A Literature Review of the Passenger Benefits of Real-Time Transit Information

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Abstract

Recently, it has become common practice for transit operators to provide real-time information (RTI) to passengers about the location or predicted arrival times of transit vehicles. Accompanying this is a growing body of literature that aims to assess the impacts of RTI on transit passenger behavior and perceptions. The primary objective of this research is to compile a literature review of studies that assess the passenger benefits of RTI provision. The results suggest that the primary behavioral changes associated with providing RTI to passengers pertain to decreased wait times, reductions in overall travel time due to changes in path choice, and increased use of transit. RTI may also be associated with increased satisfaction with transit service and increases in the perception of personal security when riding transit. A second objective of this review was to identify areas for future research based on remaining gaps in the literature; two keys areas that were identified are assessing actual behavioral changes of path choice of transit riders and conducting cost-benefit analyses post implementation of RTI systems. The results of this study have immediate implications for public transit operators considering implementation or expansion of RTI systems and researchers seeking topics for future investigation.

Keywords

Public transit; real-time information; wait times; ridership; path choice

1. Introduction and Motivation

The transit industry has benefitted from numerous technology changes over the past two decades. One example is the widespread availability of real-time information, which provides the position or predicted arrival time of a transit vehicle at a stop or station. Real-time information is typically used for operations and control purposes by the transit provider, but it is increasingly distributed directly to passengers via signage at stops or stations and through web-enabled or mobile devices (Schweiger, 2011).

Real-time information has become commonplace in the transit industry due in large part to three recent technology changes. First, with the removal of Global Positioning Systems (GPS) selective availability in 2000, automated vehicle location systems have become less expensive and easier to implement. Next, the development of the General Transit Feed Specification (GTFS) format for transit schedules began a surge of data standardization that has carried over into real-time information. Finally, the proliferation of smartphones in recent years has made real-time information more easily available in mobile formats.

As the industry practice of providing real-time information to passengers has increased, the body of literature evaluating the passenger impacts of this new information source has also grown, which presents an opportunity to synthesize findings and identify remaining gaps in the literature. Synthesizing initial trends is important for transit providers who want to understand the impacts of real-time information to appropriately plan service and weigh trade-offs between investments; similarly, researchers want to assess directions for future research about questions that remain unanswered. While there have been prior literature reviews of traveler information (e.g., Chorus et al., 2006; Ben-Elia and Avineri, 2015), there have only been limited summaries of up-to-date research specific to the passenger benefits of real-time transit information (e.g., Turnball, 2003; Dziekan and Kottenhoff, 2007; Whitelegg, 2016). Therefore, to fill this gap in the literature, the primary objective of this paper is to summarize the benefits of real-time information for transit passengers - with an emphasis placed on quantitative findings – and the secondary aim is to identify areas where future research is needed.

2. Terminology and Theory

Real-time information refers to up-to-the-minute tracking of transit vehicles by automatic vehicle location systems or track circuit systems. Vehicle location information is sent to a central server, typically located at the transit provider, and then it is disseminated to riders, either directly or through application programming interfaces (API) used by third party software developers.

2.1 Terminology

Although real-time information (RTI), real-time transit information (RTTI), real-time passenger information (RTPI), and advanced passenger information systems (APIS) are all commonly used terms in the literature, for this paper, the term real-time information (RTI) will be used.

A few distinctions between RTI and other forms of transit information should be made. First, schedules refer to the predefined location and time of vehicles published by the transit operator. When transit vehicles are running on-time, schedule information and RTI are the same, but when transit vehicles are not, RTI is a more accurate method of tracking the actual location of transit vehicles. There is prior research that examines passenger use of schedule information versus RTI (e.g., Molin & Timmermans, 2006; Fonzone, 2015; Mulley et al., 2017), but this is not considered in this review as it does not focus on the benefits of RTI. A second type of information is transit service alerts that report major delays, and while these are often provided to passengers in real-time as incidents occur, they can include varying levels of information. Prior literature that focuses on the passenger impacts of alerts about major delays (e.g., Bai and Kattan, 2014) is not reviewed here.

2.2 Theoretical Impacts of RTI on Passengers

When considered from the passenger perspective, RTI can impact numerous transportation decisions made by the traveler (e.g., Daigle & Zimmerman, 2004; Ferris et al., 2010; Cats, et. al., 2011; Brakewood et al., 2014; Fonzone, 2015). Theoretically, RTI could impact a person's decision to make a trip (travel choice), the decision to take transit for that trip versus another mode (mode choice), the specific path that the person takes on transit (route choice), the stop at which the person boards a transit vehicle (boarding stop choice), and the time at which a person leaves his/her origin to arrive at that stop (departure choice). This decision-making process provides a passenger-centric framework that is shown in Figure 1.

[Figure 1 near here]

This paper categorizes RTI benefits into five major elements for which multiple studies have been undertaken. Three of these areas fall under behavioral outcomes associated with RTI: *wait time*, *travel time*, and *transit use*. RTI could impact levels of transit use by impacting a passenger's decision to make a trip or not make a trip (travel choice) or by impacting a passenger's choice to take transit versus another mode (mode choice). Both of these impacts can be quantified as increased (or decreased) transit use. RTI could also influence which route a passenger chooses (route choice) and therefore impact their overall travel time, as different paths typically have different travel times. Likewise, RTI could play a role in the decision of which stop a passenger boards a transit vehicle (stop boarding choice) or what time they choose to leave their point of origin (departure time choice), and both could impact the traveler's total travel time and their wait time. Because the prior literature often divides transit travel time into wait time and in-vehicle travel time components, the wait time component is presented separately in the literature review that follows.

