May 2023

Report No. 23-044

Maura Healey
Governor

Kim Driscoll
Lieutenant Governor

Monica Tibbits-Nutt
Acting MassDOT Secretary & CEO

Outdoor Information Panels to Convey Real-Time Travel Information for Ridership Recovery

Principal Investigator (s)
Dr. Song Gao
Dr. Elaine Christofa

University of Massachusetts Amherst

Research and Technology Transfer Section
MassDOT Office of Transportation Planning

U.S. Department of Transportation
Federal Highway Administration

Technical Report Document Page

1. Report No. 23-043	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Outdoor Information Panels to Convey Real-Time Travel Information for Ridership Recovery		5. Report Date July 2023 6. Performing Organization Code
7. Author(s) Song Gao, Eleni Christofa, Guocheng Jiang, and Austin Pszenny		8. Performing Organization Report No. 23-043
9. Performing Organization Name and Address University of Massachusetts Amherst 130 Natural Resources Road, Amherst, MA, 01003		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Massachusetts Department of Transportation Office of Transportation Planning Ten Park Plaza, Suite 4150, Boston, MA 02116		13. Type of Report and Period Covered Summary Report July 2023 [May 2021- July 2023] 14. Sponsoring Agency Code n/a
15. Supplementary Notes Project Champion - Yanni Poulakos - MBTA		

16. Abstract

The MBTA has launched an Outdoor Information Panel (OIP) program. This will update legacy outdoor advertising locations or add other strategic locations near major roadways through digitization, for which 25% of the playlists will have dedicated "set aside" time to deliver real-time travel information (RTTI). This project developed guidelines for determining the location, content, graphic design of OIPs and the cadence of RTTI, and provided new understandings of transit users' and non-users' potential transit use increases in response to OIPs for various trip purposes. More specifically, the research team first conducted a literature review regarding benefits of RTTI, RTTI provisions by other transit agencies, and changeable message sign (CMS) design guideline to provide the basis for subsequent interview and survey designs. After that, an online interview was conducted with a small number of participants to obtain preliminary insights that can guide the design of the subsequent survey questionnaire by narrowing down the large array of information contents. An online survey was then designed and randomly sampled households in the Great Boston Area (GBA) were recruited through postcards. The interview and survey included questions on participant demographics, travel experience, preferred real-time information content, location, graphic design and load, and potential behavioral changes in response to and perceived values of OIPs. Finally, recommendations were provided on the guidelines for deploying OIPs.

17. Key Word Outdoor Information Panel, Real-Time Travel Information, Interview, Household Survey		18. Distribution Statement	
19. Security Classif. (of this report) unclassified	20. Security Classif. (of this page) unclassified	21. No. of Pages 122	22. Price n/a

Form DOT F 1700.7 (8-72)Reproduction of completed

This page left blank intentionally.

Outdoor Information Panels to Convey Real-Time Travel Information for Ridership Recovery

Summary Report

Prepared By:

Song Gao
Principal Investigator

Eleni Christofa
Co-Principal Investigator

Guocheng Jiang
Graduate Researcher

Austin Pszenny
Undergraduate Researcher

University of Massachusetts Amherst
130 Natural Resources Road
Amherst, MA 01003

Prepared For:

Massachusetts Department of
Transportation Office of
Transportation Planning
Ten Park Plaza,
Suite 4150 Boston,
MA 02116

July 2023

This page left blank intentionally.

Acknowledgements

Prepared in cooperation with the Massachusetts Department of Transportation, Office of Transportation Planning, and the United States Department of Transportation, Federal Highway Administration.

The Project Team would like to acknowledge the efforts of Yanni Poulakos, Elizabeth Winters Ronaldson, Rocio Tua and Emily Kesley (MBTA), and Lily Oliver and Nicholas Zavolas (MassDOT).

Disclaimer

The contents of this report reflect the views of the author(s), who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Massachusetts Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

This page left blank intentionally.

Executive Summary

This study of Outdoor Information Panels to Convey Real-Time Travel Information for Ridership Recovery was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

The MBTA has launched an Outdoor Information Panels (OIP) program. This study will update legacy outdoor advertising locations or add other strategic locations near major roadways through digitization, for which 25% of the playlists will have dedicated "set aside" time for MBTA purposes. As most locations eligible for digital upgrade will be near decision-making points for persons traveling in vehicles to potentially switch to public transit, optimizing MBTA set aside time with real-time travel information (RTTI), e.g., train departures, parking availability, will be critical information delivery to not only transit users but also non-users to nudge them towards a behavior change at that point or in the future.

Through this study, the research team achieved the following:

1. Developed guidelines for determining the location, content, graphic design and cadence of OIPs with high potential for incentivizing mode shift, recovering ridership loss due to COVID-19, and building rider trust post COVID-19.
2. Identified transit users' and non-users' potential transit use increases in response to OIPs for various trip purposes.

A literature review was conducted to help the research team ground their work on the state of practice of RTTI provision, specifically that delivered through roadside signs. The literature review is presented in five key aspects for the OIP program: (a) benefits of RTTI to existing transit users and non-user, (b) desirable information contents for both existing users and non-users, (c) deployed RTTI systems in the United States, (d) CMS design guidelines, and (e) information needs during and after the COVID-19 pandemic. The literature review shows that the provision of RTTI is found to have positive impacts on improving existing users' experience in reducing wait time, improving perceived security, improving service satisfaction, and increasing ridership. In addition, appropriate information will help encourage non-users to shift from private car use to transit use. According to the literature review, the most valued transit information contents identified by existing transit users when they consult RTTI is the tracking information (i.e., arrival time and actual location of the next buses). In terms of non-users, there are four major information contents considered essential: (a) travel time, (b) fare, (c) accessibility factors such as walking to stops, and (d) comfort or convenience factors such as parking availability and seat availability. Among them, travel time, schedule, and fare information have been reported to be the most valued factors. Examples of RTTI provision from other transit agencies are included to help generate ideas for our RTTI design. The most prevalent information displayed by agencies include travel time, actual location of buses and service alert messages. There are four most widely used media for presenting travel information: (a) internet, (b) changeable message signs (CMSs), (c) short message services (SMSs), and (d) interactive kiosks. The majority of the reviewed transit agencies are using installed CMSs at bus or train stops. No transit agency has been identified thru this study that is using the installation of transit information message signs along highways. CMS display design, e.g., font size, color, spacing and information load, is reviewed based on two design manuals with very similar specifications. As indicated in the literature review, using real-time or historical ridership data to inform riders of crowding levels on buses or trains during the COVID-19 epidemic showed that using real-time or historical ridership data to inform riders was potentially helpful for transit riders during and after the pandemic.

An online interview and a household survey were conducted in sequence to help the research team gather Great Boston Area (GBA) travelers' travel experience, preferred real-time information contents and location and billboard graphic designs. The online interview enabled open-ended exploration of the topic of interest via a one-on-one conversation between the researcher and a limited number of selected participants who possess certain common characteristics (e.g., daily commuter in GBA) and exhibit diversity regarding other key characteristics (e.g., transit usage frequency, most used highway segment). The interview questionnaire was structured in three sections: (1) travel experience, (2) desired contents, and (3) adequate information load. An online screening questionnaire was implemented in Qualtrics. 16 participants were selected with a balanced mix of transit user type (frequent, occasional and non-user), age, gender, household income, employment status and geographic coverage of two major trip origin-destinations (ODs). 11 persons eventually participated in the interview from August 11 through 24, 2022 via Zoom.

The subsequent online household survey was designed based on the results of online interview and was comprised of five sections: (1) demographics, (2) travel experience, (3) desired information contents, (4) potential behavior change, and (5) billboard design. The survey generally followed the structure of the online interview including the screening questionnaire by refining and transforming interview questions into multiple choice questions. This survey was distributed to randomly selected 10,000 households in the six counties of Great Boston Area (GBA). Reminder text messages were sent to 5,843 of the 10,000 households for which a cell phone number is available. 182 responses were received and 153 of them are considered valid.

The major findings from the online interview and household survey include:

- 1) Real-time total travel time by transit, 2) next two train arrivals, and 3) real-time parking availability at the start MBTA station, were identified as the top three information items for encouraging travelers to use commuter rail and subway transit more often as selected by all interview and survey participants, Total travel costs by transit and real-time crowding levels on transit were also considered moderately useful by interview and survey participants. Specifically, those participants responding to commuter rail trips care more about total travel cost by transit and real-time parking cost at the destination if travelling by car compared to those responding to subway trips. In contrast, participants responding to subway trips placed higher value on next two train arrivals. The findings also indicate that for major events, 1) travel time by transit, 2) next two train arrivals, 3) total travel cost by transit, 4) parking cost at the destination if travelling by car, and 5) real-time parking availability at the start MBTA station were identified as the top five information items by interview and survey participants,

- The billboards displaying transit route, travel time, and costs are the most preferred information combination, accounting for 41.1% of the participant responses. Transit route, parking availability at the start and travel time were also considered as a useful combination in encouraging people to use transit more often, accounting for 36.4%
of the total.

- The majority of participants expressed a preference to locate billboards closer to the start of a trip.

- Over half of participants indicated that the use of RTTI on highway billboards would increase their transit use frequency. Social/recreational and major event trips are more likely be influenced by RTTI than job, family and shopping trips. Frequent users are more likely to increase transit usage than occasional and non-users. Between just under20% and just under 40% of occasional and non-users state a transit user frequency increase of once a month or more across the five trip purposes.

- Almost 80% of current frequent users think that providing RTTI on highway billboards would definitely or probably improve their travel experience.

- Billboard designs with light background and horizontal presentation of content were preferred by questionnaire and survey participants.

- Accuracy of RTTI is considered by many participants as a factor that exerts a significant effect on improving travel experience. Poor transit accessibility and service coverage is considered one of the main reasons for not using transit more often.

- The retention rate of a four-unit information load is 85%, and that of a five-unit one is 52%, which is improved to 70% with two staggering billboards that are close to each other displaying the same content.

This Summary Report concludes with the identification of a number of findings listed below to assist the MBTA in their consideration for the location, content and design for the use of RTTI in highway billboards to encourage persons traveling in vehicles to potentially switch to public transit.

- Location: Given the radial nature of MBTA services, it is recommended that inbound trips be displayed on locations relatively far from downtown, e.g., around the 128 beltway or farther. For locations close to downtown, it is recommended that the information be clearly understood as something to be used in the future to avoid driver frustration, such as new or underutilized MBTA services not in the immediate area, a future major event, or the new fare system.

- Contents: Three or four-unit information load is recommended for non-staggering billboards and five-unit information load could be used for staggering billboards. Depending on how many information units are on a billboard, it is recommended to take the same number of items from the top of the top 5 real-time information items list.

- Graphic Design: Designs with light background and horizontal presentation of content are recommended.

- Cadence: It is recommended that RTTI be displayed for 10 seconds for each 40 seconds where the other 30 seconds are used for commercial ads not related to MBTA.

Table of Contents

List of Tables

List of Figures

List of Acronyms

Acronym	Expansion
ATIS	Advanced Travel Information Systems
AVL	Automatic Vehicle Location
BART	San Francisco Bay Area Rapid Transit
CCRTA	Cape Code Regional Transit Authority
CMS	Changeable Message Sign
COTA	Central Ohio Transit Authority
CTA	Chicago Transit Authority
FHWA	Federal Highway Administration
GBA	Greater Boston Area
LACMTA	Los Angeles County Metropolitan Transportation Authority
LIRR	Long Island Rail Road
MassDOT	Massachusetts Department of Transportation
MBTA	Massachusetts Bay Transit Authority
MTI	Multi-modal Traveler Information
MUTCD	Manual on Uniform Traffic Control Devices
NB	Northbound
OBA	OneBusAway
OD	Origin-Destination
OIP	Outdoor Information Panels
PC	Project Champion
RTIS	Real-Time Information Signs
RTTI	Real-Time Travel Information
SDOT	Seattle Department of Transportation
SEPTA	Southern Pennsylvania Transportation Authority
SP	State Preference
SPR	State Planning and Research
TMC	Transportation Management Centers
UMTC	UMass Transportation Center

This page left blank intentionally.

1.0 Introduction

This study of Outdoor Information Panels to Convey Real-Time Travel Information for Ridership Recovery was undertaken for the MBTA as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

1.1 Background

The MBTA has launched an Outdoor Information Panels (OIP) program. This will update legacy outdoor advertising locations or add other strategic locations near major roadways through digitization, for which 25% of the playlists will have dedicated "set aside" time for MBTA purposes. As most locations eligible for digital upgrade will be near decision-making points for persons traveling in vehicles to potentially switch to transit, optimizing MBTA set aside time with real-time travel information (RTTI), e.g., train departures, parking availability, will be critical information delivery to not only transit users but also non-users to nudge them towards a behavior change at that point or in the future.

Through this study, the research team achieved the following:

1. Developed guidelines for determining the location, content, graphic design and cadence of OIPs with high potential for incentivizing mode shift, recovering ridership loss due to COVID-19, and building rider trust post COVID-19.
2. Identified transit users' and non-users' potential transit use increases in response to OIPs for various trip purposes.

1.2 Document Organization

This Summary Report is organized as follows. Section 2.0 provides a review of the literature. Section 3.0 elaborates the design of online interview and household survey, the procedure of recruiting participants and conducting the interview and household survey. Section 4.0 presents the results of online interview and household survey. Section 5.0 provides the recommendations. Section 6.0 provides conclusions.

This page left blank intentionally.

2.0 Literature Review

This literature review is conducted to help the research team ground their work on the state of practice of RTTI provision, specifically that delivered through roadside signs. This review will guide the research team in designing focus group and survey questions that are most relevant and most likely to lead to optimized locations, contents and formats of OIPs. Literature related to the benefits and desired contents of RTTI is limited to empirical studies using either real-world or laboratory observational data and it does not differentiate among the various formats of delivering RTTI. Examples of RTTI provision from other transit agencies are included to help generate ideas for our RTTI design. Display design, e.g., font size, color, spacing and information load, is reviewed based on two design manuals with very similar specifications. The COVID-19 review focuses on the contents of RTTI that are potentially helpful for transit riders during and after the pandemic, instead of a broad review of the impact of COVID-19 on transit ridership.

The remainder of the document is organized as follows. Section 2.1 reviews the benefits of RTTI to users and non-users, in terms of the extent to which RTTI is conducive to improving existing user experience or enticing non-users to shift from private car use to public transit. Section 2.2 reviews studies that have implemented RTTI presenting different information attributes (e.g., estimated waiting time, fare) and draws conclusions on attributes with greater impact on non-riders' potential shift to transit. Section 2.3 reviews RTTI systems deployed by transit agencies in the United States that fall in three categories: those in Massachusetts, those comparable in size to MBTA and those with unique features. Section 2.4 reviews display design of changeable message signs (CMS) to convey information to riders effectively. Section 2.5 reviews information content that transit users value during the COVID-19 pandemic and the effect of these types of information on the ridership. Finally Section 2.6 provides a summary of all the reviewed information.

2.1 Benefits of RTTI to Transit Users and Non-Users

Existing transit users and car drivers who seldom use transit will respond differently to the provision of RTTI and may value different aspects of transit information. Therefore, the benefits of RTTI on existing users and non-users are reviewed separately in two sub-sections.

2.1.1 Benefits of RTTI to Existing Transit Users

Brakewood and Watkins (2019) synthesized studies that assessed benefits brought by the provision of RTTI *(1)*. They reviewed 28 studies and summarized five key benefits of RTTI in terms of passenger behavior and perception: decreased wait time, decreased total travel time, increased transit use, increased passenger satisfaction, and increased perceived security. These 28 studies used either simulations or surveys to evaluate benefits, and our report focuses on survey-based studies using empirical data. Since all the six studies that accessed the benefit of decreased total travel time were based on simulation, our report excludes total travel time and focuses on the other four benefits: decreased waiting time, increased transit use, increased satisfaction, and improved feeling of security.

Six survey-based studies from Brakewood and Watkins (2019) and other five studies are summarized in a chronological order in Table 2.1. The information contents are listed in the last column to provide an overview of prevalent information content used in previous studies.

Table 2.1: Benefits of RTTI to existing transit users

Author (Year)	Media	Wait Time	Transit Use	Satisfaction	Security	Information Content
Lappin (2020)	Both	⊕	-	⊕	-	Real-time bus location, arrival time of the next buses, connecting service
Schweiger (2023)	Both	-	⊕	⊕	⊕	Real-time bus location, wait time at stops
Dziekan and Vermeulen (2006)	Both	⊕	-	-	X*	Departure information
Caulfield and O'Mahony (2007)	Both	⊕	○	⊕	○	Real-time bus location, arrival time of the next buses
Politis et al. (2010)	Signage	-	⊕	-	-	Arrival time of the next buses
Watkins et al. (2011)	Device	⊕	-	-	-	Real-time bus location, arrival time of the next buses
Tang and Thakuriah (2012)	Signage	-	⊕	-	-	Real-time bus location, arrival time of the next buses
Chow et al. (2014)	Signage	⊕	○	⊕	-	Arrival time of the next buses
Barekewood et al. (2014)	Device	-	X*	⊕	⊕	Real-time bus location, arrival time of the next buses
Ge et al. (2017)	Signage	-	⊕	X	-	Arrival time of the next buses
Kaplan et al. (2017)	Device	-	⊕	-	-	Fare information, arrival time of the next buses, facility for disability

⊕: A sun cross indicates a statistically significant, positive effect on users' experience.

○: A circle indicates a numerically small positive effect on users' experience.

X: a cross indicates a negative effect.
-: A hyphen indicates that the specific benefit was not studied in the corresponding study.
*: An asterisk indicates that the result is not statistically significant.
Adapted from Brakewood and Watkins (2019) by selecting only studies with empirical data.
The last column on information content is added by the authors.

Reduced Wait Time

Many studies find that RTTI can reduce both passenger's perceived and actual wait times after they reach a transit station. The majority of transit lines operate on fixed schedules; however, transit service is not always reliable. Often times transit vehicles do not arrive at or depart the stop on time, resulting in unnecessary service delays and increased wait times. With RTTI, passengers can check the next transit vehicle arrival time and decide when to arrive at stops. This allows them to arrive at the stop when the transit vehicle is actually approaching, rather than arriving at the stop according to the schedule, and thus reduces actual wait time. In addition, RTTI changes riders' perceived wait time by reducing riders' uncertainty and anxiety while waiting at stops.

Dziekan and Vermeulen (2006) investigated the impact of a newly implemented RTTI system, which presented transit information via SMS and the Internet in the Hague, Netherlands *(2)*. Questionnaires were administered to passengers and the collected data were used to conduct a before-and-after evaluation to investigate behavioral effects of traveler information systems. The questionnaire asked respondents to state their perceived average wait time in minutes and rate the perceived security on a scale from 1 (very bad) to 10 (very good). Results demonstrated that the average perceived wait time at stops was shortened from 6.3 minutes to 5.0 minutes, a 20% reduction. However, only minor changes of perceived security were observed.

Watkins et al. (2011) investigated traveler response to the OneBusAway (OBA) transit traveler information system in the Seattle metropolitan area *(3)*. They recorded the arrival and board times of passengers at the bus stop and conducted surveys by randomly choosing respondents and asking them question about waiting. Results show that passengers who used RTTI spent 7.5 minutes on average waiting for bus, which was 1.4 minutes (30%) less than that of passengers who arrived at the bus stop according to service schedule. Additionally, this study found a 0.73 minute reduction of perceived time after using RTTI.

Chow et al. (2014) conducted a before-and-after survey to investigate the impact of RTTI signage across Massachusetts' heavy rail system *(4)*. Passenger's perceived is collected by an in-station survey. The actual passenger wait time at train stations was obtained by calculating train headway from tracking data. Ridership was estimated from fare collection data provided by the MBTA. Result show that passengers' average perceived wait time was reduced by 0.85 minutes after installing travel information signs at the station.

Improved Perceived Security

A number of studies have revealed that the use of RTTI can also provide an improved feeling of security. RTTI can improve passengers' feeling of security while waiting at stops by helping passengers feel more in control of their trips. RTTI signage displaying the next service time (e.g., next bus departure time) at stops can significantly reduce passengers' anxiety about how much longer they need to wait. In addition, the provision of RTTI allows passengers to arrive at stops according to the tracking data and thus, the actual wait time at stops is greatly reduced. The decrease in the wait time of passengers at transit stations will contribute to an increase in their feeling of security.

Brakewood et al. (2014) conducted a behavioral experiment with a before-after control group design regarding a bus real-time information service in Tampa, Florida *(5)*. The RTTI was provided via mobile devices. Two web-based surveys were designed to obtain information before and after the implementation of the RTTI system. The survey asked respondents to state how frequently they have experienced some specific feelings while waiting for the bus.

Eight types of feelings were included in the survey, namely, bored, productive, anxious, relaxed, frustrated, embarrassed, safe at night and safe during the day, and the experience frequency of such feelings was rated on a five-point scale: never, rarely, sometimes, frequently, and always. Results show that the RTTI helped decrease the level of anxiety and frustration when passengers had to wait for the bus. Moreover, feelings of security during the daytime significantly increased, which was attributed to less time waiting at bus stop where passengers may feel vulnerable and unsafe due to passing traffic and possible crime. While findings of Brakewood et al. (2014) indicate an increase in perceived security during the daytime, there was no significant difference regarding to the perceived security at night *(5)*.

Schweiger (2003) synthesized the development of automatic vehicle location (AVL) systems and investigated the state of the practice of real-time bus arrival information systems *(6)*. A survey was conducted among multiple U.S. transit agencies to determine the reasons for introducing real-time arrival information systems. Results indicated that the combination of AVL systems and real-time arrival information systems informed people travelling at nighttime of the estimated arrival time for the next buses and reassures them that the next bus is not far away, consequently improving passenger's perceived security.

There are some studies showing the opposite effect. In the study mentioned before, Dziekan and Vermeulen (2006) estimated the change of passengers' feeling of security while waiting at bus stops before and after the implementation of the RTTI system *(2)*. Passengers' feeling of security was rated on a scale from 1 (bad) to 10 (good). Results show that passengers' perceived security decreased from 7.9 to 7.6, but such difference was not statistically significant.

Improved Service Satisfaction

As discussed in previous sections, passengers will perceive that transit service is reliable if buses or trains always arrive and depart on time. In addition, passengers will spend less time waiting for transit service and they will feel more secure and less frustrated and anxious while waiting at transit stops. These benefits brought by RTTI are expected to lead to an increase in passengers' satisfaction level.

Lappin (2000) synthesized research on passenger satisfaction of using advanced travel information systems (ATIS) starting with some that were implemented in 1996 and conducted an evaluation in Seattle, San Antonio, and Phoenix *(7)*. Lappin argued that drivers' main purpose of consulting ATIS is to reduce trip uncertainty, by assessing the extent of traffic congestion delay and estimating travel time. The project findings indicate that ATIS can help passengers reduce stress, improve satisfaction of taking transit, and increase feeling of control over time and travel decisions.

Brakewood et al. (2014) estimated the impact of RTTI on passengers' satisfaction level using a web-based survey in Florida. Respondents were required to state whether they were satisfied with the bus services with regards to several aspects, including bus service frequency, wait time, on-time bus arrival rate, transfer frequency, and overall rating *(5)*. These indicators were rated based on a five-point scale. Results show that the passenger satisfaction level increased significantly after the installation of RTTI systems. Passengers were particularly satisfied with the decreased wait time and increased on-time bus arrivals.

Chow et al. (2014) evaluated passengers' satisfaction level with the Massachusetts's heavy rail service system *(4)*. Similar to the previous study, the satisfaction level was rated on a five-point scale. Results demonstrated that passengers' satisfaction level increased from 3.41 to 3.46 after the RTTI signage was installed, and that RTTI had a particularly significant impact on increasing passenger comfort while waiting at the station.

Ge et al. (2017) conducted experiments in three buildings located in the downtown area of Seattle to investigate the impact of real-time multi-modal transportation information signage on building occupants' travel behavior and attitudes *(8)*. Workers were divided into a treatment group and a control group, and a web-based survey was conducted which required respondents to state their satisfaction level with various transportation modes. However, findings indicated a minor change in respondents' satisfaction level.

Increased transit use

Reliability is an essential feature which will affect passengers' willingness to choose transit. Unreliable transit service, i.e., buses or trains not arriving or departing on time, will not only lead to wasted time, and consequently productivity, but also loss of passengers' trust in the transit service. Such effects may expand over time and result in transit use reduction.

As reviewed in previous sections, RTTI is capable of reducing passengers' perceived and actual wait time, and improve passengers' perceived security, which leads to improved passengers trust in transit service and an enhanced perception of transit service reliability, convenience and efficiency. As a result, existing transit users will be more likely to use public transit resulting in increased transit ridership. Many studies have confirmed the positive effect of RTTI on increasing the frequency of passengers' transit use.

In the previously mentioned study conducted by Schweiger (2003), a survey received from nine transit agencies deploying RTTI systems in the United States indicated that RTTI systems were considered by many agencies as an effective method to improve level of customer service, increase customer convenience, and increase ridership *(6)*. In addition, responding agencies estimated that the implementation of a real-time bus arrival information system could contribute to a 1% to 3% increase in ridership.

Politis et al. (2010) evaluated the effect of an Advanced Bus Passenger Real Time Information System in Thessaloniki, Greece *(9)*. The estimated arrival time for the next buses was displayed on an LED message sign at each bus stop. The researchers administered questionnaires to respondents at bus stops along a main central corridor of the city and segmented passengers into different categories according to their trip purposes and socioeconomic characteristics. The number of new trips generated by the RTTI system was assessed using data from the survey. Results showed that nearly 20% of the respondents took over 100 new trips after the implementation of the RTTI system.

