makers better understand how to most cost-effectively improve the attractiveness of MBTA services relative to TNCs and other modes. Closing the attractiveness gap between the MBTA and TNCs is at the core of supporting the Modal Equilibrium loop (B1) and avoiding the Death Spiral loop (R1).

5.2 Promote the mutual benefits

There is strong evidence that TNCs are helping to alleviate transportation deserts and provide access to public transit options where they may not have existed before [9]. Measures to streamline multi-modal travel between a TNC and the T will support this beneficial dynamic. For example, a shared payment or transfer system that would allow a rider to move efficiently from one mode to the other without the need to make additional transactions would make both modes more attractive. Further, TNCs could tailor pick-up and drop-off services to improve timing of first and last mile travel for public transit commuters.

In order for this to happen, it is important to achieve strong cooperation between the TNCs and the public sector, and that all parties understand that this cooperation is for the benefit of the citizens. A first step towards this cooperation would be in the form of data-sharing, so that both entities are able to understand the whole picture and analyze the situation in a more informed way.

5.3 De-incentivize the negative impacts of TNCs

The city lacks the authority to directly regulate TNCs, but it does have the authority to regulate access to its roads and infrastructure. A road congestion-based road access surcharge pricing structure might help to close the attractiveness gap by lowering TNC attractiveness in high-traffic times, while improving bus attractiveness by alleviating congestion.

Other measures to reduce the congestion effect of TNCs may include limiting access to some roads or designating specific TNC pick-up/drop-off locations throughout the city to improve traffic flow. A method to reward TNC drivers for minimizing total unoccupied (without a passenger) miles traveled could considerably reduce the additional TNC congestion and save drivers the expense of wasted fuel.

5.4 *Bite the maintenance bullet*

In a dystopian, but not too implausible, potential future, the decline in MBTA ridership precipitates the demise of the whole public transportation system; the TNCs have cannibalized so much transit ridership that the MBTA can't afford to operate. The studies strongly indicate that without public transit, TNCs are inadequate to meet the mobility needs of the city, so in this future the city is suffering from severe mobility inequity [6]. To avoid this dystopia, the city might have to embrace a severe worse-before-better investment in capabilities to bring MBTA service quality up to a level to make it truly competitive with TNCs. The longer this effort is delayed, the further the MBTA will fall behind and continue down the transit death spiral.

The MBTA is a state agency and pays for any extensions or improvements, while most riders of the MBTA are in the city of Boston. Thus, there are complications about revenue allocation and decisions around the MBTA.

5.5 *Promote ride-sharing and on-demand transit*

Because most TNC vehicles are powered by gasoline engines, on the whole TNCs generate more pollution and contamination per person when compared to other modes of transportation. A way of mitigating these inefficiencies and lowering the pollution and contamination rates is to incentivize the use of ride-sharing and on-demand transit (or micro transit). This could be implemented by creating a tax structure that would penalize more the TNC riders that choose to use the service in an individual manner, instead of in a shared manner.

6. Next Steps for the organization

This work proposes a set of tools to better understand the dynamics of TNCs in the transportation system in Boston. In order for these tools to be fully functional and provide enough information to serve as a foundation for policy recommendations, the following steps should be accomplished:

1. Develop the conjoint analysis and focus group studies to characterize the T Attractiveness and TNC Attractiveness utility function: This effort includes the refinement and broader distribution

of a choice-based survey as well as testing and refining the mixed utility of certain variables. In particular, a focus on mixed-use rides and the last mile might more acutely focus the analysis on the area with highest potential for impact. The wide distribution survey for conjoint analysis will provide a very large dataset with the intention of accurately capturing the full demographics of the ridership base. Focus group studies will enable researchers to gain a deeper understanding of the complex decision factors driving mode choice for riders.

The City of Boston should plan to develop and conduct the conjoint survey and focus group over 2-3 months, subject to the availability and capacity of the resources they have. The conjoint survey should include a wide range of the Boston demographics, including mixed-use and last mile riders. The more data points that the city can collect the better picture the city will have of the riders' preferences/utility. The focus group study does not have to be deployed to a large number of people but has to cover a various type of riders. See Appendix A2 for the In-Depth Interview Guide and Questionnaire for the focus group.

2. Build out the system dynamics model: A functional model that is sufficiently complex to provide useful analysis will be a multi-month effort. Some of the basic ridership data that the model will require is already available through MBTA data collection and data sharing agreements between the City of Boston and major TNCs. Other data would be obtained through the insights and results from the conjoint analysis and focus group discussions described in this work.

The conjoint analysis and focus group discussions are designed with the goal of fully characterizing the factors that contribute to riders' calculations of "attractiveness" around which the causal diagram is built. When the most powerful factors contributing to attractiveness are understood, they can be built into the model as exogenous or endogenous variables and they can be quantified according to their calculated utility weighting. The survey can be expanded to quantify riders' first/last mile need and how much TNCs are contributing to access to public transportation. The remaining variables in the diagram can be characterized using existing data on ridership, road congestion, revenue, and money spent on upgrades and maintenance. This data applied in a functioning system dynamics model would be able to support or contest the utility weighting resulting from surveys. With a believable system dynamics model, policy makers can make policy decisions to influence riders' decisions based on the most powerful attractiveness factors.

Appendix

A.1 Model survey

A survey about your transportation preferences

Please rate the following transportation modes in terms of how desirable they are.

	Undesirable	Somewhat Desirable	Very Desirable	No Opinion
Own Car	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public bus	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Subway	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lyft, Uber, etc.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

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0% 100%

Figure 9: Question #1 sample survey

A survey about your transportation preferences

How many...

	0	1	2	3	4	5+
...Adults (of driving age) live in your household?	<input type="radio"/>					
...Cars are owned and/or leased in the household?	<input type="radio"/>					

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0% 100%

Figure 10: Question #2 sample survey

A survey about your transportation preferences

In a given week, how often do you use each of the following modes of transportation?
Please assign a fractional value for each, totaling 100. For example, 5 roundtrip car rides per week (to work) and 3 more other items, 4 subway rides (to events), and 2 bike rides (groceries), and 1 UberX for a weekly dinner, might result in: 65 car, 20 subway, 10 bike, 5 UberX/Lyft.

Bike

Drive my own car

Public bus

Subway

Uber X / Lyft

UberPOOL / Lyft Line

Walk

Total

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Figure 11: Question #3 sample survey

A survey about your transportation preferences

What is your age range?

- 15-18
- 19-25
- 26-30
- 31-40
- 41-50
- 51-60
- >60

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Figure 12: Question #4 sample survey

A survey about your transportation preferences

What is your occupation status?

- Student
- Employed full-time
- Employed part-time
- Self-employed
- Looking for a job
- Retired

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Figure 13: Question #5 sample survey

A survey about your transportation preferences

In what area of Massachusetts do you reside?

- Back Bay/South End/West End
- East Boston/South Boston/Seaport
- Cambridge/Somerville/Charlestown
- Allston/Brighton/Chelsea
- Roxbury/Dorchester/Jamaica Plain
- Other areas within the 93 beltway
- Regions within the 95 belt
- Regions outside the 95 belt
- Other, please specify
- I do not reside in Massachusetts

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Figure 14: Question #6 sample survey

A survey about your transportation preferences

How far, in miles, are you from the nearest subway, bus, or train station? (please round to whole miles)

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Figure 15: Question #7 sample survey

A survey about your transportation preferences

What is your combined household income?

- Under \$15,000
- \$15,000 - \$34,999
- \$35,000 - \$49,999
- \$49,999 - \$74,999
- \$75,000 - \$99,999
- \$100,000 - \$149,999
- \$150,000 - \$199,999
- \$200,000 and over

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0%  100%

Figure 16: Question #8 sample survey

A survey about your transportation preferences

Please provide additional commentary you may have about your transportation modes, about your decision variables when selecting how to mobilize, or about your experience taking the survey itself. As mentioned at the outset, your feedback is part of a learning process for the potential deployment of a broad user survey.

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0%  100%

Figure 17: Question #9 sample survey

A survey about your transportation preferences

All else being equal, which of the following transportation modes would you select to travel for an appointment?