Tang and Thakuriah (2012) investigated the impact of the Chicago Transit Authority (CTA) real-time bus information system on ridership *(10)*. This study collected bus ridership data in the Chicago metropolitan area at monthly intervals from January 2002 through December 2010 and constructed a longitudinal model to examine the effects on bus ridership after the introduction of bus real-time tracking information. The ridership of buses providing real-time tracking information was compared with those not providing such information. Results showed that bus routes equipped with a RTTI system had 126 more trips on average on a weekday in comparison to those without such a system.

Kaplan et al. (2017) conducted two case studies in Copenhagen, Denmark and Natal, Brazil by collecting data from a survey of 1,123 university students to investigate the change of transit use after providing necessary transit information to passengers *(11)*. The web-based survey asked respondents to state their transit use pattern and rate their perceived transit service experience and the quality of transit information provided. Results indicated that transit information with high quality was capable of increasing passengers' perceived transit level of service and perceived transit familiarity, consequently contributing to a higher frequency of transit use.

Other studies showed that the introduction of RTTI does not increase transit ridership. Caulfiled and O'Mahony (2007) conducted a web survey to gather people's travel behavior preferences in Dublin, Ireland (12). In their study, RTTI systems were found to contribute more towards increasing the comfort and satisfaction for passengers, than increasing transit use.

Chow et al. (2014) found minor increase of ridership after the implementation of RTTI signage across heavy rail system in Massachusetts, but the author thought the result was just preliminary and more evidence was needed to confirm the positive effect of RTTI in increasing ridership *(4)*.

Summary of RTTI Benefits to Existing Users

To summarize, this section discusses major benefits of RTTI in four aspects:

- RTTI can reduce both passengers' actual wait time and perceived wait time at stops, as passengers can adjust departure time according to the arrival time of the next buses or trains;
- RTTI has a positive effect on passengers' feeling of security, as they spend less time at stops where they may feel unsafe;
- the decreased actual and perceived wait time, as well as the increased perceived security are likely to increase passenger satisfaction level,
- and frequency of transit use.

2.1.2 Benefits of RTTI to Non-Users

Unlike existing users who already view transit as a transportation means, many non-users rarely using transit before may perceive riding transit as inconvenient and time-consuming, thereby not considering it as a potential alternative. Consequently, the benefits brought by

RTTI to non-users and the extent to which RTTI influences non-users will differ from that to existing users. This section further reviews the benefits of RTTI to non-users.

Mode Shift

Bonsall et al. (2004) found that car drivers are likely to underestimate the cost of driving and overestimate the cost of riding public transit *(13)*. Such preconception sets up a habitual and psychological barrier for car drivers to consider and use other alternatives. In addition, Chorus et al. (2006) investigated the effect of transit information among car drivers. Results showed that the effect of transit information is limited even among the group of car drivers who considered transit as a potential alternative while travelling *(14)*. However, if the appropriate information is provided, non-users, to some extent, will still consider transit as an alternative travel mode.

Abdel-Aty et al. (1996) carried out a telephone interview in Sacramento and San Jose, California to examine the effect of a transit information system on commuters' tendency to use transit *(15)*. Results demonstrate that properly provided transit information will entice about 38 percent of respondents who rarely used public transit before to consider it as a potential alternative.

Kenyon and Lyons (2003) studied the effect of multi-modal traveler information (MTI), which provided travelers with information about various kinds of transportation modes *(16)*. The study observed a series of focus groups across England and assessed the use of MTI and its potential effects. Findings revealed that the majority of travelers rarely consulted information about alternative modes due to their prejudice about transit service, thereby leading to the unawareness of possible alternative modes for their travels. Results also suggested that the presentation of various transportation modes for a trip could help eliminate travelers' preconception about public transit service, and thus, overcome habitual and psychological barriers to considering other alternatives. The authors argued that this might contribute to a mode choice change and persuade non-users to use transit.

Summary of Benefits of RTTI to Non-Users

To sum up, appropriate transit information provided to non-users is shown to be helpful in overcoming their prejudice about transit and changing their attitudes, and thus could entice them to consider transit as a potential alternative, even though observed switching behaviors of non-users due to RTTI is limited.

2.2 Desired Information Contents

In general, RTTI systems provide travelers with public transit services information such as schedule, fare, number of transfers, expected travel time to destination, estimated arrival time, and real-time location of the next buses or trains. These types of information are considered useful to improve the perceived level of service, enhance passengers' trust, and change non-users' attitudes toward public transit. As a result, existing transit users might increase the frequency of transit trips and non-users may start to shift to transit from private car use. In this section, we focus on the information contents that are most valued or desired by existing users and non-users.

2.2.1 Information Contents Most Valued by Existing Users

Harmony and Gayah (2017) conducted a web-based survey to determine the type of information transit users consider important *(17)*. Results indicated that transit users place the highest value on vehicle tracking information, such as the arrival and departure times and actual location of the next buses or trains. In contrast, transit users were not as concerned about vehicle attributes or facility characteristics, such as seat availability, operational status of elevators and parking availability.

Table 2.1 in the previous section includes a column for information contents displayed in the studied RTTI systems. Even though these studies did not explicitly state that these contents are most desired, the fact that they were displayed suggests their value. It can be seen that location tracking information and estimated arrival time are the two most widely used contents.

To sum up, the synthesis in Table 2.1 is in line with the conclusion of Harmony and Gayah (2017) that vehicle tracking information such as the arrival and departure times, and the actual location of transit vehicles are the most desired contents of RTTI *(17)*.

2.2.2 Information Contents Conducive to Mode Shift of Non-Users

The most valued information contents for existing users were reviewed in the previous section. Whether such information contents would have similar impacts on non-users and entice them to transit use is worth exploring.

Table 2.2 shows information contents considered helpful in encouraging non-users to shift from private car use to transit use based on the literature. In the following sections, these studies are reviewed in detail, grouped by type of transit information content.

Table 2.2: Desirable transit information contents for non-users' mode shift

Factors	Kitamura et al. (1995)	Abdel-Aty et al. (1996)	Khattak et al. (1996)	Abdel-Aty (2001)	Kenyon and Lyons (2003)	Ha et al. (2020)
Fare information	○	○	○	○	○	○
Wait time	-	○	○	○	○	-
Walking time to station	-	○	-	○	-	○
In-vehicle time	-	○	○	-	○	○
Number of transfer	-	-	-	○	-	○
Delay in terms of time	-	-	-	-	-	-
Arrival/Departure time	○	○	○	○	-	-
Frequency of service	○	○	○	○	-	-
Real-time Location of vehicle	○	-	-	-	-	-
Seating availability	-	-	-	○	○	-
Location-aware function	-	-	-	○	-	-
Parking availability	-	-	-	-	○	-
Elevator's availability	-	-	-	-	○	-

○: A circle indicates that the specific transit information content was found desirable for non-users.

- : A hyphen indicates that the specific transit information was not studied in the corresponding study.

Travel time

In order to explore travelers' response towards advanced traveler information system, Khattak et al. (1996) conducted a survey among Bay Area automobile commuters to estimate the effect of traveler information on travelers' route choice, departure time, and mode preference *(18)*. The researchers developed a multi-nominal Logit model based on combined revealed and stated preference data. Results suggested that travel time was one of the most important factors contributing to a mode shift from car use to other alternatives.

Abdel-Aty et al. (1996) conducted a telephone interview in Sacramento and San Jose, California to investigate which type of information non-users placed the highest value on *(15)*. They designed a state preference (SP) survey and built binary logit model to evaluate the effect of various factors. Results showed that travel time had the most significant impact on non-users' propensity of transit use.

Ha et al. (2020) examined the impact of various travel information contents on commuters' mode choice *(19)*. By applying discrete choice models, the study found that the most valued travel factors by commuters when making decisions on transportation modes were travel time and travel cost. In addition, the convenience and accessibility factors such as the number of transfers and walking distance to stations had a significant impact on traveler's mode choice as well.

Fare/Cost

Abdel-Aty (2001) designed and conducted a stated preference survey through telephone interviews from 1000 morning commuters in Sacramento and San Jose, California to determine the transit information contents that were considered essential by travelers *(20)*. This survey asked respondents to rank the top three most important information items that they were concerned about while considering transit use. An ordered Probit model was developed to assess the importance of transit attributes. Results showed that shorter wait times at transit stops, more frequent service, and shorter walking time to stops would increase travelers' probability of using transit. Particularly, the relatively low fare information displayed on the transit information system was found to significantly increase travelers' transit use. Furthermore, fewer transfers and higher seat availability would entice more non-users to public transit. Abdel-Aty argued that fare information, wait time at stops, walking time to stops, number of transfers, service frequency and seat availability were significant attributes contributing to mode shift. Especially, fare information exerted the greatest impact of encouraging non-users to use public transit.

Route Map and Schedule

Kitamura et al. (1995) conducted an in-laboratory interview with 50 full-time workers who commuted during the morning peak from Sacramento, California *(21)*. This interview was designed to evaluate the effect of a PC-based transit pre-trip information system on changing traveler's attitudes toward public transit and determine the most crucial information content. This study conducted a before and after SP survey to collect respondents' attitude towards different transportation modes and determine their valuations of different types of travel information, including schedule, travel time, frequency, fares, stop location, route map and service type. Results show that route map and schedule are the most important types of information contents when travelers are planning a transit trip and making decision on the travel mode.

Comfort and Convenience

Kenyon and Lyons (2003) designed an experiment to examine the impact of multi-modal travel information on mode shift *(16)*. Multiple transportation modes' information regarding different contents including fare, travel duration, travel comfort and convenience were provided in the experiment. Results suggest that the provision of information about various transportation modes help overcome travelers' prejudice that public transit is uncomfortable, unsafe or inconvenient. Especially, the comfort and convenience factors, as well as information suggesting the safety and flexibility of public transit would help travelers change their subjective attitudes and travel habits, and thus persuade non-users to consider transit.

Summary of Information Contents Conducive to Encouraging Mode Shift of Non-Users

To summarize, the following three groups of information content are useful in changing the attitudes and potentially behaviors of non-users who tend to perceive transit as an unreliable and inefficient travel mode.

- Many studies found that travel time, fare, and service schedule are the most essential information items encouraging non-users to shift from driving car to riding transit.

- The frequency of service, number of transfers, seat availability, and walking time to stops are also among the transit information content types that travelers considered important and useful.

2.3 Deployed RTTI Systems in the United States

In practice, RTTI systems have been deployed by many transit agencies in the United States. Although transit agencies vary in size and type of services offered, they all have the same goal of enhancing transit service and improving. passengers' experience. Reviews on the implementation and operation strategies of RTTI systems by various transit agencies will provide insights for our project.

Harmony and Gayah (2017) conducted a survey among 58 transit agencies from across the United States to investigate the information supply situation (17). Results showed that approximately 69 percent of surveyed agencies offered some form of RTTI. Provision of RTTI was affected by several characteristics such as agency size, geographic location, and the type of transit services offered. A larger transit agency in urban area was more likely to provide RTTI and the information contents most often provided by transit agencies included vehicle locations, route disruptions and emergencies. Other information items such as seat availability and parking availability were less often provided.

Table 2.3 summarizes the information contents displayed by RTTI systems of various transit agencies in the United States. The following Section 2.3.1. reviews RTTI systems in Massachusetts. Section 2.3.2 reviews RTTI systems of transit agencies comparable to MBTA in terms of size and transit services. Section 2.3.3. reviews RTTI systems with unique operation strategies.

Table 2.3: Transit attributes displayed by transit agency information systems

Agency	Meida	Arrival time	Wait time	Direction	Location of vehicle	Service alert	Alternative mode nearby
Chicago	Internet	-	○	○	○	○	○
Cap Cod	Internet	-	-	○	○	○	-
Central Ohio	Internet and Kiosk	○	○	○	○	○	-
Los Angeles	Signage	-	○	-	○	○	-
Massachusetts	Signage	-	○	-	-	○	○
Pennsylvania	Internet and SMS	○	-	○	○	○	-
Seattle	Signage and Kiosk	○	-	○	-	○	-

○: A circle indicates that the specific attributes displayed by the corresponding transit agency
-: A hyphen indicates that the specific benefit was not displayed by the corresponding transit agency.

2.3.1 RTTI Systems in Massachusetts

Massachusetts Bay Area Authority (MBTA)
Previous transit information system projects in Massachusetts give insights into future project design, implementation and operation. MBTA operates public transit service in the Greater Boston region. In order to improve bus riders' experience and enhance their trust in public transit service, MBTA has proposed a Better Bus Project, which is a major component of MBTA's efforts to improve bus service. As a part of the Better Bus Project, MBTA installed message signs displaying the real-time bus information at 18 high-ridership bus stops in 2020 (see Figure 2.1). This stop-specific information included bus arrival times, service alerts and nearby modes or routes. Nowadays, CMS has become the most prevalent medium to display RTTI across the United States because of their ease of installation and quick adjustments. It is worth noting that most of such transit information message signs are installed at bus stops or subway stations (Massachusetts Bay Area Transit, 2020) (22).

Figure 2.1: MBTA message sign at a bus stop

Cape Cod Regional Transit Authority (CCRTA)
CCRTA provides public transportation services of seven fixed routes year-round for all 15 Cape Cod communities. Unlike the Better Bus Project of MBTA, CCRTA presents RTTI by showing actual bus locations on a map via the website or mobile application. CCRTA customers can get access to a bus location map to track bus services and know the actual bus location, the direction of travel and estimated arrival time. Other information is accessible online as well as shown in Figure 2.2 (Cape Code Regional Transit Authority, 2021) *(23)*. In Figure 2.2, a blue line delineates the bus route from Sealine Hyannis to Falmouth/Woods Hole in the Cap Cope region, with red dots representing bus stops along the route. Each red dot is accompanied by a box displaying information about the stop, including starting point, direction and departure time.

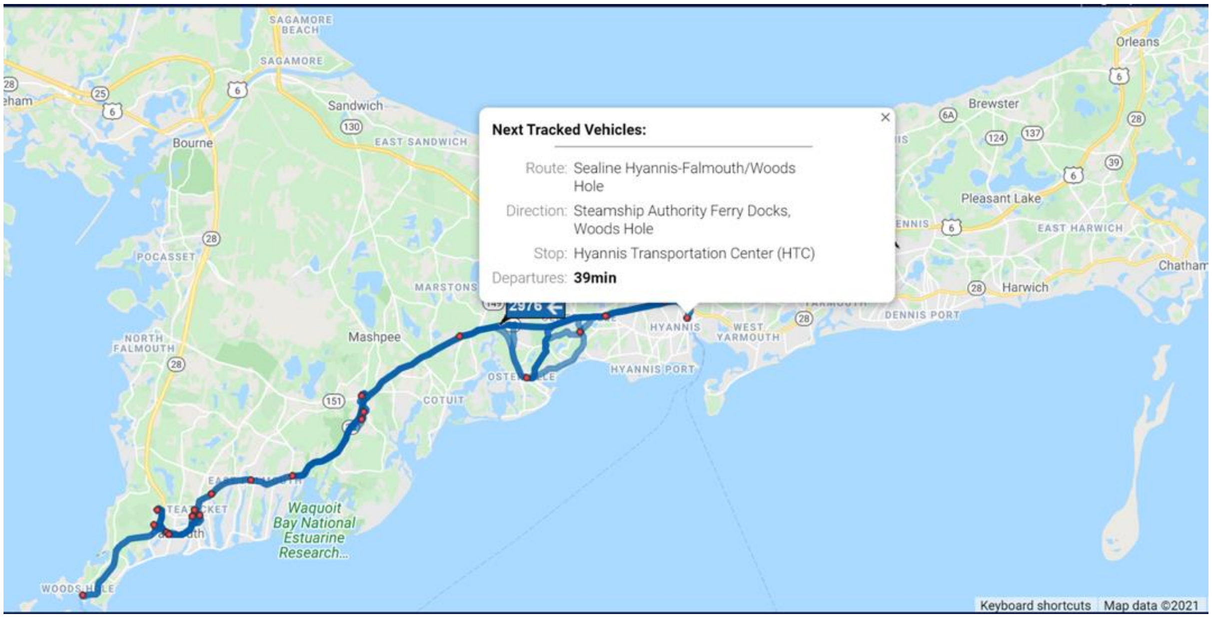


Figure 2.2: CCRTA RTI system

2.3.2 RTTI Systems of Transit Agencies Comparable to MBTA

Reviews of RTTI systems implemented in regions with comparable size and population to the Greater Boston Area provide examples of how to design RTTI systems in metropolises with large travel demands. A city with a large population, dense roadway network and rich experience in running public transit service, serves as a good example.

Chicago Transit Authority (CTA)

The Chicago Transit Authority (CTA) operates an advanced mass transit service system of 140 bus routes and 8 rapid transit lines has a daily ridership of 1.51 million which is comparable to that of MBTA. In order to increase the reliability of transit service, CTA has established an advanced transit service tracking systems called “CTA Bus Tracker" (Figure 2.3). Like the project of CCRTA, the CTA Bus Tracker is capable of displaying actual vehicle locations and accurate arrival times on a map of the service area available via the Internet. The type of information showed on the CTA Bus Tracker includes bus service status, estimated arrival time, bus actual location, and schedule (Chicago Transit Authority, 2021) *(24)*. In Figure 2.3, the bus tracking information at the Chicago State University stop is shown on a web browser window, within which the estimated arrival time of multiple approaching buses is shown.

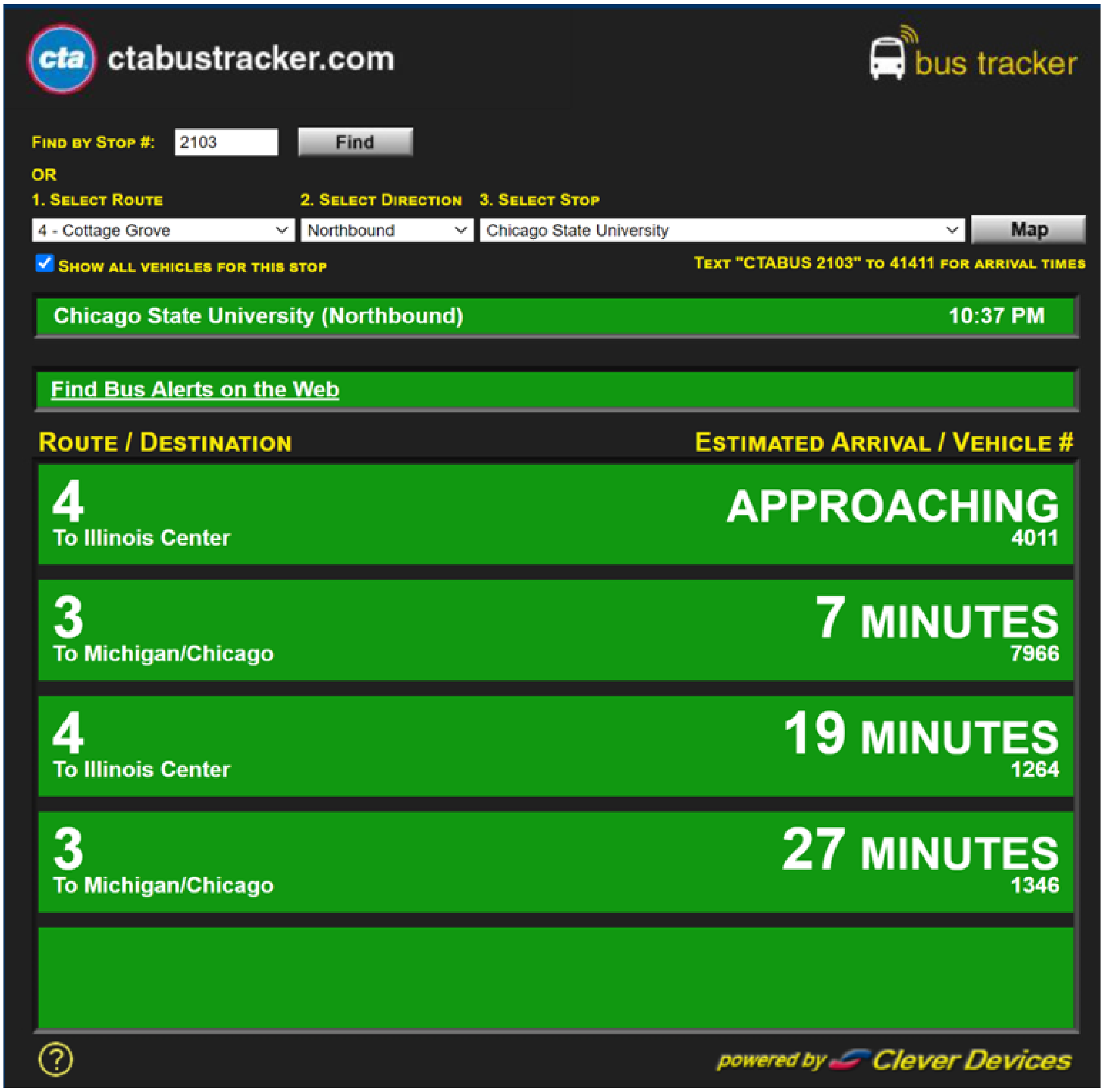


Figure 2.3: CTA bus tracker

Los Angeles County Metropolitan Transportation Authority (LACMTA)
LACMTA operates a large transit system including bus, light rail, heavy rail, and bus rapid transit services. Starting in 2011, LACMTA installed RTTI message signs (Figure 2.4) at major bus stops in Santa Monica. Unlike regular message signs that only display the arrival time of next buses, the message signs in Santa Monica have the capability of providing detailed route information, location stop identification, as well as a mobile phone number travelers can call to obtain more information. LACMTA hopes that such detailed information can change riders' perception of transit service and improve transit users' experience in Los Angeles (ITS International, 2012) *(25)*.

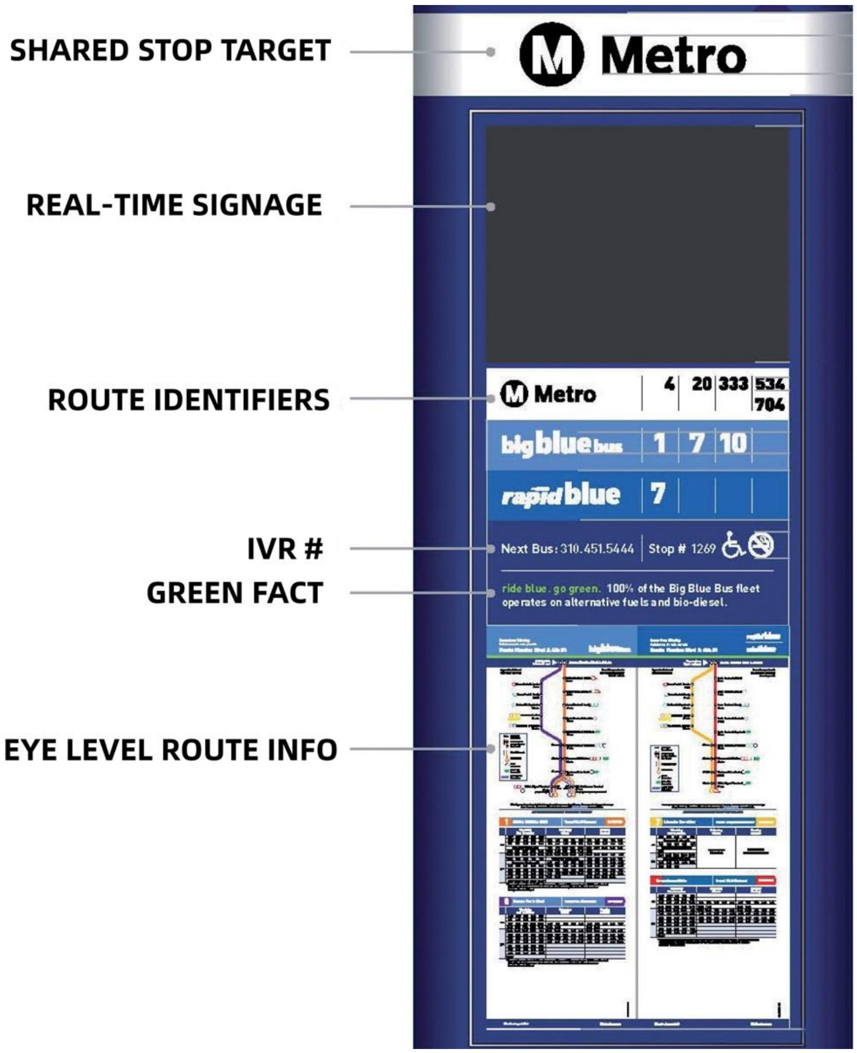


Figure 2.4: LACMTA message sign example

Southeastern Pennsylvania Transportation Authority (SEPTA)

SEPTA operates bus, rapid transit, and commuter rail service for nearly 4 million people in five counties in and around Philadelphia, Pennsylvania. SEPTA presents real-time service information including service alert, detour information, elevator availability, estimated travel time/delay, actual location tracking, and advisory messages on their website (Figure 2.5). SEPTA also provides an SMS service which follows a "request-response" format. SEPTA Transit customers can text a message to request their desired information for specific transit lines *(26)*. In Figure 2.5, on the right side, a blue line delineates the bus route from Parx Casino to 54th-City with bus symbols representing the real-time locations of buses. On the left side, detour information is displayed, including the location, reason, start time, and end time.