1 / 10

Transportation Mode	Own Car	Lyft, Uber, etc.	Public bus	Public bus	Subway
Total Time	10-12 minutes	16-18 minutes	10-12 minutes	16-18 minutes	13-15 minutes
Walking Distance (each way)	less than a quarter mile	greater than a half mile	less than a quarter mile	greater than a half mile	less than a half mile
Price per ride	\$20-\$24	\$5-\$9	\$15-\$19	<\$5	\$10-\$14
	Select	Select	Select	Select	Select

None, I wouldn't choose any of these.

Select

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Figure 18: Question #10-19 sample survey. Note: 10 questions would be created for each respondent by randomly combining the different attributes and levels for each option

A.2 In-Depth Interview Guide and Questionnaire

A.2.1 In-Depth Interview Guide

In order to successfully develop in-depth interviews, it is important to be aware of the following guidelines:

- Generally, in depth interview and following user interaction for 20 diverse people would give good enough insight
- Restate the challenge: e.g. Create equitable, affordable and most convenient travel experience for riders in Boston
- Think in a human-centered way: understand riders, their days, how they travel, why they choose the transportation mode, etc.
- Ask questions and observe non-verbal cues (body language and emotions)
 - Do not ask leading questions and ask open-ended questions
 - Listen to interviewees' stories (encourage stories)
 - Take notes and record if permitted by interviewees. Take pictures if necessary
- Try to find out: What? How? Why?
- Interview steps: 1) Introduction of interviewer 2) Introduction of the project 3) Build rapport 4) Evoke stories 5) Explore emotions 6) Question statements 7) Thank and wrap-up
- Interview and look for different users that have different preferences (e.g. strong preference for ride-sharing, for public transportation and no strong preference)
- Understand needs, pain points and underlying reasons why riders make certain decisions
- What do they want in travelling? What do they value?
- When interviewing, write down tensions, contradictions, and surprises
- After interviewing riders, share insights with each other. Record the insights/ideas.
- Group the ideas and synthesize them to find meaning. Individual stories may sound different but may stem from the same, larger problem.
- Identify opportunity areas in the form of: How might we **ACTION WHAT** for **WHOM** in order to **CHANGE SOMETHING**. City of Boston needs to identify these opportunity areas (e.g. How might we provide an equitable, affordable and most convenient travel experience for riders in Boston so more people have increased access to mobility?)
- When coming up with solutions or actions to take, need to think of the following factors: Feasibility, desirability and viability
- When identify good ideas:
 - Always keep people top of your mind.
 - Your ideas should be human led, not technology driven.
 - Keep constraints in mind.

A.2.2 Proposed Questionnaire

- What is your daily routine?
- Can you tell me about what you do when you get up in the morning (on weekdays/weekends)?
 - Ask follow up questions, and try to get a sense if the interviewee has concerns, feels annoyed about something or feels comfortable and enjoys doing certain things.
 - Why does [] make you feel concerned/annoyed? Why do you enjoy doing []?

- **In the morning**, How do you get to work/school/other destinations (routine)/ your appointments/recreational plans (non-routine)?
 - *Try to capture what (not necessarily direct) drivers/factors make them choose certain transportation mode.*
 - Why do you choose the transportation mode (it could be a particular day or a particular situation (e.g. rainy day or regularly choosing the mode)? What factors do you consider when you commute/travel?
 - *Ask follow up questions such as: what do you like/dislike about the chosen mode?*
- **During the day**, do you travel (routine or non-routine)?
 - Which transportation mode do you choose? Why? What factors do you consider when you commute/travel?
 - *Ask follow up questions such as: what do you like/dislike about the chosen mode?*
- What do you like about your travel (it could be people watching, alone time etc.)?
- What bothers you when you commute/travel?
- What do you want to see improve when you travel and why?
- What would be your ideal commuting/travelling scenario?
 - *It does not have to be about choosing the ideal transportation mode.*
 - *It does not have to be realistic; it can about ideal future scenarios.*
- If possible, follow the interviewees to observe their emotions, how they interact with the chosen transportation mode and the people around them (e.g. other passengers in public transportation, drivers, other car-sharing passengers). For example:
 - When they leave the house/ use the app to order a ride
 - When they get on the ride & during the ride & when reach/get to final destination
 - If they walk to the station/ during the ride/ when get to final destination

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