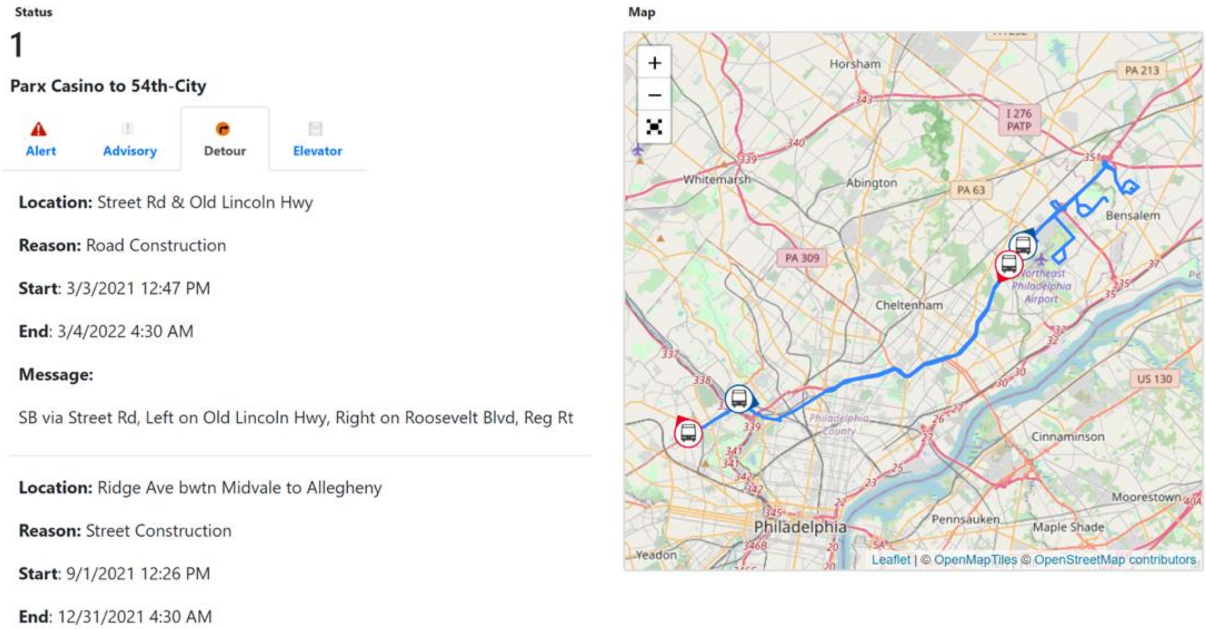


Figure 2.5: SEPTA RTTI website

2.3.3 RTTI Systems with Unique Features

Seattle Department of Transportation (SDOT)

In order to provide customers with detailed and real-time transit information, SDOT has proposed real-time information signs (RTIS) located at transit stops with high boarding activity. RTIS signs are designed to provide up-to-the-minute estimates of upcoming bus and train arrivals. Unlike other transit agencies using uniform message signs, SDOT decided to install three types of RTIS signs depending on the particular type of bus corridor or stop and integrate these transit information systems with other useful functions (Seattle Department of Transportation, 2021) *(27)*.

1. Outdoor signs. Outdoor signs are the most basic type of changeable message signs. Like other transit agencies, SDOT installs multi-line RTIS signs on poles outside bus stops to inform passengers of the estimated arrival time of the next buses.

Figure 2.6: SDOT: outdoor sign

2. Storefront signs. SDOT also installs RTIS signs providing estimated bus arrival time in storefront windows of businesses where there is high boarding activity. These storefront signs are also expected to attract customers in need of transit information to these stores, thus making business owners more willing to help install and operate the RTIS signs.

Figure 2.7: SDOT: storefront sign

3. Transit information kiosks. SDOT installs transit information kiosks at bus stops with the highest boarding activity. SDOT cooperates with the Federal Transit Administration to integrate these touchscreen information kiosks with a function that enables customers to pay for their rides before the bus arrives. Therefore, the kiosks not only give passengers access to the desired information, but also reduce their boarding time.

Figure 2.8: SDOT: information kiosk

Central Ohio Transit Authority (COTA)

The Central Ohio Transit Authority, serving the Columbus metropolitan area, presents RTTI in both visual and audio format in an effort to assist people with disabilities. In 2010, COTA introduced a real-time transit tracking system displaying departure time and actual bus location on a mobile application. Before 2010 when information technology was not as advanced as today, COTA used a system called "RideFinder" to present the RTTI to passengers via touch-screen kiosks. Interactive kiosks were considered another effective method of providing real-time bus information by showing actual vehicle locations on a map of the service area. Touchscreen interactive kiosks not only display a map of fixed shuttle routes with actual location and estimated arrival time of the buses, but also grant passengers the access to weather and fare information. Furthermore, messages including bus routes, estimated arrival time and stop dentification were provided in audio format and broadcast with the touch of a button on the kiosk to help the visually impaired access the RTTI (Schweiger, 2003) *(6)*.

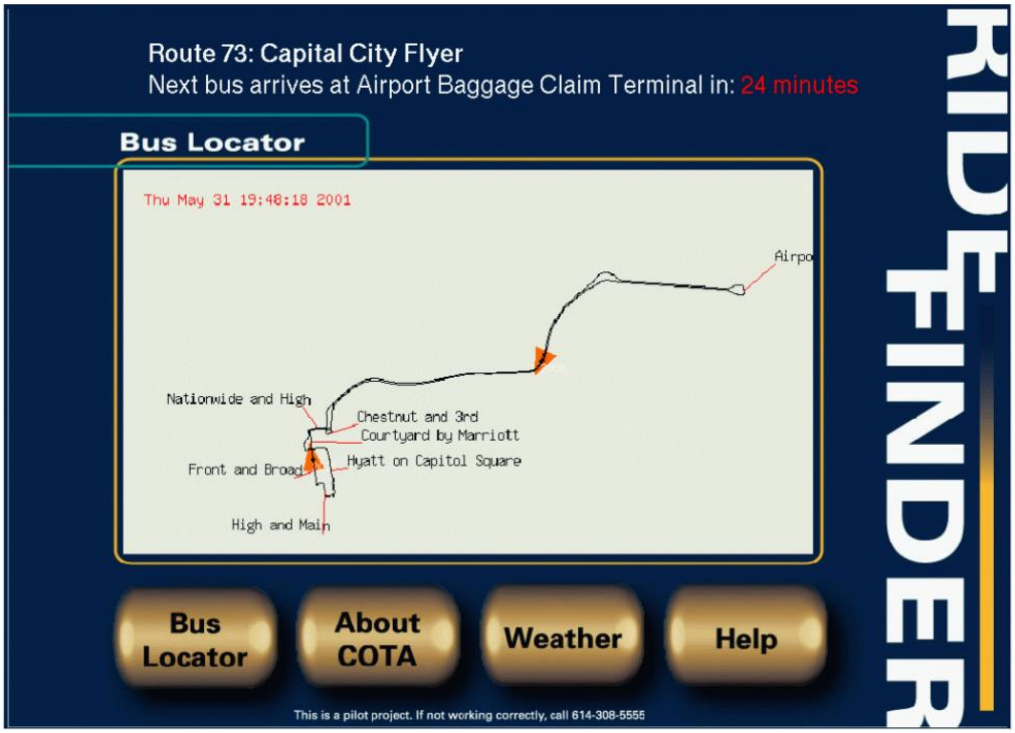


Figure 2.9: COTA interactive kiosk

Summary of RTTI Systems of Transit Agencies Comparable to MBTA
In general, there are four methods for transit agencies to provide RTTI: website or mobile applications, CMS, SMS services, and interactive kiosks. Among them, CMS is the most widely used method. The most often displayed information content types are listed as follows:

- Route number
- Bus stops
- Direction of travel
- Estimated arrival time
- Estimated waiting time
- Actual location of buses
- Service alert message
- Alternative transit modes nearby

Furthermore, the function of transit information systems can be extended to attract customers or enable passengers to pay before boarding. It is worth noting that most reviewed transit authorities choose to present RTTI online or by installing signage at transit stops. To the best of our knowledge, there are no transit agencies that have installed CMS along highways to present RTTI to drivers who are traveling on highways. It will be both a challenge and an opportunity for MBTA to design and implement such an RTTI signage system.

2.4 CMS Design Guidelines

As discussed in the previous section, CMS is the most widely used medium for presenting travel information. Transportation Management Centers (TMC) have traditionally been using CMS to inform motorists of any incidents that occurs on highways. In recent years, CMS is increasingly used to display travel time messages or other travel information during non-incident periods. Posting RTTI messages on CMS along highways could be an effective way to provide drivers with information about alternative travel modes they could choose to reduce their travel time or improve their experience.

In Section 2.2, several information contents are found to be crucial for encouraging users to increase the frequency of transit use or enticing non-users to shift from private car use to transit use. However, information content is not the only important element in conveying RTTI. The way these information items are displayed on message signs also influence drivers' understanding of and reactions to RTTI. In this section, display design guidelines for RTTI signage are reviewed in detail, based on two major references: MUTCD (Federal Highway Administration, 2012) and Dudek (2004) *(28,29)*.

2.4.1 Background and Color

In order to ensure the visibility and legibility of display, MUTCD suggests that colors used for the legends and backgrounds on CMSs should be as provided in Table 2.4. If the background of a CMS is black, the color used for the legend should match the background color that would be used on a standard sign for that type of legend. In addition, MUTCD encourages the use of CMSs with advanced technologies for greater legibility of their displays and enhanced recognition of the message so that a CMS has no apparent loss of resolution or recognition when compared with a static message sign. In addition, such signs are of the full-matrix type and can typically display full-color legends.

Table 2.4: MUTCD commonly used colors for a CMS

Legend or Background	Color	Regulartory Sign	Warning Sign	Temporary Traffic Control Sign	Guide Sign	Motorist Service Sign	Incident Management Sign	School, Pedestrian, Bicycle Sign
Legend	Black							
Legend	Green							
Legend	Red	X***						
Legend	White	X			X	X		
Legend	Yellow		X	X			X	X
Legend	Orange			X				
Legend	Fluorescent Yellow-Green							X
Legend	Fluorescent Pink						X	
Background	Black	X	X	X	X	X	X	X
Background	Blue					X**		
Background	Brown							
Background	Green				X**			
Background	Orange*							
Background	Red*							
Background	White							
Background	Yellow*							
Background	Purple							
Background	Fluorescent Yellow-Green				X			
Background	Fluorescent Pink							

* Fluorescent versions of these background colors may also be used.
** These alternative background colors would be provided by blue or green lighted pixels such that the entire CMS would be lighted, not just the legend.
*** Red is used only for the circle and slash or other red elements of a similar static regulatory sign.

2.4.2 Font Size and Spacing

According to MUTCD, the minimum letter height should be 18 inches for CMS on roadways with speed limits of 45 mph or higher. The minimum letter height should be 12 inches for CMS on roadways with speed limits of less than 45 mph. MUTCD suggests that using letter heights of more than 18 inches will not result in proportional increases in legibility distance.

Additional MUTCD guidelines suggest that spacing between characters in a word should be between 25 to 40 percent of the letter height. The spacing between words in a message should be between 75 and 100 percent of the letter height. Spacing between the message lines should be between 50 and 75 percent of the letter height. In addition, word messages on a CMS should be composed of all upper-case letters.

2.4.3 Message Length

According to MUTCD, the maximum length of a message should be dictated by the number of units of information contained in the message, in addition to the size of the CMS. MUTCD suggests that CMS can divide a long message into shorter messages displayed sequentially in no more than two phases. Each phase shall consist of no more than three lines of text, with no more than 20 characters per line.

Dudek (2004) points out that about 85 percent of motorists can begin reading a message on the LED message signs with 18-inch characters at about 800 ft under ideal visibility conditions *(29)*. However, the distance at which motorists can begin reading a message reduces to 600 ft when the sun is behind the message sign or during nighttime light conditions. Therefore, it is recommended to display a maximum of 3 information lines on highways because drivers have only a limited amount of time available, up to 6 seconds when driving on highways, to view and read the displayed dynamic traffic information on a message sign. If the message exceeds the amount of information, multiple actions can be taken: (a) splitting messages into two phases, (b) deleting "dead' words, and (c) using abbreviations. Figure 2.10 shows an example of message shortening by deleting unnecessary words.

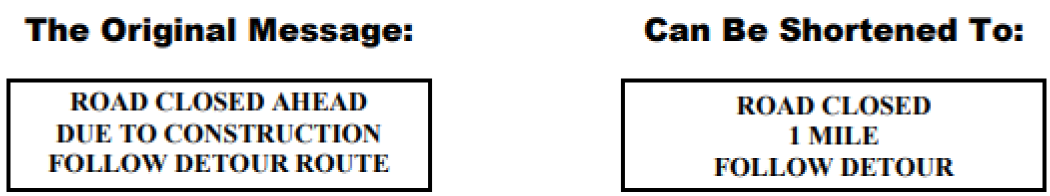


Figure 2.10: Shortened message

2.4.4 Message Load

Message load refers to the amount of information in the overall message, usually expressed in terms of units of information (informational unit). In MUTCD, a unit of information is defined as a single answer to a single question that a driver can use to make a decision, such as the location and time of the problem, the effect of the problem, and the needed actions. The MUTCD suggests that the message load should not be more than four units. Dudek (2004) provides a similar suggestion and recommends including no more than four units of information on a message sign when traffic operating speeds are 35 mph or more *(29)*. Figure 2.11 presents examples of one informational unit.

UNITS OF INFORMATION

Question		Answer		Info Unit
1. What happened?	,	ACCIDENT	,	1 unit
2. Where?	,	AT EXIT 12	,	1 unit
3. What effect on traffic?	,	MAJOR DELAY	,	1 unit
4. Who is advisory for?	,	NEW YORK	,	1 unit
5. What is advised?	,	USE ROUTE 46	,	1 unit

Figure 2.11: Information units

2.4.5 Message Duration and Cadence

As discussed before, CMS should include no more than two phases. In MUTCD, the minimum time that an individual phase is displayed should be based on the rule of 1 second per word or 2 seconds per unit of information. The display time for a phase should never be shorter than 2 seconds. When two phases are required, the maximum cycle time of a two-phase message should be 8 seconds and the duration between the display of two phases should not exceed 0.3 seconds.

There are no guidelines regarding message cadence in MUTCD or Dudek (2004) *(29)*.

2.4.6 Message Order

Message order refers to the sequence that specific information is displayed on CMS. It is of great importance for CMS to convey the traffic information and the needed action for motorists in a proper way. According to Dudek (2004), a CMS informing motorists of an incident ahead should include the problem, location, and the description of current situation or prescriptive message *(29)*. In general, the problem is supposed to be identified in the first line, the location of the problem is displayed in the second line, and the description of current situation or prescriptive message should appear at the end of CMS. Figure 2.12 shows two examples of a proper message order.

Message 1		Message 2	
ACCIDENT	*(Problem)*	**ACCIDENT**	*(Problem)*
PAST ROWLAND	*(Location)*	**PAST ROWLAND**	*(Location)*
KEEP RIGHT	*(Action)*	**2 LEFT LANES CLOSED**	*(Lanes Closed)*

Figure 2.12: Message order

2.4.7 Installation of CMS

According to the MUTCD, the following factors should be considered when installing CMS:

- Located sufficiently upstream of known bottlenecks and high crash locations.
- Located sufficiently upstream of major diversion decision points.
- Not located within an interchange except for toll plazas or managed lanes.
- Not positioned at locations where the information load on drivers is already high.
- Not located in areas where drivers frequently perform lane-changing maneuvers.

In order to make messages visible to more drivers on a multi-lane highway or a highway with a large percentage of trucks, CMS can be installed overhead on freeways and expressways. To ensure visibility, overhead signs on freeways and expressways shall provide a vertical clearance of no less than 17 feet to the sign, light fixture, or sign bridge over the entire width of the pavement and shoulders. For overhead sign supports, the minimum lateral offset from the edge of the shoulder to the near edge of the overhead sign supports shall be 6 feet. In addition, overhead sign supports shall have a barrier or crash cushion to shield them if they are within the clear zone.

2.4.8 Legibility Distance

The location where the message sign should be installed has a great impact on the accurate and proper information conveyance as well. Signs requiring separate decisions by the motor vehicle driver shall be spaced sufficiently far apart for the appropriate decisions to be made. In MUTCD, the maximum distance at which a driver can first correctly identify letters and words on a sign is called the legibility distance of the sign.

MUTCD recommends using post or 85 percentile speed limits when consider the maximum distance. CMS used on roadways with speed limits of 55 mph or higher should be visible from 1/2 mile under both day and night conditions. The message should be designed to be legible from a minimum distance of 600 feet for nighttime conditions and 800 feet for normal daylight conditions. When environmental conditions that reduce visibility and legibility are present, messages composed of fewer units of information should be used and consideration should be given to limiting the message to a single phase.

Deduk’s handbook suggests that based on the required legibility distance, the potential locations for the message sign are determined by the message load and posted speed limit. The message location should allow ample time for motorists to read, comprehend and then react to the messages. For instance, on a highway with a post speed limit of 65 mph, the message sign with four information units should be installed 750 ft away. Figure 2.13 shows the relationship between message detection, reading, decision, and out-of-vision. Figure 2.14 shows the relationship between units of information and required viewing distance for various speed limits.

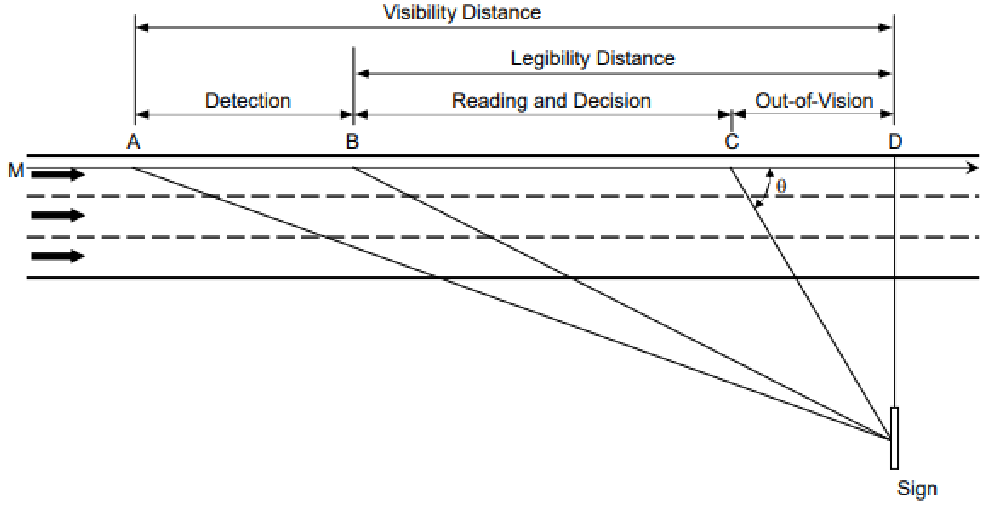


Figure 2.13: Message distance

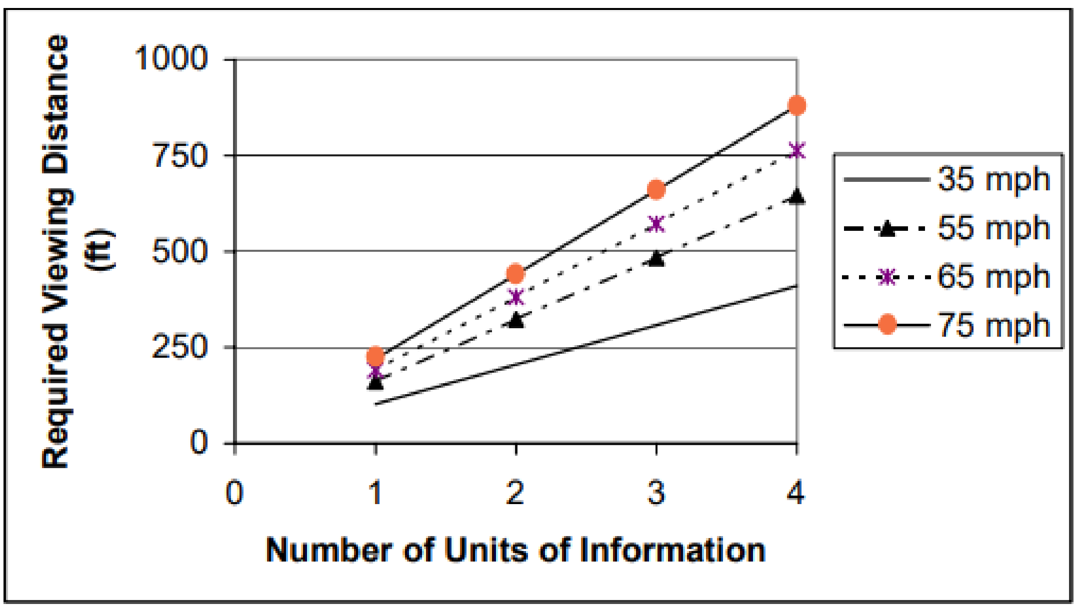


Figure 2.14: Relationship between units of information and required viewing distance for various speed limits

2.4.9 Dynamic Features

Many types of CMS have the capability to create dynamic features within a message. Such dynamic features include flashing a message or a line in a message, and alternating lines in a two-phase message.

There are widespread arguments that flashing message can attract the attention of drivers and emphasize the importance of the message and thus they display traffic information messages that flash or have one line that flashes. However, Dudek et al. (2000) and Dudek and Ullman (2002) conducted a single-task human factors laboratory studies to examine whether the flashing message affects drivers' reading time and comprehension level *(30, 31)*. And a follow-up driving simulator studies conducted by Dudek et al. (2005) gave further insights into the effect of such dynamic features on drivers *(32)*. Results indicated that flashing one line of three-line messages significantly increased average reading time. In addition, comprehension levels were lower, which means flashing message will make the information hard to understand by motorist on the highway.

Another dynamic feature is formatting a message in such a way that the top two lines remain constant, and a third bottom line is changed on the second phase of a message. Even though such dynamic feature did not adversely affect message recall, evidence shows that average reading times increased significantly. Therefore, it is not recommended to display traffic information message with such dynamic features.

According to MUTCD, CMS shall not include advertising, animation, rapid flashing, dissolving, exploding, scrolling, or other dynamic elements.

2.5 Information Needs during and after COVID-19

The strict restriction on social distancing during the COVID-19 pandemic has led to a large decline in transit ridership in 2020. Transit rider customers choose to drive their own cars rather than to use public service for fear of getting infected in a crowded bus or train. In order to restore transit rider customers' trust in public transit service and recover the ridership, transit agencies in many cities use real-time data on ridership to reflect crowding levels of bus or train routes during COVID-19. With this information, transit riders can modify their departure time to less crowded time or choose less crowded routes. For example, in July 2020, New York's MTA updated a mobile application for the Long Island Rail Road (LIRR) commuter train. The apps provide riders with real-time ridership data showing how many riders are on-board at each stop.

Other agencies are using recent historical passenger data (within the last two weeks) to provide ridership information. Southeastern Pennsylvania Transportation Authority (SEPTA) introduced a Seat Availability Dashboard to provide passengers with additional information to help passengers understand the most current standards for social distancing. It computes the estimated seat availability based on recent observed conditions from the previous two weeks and provide riders with three categories of crowding level at each stop on a trip: Many Seats Available, Few Seats Available, and Standing Room Only. Chicago Transit Authority (CTA) introduced a bus crowding dashboard in June 2020 that shows real-time crowding level by hour by route. Furthermore, CTA is working on a similar crowding information dashboard which provides real-time ridership information for rail lines. San Francisco Bay

Area Rapid Transit (BART) also introduced train loading information using historical data to help riders make decision on the departure time and routes.

2.6 Summary of Literature Review

The literature review presents a detailed review of the five key aspects for the Outdoor Information Panel projects: (a) benefits of RTTI to existing transit users and non-user, (b) desirable information contents for both existing users and non-users, (c) deployed RTTI systems in the United States, (d) CMS design guidelines, and (e) information needs during and after the COvID-19 pandemic. Major conclusions are summarized as follows.

2.6.1 Benefits of RTTI to Transit Users and Non-Users

The provision of RTTI is found to have positive impacts on improving existing users' experience in four aspects:

- Reduced wait time. RTTI can lower transit travel time uncertainty and increase passengers' control over time by providing passengers with estimated arrival time and/or actual location of next buses or trains. Studies have suggested as much as 20% decrease in passenger's perceived wait time and 1 to 2 minutes decrease in passenger's actual wait time.
- Improved perceived security. RTTI will improve passengers' feeling of security because they spend less time on stops where they may feel unsafe due to passing vehicles or potential crimes.
- Improved service satisfaction. The decreased wait time and increased perceived security work together to enhance customers' trust in public transit service and improve their satisfaction level.
- Increased ridership. Some transit agencies estimate that RTTI systems contribute to 1% to 3% increase in ridership. A couple of academic studies show positive impact of RTTI on increasing transit ridership.

In terms of non-users, appropriate information will help encourage non-users to shift from private car use to transit use. One study shows that properly provided transit information will entice about 38 percent of respondents who rarely used transit before to consider using public transit.

2.6.2 Desired Information Contents

The most valued transit information contents by existing transit users when they consult RTTI is the tracking information (i.e., arrival time and actual location of the next buses). In terms of non-users, there are four major information contents considered essential: (a) travel time, (b) fare, (c) accessibility factors such as walking to stops, and (d) comfort or convenience factors such as parking availability and seat availability. Among them, travel time, schedule, and fare information are the most valued factors.

2.6.3 Deployed RTTI Systems in the United States

RTTI systems have been deployed across the United States, including MBTA, CTA, LACMTA, and SDOT. The most prevalent information displayed by these agencies include travel time, actual location of buses and service alert messages. There are four most widely used media for presenting travel information: (a) internet, (b) CMS (changeable message sign), (c) SMS (short message service), and (d) interactive kiosks. The majority of reviewed transit agencies installed CMS at bus or train stops. No transit agency has been identified thru this study that is using the installation of transit information message signs along highways.

2.6.4 CMS Design Guidelines

Multiple factors need to be considered when designing and installing CMS:

- Color and background. The color used for the legend on a CMS is supposed to match the background color that would be used on a standard sign for that type of legend.

- Font size and spacing. The minimum letter height should be 18 inches for a CMS on roadways with speed limit of 45 mph or higher. The spacing between characters in a word should be between 25 to 40 percent of the letter height. The spacing between words in a message should be between 75 and 100 percent of the letter height.

- Message length. Messages on a CMS should be limited to no more than two phases and each phase shall consist of no more than three lines of text, with no more than 20 characters per line.

- Message load. No more than four units of information should be included on a message sign when traffic operating speeds are 35 mph or higher.

- Message order. The sequence of information content on CMS should be problem, location, description of current situation or prescriptive message.

- Message duration and cadence. The display time for a phase should be more than 2 seconds. The maximum cycle time of a two-phase message should be 8 seconds. There is no guidance on message cadence.

- Installation. CMS should be located upstream of bottlenecks, high crash locations, and major diversion crash locations. CMS should not be located within an interchange except for toll plaza or managed lanes. When a CMS is installed overhead on highway, a vertical clearance of not less than 17 feet, and a minimum lateral offset of 6 feet are required.

- Legibility distance. CMS should be designed to be legible from a minimum distance of 600 feet for nighttime conditions and 800 feet for normal daylight conditions.

- Dynamic features. CMS shall not include advertising, animation, rapid flashing, dissolving, exploding, scrolling, or other dynamic elements.

2.6.5 Information Needs during and after COVID-19

In order to restore customers' trust in public transit service and recover ridership, transit agencies such as those in New York, Chicago, and Philadelphia have started to use real-time or historical ridership data to inform riders of crowding levels on buses or trains so that riders can travel at less crowded times or on less crowded routes.

This page left blank intentionally.

3.0 Research Methodology

An online interview and a household survey are conducted in sequence to help the research team gather Great Boston Area (GBA) travelers' travel experience, preferred real-time information contents and location and billboard graphic designs. The findings are the basis for the research team in developing guidelines for setting up new digital billboards or updating legacy billboards at optimized locations, determining the optimized information combination displayed on billboards, and adopting the optimized billboards graphic design that would attract travelers most.

3.1Map of Potential OIP Locations and MBTA Stations

In order to better assist MBTA in their decision making regarding OIP locations, the research team has produced a map of potential OIP locations and corresponding MBTA stations. This section provides a user guide for the map on reading the information displayed on the OIP map and explain how potential OIP locations are chosen and how influencing MBTA stations for each OIP location are selected and classified. The web based interactive OIP Map can be accessed at https://people.umass.edu/sgao/OIP/.

3.1.1 Map Contents

Each potential OIP location is given an individual blue marker based on their associated latitude and longitude of the physical sign location. Click on a mark and a popup will appear with information of the OIP and associated MBTA stations. Click on any other place on the map or x at the upper right corner of the popup to close it. The OIP marks and popups are shown in Figure 3.1. Each part of a popup is numbered in Figure 3.2 and described in a corresponding subsection.

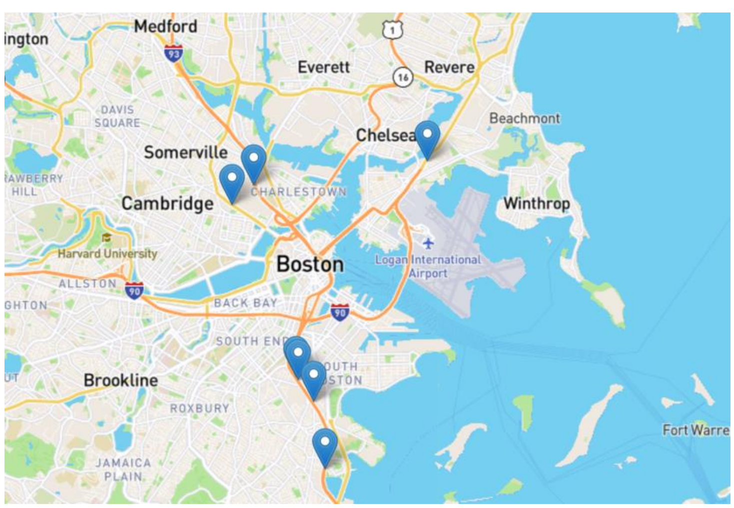


Figure 3.1: A screenshot of the OIP map

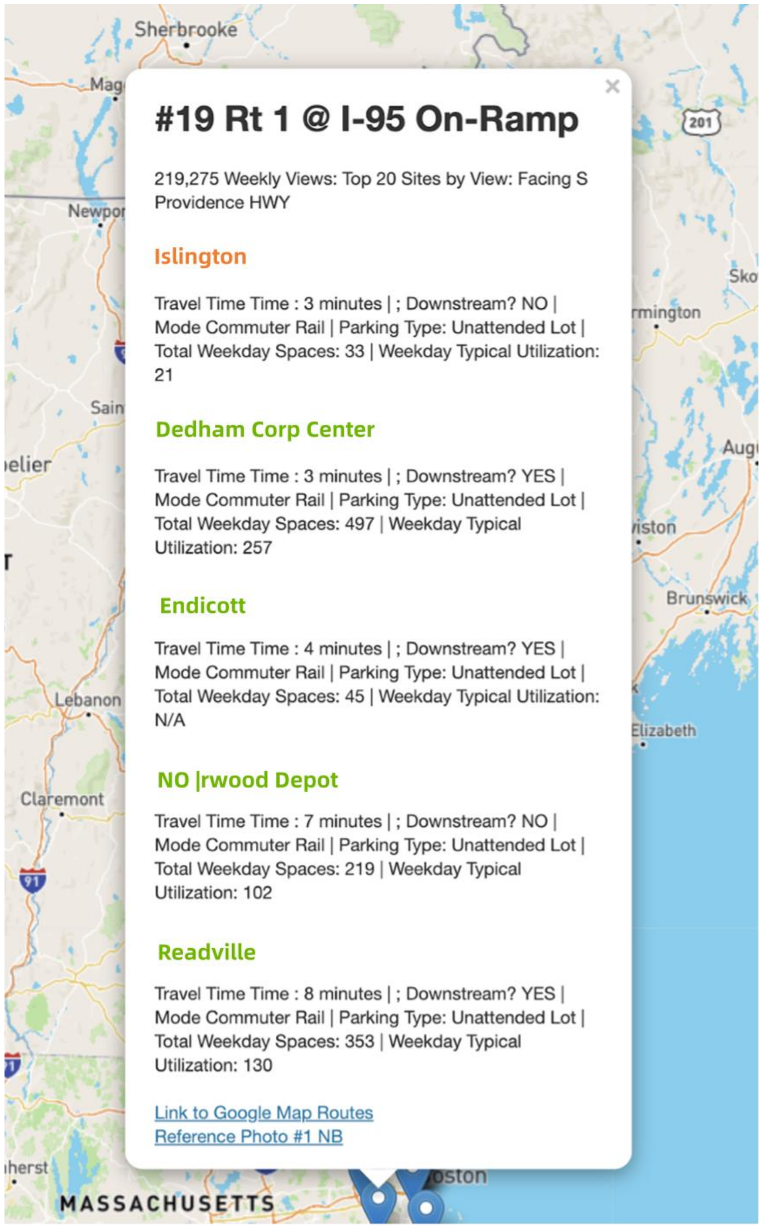


Figure 3.2: An example of a popup

OIP Description

The name and characteristics of the OIP is taken from the Impressions map provided by MBTA unless otherwise specified. The characteristics of the OIP include:

- Weekly views.
- Category: Top 20 sites by views, Category B (>100K weekly views), Category C (>50k <100k view), Category D (<50k views), or Digital (CCO contract + OIP sites).
- Facing direction: digital OIP is assumed to be facing both directions if not specified.

Five Closest MBTA Stations with Parking

The five closest MBTA stations with parking are displayed in increasing order of distance. Each station's color indicates its suitability to be displayed on the OIP: green = good; orange = fair; red = poor. The criteria of classification are described in Section 3.1.2. Information for each station includes:

- Travel time from the highway point closest to OIP location to the station with a travel direction opposite the OIP facing, that is, northbound (NB) if the OIP if facing south.
- Whether or not the station is downstream of the OIP following the travel direction.
- Number of parking spaces.
- Typical weekday utilization.
- Transportation mode for the station: rapid transit or commuter rail.
- Parking lot type: garage, attended lot, or unattended lot.

Link to Google Maps Showing Routes from OIP to MBTA Stations

The Google Maps link leads to a separate Google map, showing routes from an OIP to all five stations. The first layer is the OIP, and other layers are routes from the OIP to each station. If the OIP has two faces, routes are generated for both travel directions. For example, #17 I-93 SB @ Exit 26B and its routes to the five closest MBTA stations are shown in Figure 3.3.

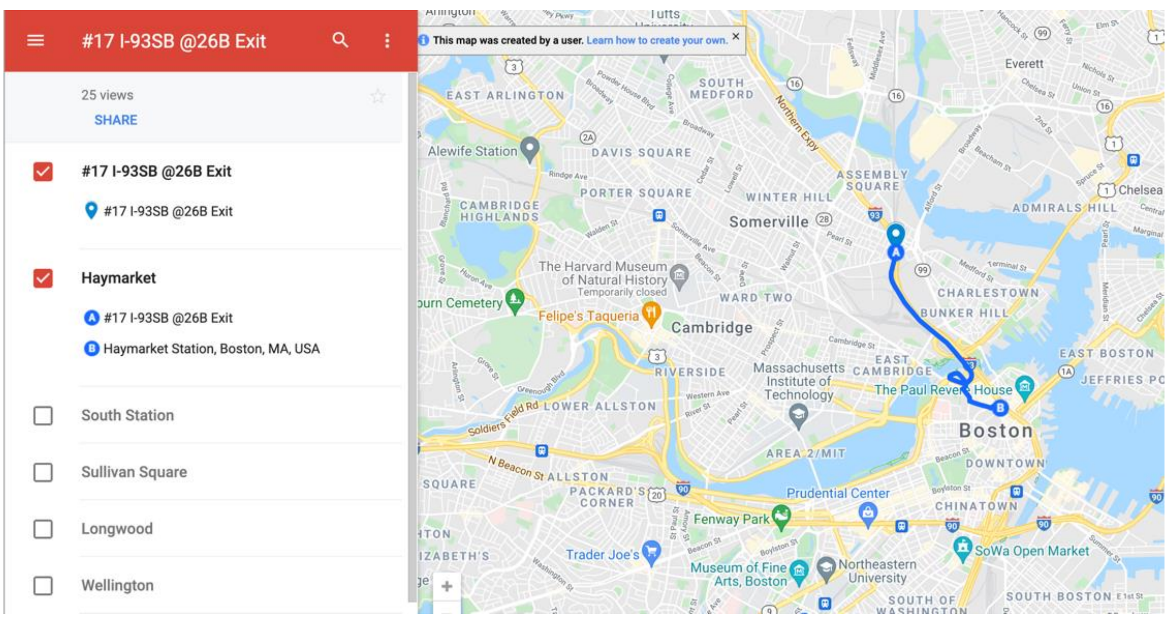


Figure 3.3: An example of a Google map showing routes from an OIP to MBTA stations

Links to Photos of OIP

The photo link leads to a separate webpage showing a Google Street View photo of the OIP for better visualization of the sign location and position in relation to the roadway. For example, the southbound view for the OIP named #17 I-93 SB @ Exit 26B is shown in Figure 3.4.

Figure 3.4: An example of Google Street View of OIP location

3.1.2 Methodologies

OIP Location Selection

Using the Google Map Impressions provided by MBTA, all raw OIP location points with associated latitudes and longitudes were uploaded into ArcGIS. A buffer analysis was conducted in ArcGIS and a point layer of all OIP locations within a 500m radius of interstate and major Massachusetts highways was generated. These locations were further narrowed down by manual inspection, disregarding duplicate OIP locations and removing OIP locations not visible from the associated highway.

MBTA Stations Selection

Using the generated acceptable OIP point layer, an ArcGIS network analysis was run to generate the closest five MBTA stations for each OIP location.

MBTA Stations Classification

Each station’s suitability to be displayed on a given OIP is classified as good, fair or poor, depending on the travel time from the OIP to the station and the station’s location relative to the OIP, shown in the Table 3.1.

Table 3.1: Suitability of MBTA Stations

Travel Time < 10 min?	Downstream of OIP	Not Downstream of OIP
Yes	Good (green)	Fair (orange)
No	Fair (orange)	Poor (red)

Parking vacancy is not included in the criteria since users and non-users could have different needs regarding this piece of information. On one hand, users need to know whether a busy parking location still has enough space, so it is desirable to show vacancies of parking locations that are usually filled up. On the other hand, non-users need to be persuaded that there are enough spaces if they are to switch to transit, so it is desirable to show parking locations that are not so busy. Further discussions with the project champion (PC) and during focus groups could provide guidance on this criterion.

3.2 Online Interview

An interview enables open-ended exploration of the topic of interest via a one-on-one conversation between the researcher and a limited number of selected participants who possess certain common characteristics (e.g., daily commuter in GBA) and also exhibit diversity with regard to other key characteristics (e.g., transit usage frequency, most used highway segment). The main reason for adopting a one-on-one interview process rather than focus group interview process in this study is to ensure that participants' opinions and ideas could be gathered thoroughly without interference from others' opinions.

The goal of the online interview is to generate as many ideas about the billboard as possible in a brainstorming fashion, which provides the basis for designing a relevant subsequent survey distributed to randomly sampled households in GBA.

3.2.1 Questionnaire Design and Testing

Design
The interview questionnaire is structured in three sections: (1) travel experience, (2) desired contents, and (3) adequate information load. Interview slides are prepared and presented to interview participants to help them understand questions and ensure uniformity across participants.

The research team worked with Outfront Media to design an array of graphics to illustrate individual information contents, e.g., travel time, cost, parking availability and so forth (see Figure 3.5) to help interviewees more easily put themselves in the context and inspire them to talk about ideas.

Full billboard graphics that contains three, four or five information units were designed to test the retention of information. Participants were shown billboards with various number of information units for 3 seconds, roughly the amount of time a driver can safely look at a highway billboard for and asked to recall the content afterwards. In the case with staggered billboards, the same billboard was shown for 3 seconds, disappeared for 20 seconds and was shown for 3 second again.

Testing
Pilot interviews were conducted with two student volunteers from UMass Amherst. Adjustments and improvements were made to the interview based on their feedback.

Figure 3.5: Graphics of individual information contents

3.2.2 Participants

Recruitment

In June 2022, a recruitment email was sent to the UMass Transportation Center (UMTC) listserv with about 1000 subscribers in the state.

Screening

An online screening questionnaire was implemented in Qualtrics. 61 persons responded to the recruitment email and were directed to take the screening questionnaire. 48 did, and 40 of these responses were valid. 16 participants were selected with a balanced mix of transit user type (frequent, occasional and non-user), age, gender, household income, employment status and geographic coverage of two major trip origin-destinations (ODs). Travelers who use transit more than twice a week are considered frequent users, who use transit between once a month and twice a week are considered occasional users, and who use transit less than once a month are considered non-users. 8 non-users were selected due to their high proportion among highway drivers. 11 persons eventually participated in the interview from August 11 through 24, 2022 via Zoom.

Demographics and Travel Patterns

Figure 3.6 and Figure 3.7 show the distribution of demographics, transit user type and whether frequently used travel mode has changed due to COVID-19 of the 11 interview participants. Notably half of the selected non-users did not participate, probably because they are in general less invested in transit than users.

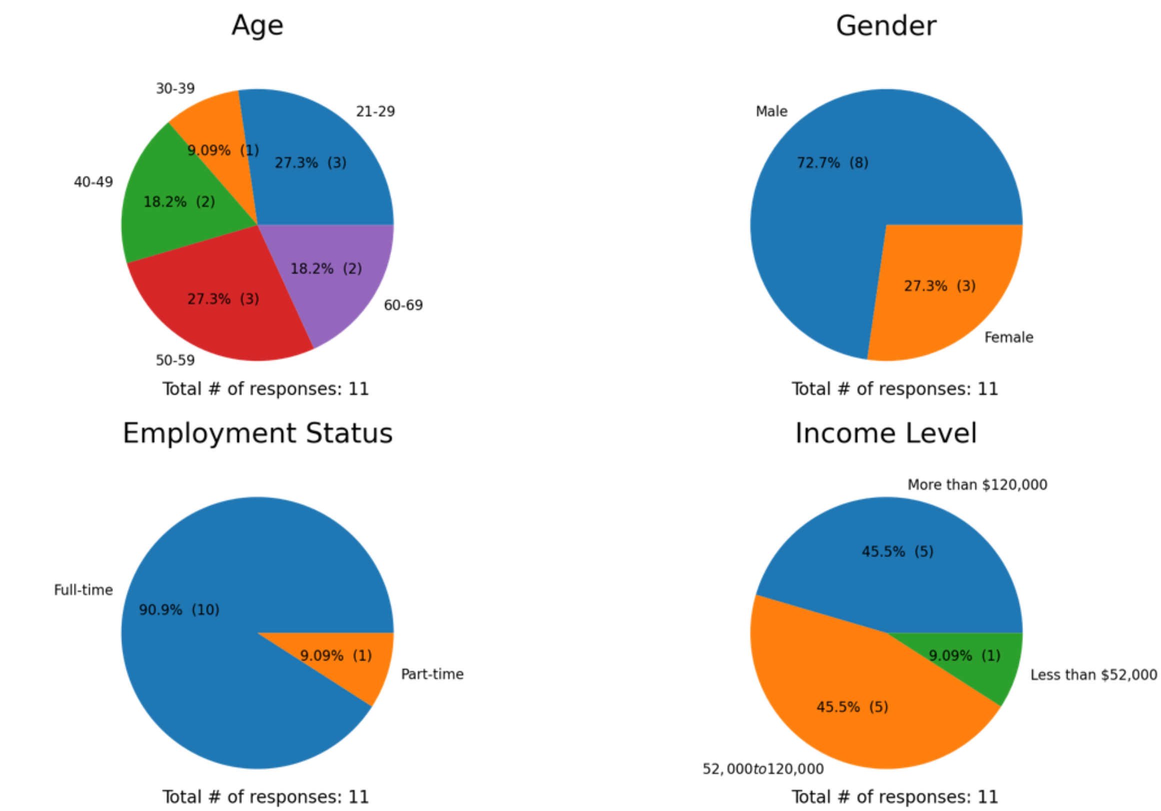


Figure 3.6: Demographics of the interviewees

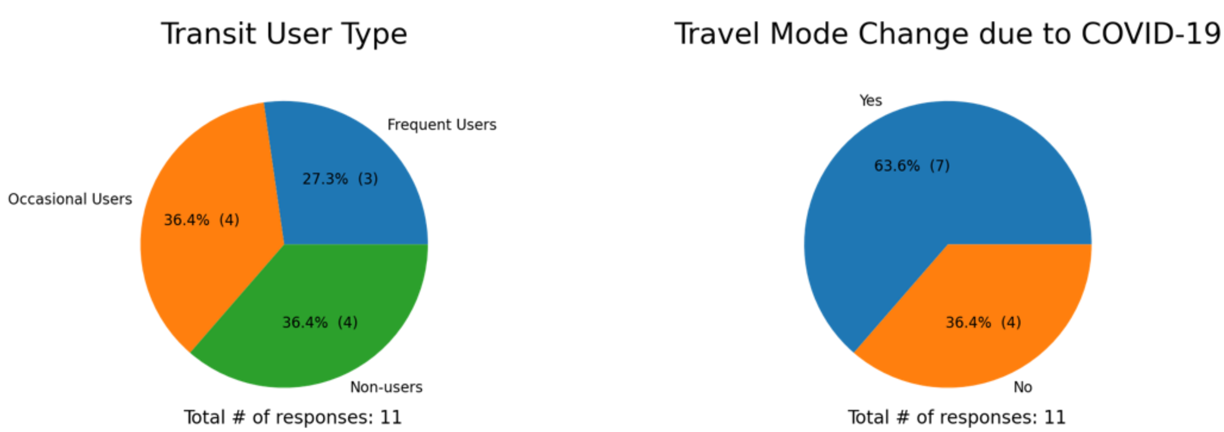


Figure 3.7: Transit user type and travel mode change due to COVID-19

3.2.3 Data Processing

Audio recordings for these 11 interviews were transcribed to text files. The transcribed text is cleaned up by stripping off nonessential words and all personal information. Each participant was assigned an ID to maintain anonymity. The analysis of transcripts is comprised of three main phases including preparation, organizing and reporting. First, the text was scrupulously reviewed for making sense of the data and ensuring accuracy. Then, the text is coded by notes, keywords and sentences. After that, participants' responses were organized and classified into various question groups. Finally, the identified groups are integrated, analyzed and interpreted in order to explain the participants' opinions.

3.3 Household Survey

3.3.1 Questionnaire Design and Testing

Design

The online household survey is comprised of five sections: (1) demographics, (2) travel experience, (3) desired information contents, (4) potential behavior change, and (5) billboard design. The survey generally follows the structure of the online interview including the screening questionnaire by refining and transforming interview questions into multiple choice questions. Information load questions are not in the survey as the content-recall process calls for open-ended questions whose results are generally known from the literature and the interview and do not warrant the extra effort imposed on participants.

In the travel experience section, the frequently used highway segment question has been changed to ask respondents to select one predefined highway segment on a Boston highway map (Figure 3.8), rather than asking them to select the start and end exits of a specific highway. 19 highway segments on Route 1, Route 2, Route 3, Route 9, Route 24, Route 128, I-90, I-93, I-95, I-495 are defined based on major interchanges. In Figure 3.8, a Boston map with multiple lines of different colors, each color representing different predefined highway segment, is presented. For instance, light green line represents the segment of I-93 located in

the northern part of Boston, while dark green line represents the segment of I-93 located in the southern part of Boston. Some towns, such as Quincy and Cambridge, are marked by dots.

In the desired information section, billboard content options are customized according to the previously selected frequently used highway segments. Nine transit trips, five by commuter rail and four by subway from various parts of the GBA to downtown Boston are chosen based on which real-time information content values (e.g., travel time, fare, parking cost) are calculated. Each transit trip corresponds to one or more highway segments in the general travel direction, as shown in Table 3.2. If a participant does not select a most frequently used highway, the commuter trip from Waltham to North Station is displayed.

Figure 3.8: Highway segments in GBA

Table 3.2: Nine transit trips to downtown Boston

Transit Service	Transit Line	Origin	Destination	Event	Corresponding Highway Segments
Commuter Rail	Fitchburg Line	Waltham	North Station	No	Route 2 / I-95 C / I-495 C
Commuter Rail	Rockport Line	Glouester	North Station	No	Route 1 B / Route 128 / I-95 D
Commuter Rail	Needham Line	Needham Heights	South Station	No	I-95 B / I-495 B
Commuter Rail	Providence Line	Attleboro	South Station	No	I-95 A / I-495 A
Commuter Rail	Greenbush Line	E.Weymouth	South Station	No	Route 3 A
Subway	Red Line	Braintree	South Station	No	Route 24 / I-93 A
Subway	Orange Line	Forest Hill	Downtown Crossing	No	Route 1 A
Subway	Green Line D	Riverside	Park Street	No	Route 9 / I-90
Subway	Red Line	Alwife	Park Street	No	Route 3 B / I-93 B / I-495 D
Subway	Red Line + Green Line D	Quincy Center	Kenmore	Yes	-

Figure 3.9 displays a screenshot of the billboard content questions for a Red Line trip from Braintree to South Station. A sample billboard representing the transit trip is presented in the question, and information contents including real-time total travel time by transit, total travel cost by transit, and so forth serve as options.

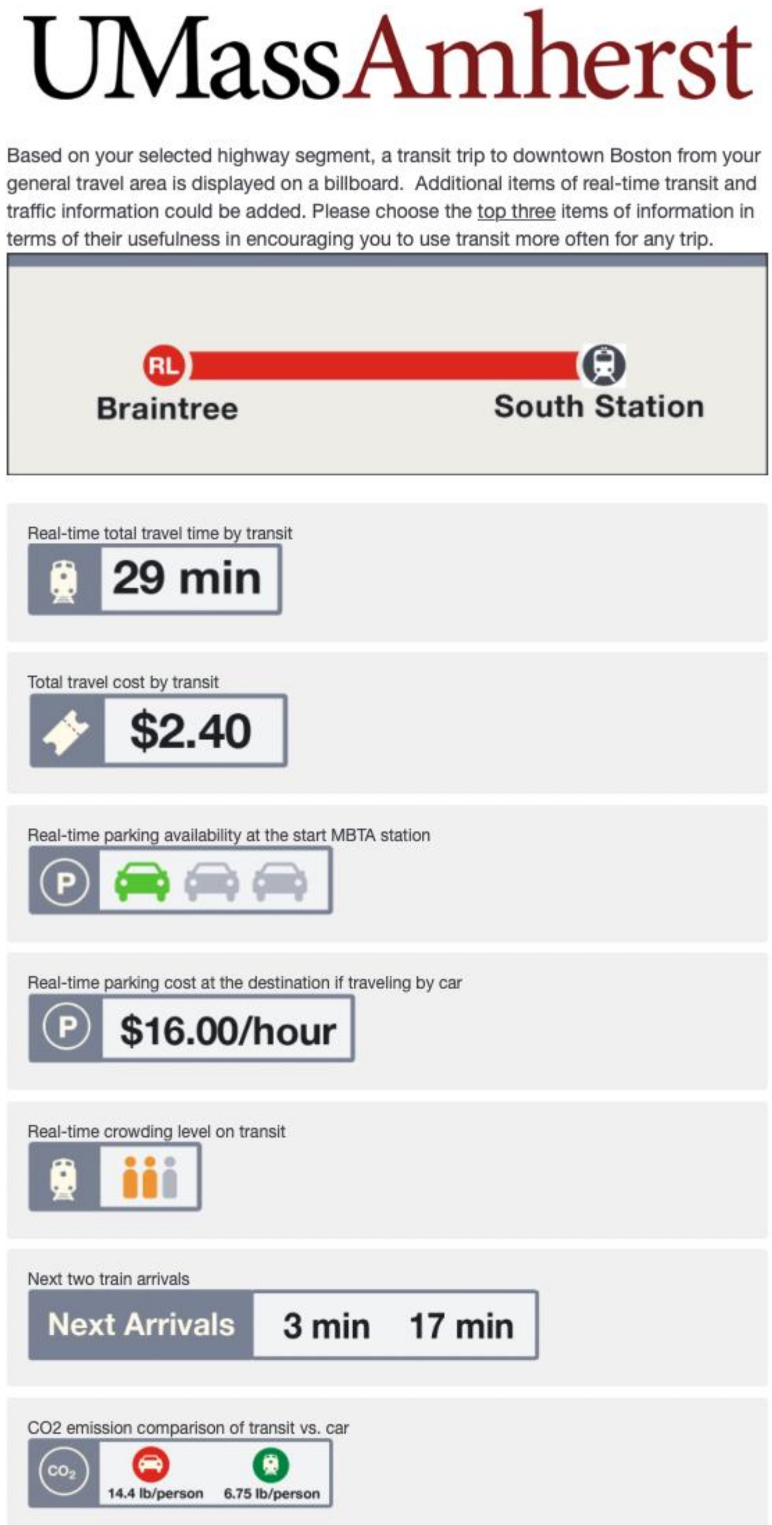
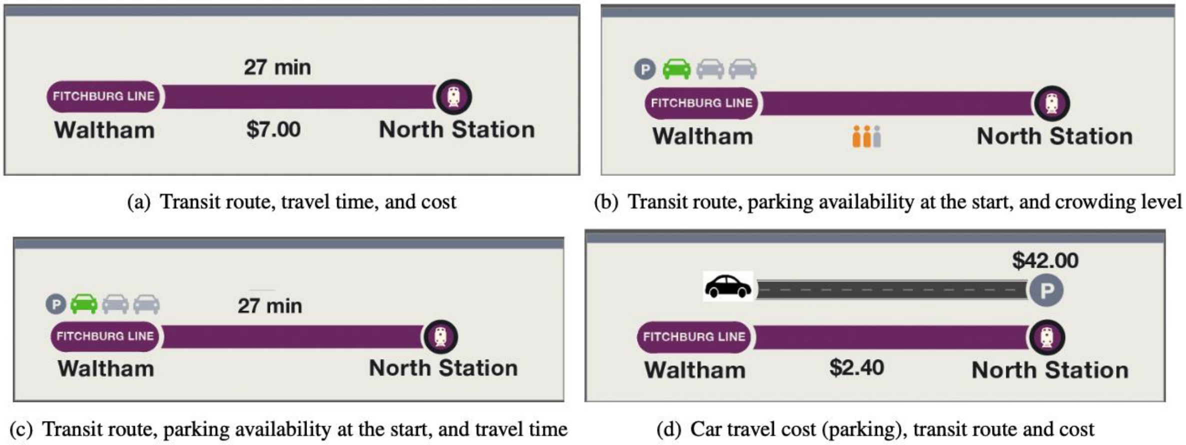


Figure 3.9: The desired content question for a Red Line trip from Braintree to South Station

In addition, participants are asked to rank full billboards with various content combinations to capture potential synergies among information elements that might be missing from the previous question about individual content only (Figure 3.10(a) through Figure 3.10(d)).



(a) Transit route, travel time, and cost

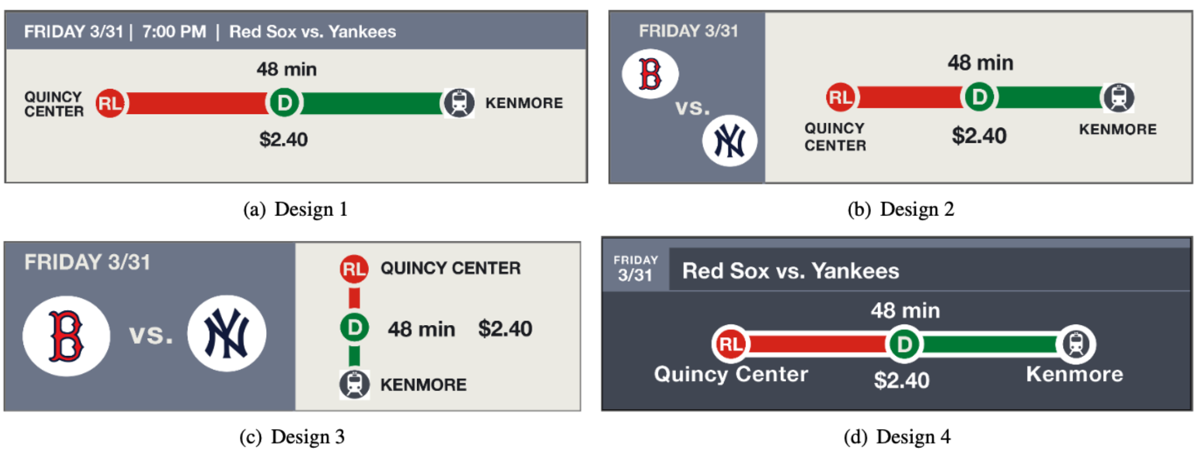
(b) Transit route, parking availability at the start, and crowding level

(c) Transit route, parking availability at the start, and travel time

(d) Car travel cost (parking), transit route and cost

Figure 3.10: Full billboards with various content combinations

In addition to content, a graphic design question is included to test various layouts, fonts and colors with the help of OutFront Media. Figure 3.11(a) through Figure 3.11(d) show the four billboard designs.



(a) Design 1

(b) Design 2

(c) Design 3

(d) Design 4

Figure 3.11: Billboard graphic design options for a Red Sox game trip

Testing

Pilot online surveys were conducted with two students from UMass Amherst. Both acknowledged that the survey was well designed.

3.3.2 Participants

Recruitment

A postcard (Figure 3.12) is designed with the help of UMTC staff. 10,000 randomly sampled household names, addresses and cell phone numbers from the six counties in GBA are obtained from Marketing Systems Group. 10,000 postcards were printed by Amherst Copy. They were mailed by UMass Mail Service on December 19, 2022.

5,843 of the 10,000 households have cellular phone numbers attached. Reminder text messages containing the online survey URL were manually sent to these potential participants in March and April 2023.

Figure 3.12: The recruitment postcard

Demographics and Travel Patterns
Through the method of mailing 10,000 postcards to sampled household address, 151 responses have been received on Qualtrics by Feb 3, 2023. 125 of these responses are considered valid with at least 60% of the survey finished. The response rate for postcard survey is 1.51%. After the 5,843 reminder text messages, 34 additional responses have been received on Qualtrics by Apr 30, 2023. 28 of them are considered valid. The response rate for text message survey is 0.58%. There are 185 responses and 153 valid responses received in total, including 72 non-users, 40 occasional users, and 41 frequent users. Figure 3.13 shows Demographics of survey participants.

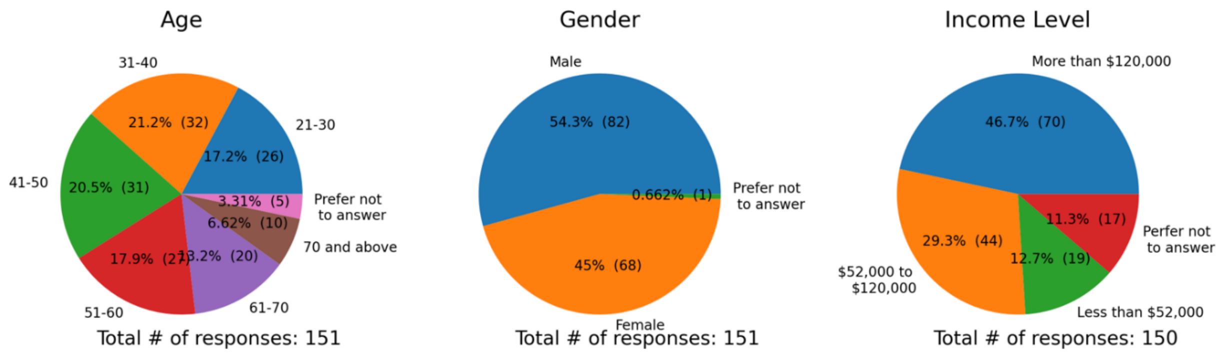


Figure 3.13: Demographic information

Table 3.3 shows the age distribution of those over 20 years old in the six GBA counties, Essex, Middlesex, Suffolk, Norfolk, Plymouth, and Bristol from the 2020 Census Data. The percentage number in the "Male" or "Female" row represents the gender percentages in the corresponding age segment, and that in the "Total" row represents the overall percentage by age segment. Table 3.4 shows the differences between census data and the sample data excluding the "Prefer not to answer" responses. People older than 70 are underrepresented by about 8.0%, which might not be a major concern since older people tend to drive less. Females are underrepresented by about 6.7%, probably due to the significantly higher female/male ratio among those over 70.

Table 3.3: Population over 20 years old in the six counties of GBA (2020 Census)

	Age	20-29	30-39	40-49	50-59	60-69	≥70	Overall
Population	**Male**	378,220	358,550	354,314	407,387	317,254	266,706	2,082,431
Population	**Female**	368,275	361,249	371,485	428,005	351,201	373,782	2,253,997
Population	**Total**	746,495	719,799	725,799	835,392	668,455	640,488	4,336,428
Percentage	**Male**	50.7%	49.8%	48.8%	48.8%	47.5%	41.6%	48.0%
Percentage	**Female**	49.3%	50.2%	51.2%	51.2%	52.5%	58.4%	52.0%
Percentage	**Total**	17.2%	16.6%	16.7%	19.3%	15.4%	14.8%	100%

Table 3.4: Differences between sample data and 2020 census data

	20-29	30-39	40-49	50-59	60-69	≥70	Male	Female
Sample Data	17.8%	21.9%	21.2%	18.5%	13.7%	6.8%	54.7%	45.3%
Census Data	17.2%	16.6%	16.7%	19.3%	15.4%	14.8%	48.0%	52.0%
Difference	+0.6%	+5.3%	+4.5%	-0.8%	-1.7%	-8%	+6.7%	-6.7%

Table 3.5 shows the median household income in the six counties of GBA. The median income of those who answer the income questions falls between $52,000 and $120,000, probably closer to $120,000 than $52,000, as the portion of those more than $120,000 is just around 50%. Thus, the income distribution also roughly matches the census data.

Table 3.5: Median household income in the six counties of GBA (2020 Census)

Middlesex	Essex	Suffolk	Norfolk	Plymouth	Bristol	Massachusetts
$112.764	$87,433	$113,683	$115,357	$100,082	$73,102	$89,645

Figure 3.14 shows transit use frequencies at the present and before the pandemic. The share of (frequent and occasional) transit users is much higher than in the traveling population (7% in 2016 according to CTPS base model) due to transit users' much higher tendency to respond to a survey about transit information. The comparison with before the pandemic suggests that transit users have reduced frequency or switched to driving since the pandemic.

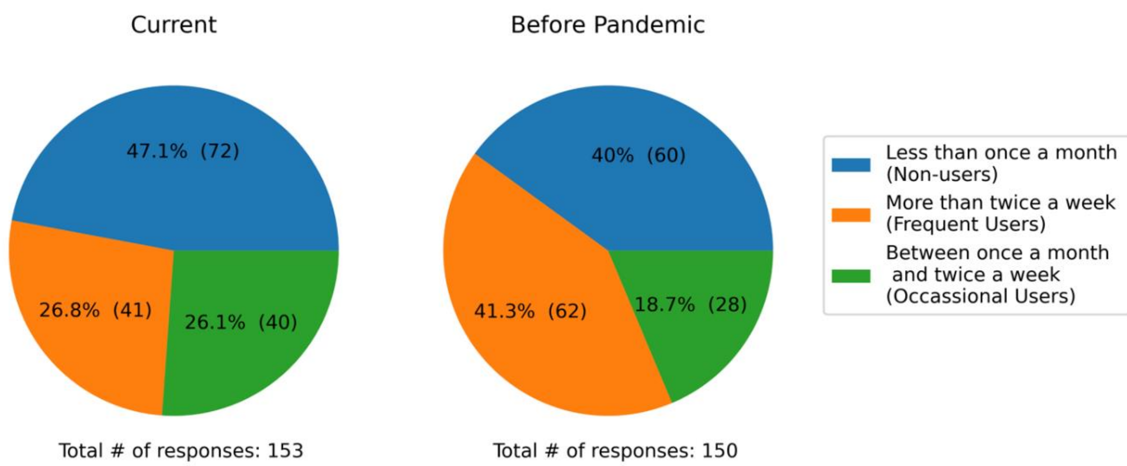


Figure 3.14: Transit usage frequency (user type)

3.3.3. Data Processing

The data is exported from Qualtrics and tabulated without weighting. The comparison with the 2020 Census data shows a good if not perfect match, which gives a high level of confidence on the initial results reported here.

This page left blank intentionally.

4.0 Results

4.1 Online Interview

Interview questions and participants' responses were synthesized in Excel spreadsheets. Results of online interviews are reported below in five categories with selected quotes: (1) Perceptions of real-time travel information, (2) Memorable billboards, (3) Reasons for not using transit, (4) Desired information contents, and (5) Information load.

4.1.1 Perceptions of Real-Time Transit Information

9 out of 11 participants have seen or used real-time transit information (RTTI) provided by MBTA. Estimated arrival time for next trains is the most seen content (8 out of 11). Inaccuracy is the most mentioned shortcoming about RTTI.

> *"..., it's not always accurate, especially the Green Line. It sometimes it says arriving and it's still not even anywhere near. So sometimes it'll flash three minutes and trains to arriving but it's not even coming yeah." —- Participant 2*

> *"I think it's helpful when it's within five minutes, although I've seen the time change so it's not always accurate. Also, sometimes they freeze the time. So, it's kind of confusing. " —- Participant 3*

4.1.2 Memorable Highway Billboards

Humorous contents, good visibility, and appropriate placement are the major attractive features of billboard that would draw drivers' attention. Being too bright at night is thought to be distracting drivers from driving.

> *"I enjoy that when they display something humorous, and you know sure they have a sense of humor. " —- Participant 5*

> *"I think when a billboard is, it's in a place that's not immediately next to other things that will kind of drown out what you're seeing on it, or kind of make it so. It doesn't stand out as much. Then it just becomes part of the scenery, and you don't notice it." —- Participant 10*

> *"I don't know actually. I will see the very, very bright ones, (and they) are very distracting at night. " —- Participant 2*

> *"Sometimes the information that's provided takes multiple screens to explain the situation. And I find that unless I'm in traffic, I might not always have the opportunity to read the full message that is displayed. And get that's difficult for depending on the message that they're trying to convey. And I also have found that some billboards are just situated in*

locations that are not safe to read, while driving on the highway at high speeds so. Those are the two most difficult things that I've come across. " —- Participant 6

4.1.3 Reasons for Not Using Transit More Often

Insufficient service frequency, coverage, or connections are cited as main reasons for not using transit more often.

> *"So, I think the schedule for the MBTA commuter rail is very tough and it's sometimes about three hours apart appear in this area, and especially the weekends, are very tough. So, it's mainly schedule, if it were running more frequently, I think there'd be more access to it." —- Participant 2*

> *"There's also no real good solid connection. There's one bus that goes between like Milford and Hill it goes from Lawrence to Lowell. " —- Participant 2*

> *"The main reason is mostly just time. I think that the route that I have to take in order to get to work, where some of the other locations that I have to go, will add considerable time to my commute. The other is cost, I mean the fares are reasonable, but if I have to take multiple forms like if I have to go from one train to another train and then to a bus, the cost adds up pretty quickly. " —- Participant 6*

> *"Yes, if the transit is reliable and safe, I would absolutely prefer transit over driving. But it's really a matter of that there just aren't any close station, so I would end up taking a lot longer to get to work if I if I had to use a combination trains and buses so. " —- Participant 4*

4.1.4 Desired Information Contents and Effects on Mode Choice

Travel cost and travel time are the two most important types of information that may encourage participants to use transit more frequently or improve their experience with existing transit trips. Major event, transit route, parking availability, parking cost, next train arrival time, crowding level, and emission comparison are considered influential information types as well.

> *"And then I think for some of these, like other comparisons of the travel costs, the real time for travel, I think you'd want to have it combined with the train times and the train transit stuff. I think if you just have the signs by themselves, it might be a little confusing. Because they might just seem like informational signs, but if you are making it clear to the viewer that there's a comparison being made to try to incentivize taking transit versus taking a car, I think that will make sense to people but. Yeah, I mean I would probably caution from including total travel time of a car, just because that can be different for everyone, depending on if they need to*

make stops or through heavy traffic. So, I don't know, in my opinion, time should be included per car traveling comparison" —- Participant 4

Some participants think that mode switch of recreational trips is more likely to be induced by RTTI than that of commuting trips, due to the stickiness of commuting trips.

"I feel like this is great for like you just said, for an event, for a concert and sporting event because some people are just kind of do that they get the car and they go and they don't really think about what their plan. For work, I think people think a little bit more in advance. So, I think if I got in the car for a Red Sox game, and I saw this on the billboard I would or a series of billboards, I would start saying, oh this looks like a better idea than driving into Kenmore Square, but if I was going to work on, I think I'd probably have my mind made up, I think. " —- Participant 7

Other participants think that RTTI is more useful for commuting trips since they are more consequential than recreational trips.

"I think it's probably more effective on a commuting trip than a recreational. I mean, when I'm commuting and more like. . . I'd say not interested, but more pressed to get to a certain place by a certain time, so if you know from delayed to get to work. You know it's going to mean a lot more to me than it is to personal trip or I'm you know 15 or 20 minutes late, so I think this information is more probably more appealing as a commuter than it is as a recreational user." —- Participant 1

4.1.5 Information Load

When seeing billboards once, participants can memorize about 85% of information contents from four-unit billboards, and about 52% of information contents from five-unit billboards. Participants have difficulties memorizing exact numbers, such as the travel time. When seeing billboards twice, participants can memorize about 70% of information contents from five-unit billboards. However, participants still perform poorly on memorizing exact numbers and comparing the travel time of different travel modes. Only half of participants can correctly remember which mode's travel time is less.

4.2 Household Survey

Results of household survey are reported in four main categories: (1) travel experience, (2) desired information contents, (3) potential behavioral changes, and (4) preferred billboard design.

4.2.1 Travel Patterns

Figure 4.1 shows the distribution of most frequently used highway segments. I-93 is the most frequently used highway in the survey, accounting for over one fourth of all the responses (30 out of 115), followed by I-95 (18) and I-90 (16). I-93 Segment B from North Suburban to

Boston is the most frequently used highway segment, followed by I-90 from MetroWest to Boston, and Route 1 Segment B from North Shore to Boston. The chart suggests that survey respondents are spread out over the GBA, and thus geographic generality of the results.

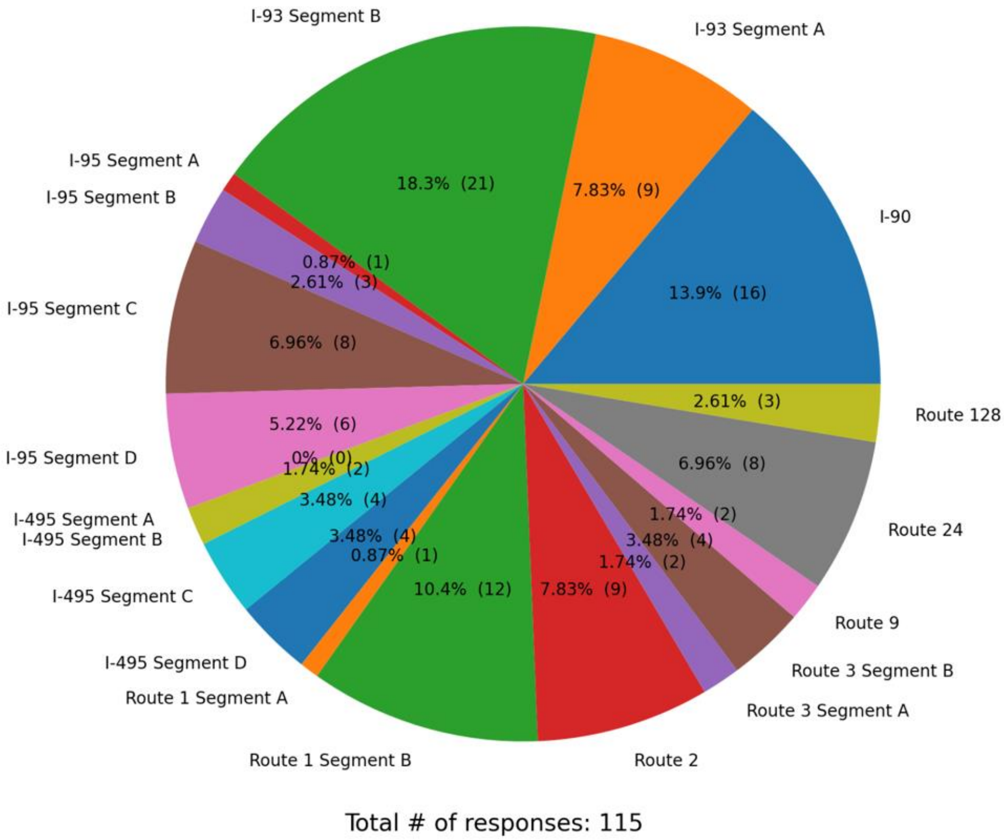


Figure 4.1: Frequently used highway segment

Figures 4.2 and 4.3 show the time-of-day and speed distributions of trips on most frequently used highway segments. 61.1% of participants make the trip during the morning peak and 4.03% during the afternoon peak, with a combined 65% peak period travel. 47.0% drive at a speed between 30 and 50 mph and 15.4% at lower than 30 mph, corresponding to peak period travel.

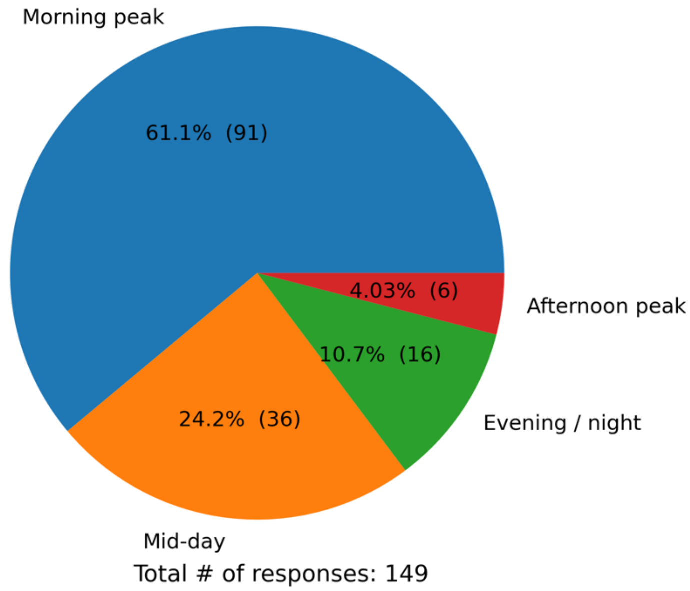


Figure 4.2: Time-of-day of trips on most frequently used highways

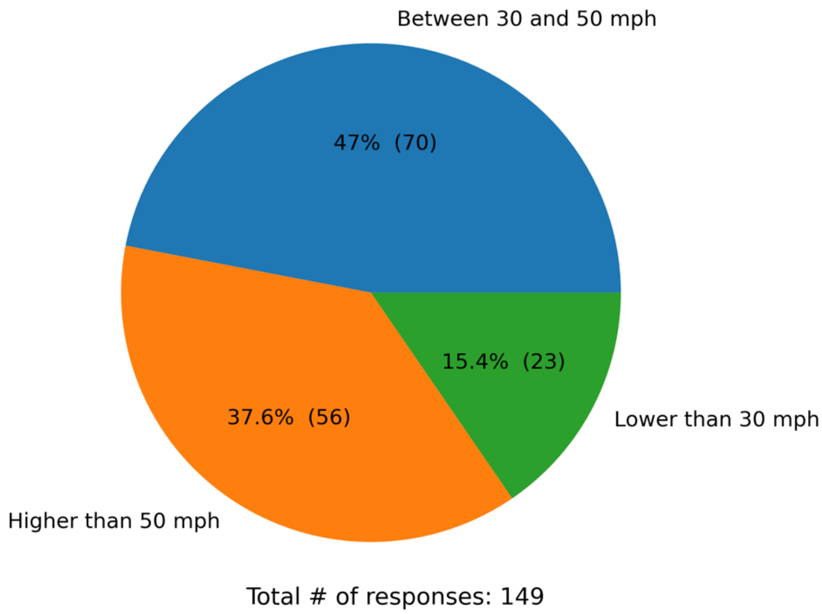


Figure 4.3: Speed of trips on most frequently used highways

4.2.2 Desired Information Contents

Figure 4.4 shows the distribution of top three information items in terms of encouraging travelers to use transit more often, including both commuter rail and subway trip-based responses. The number of selections is roughly three times of the number of responses, as each participant chooses top three or fewer items. Overall, real-time total travel time by transit, next two train arrivals, real-time parking availability at the start MBTA station, total travel cost by transit and real-time transit crowding level are the top five items, accounting for 30.2%, 21.8%, 15.1% 10.6% and 10.6% of the total respectively.

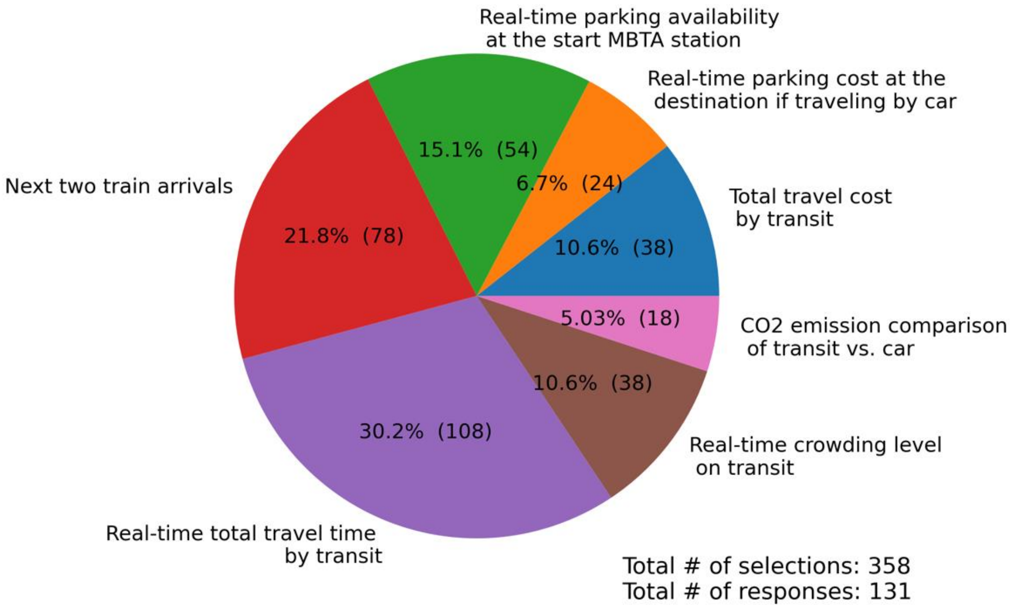
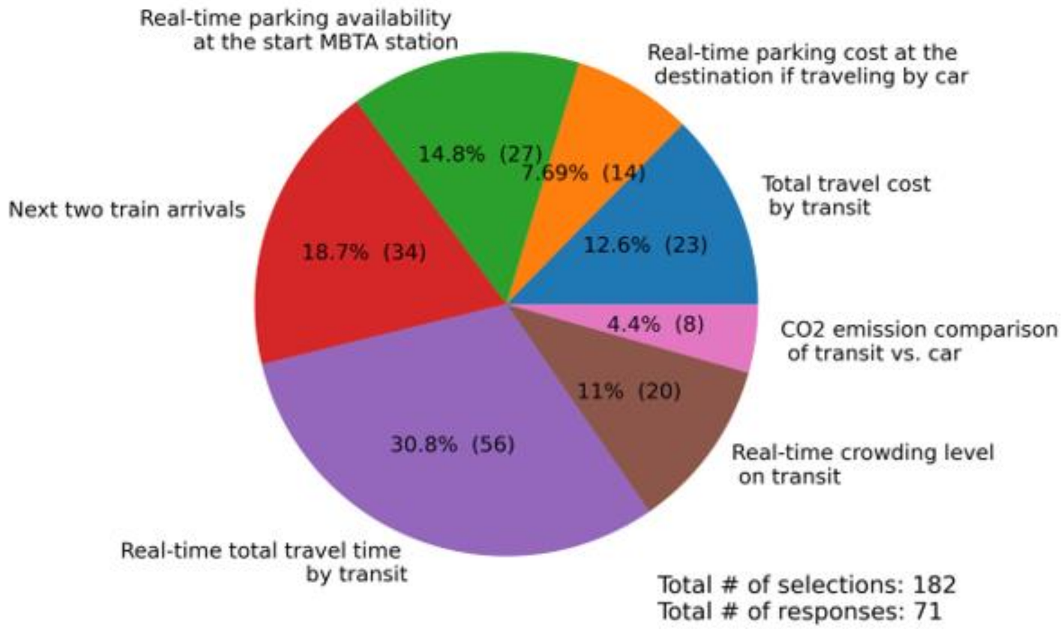
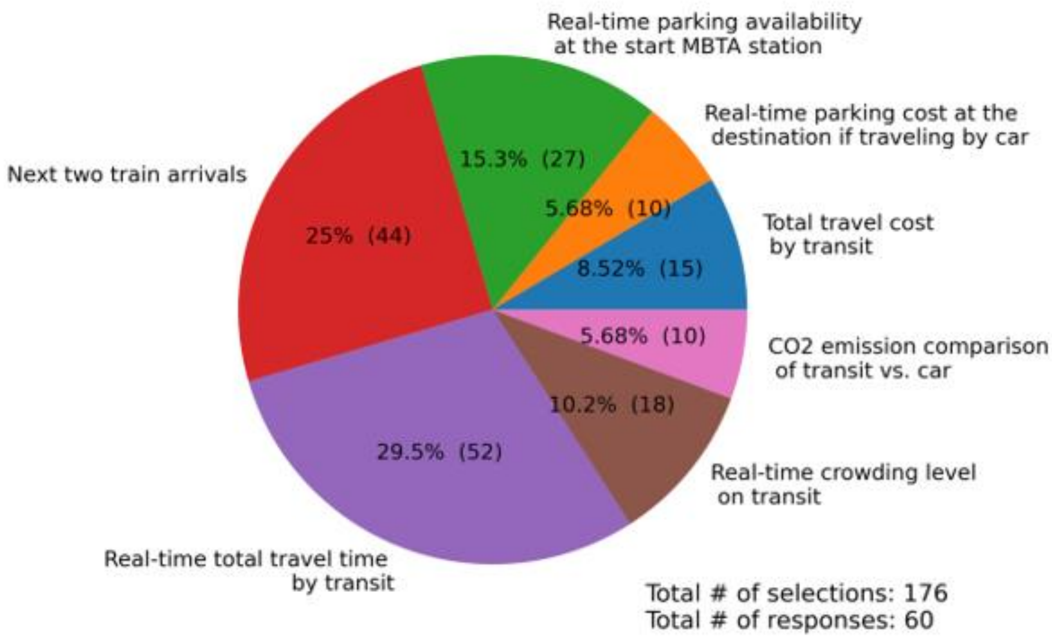


Figure 4.4: Top three information items by all participants

Figures 4.5(a) and 4.5(b) show the distribution of top three information items by commuter rail and subway-based responses respectively. Commuter rail trip-based responses put more value on the total travel cost by transit (blue pie) and real-time parking cost at the destination if traveling by car (orange pie) than subway trip based responses, which place more value on next two train arrivals (red pie). Conceivably, commuter rail users might pay more attention to the trip cost due to its higher fare than that of subway, while subway users place a higher value on next two trains arrival since frequency-based subway services do not have a schedule for each train as commuter rail services do.



(a) Commuter Rail Trip Based Responses



(b) Subway Trip Based Responses

Figure 4.5: Top three information items by mode

Figure 4.6 shows the top three information items based on a Red Line trip from Braintree to South Station. The result is consistent with the overall one, suggesting that there is no major geographic idiosyncrasy.

Figure 4.7 shows the top three information items for a major event such as a Red Sox game. Similarly, each participant chooses at most three items and thus the number of selections is about three times that of responses. Real-time total travel time by transit, next two train arrivals, real-time parking availability at the start MBTA station, real-time parking cost at the destination if traveling by car, and total travel cost by transit are the top five, accounting for 27.5%, 19.0%, 14.4%, 13.6% and 13.1% of the total respectively. Compared with non-major event trips, it seems that participants place higher value on the cost of travel, including total travel cost by transit and real-time parking cost at the destination if travelling by car. This might be due to participants' expectation of high parking cost at the event venue and being less familiar with the destination station than the major terminals (South Station, North Station).

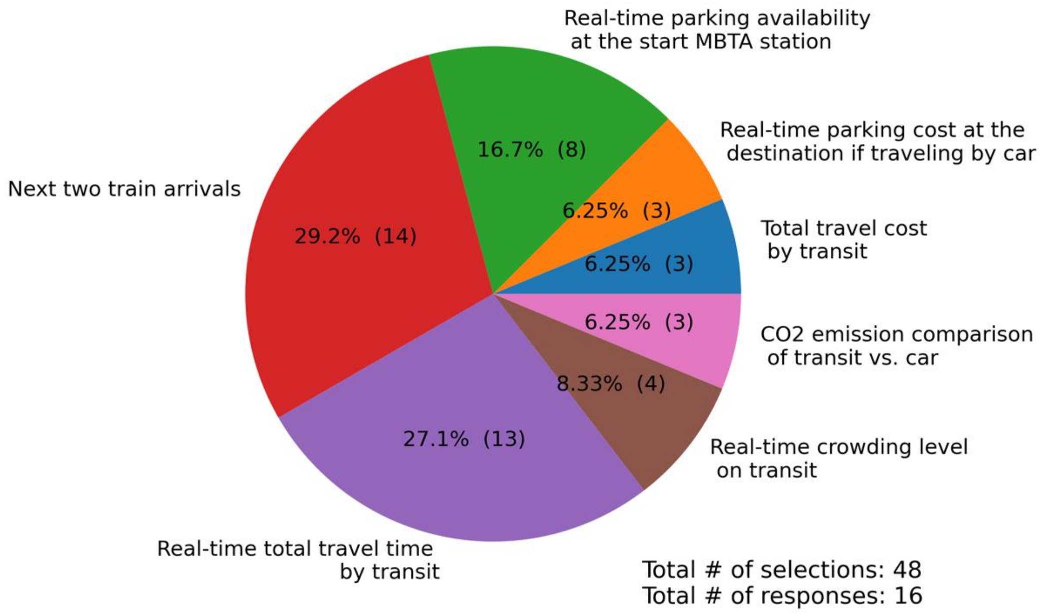


Figure 4.6: Top three information items based on a transit trip from Braintree to South Station (Red Line)

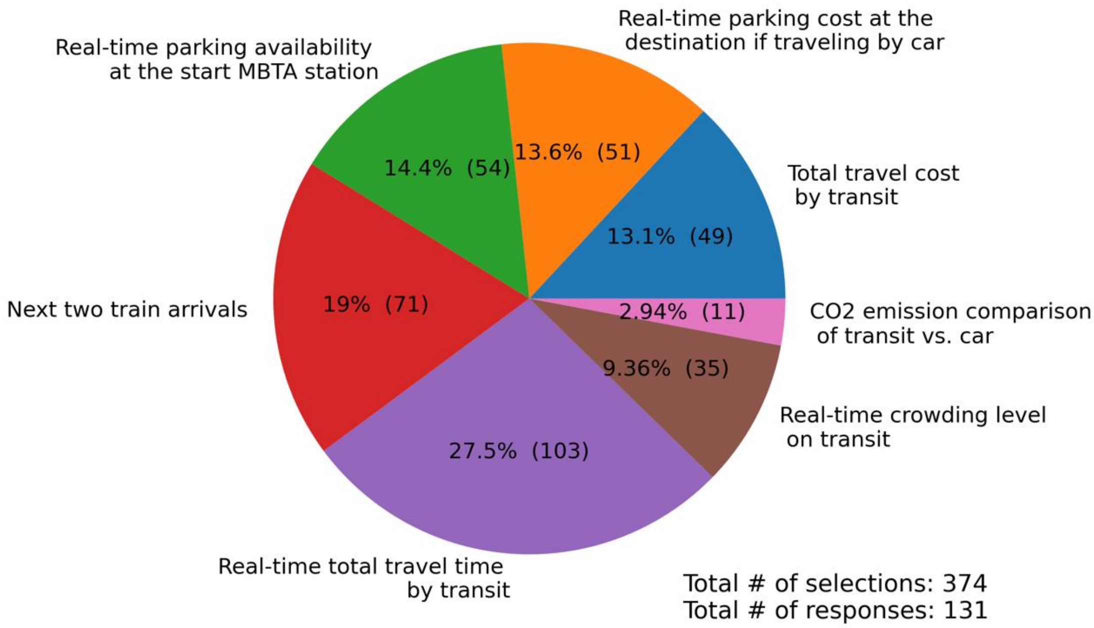


Figure 4.7: Top three information items for a major event (Red Sox game)

Additional useful information items suggested by participants are summarized in Table 4.1, among which distance/walking distance from/to the transit station, estimated time savings by transit vs driving, and delay or service alert appear several times.

Table 4.1: Other useful information items proposed by participants

Participants	Useful Item #1	Useful Item #2	Useful Item #3
8	Distance to nearest public transit option	Optionas for reserving parking at the nearest public transit option	Schedule for nearest public transit option if not continuous
10	General information about events also happening in the Boston Metro area that day		
11	Exit for station MBTA		
17	If there are any delays (and a short comment on what the delay is about)		
19	Major transit delays or issues		
20	Weather alerts		
22	Are masks required?	Accessibility?	
24	Alternative route information to my desitnation		
31	Traffic jam	Traffic accident	Holiday / Reroute
35	Availability of parking at destination	Estimated cost of ride share app	Estimated time to find parking
40	Delays or service issues		
44	Time saved to travel by MBTA vs car traffic		
57	Services around – gas, atm		
60	Incentives for the public… if we use publilc transit, it will get expanded / less expensive		
64	Walk distance from station to venue		
67	Cost compared to average drive	Cost subsidized by taxpayers	Travel time compared to driving travel time
72	Time on highway		
81	Distance to nearest transit station	Arrival of last train for daily service (evening events)	
87	Suggested MBTA location based on traffic		
139	Estimated time saving by mass transit vs. driving (real-time) when over 10 min	Accident alert with estimated clearance time	Estimated delay time based on weekly running average
142	Walking distance from MBTA station to event venue or frequently visited area		
147	Safety at parking site	Lighting at parking site	Functioning machines for tickets at parking site

Figure 4.8 shows the distribution of rank 1 full billboards. Note that information items used in the various combinations are limited to total transit travel time, fare, crowding level, parking availability at the start transit station, and parking cost at the destination if traveling by car. The combination of transit travel time and fare is most preferred, closely followed by that of parking availability and transit travel time. This is consistent with the result from the top three information item question that travel time, parking availability at the start and travel cost are among the most preferred. Next two train arrivals are not included in the full billboard question, due to the research team's judgement that highway drivers can hardly take action on the spot in response to the billboard information given that it is not always present

(25% of the time). This limitation is not explained in the survey due to the concern of unnecessary distraction from the main questions.

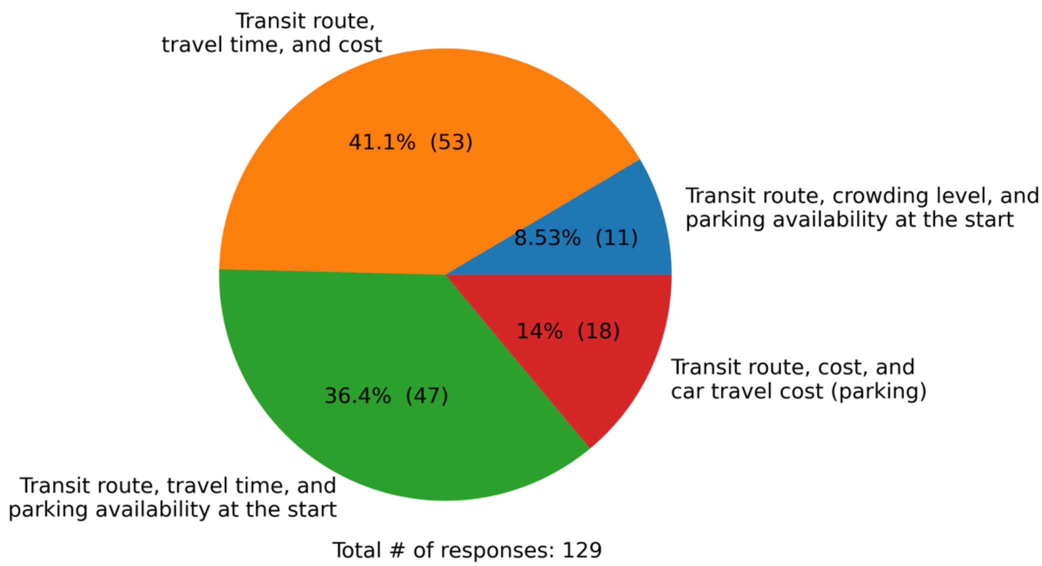


Figure 4.8: Rank 1 of the full billboards

In the open-ended question about other useful information content combinations, participants mainly suggest including more information items instead of new items, probably due to the strong framing effect of the graphics. Some do mention next transit vehicle arrivals. Certain quotes are included below.

> *"Transit route, parking availability at the start, cost of transit, cost of parking at the transit start station." —- Participant 5*

> *"Transit route, parking availability, crowdedness, travel time." —- Participant 14*

> *"Parking availability, travel time and next transit vehicle arrival." —- Participant 61*

> *"Passenger volume, transit time, parking at station." —- Participant 37*

> *"Route, cost to park, parking availability, travel time." —- Participant 134*

> *"I would suggest to always including the time." —- Participant 106*

> *"Add parking at station to #1" —- Participant 8*

Table 4.2 shows transit trips that participants would like to see information about. The corresponding highway segments are estimated based on the extent of overlapping. Presumably participants would like to see information about their own trips, therefore it is not surprising that I-93 is still the most frequently mentioned highway and I-93 segment B the most frequently mentioned roadway segment. The majority of trips start from the north of

Boston. There are more north-south trips than east-west trips, which is not surprising given the geography of GBA.

Table 4.2: Transit trips participants would like to see information about

Start	End	Highway Segments	Start	End	Highway Segments
Sudbury	South Station	Route 9 / I-90	Lexington	Boston	Route 2/ Route 3 B / I-93 B
Worcester	South Station	I-90	Somerville	Boston	Route 3 B / I-93 B
Wonderland	Govt Center	Route 1	Alewife	Central Square	Route 2 / Route 3 B
Sullivan	Fenway	Route 9 / I-90	Alewife	Park Street	I-93 B / I-90 / I-95 C
Newburyport	Boston	Route 1 B / I-95 D	Waltham	Boston	I-90
Back Bay	Malden	Route 1 B / I-93 B	Lowell	Boston	Route 3 B / I-495 D / I-93 B
Medford/Tufts	Park Street	I-93 B	Route 3 South	Alewife	Route 2 / Route 3 B / I-93 B
Hyde Park	North Station	I-93 A	North Andover	Milton	I-495 D / Route 3 B / I-95 BC / I-93 A
Quincy	Boston	I-93 A	Beverly	North Station	Route 128 / Route 1 B
Weymouth	Downtown Boston	Route 3 / I-93 A	Park Street	Longwood	I-90
Boston	Framingham	Route 9 / I-90	Oak Grove	State Street	I-93 B
Union Square	Downtown Crossing	I-93 B	Alewife	South Station	Route 3 B / I-90 / I-93 B
Auburndale	South Station	I-90	Haverhill	Boston	I-495 D / I-93 B / Route 1 B / I-95 D
Oak Grove	Downtown Crossing	I-93 B	Concord	Aquarium	Route 2 / I-93 B / I-90 / I-95 C
Brockton	Downtown Boston	Route 24 / I-93 A	Riverside	Govt Center	Route 3 B / I-90
Roslindale	North Station	Route 9 / I-93 A	Lowell	North Station	Route 3 B / I-93 B / I-495 D
Lynn	North Station	Route 1 B	Lowell	Wedgemere	Route 3 B / I-495 D / I-93 B
Woburn	North Station	I-93 B	Reading	North Station	I-93 B / I-95 C / Route 1 B
Providence	N.E. Aquarium	I-95 A / I-93 A	Hopkinton	Boston	I-90
Quincy	Park Street	I-93 A	Arlington	Kenmore	Route 3 B
Ipswich	North Station	Route 1 B / I-95 D	Salem	North Station	Route 1 B / Route 128
Manchester	Arlington Center	Route 3 B / I-93 B	Boxford	North Station	Route 1 B
Reading	Cambridge	I-93 B	Hingham	Boston	Route 3 A / I-93 A
Boston College	Kenmore	Route 3 B / I-90	Dedham	Boston	I-90 / I-93 A / I-95 B
Newton Corner	Downtown Boston	Route 9 / I-90	New Bedford	South Station	Route 24 / I-93 A
Wareham	Downtown Boston	Route 24 / I-93 A	Roxbury	Cambridge	Route 3 B / I-90
Belmont	Downtown Boston	Route 3 B / I-90	Salem	Boston	Route 1 / I-95 C / I-93 B
Newburyport	Fenway	Route 1 B / I-95 D	Newburyport	North Station	Route 1 B / I-95 D
Groveland	Lynn	I-95 D	Frankin Forge Park	South Station	I-495 B / I-95 A / I-93 A

4.2.3 Billboard Location

Figure 4.9 shows preferred billboard location distribution. 55.2% of the participants prefer "Close to the start", followed by "Anywhere in the general travel direction" (17.6%) and "Others" (12.8%). Current digital billboards are generally close to the end of a trip (Boston) with a few that are more upstream. The result points to locations for future conversion of legacy billboards or setting up new digital ones.

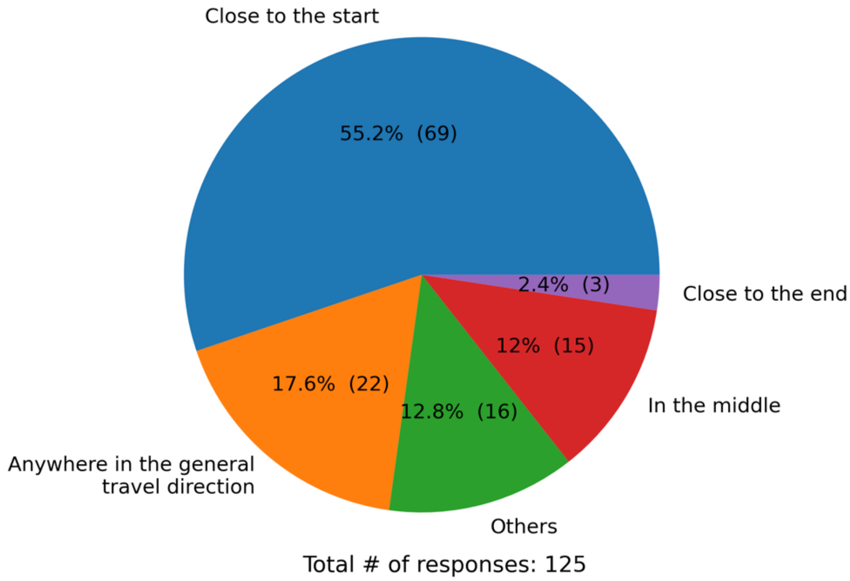


Figure 4.9: Distribution of preferred billboard location

Participants selecting "Others" provide some useful suggestions and comments in the text entry box. Several participants point out that the billboards should be located sufficiently upstream of known bottlenecks or major diversion decision points to allow ample time for drivers to read, comprehend and then react to the messages. Such suggestion is consistent with literature review on the Changable Message Sign (CMS) installation guideline. It also should be noted that some respondents oppose setting up more billboards in their neighborhoods and prefer to access real-time information through smartphones.

> *"Close to the start transit stop on the drive towards that transit stop with enough time to decide if a traveler will change their plans to use public transit." —- Participant 5*

> *"In places near the start where people are likely to be stuck in traffic." —- Participant 51*

> *"Prior to a major highway interchange. . . ..in this case several miles before route 93." —- Participant 108*

> *"I live very close to a T station and I am against more billboards in the surrounding neighborhoods. I think online would be preferable so people can access from their smartphones." —- Participant 76*

4.2.4 How Information Is or Is Not Useful

Participants use text entry box to share additional comments regarding how the information is or is not useful. Some useful comments are shown below. Poor public transit accessibility and service coverage is a major factor discouraging travelers from using transit more often, which is consistent with the findings from the online interview. The accuracy of the real-time information is considered by some as an important factor affecting travel experience.

"If you could include an average travel cost for gas in a car that may be persuasive to people." —- Participant 18

"The T is most useful for commuting and visiting friends in other towns." —- Participant 19

"I'm a veteran transit user, so I know my routes. I am vastly more likely to bike to a station than drive, so this is more of an intellectual exercise outside of sporting/major events" —- Participant 51

"If i lived closer to a commuter station and did not have to go for a long walk or get in the car to get to the station, I would be more likely to use it. I'd be much more likely to use the T if the green or orange line got a new branch to dedham, rather than only commuter rail options." —- Participant 57

"The fundamental problem is that it takes over an hour to get to Kenmore Square from Arlington via transit, and only 20 to 40 min via car. Unless you build new routes it's not solvable." —- Participant 73

"My current commute can not be done with Mass transit(amesbury to north andover)b it if working in boston I'd love to take the Newburyport train in. " —- Participant 78

"The information would need to be real time in order to be at all useful. Information displayed on signage at alewife is always wrong with respect to the arrival of the next train and travel times. It makes trip planning incredibly frustrating."

—- Participant 80

"This should include the new train extentions to New Bedford & Fall River. Cape Cod (summer!) would be helpful too. Also the Logan airport should be a focus on this project." —- Participant 136

"Safety factors." —- Participant 144

4.2.5 Billboard Design

Figure 4.10 shows the distribution of rank 1 full billboard designs. Design 2 is the most preferred, followed by Designs 1 and 3. It appears that participants prefer billboards with a light than dark background and information arranged horizontally than vertically.

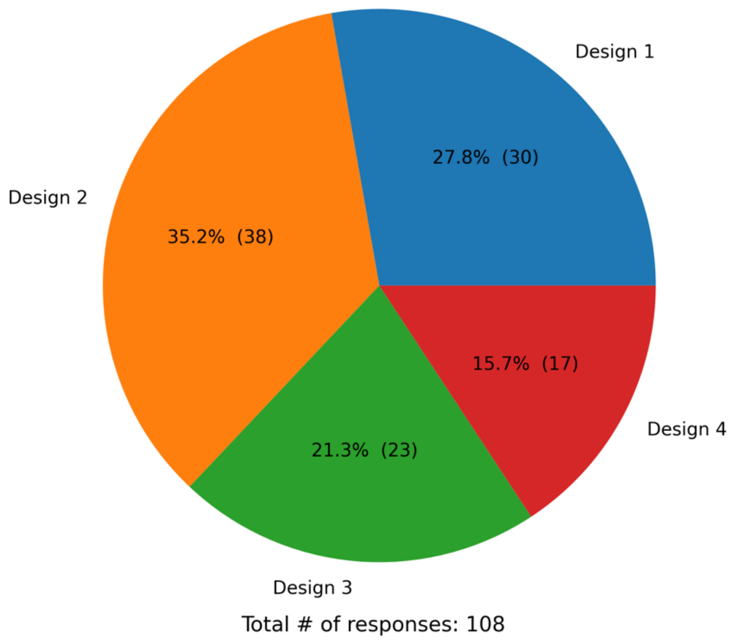


Figure 4.10: Rank 1 selection of the billboards design

4.2.6. Potential Behavioral Changes and User Experience Improvement

Figure 4.11 shows participants' stated increase of transit use frequency after seeing their most preferred RTTI on highway billboards by trip purpose and transit user type. Five trip purposes are presented: work (e.g., to/from work, work-related business), family (e.g., school/church, medical/dental, family/personal business), shopping, social and recreational (e.g., visiting friends/relatives, seeing a movie) and major event (e.g., Red Sox game, Patriots game).

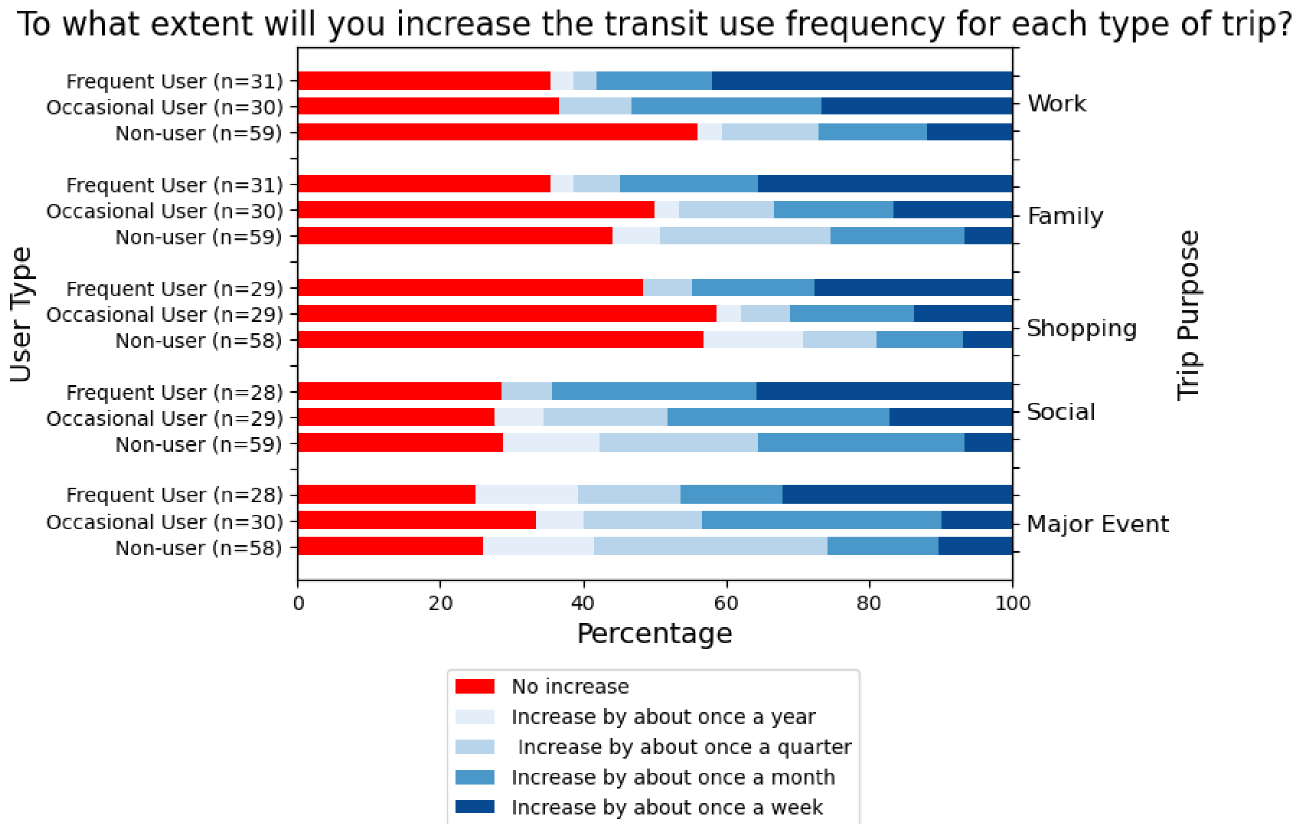


Figure 4.11: Stated increase of transit use frequency

Each trip purpose contains three bars each representing a transit user type: frequent user (more than twice a week), occasional user (between twice a week and once a month) and non-user (less than once a month), and the number of participants in each type is included in parentheses. Bars are of the same length of 100%, and starting from the left side ranging from red to dark blue, corresponding to five categories of stated frequency change in an increasing order: no increase, increase by about once a year, quarter, month and week.

Regardless of transit user type, the more flexible trip purposes, that is, social/recreational and major events, are potentially more influenced by RTTI, with around 75% of participants showing a tendency to increase transit use frequency to some extent, than the other three less flexible ones, that is, work, family, and shopping, with around 50% of occasional and non-users and 60% of frequent users displaying the same tendency. This is intuitive given the usual fixed arrival time requirement for work or family trips and the need to carry purchased items for shopping trips.

For a given trip purpose, generally non-users and occasional users show a markedly lower tendency to increase their transit use frequency than frequent users. Non-users are the largest chunk in the general traveling population, and it is promising to see that between just under 20% and just under 40% of them state a transit user frequency increase of once a month or more across the five trip purposes. It should be cautioned that these are stated increases instead of observed, real ones, and at best serves as an indication of the utility of RTTI.

Figure 4.12 shows the distribution of perceived improvement of transit service experience for current frequent transit users. 78.8% of them agree that RTTI on highway billboard definitely or probably would improve their travel experience.

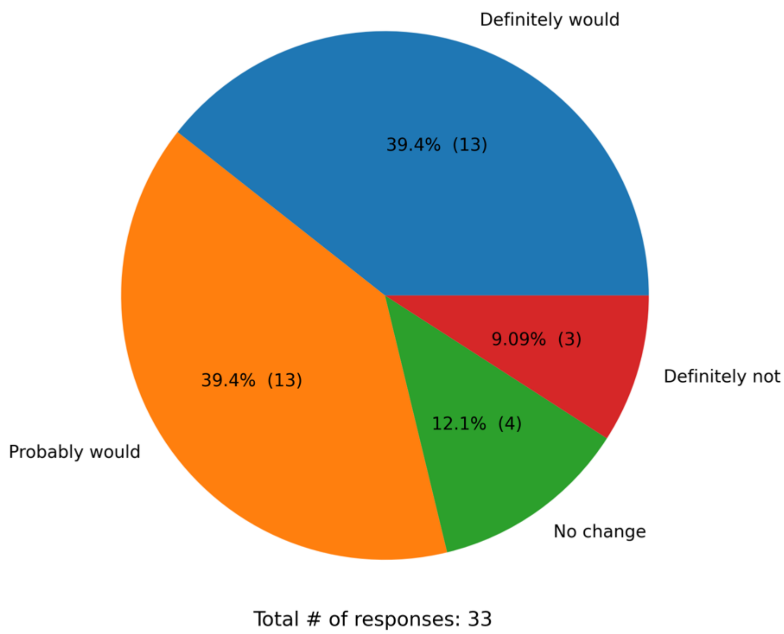


Figure 4.12: Improvement of travel experience for current frequent transit uses

4.3 Conclusions

Based on the analysis of the results on the household interviews and on-line surveys described in the previous sections, several major conclusions could be drawn.

- Real-time total travel time by transit, next two train arrivals, and real-time parking availability at the start MBTA station are the top three information items in terms of encouraging travelers to use transit more often as selected by all participants, including for both commuter rail and subway trips.

- Total travel cost by transit and real-time crowding level on transit are also considered moderately useful information items. Specifically, participants responding to commuter rail trips care more about total travel cost by transit and real-time parking cost at the destination if travelling by car compared to those responding to subway trips. In contrast, participants responding to subway trips place higher value on next two train arrivals. For major events, travel time by transit, next two train arrivals, total travel cost by transit and parking cost at the destination if travelling by car, and real-time parking availability at the start MBTA station are the top five information items.

- The billboard displaying transit route, travel time, and cost are the most preferred information combination, accounting for 41.1% of the total responses. Transit route, parking availability at the start and travel time are also considered as a useful combination in encouraging people to use transit more often, accounting for 36.4% of the total.

- The majority of participants express a preference to set up billboards closer to the start of a trip.

- Over half of participants indicate that RTTI on highway billboards would increase their transit use frequency. Social/recreational and major event trips are more likely be influenced by RTTI than work, family and shopping trips. Frequent users are more likely to increase transit usage than occasional and non-users. Between just under 20% and just under 40% of occasional and non-users state a transit user frequency increase of once a month or more across the five trip purposes.

- Almost 80% of current frequent users think that RTTI on highway billboards would definitely or probably improve their travel experience.

- Billboard Design 2 is the most preferred, followed by Design 1.

- Accuracy of RTTI is considered by many participants as a factor that exerts a significant effect on improving travel experience. Poor transit accessibility and service coverage is considered one of the main reasons for not using transit more often.

- The retention rate of a four-unit information load is 85%, and that of a five-unit one is 52%, which is improved to 70% with two staggering billboards.

5.0 Implementation and Technology Transfer

This Summary Report concludes with the findings listed below to assist the MBTA in the location, content and design in the use of RTTI in highway billboards for persons traveling in vehicles to potentially switch to public transit.

5.1 Findings

Many transit agencies use CMS to display RTTI to travelers, almost exclusively at bus stops or train stations targeting existing transit users, while a prevalent channel to reach out to non-users is lacking. This study fills this gap by studying RTTI displayed on OIPs along highways to reach out to a wider audience, most importantly non-users who have seldom or never used transit. Highway digital billboards in this project have some distinctive features compared with other delivery modes of RTTI. Similar to other more commonly used modes such as smartphone, transit station displays and web portal, highway digital billboards are able to provide RTTI on vehicle arrival, parking availability, travel time, crowding and other relevant items given the digital nature of the billboards. Conversely, from the viewpoint of a driver, RTTI from highway digital billboards is available only when s/he drives by during the showing window, which is 10 seconds every 40 seconds or 20 seconds every 80 seconds, and the dwell time is typically limited to 2-3 seconds due to safety consideration. Staggering billboards such as those on the Leverett Connector could increase the chance that a message is seen, but not guaranteed.

Therefore, the research team has identified two major benefits for providing RTTI via highway digital billboards:

1. To raise awareness of MBTA services (branding). For occasional and non-users, this awareness could be about availability of services in surrounding areas, comparative advantages of transit over driving, and contribution to social goals such as the environment and equity. For frequent users, this awareness could be about availability of underutilized services or new services, e.g., Greenbush Commuter Rail, Green Line Extension.

2. To provide available real-time tracking for transit users to reduce their uncertainty, encourage use of MBTA services and improve their transit travel experience. However, it is not expected that this is a reliable information source for decision making on the spot.

Specific recommendations regarding the location, content, design and cadence of RTTI on highway billboards are provided below.

5.1.1 Location

Survey participants prefer billboards at the start of trips, probably due to the perception of having the chance to respond to the information. Even if it is not expected that drivers can reliably respond on the spot due to the reasons stated above, having a chance to respond, no matter how small the chance, is arguably better than a zero chance.

The locations are limited by the distribution of existing MBTA digital billboards and legacy ones that can be converted later. Given the radial nature of MBTA services, inbound trips should be displayed on locations relatively far from downtown, e.g., around the 128 beltway or farther. For locations close to downtown, RTTI information should be clearly understood as something to be used in the future to avoid driver frustration, such as new or underutilized MBTA services not in the immediate area, a future major event, or the new fare system.

5.1.2 Contents

Table 5.1 summarizes the top five information items in the order of the most to less preferred for non-major events and major event trips respectively.

Table 5.1: Top 5 real-time information items for non-major event and major event trips

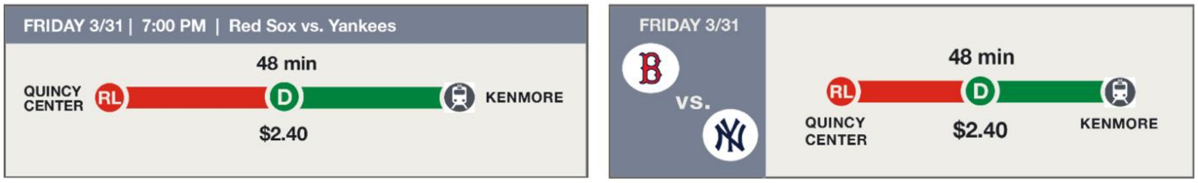
Rank	Non-Major Event Trips	Major Event Trips
1	Transit total travel time	Transit total travel time
2	Next two train arrivals	Next two train arrivals
3	Parking availability at the start station	Total transit cost
4	Total transit cost	Parking cost at the destination if traveling by car
5	Transit crowding level	Parking availability at the start station

Three or four-unit information load is preferred for non-staggering billboards and five-unit information load could be used for staggering billboards. A transit route needs to be always present, which already includes three information units: the start, end, and transit line. Assume that a transit route remains unchanged on the billboard for a certain period, say, several weeks, then drivers potentially drive by the billboard multiple times over that period and the transit route itself eventually does not require much cognitive resource. Therefore, the information load requirement applies to the remaining items only.

Depending on how many information units are on a billboard, the same number of items are taken from the top of the list above. For example, it is recommended that a three-unit billboard's content for a non-major event trip be "real-time transit total travel time + real-time next two arrivals + real-time parking availability at the start MBTA station".

5.1.3 Graphic Design

Designs 1 and 2 shown in Figure 5.1 are best displayed with light background and horizontal presentation of content.



(a) Design 1 (b) Design 2

Figure 5.1: Billboard design

5.1.4 Cadence

RTTI should be displayed for 10 seconds for each 40 seconds where the other 30 seconds are used for commercial ads not related to MBTA. This is preferred to other arrangements such as 20 seconds of RTTI for every 80 seconds, since drivers can hardly dwell on a billboard for longer than 10 seconds when driving on highways: 2-3 seconds when traveling at speed limit and slightly more when in traffic.

This page left blank intentionally.

6.0 Conclusions

Through this study, the research team achieved the following:

1. Developed guidelines for determining the location, content, graphic design and cadence of OIPs with high potential for incentivizing mode shift, recovering ridership loss due to COVID-19, and building rider trust post COVID-19.
2. Identified transit users' and non-users' potential transit use increases in response to OIPs for various trip purposes.

During the project, the research team first conducted a literature review that provided the basis for designing and conducting an online interview and household survey. The online interview and a household survey were then conducted in sequence to help the research team gather Great Boston Area (GBA) travelers' travel experience, preferred real-time information contents and location and billboard graphic designs. The interview questionnaire was structured in three sections: (1) travel experience, (2) desired contents, and (3) adequate information load. The subsequent online household survey was designed based on the results of online interview, and included five topical sections: (1) demographics, (2) travel experience, (3) desired information contents, (4) potential behavior change, and (5) billboard design.

The major findings of this study are summarized as follows:

- Real-time total travel time by transit, next two train arrivals, and real-time parking availability at the start MBTA station are the top three information items that could encourage travelers to use transit more often as selected by all participants, including for both commuter rail and subway trips. Total travel cost by transit and real-time crowding level on transit were also considered to be moderately useful information items to encourage travelers to use transit more often. Specifically, participants responding to commuter rail trips care more about total travel cost by transit and real-time parking cost at the destination if travelling by car compared to those responding to subway trips. In contrast, participants responding to subway trips place higher value on next two train arrivals. For major events, travel time by transit, next two train arrivals, total travel cost by transit and parking cost at the destination if travelling by car, and real-time parking availability at the start MBTA station are the top five information items.

- The billboard displaying transit route, travel time, and cost is the most preferred information combination, accounting for 41.1% of the total participant responses. Transit route, parking availability at the start and travel time are also considered as a useful combination in encouraging participants to use transit more often, accounting for 36.4% of the total.

- The majority of participants expressed a preference to set up RTTI highway billboards closer to the start of a trip.

- Over half of participants indicate that RTTI highway billboards would increase their transit use frequency. Social/recreational and major event trips are more likely be influenced by RTTI than work, family and shopping trips. Frequent users are more likely to increase transit usage than occasional and non-users. Between just under
20% and just under 40% of occasional and non-users state a transit user frequency increase of once a month or more across the five trip purposes.

- Almost 80% of current frequent users think that RTTI on highway billboards would definitely or probably improve their travel experience.

- Billboard designs with light background and horizontal presentation of content are preferred.

- Accuracy of RTTI is considered by many participants as a factor that exerts a significant effect on improving travel experience. Poor transit accessibility and service coverage is considered one of the main reasons for not using transit more often.

- The retention rate of a four-unit information load is 85%, and that of a five-unit one is 52%, which is improved to 70% with two staggering billboards.

Recommendations for MBTA consideration in its deployment of RTTI highway billboards are provided as follows:

- <u>Location</u>: Given the radial nature of MBTA services, it is recommended that inbound trips be displayed on locations relatively far from downtown, e.g., around the 128 beltway or farther. For locations close to downtown, it is recommended that the information be clearly understood as something to be used in the future to avoid driver frustration, such as new or underutilized MBTA services not in the immediate area, a future major event, or the new fare system.

- <u>Contents</u>: Three or four-unit information load is recommended for non-staggering billboards and five-unit information load could be used for staggering billboards. Depending on how many information units are on a billboard, it is recommended to take the same number of items from the top of the TOP 5 real-time information items list.

- <u>Graphic Design</u>: Designs with light background and horizontal presentation of content are recommended.

- Cadence: It is recommended that RTTI be displayed for 10 seconds for each 40 seconds where the other 30 seconds are used for commercial ads not related to MBTA.

This page left blank intentionally

7.0 References

1. Brakewood, C. and Watkins, K. (2019). A literature review of the passenger benefits of real-time transit information, Transport Reviews 39(3): 327–356.
2. Dziekan, K. and Vermeulen, A. (2006). Real-time information displays psychological effects of and design preferences for real-time information displays, Journal of Public Transportation 9(1): 1–19.
3. Watkins, K. E., Ferris, B., Borning, A., Rutherford, G. S. and Layton, D. (2011). Where is my bus? impact of mobile real-time information on the perceived and actual wait time of transit riders, Transportation Research Part A: Policy and Practice 45(8): 839–848.
4. Chow, W., Block-Schachter, D. and Hickey, S. (2014). Impacts of real-time passenger information signs in rail stations at the massachusetts bay transportation authority, Transportation Research Record: Journal of the Transportation Research Board 2419: 1–10.
5. Brakewood, C., Barbeau, S. and Watkins, K. (2014). An experiment evaluating the impacts of real-time transit information on bus riders in tampa, florida, Transportation Research Part A: Policy and Practice 69: 409–422.
6. Schweiger, C. L. (2003). Real-time bus arrival information systems a synthesis of transit practice, Technical report, Federal Transit Administration. Federal Transit Administration.
   URL: https://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_syn_48.pdf
7. Lappin, J. E. (2000). What have we learned about advanced traveler information systems and customer satisfaction?, Technical report, Federal Highway Administration. Federal Highway Administration.
   URL: https://rosap.ntl.bts.gov/view/dot/34490
8. Ge, Y., Jabbari, P., Mackenzie, D. and Tao, J. (2017). Effects of a public real-time multi-modal transportation information display on travel behavior and attitudes, Journal of Public Transportation 20: 40–65.
9. Politis, I., Papaioannou, P., Basbas, S. and Dimitriadis, N. (2010). Evaluation of a bus passenger information system from the users' point of view in the city of Thessaloniki, Greece, Research in Transportation Economics 29(1): 249–255.
10. Tang, L. and Thakuriah, P. V. (2012). Ridership effects of real-time bus information system: A case study in the city of chicago, Transportation Research Part C: Emerging Technologies 22: 146–161.
11. Kaplan, S., Monteiro, M. M., Anderson, M. K., Nielsen, O. A. and Santos, E. M. D. (2017). The role of information systems in non-routine transit use of university students: Evidence from brazil and denmark, Transportation Research Part A: Policy and Practice 95: 34–48.
12. Caulfiled, B. and O'Mahony, M. (2007). An examination of the public transport information requirements of users, IEEE Transactions on Intelligent Transportation Systems 8: 21–30.
13. Bonsall, P., Firmin, P. and Beale, J. (2004). Perception of modal attributes: how accurate and how susceptible to change?, Paper presented at the 83rd meeting of the Transportation Research Board, Washington, D.C.

14. Chorus, C. G., Molin, E. J., Wee, B. V., Arentze, T. A. and Timmermans, H. J. (2006). Responses to transit information among car-drivers: Regret-based models and simulations, Transportation Planning and Technology 29: 249–271.
15. Abdel-Aty, M. A., Kitamura, R. and Jovanis, P. P. (1996). Investigating effect of advanced traveler information on commuter tendency to use transit, Transportation Research Record 1550: 65–72.
16. Kenyon, S. and Lyons, G. (2003). The value of integrated multimodal traveler information and its potential contribution to modal change, Transportation Research Part F: Traffic Psychology and Behaviour 6: 1–21.
17. Harmony, X. J. and Gayah, V. V. (2017). Evaluation of real-time transit information systems: An information demand and supply approach, International Journal of Transportation Science and Technology 6: 86–98.
18. Khattak, A., Polydoropoulou, A. and Ben-Akiva, M. (1996). Modeling revealed and stated pretrip travel response to advanced traveler information systems, Transportation Research REcord 1537.
19. Ha, J., Lee, S. and Ko, J. (2020). Unraveling the impact of travel time, cost, and transit burdens on commute mode choice for different income and age groups, Transportation Research Part A: Policy and Practice 141: 147–166.
20. Abdel-Aty, M. A. (2001). Using ordered probit modeling to study the efect of atis on transit ridership, Transportation Research Part C 9: 265–277.
21. Kitamura, R., Reddy, P., Vaughn, K. M. and Jovanis, P. P. (1995). Transit pre-trip information systems: An experimental analysis of information acquisition and its impacts on mode use, Paper presented at the 2nd World Congress on ITS, Yokohama, Japan.
22. Massachusetts Bay Area Transit (2020). Mbta brings real-time information to 18 high-ridership bus stops, https://www.masstransitmag.com/technology/passenger-info/signage-and-displays/press-release/21126916/massachusetts-bay-transportation-authority-mbta-mbta-brings-realtime-information-to-18-highridership-bus-stop. Accessed: 2020-02.
23. Cape Code Regional Transit Authority (2021). https://www.capecodtransit.org/. Accessed: 2021-09.
24. Chicago Transit Authority (2021). Chicago transit authority website, https://www.transitchicago.com/. Accessed: 2021-09.
25. ITS International (2012). Transport technology transforming bus stops in los angeles, https://www.itsinternational.com/its9/feature/transport-technology-transforming-bus-stops-los-angeles. Accessed: 2012-01.
26. Southeastern Pennsylvania Transportation Authority (2021). http://www.septa.org/. Accessed: 2021-09.
27. Seattle Department of Transportation (2021). Real-time information sign, https://www.seattle.gov/transportation/projects-and-programs/programs/transit-program/real-time-information-signs. Accessed: 2021-09.
28. Federal Highway Administration (2012). Manual on Uniform Traffic Control Devices, Vol. 1, Federal Highway Administration of the United States.

29. Dudek, C. L. (2004). Changeable message sign operation and messaging handbook, Technical report, Operations Office of Travel Management, Federal Highway Administration. Operations Office of Travel Management, Federal Highway Administration.
30. Dudek, C. L., Trout, N., Booth, S. and Ullman, G. L. (2000). Improved dynamic message sign messages and operations, Technical report, Texas Transportation Institute. Texas Department of Transportation.
URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/1882-2.pdf
31. Dudek, C. L. and Ullman, G. L. (2002). Flashing messages, flashing lines, and alternating one-line on changeable message signs, Transportation Research Record 1803: 94–101.
32. Dudek, C. L., Schrock, S. D. and Ullman, G. L. (2005). Impacts of using dynamic features to display messages on changeable message signs, Technical report, Texas Transportation Institute. Operations Office of Travel Management.

This page left blank intentionally.

8.0 Appendices

8.1 Appendix A: Interview Screening Questionnaire

Introduction

Thank you for your response to the email/flyer. The University of Massachusetts Amherst is conducting research with travelers in the Greater Boston Area about how travel information on highway billboards influences transit usage.

We would like to ask you to fill out an online survey to see if you qualify for our interview. This survey takes about 5 minutes. There are no right or wrong answers. We would like to hear honest responses from you.

By participating in this survey, you are indicating that you understand that your responses are anonymous and will not be identified with you in any way and that you are at least 21 years old with a valid driver's license. **You may skip any question, but it will help us determine whether you qualify for the interview if you answer as many questions as you feel comfortable with.**

If you have any questions, please contact us at oipprogram2022@gmail.com.

Q1 What is your age?

○ 21-29

○ 30-39

○ 40-49

○ 50-59

○ 60-69

○ 70 and above

Q2 What gender do you identify with?

○ Male

○ Female

○ Non-binary

Q3 What is your employment status?

○ Full-time

○ Part-time

○ Self-employed

○ Unemployed

○ Others (please specify)

Q4 What is your household income?

◯ Less than $52,000

◯ $52,000 to $120,000

◯ more than $120,000

Q5 Please specify the frequency of the ***three*** most frequently used travel modes (including working from home, if applicable) over all types of trips you made ***before the COVID-19 pandemic***. If you select public transit, please also specify the mode you used to access transit, e.g., walk, bike, drive, being dropped off by another person.

	Number of times	Per week, month, or year
Public transit (please specify the mode you used to access transit, e.g., walk, bike, drive, being dropped off by another person)	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Drive alone	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Carpool	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Taxi including using Transportation Network Company service such as Uber and Lyft	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Bike	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Walk	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Work from home	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year

Q6 Are your frequently used travel modes at the present the same as before the COVID-19 pandemic?

○ YES

○ NO

Q7 Please specify the frequency of the ***three*** most frequently used travel modes (including working from home, if applicable) over all types of trips you made . If you select public transit, please also specify the mode you used to access transit, e.g., walk, bike, drive, being dropped off by another person.

	Number of times	Per week, month, or year
Public transit (please specify the mode you used to access transit, e.g., walk, bike, drive, being dropped off by another person)	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Drive alone	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Carpool	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Taxi including using Transportation Network Company service such as Uber and Lyft	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Bike	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Walk	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year
Work from home	▼ Less than 1, 1, 2, ..., 10, More than 10	▼ per week, per month, per year

Q8 What is your most frequently used highway?

- I-90
- I-93
- I-95
- I-195
- I-290
- I-495
- Others, please specify:

Q9-1 Please specify the start and end of your most frequently used highway section. You can refer to **New Exit Number** in the I-90 / Mass Pike in MA Exit List.

	Start Exit	End Exit	Others
			Describe the start and end if you do not remember exit numbers
I-90	▼ 3, ..., 137	▼ 3, ..., 137	

(Q9-2 to Q9-6 ask respondents to specify the start of end of their most used highway section based on their previously selected highway)

Q9-7 Please specify the start and end of your most frequently used highway section. You can use exit numbers or landmarks along the highway to describe them.

____

____

____

Q10 What is your 2nd most frequently used highway?

○ I-90

○ I-93

○ I-95

○ I-195

○ I-290

○ I-495

○ Others, please specify:

Q11-1 Please specify the start and end of your 2nd most frequently used highway section. You can refer to **New Exit Number** in the I-90 / Mass Pike in MA Exit List.

	Start Exit	End Exit	Others
			Describe the start and end if you do not remember exit numbers
I-90	▼ 3, ..., 137	▼ 3, ..., 137	

(Q11-2 to Q11-6 ask respondents to specify the start of end of their most used highway section based on their previously selected highway)

Q11-7 Please specify the start and end of your 2nd most frequently used highway section. You can use exit numbers or landmarks along the highway to describe them.

____

____

____

Q12 Please leave your email address so we can be in touch about the interview.

____

This page left blank intentionally

8.2 Appendix B: Interview Slides

Subject Statement of Voluntary Consent

When signing this form, you are agreeing to voluntarily enter this study. You have had a chance to read this consent form, and it was explained to you in a language which you use. You have had the opportunity to ask questions and have received satisfactory answers. You have been informed that you can withdraw at any time. A copy of this signed Informed Consent Form has been given to you.

Introduction

1.Background

The research team from UMass Amherst is conducting a research on an Outdoor Information Panels ("OIP") program which will update legacy outdoor billboards or add new digital billboards near major roadways. The billboard will set aside 25% of the time to display Real-Time Travel Information ("RTTI"). This interview is designed to gather your opinions on how information displayed on these billboards could influence your travel pattern and experience.

2.Billboard Example

I-93/Southeast Expressway, Southampton St. exit ramp, facing north

I-93/Southeast Expressway, Southampton St. exit ramp, facing south

Travel Experience

Question 1
Have you ever seen or used any real-time transit information provided by MBTA?

○ Yes

○ No

Question 2
Please describe the situation and what you like or do not like about what the information conveys and how it is delivered.

Question 3
Please describe a situation in which you wish you could have transit related information to help with travel decision making.

Queston 4
Please describe your most memorable billboard by a highway.

Question 5
What are the main reasons that you do not use transit at the present?

Desired Contents for Non-users

Question 6

Consider traveling on one or more of your often used highway sections by car. **<u>What is the start and destination of this trip? What is the trip purpose?</u>**

Imagine that there is a billboard by the highway that displays real-time transit and/or traffic information, on average one out of four days.

Question 7

Consider traveling on one or more of your often used highway sections by car. Which highway section(s) do you have in mind?

Landmark

Highway number or exit

Question 8

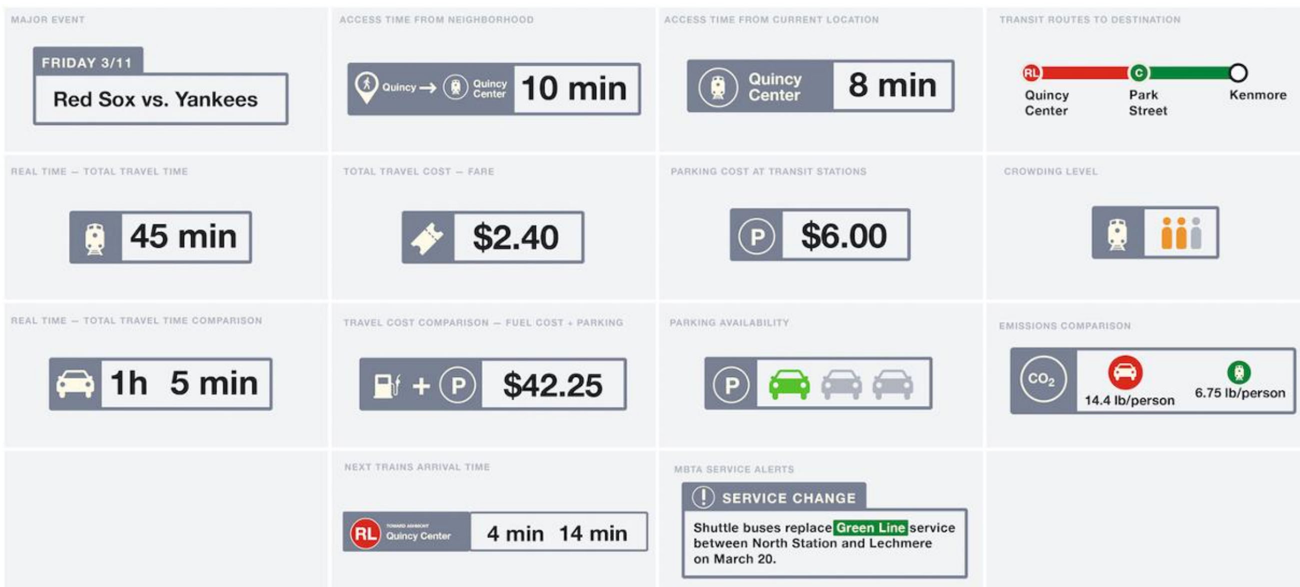
At what time of day do you make this trip in general? What is the typical traffic condition?

Question 9
Do you have other frequently used highways in mind?

◯ Yes

◯ No

Question 10
Please let us know whether any of the information contents would encourage you to use transit for a future trip. If so, please explain why, and what kind of future trip, e.g., commuting, going to a Red Sox Game, visiting relatives. Please suggest information contents that are not included in the picture.

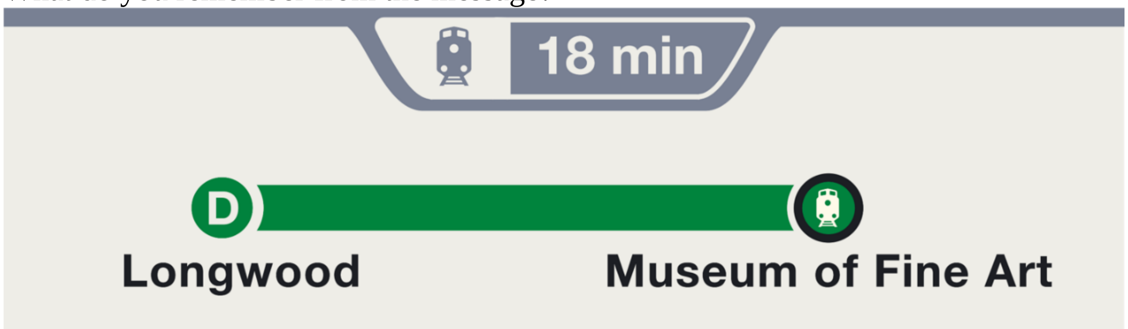


Question 11
Among the information contents discussed earlier, what are the first and second most important ones in terms of encouraging you to use transit for a future trip. What kind of trip, e.g., commuting, going to a game, visiting relatives?

Desired Information Load

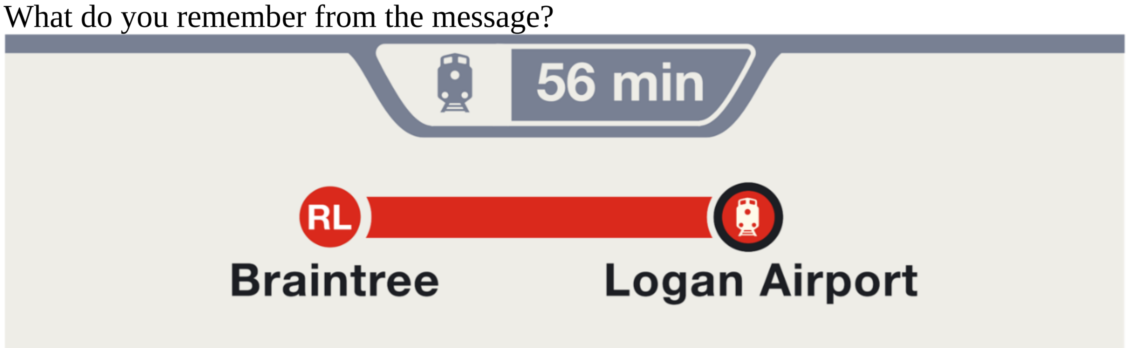
You will be shown various designs of a highway billboard displaying real-time transit information. Each image will be visible for a short amount of time. Sometimes you will see multiple images in sequence. Questions will appear after one or a set of images.

Question 12
What do you remember from the message?



Question 13
What do you remember from the message?

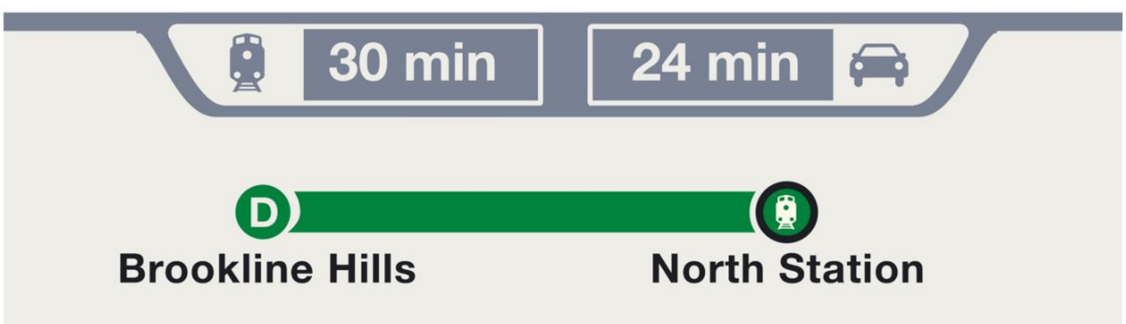
Question 14
What do you remember from the message?



Question 15
What do you remember from the message?

Question 16
What do you remember from the message?

Question 17
What do you remember from the message?



Anything Missing?

Question 18
Do you have any comments and/or suggestions for any of the questions we have discussed?

Thank you

8.3 Appendix C: Household Survey

Introduction

Researchers from University of Massachusetts (UMass) Amherst are conducting a survey of how real-time transit information on highway billboards influences transit usage. See the picture below for an example of a billboard. This survey takes about 10 minutes. There are no right or wrong answers, and we would like to hear honest opinions from you. You may skip any questions, but it will help us if you respond to as many questions as you feel comfortable with.

By clicking the Next button at the end of this page, you are indicating that you understand that your responses are anonymous and will not be identified with you in any way, and that you

- are at least 21 years old with a valid driver's license for at least 6 months,
- frequently drive on I-90, I-93, I-95, I-495, Rt 1, Rt 2, Rt 3, Rt 9, Rt 24 and/or Rt 128 in the Greater Boston Area,
- have used or have the possibility to use transit services provided by MBTA, including subway, bus, and commuter rail for the whole or part of a trip, and
- have read the consent form in the link below and agree to participate in this research study, and that you are free to skip any question that you choose. Please print a copy of this page for your records.

Consent form

You will have a chance to win **a $150 Amazon gift card** (1 out of each 50 participants) if you finish the survey.

Your opinions could inform the actual deployment of transit information on highway billboards! You will also be asked whether you might be interested in a follow-up survey of the effectiveness of live billboards.

The principle investigators of the research are Dr. Song Gao and Dr. Eleni Christofa of UMass Amherst. If you have any questions, please contact us at oipprogram2022@gmail.com.

First we would like to know a little bit about your background and use of transit.

Q1 What is your age?

◯ 21 - 30

◯ 31 - 40

◯ 41 - 50

◯ 51 - 60

◯ 61 - 70

◯ 70 and above

◯ Prefer not to answer

Q2 What gender do you identify with?

◯ Male

◯ Female

◯ Non-binary / third gender

◯ Prefer not to answer

Q3 What is your household income?

◯ Less than $52,000

◯ $52,000 to $120,000

◯ More than $120,000

◯ Prefer not to answer

Q4 How often do you currently use MBTA transit services?

◯ More than twice a week

◯ Between once a month and twice a week

◯ Less than once a month

Q5 How often did you use MBTA transit services before the COVID-19 pandemic?

◯ More than twice a week

◯ Between once a month and twice a week

◯ Less than once a month

Next we will ask you a series of questions on your preferred content, location and design of the billboards. These billboards do not currently display real-time transit information. Therefore we ask that you imagine driving on one of your most commonly used highways, and seeing transit information on these billboards.

Q6 Which highway do you have in mind? Please select <u>one and only one</u> highway segment by clicking on the rectangular area around a route number. Click again to deselect. A segment is roughly bounded by interchanges with other highways, and different segments have different colors.

	Off	On
I-95 Segment D		
I-93 Segment B		
I-495 Segment D		
Route 1 Segment B		
Route 3 Segment B		
Route 128		
Route 2		
I-495 Segment C		
Route 9		
I-495 Segment B		
Route 1 Segment A		
I-95 Segment A		
Route 3 Segment A		
I-495 Segment A		
Route 24		
I-95 Segment B		
I-93 Segment A		
I-95 Segment C		
I-90		

Q7 At what time of the day do you usually make this trip?

- ◯ Morning peak
- ◯ Mid-day
- ◯ Afternoon peak
- ◯ Evening / night

Q8 What is your typical traveling speed?

- ◯ Lower than 30 mph
- ◯ Between 30 and 50 mph
- ◯ Higher than 50 mph

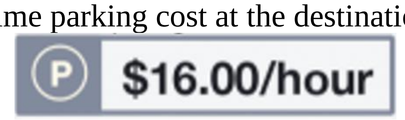
Q9-1 Based on your selected highway segment, a transit trip to downtown Boston from your general travel area is displayed on a billboard. Additional items of real-time transit and traffic information could be added. Please choose the top three items of information in terms of their usefulness in encouraging you to use transit more often for any trip.

☐ Real-time total travel time by transit

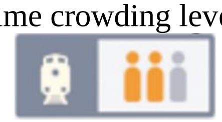
☐ Total travel cost by transit

☐ Real-time parking availability at the start MBTA station

☐ Real-time parking cost at the destination if traveling by car



☐ Real-time crowding level on transit



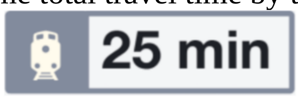
☐ Next two train arrivals

☐ CO_2 emission comparison of transit vs. car

Q9-2 to Q9-9 show different transit route based on selected highway segment.

Q9-10 As you did not select a commonly used highway in the previous question, we randomly pick a transit trip to downtown Boston displayed on a billboard. Additional items of real-time transit and traffic information could be added. Please choose the <u>top three</u> items of information in terms of their usefulness in encouraging you to use transit more often for any trip.

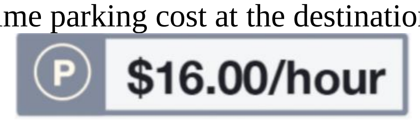
☐ Real-time total travel time by transit



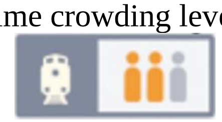
☐ Total travel cost by transit

☐ Real-time parking availability at the start MBTA station

☐ Real-time parking cost at the destination if traveling by car



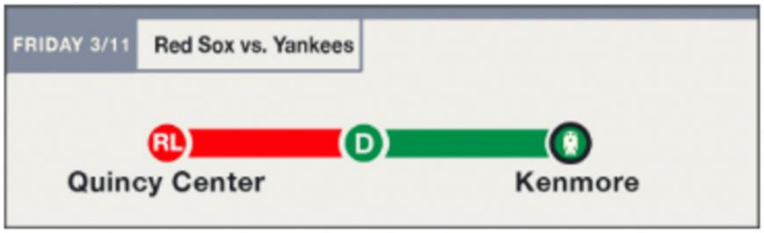
☐ Real-time crowding level on transit



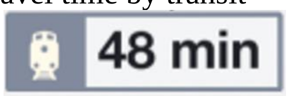
☐ Next two train arrivals

☐ CO_2 emission comparison of transit vs. car

Q10 For a major event such as a Red Sox game, the billboard could display a transit route to Fenway Park, the game venue. Additional items of transit and traffic information could be added. Please choose the <u>top three</u> items of information in terms of their usefulness in encouraging you to use transit for the event.

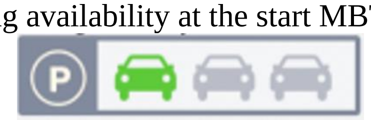


☐ Total travel time by transit

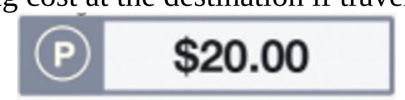


☐ Total travel cost by transit

☐ Parking availability at the start MBTA station

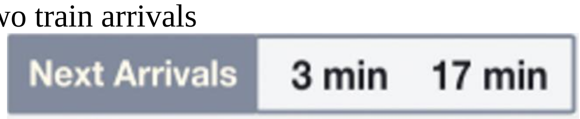


☐ Parking cost at the destination if traveling by car



☐ Crowding level on transit

☐ Next two train arrivals



☐ CO_2 emission comparison of transit vs. car

Q11 If there are useful information items that are not mentioned above, please specify:

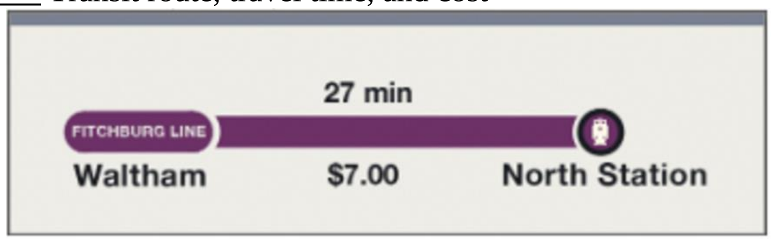
◯ Useful item #1 ____

◯ Useful item #2 ____

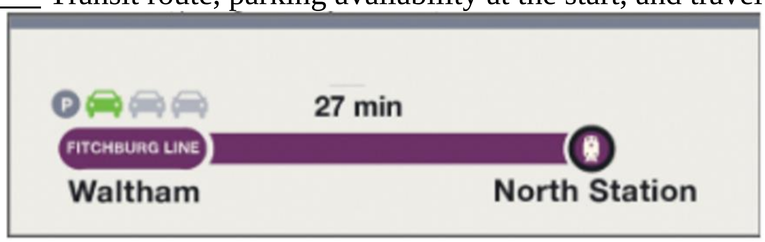
◯ Useful item #3 ____

Q12 After asking you to pick the top three individual information items, we now present four complete billboards with various contents for a specific trip. Please rank the billboards in terms of their usefulness in encouraging you to use transit more often for any trip by dragging them to the appropriate location (No. 1 is the most useful) .

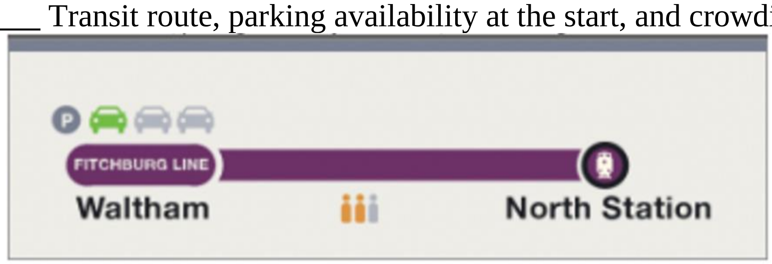
_______ Transit route, travel time, and cost



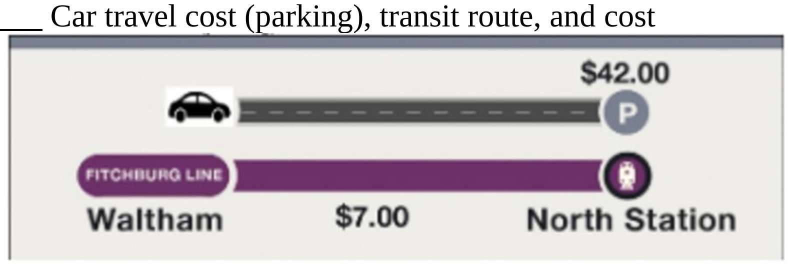
_______ Transit route, parking availability at the start, and travel time



_______ Transit route, parking availability at the start, and crowding level



_______ Car travel cost (parking), transit route, and cost



Q13 Please specify one combination of information items that you think is more useful but not included above, if any.

____

____

____

Q14 The displayed trip is one we chose without knowing your preference. Which trip would you like to see information about on the billboards? Please specify the start and end in any way you are comfortable with, e.g., by town, neighborhood or transit station.

○ Start ____

○ End ____

Q15 Where should the billboards be placed relative to the display trip?

○ Close to the start

○ In the middle

○ Close to the end

○ Anywhere in the general travel direction

○ Others, please specify:

Q16 Would you use transit more often after seeing your preferred information on the billboards? Please indicate the potential increase of transit use frequency for each type of trip.

	Increase by about once a week	Increase by about once a month	Increase by about once a quarter	Increase by about once a year	No increase
Work, e.g., to/from work, work-related business	○	○	○	○	○
Family, e.g. school/church, medical/dental, family/personal business	○	○	○	○	○
Shopping	○	○	○	○	○
Social and recreational, e.g., visit friends/relatives, see a movie	○	○	○	○	○
Major event, e.g., Red Sox game, Patriots game	○	○	○	○	○

Q17 As a current frequent transit users, would the real-time information on the billboards improve your travel experience, even if not encouraging you to make more transit trips?

○ Definitely would

○ Probably would

○ No change

○ Probably not

○ Definitely not

Q18 Please share any additional comments regarding how the information is or is not useful.

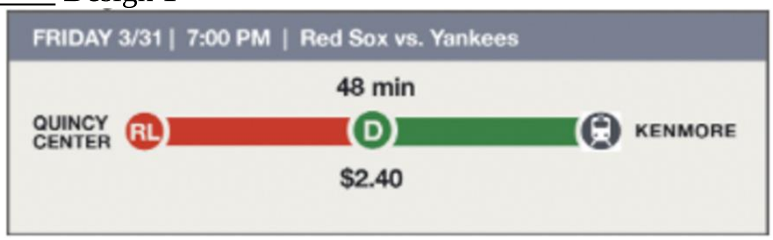
____

____

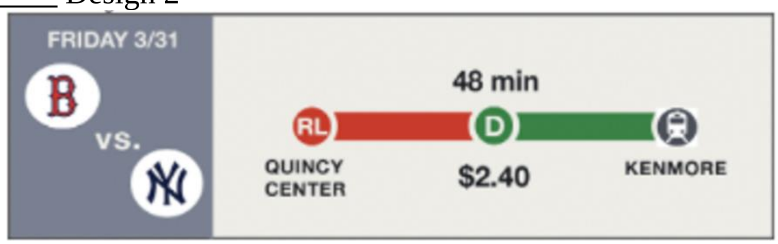
____

Q19 Four billboard designs are shown below with the same content but different layouts, colors and/or fonts. Please rank them in order of preference by dragging them to the appropriate location (No. 1 is the most preferred).

_______ Design 1

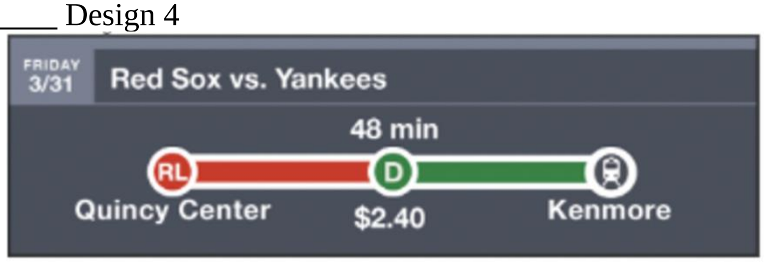


_______ Design 2



_______ Design 3

_______ Design 4



Q20 If you are interested in entering a raffle to win a $150 Amazon gift card (1 out of each 50 participants), please leave your email.

○ Email ____

Q21 Can we follow up with you when real-time transit information is actually deployed on the billboards?

○ Yes

○ No

Q22 Thank you for agreeing to a follow-up survey. Please leave your email, so we can be in touch after the billboards with real-time transit information are in live operation.

____

Please note that you are close to the end of the survey. Please use the "Back" button to navigate to earlier responses if you'd like to revise them. You will not be able to go back once you click "Next" on this page.