The framework shown in Figure 1 also displays two major factors that influence the transit passenger decision-making process related to passenger feelings and perceptions: *satisfaction with transit* and *perception of security*. The impact of RTI on these influencing factors that determine travel choice and mode choice, as well as route choice, boarding stop choice, and departure time choice, will also be considered in this literature review.

3. Methodology

This section describes the methodology for conducting the literature review, including the databases that were searched and the inclusion and exclusion criteria. Then, a framework for comparing different dimensions of the selected studies is presented.

3.1 Databases Searched

Two scholarly databases were selected for the search process. The first database was the Transport Research International Documentation, which is known as ***TRID***. TRID is maintained by the Transportation Research Board (TRB) of the US National Academies and covers all modes and transportation disciplines. This database was selected for the primary search because it contains nearly 1.2 million records of published research and is considered to be "*the world's largest and most comprehensive bibliographic resource on transportation research information"* (National Academics of Science, Engineering, and Medicine, 2018). TRID was searched using the keywords “transit real-time information” for English publications from the period of 1990 to 2017, which resulted in 1,344 records. The title of each record was reviewed, and if it pertained to RTI, the full abstract was then read to assess if the publication specifically considered passenger benefits of RTI. Based on this reading of abstracts, the full manuscript of any peer-reviewed journal articles or conference proceedings possibly evaluating passenger benefits of RTI was then downloaded and considered for this literature review.

The second database used for this search was ***Google Scholar.*** Google Scholar “provides a simple way to broadly search for scholarly literature” (Google, 2018), and therefore, it was used to broaden the scope of the search beyond transportation-specific databases (i.e., TRID). Google Scholar ranks documents by relevance by “weighing the full text of each document, where it was published, who it was written by, as well as how often and how recently it has been cited in other scholarly literature” (Google, 2018). Because publications are listed in order of relevance to the keywords, a cut-off point was needed. For this review, the first 500 articles resulting from the keywords “transit” or “public transport” and “real-time information” were considered. After the first 200 articles, nearly all relevant references were identified; however, the search was continued through 500 to assure that potentially relevant publications pertaining to the passenger benefits of RTI were not missed.

3.2 Inclusion and Exclusion Criteria

To be included in this literature review, RTI studies must meet four criteria. First, only studies published in ***English*** were included; research published in other languages was excluded. Second, only studies ***published since 1995*** were included because RTI has only become widely available in the transit industry in the last 20 years. Third, the research results must be published in ***peer-reviewed journals or conference proceedings*** to be included in this review; technical reports (such as Mehndiratta et al., 2000) for which peer review status was undetermined were excluded. Last, and perhaps most important, only studies specifically evaluating the ***passenger benefits*** of RTI are included in this literature review.

Other related areas pertaining to RTI were excluded from this review, including the following growing areas of research:

- Impacts of RTI on bus drivers (e.g., Watkins et al., 2013; Ji et al., 2014);
- Perceptions and use of transit information by special groups, such as passengers with disabilities (Patterson et al., 2004; Barbeau et al., 2010; Azenkot et al., 2011; Georggi et al., 2011) and older adults (Sochor, 2014);
- Comparisons of different aspects of transit service, which can include information provision such as RTI (Monzon et al., 2013; Imaz et al., 2015; Maitra, et al., 2015; Cats et al., 2015);
- Development and evaluation of transit vehicle arrival prediction algorithms (Lin and Zeng, 1999; Chien, Ding & Wei, 2002; Cats & Loutos, 2016a; Cats & Loutos, 2016b);
- Passenger responses to the reliability/accuracy of RTI predictions (Mishalani, et al., 2000; Rahman et al., 2017);
- Development of crowdsourced RTI systems (Steinfeld et al., 2011; Tomasic et al., 2015); and
- Strategies for disseminating RTI, including the technical aspects such as system architecture and the reasons that transit operators provide RTI to passengers (Hill,

2000; Holdsworth et al., 2007; Schweiger, 2011; Velaga et al, 2012; Barbeau, Borning and Watkins, 2014; Harmony and Gayah, 2017).

3.3 Classification of Selected Studies

Each selected study was classified in a table using five key dimensions. The first dimension is the ***media*** through which RTI is provided to the transit rider. Initially, RTI was frequently provided via stationary *signage* located at bus stops or in train stations. This was traditionally done with variable message signs, which are sometimes referred to as countdown clocks (Schweiger, 2003; Turnbull, 2003), and some transit providers now display this information on touchscreen kiosks (Kamga, et al., 2013). RTI is increasingly provided to passengers' *personal devices*, including websites accessed on computers or mobile phones, text messages to cell phones, and smartphone applications. It should be noted that there is a small literature that aims to understand which media transit riders prefer (e.g., Caulfield & O'Mahoney, 2009; Zito et al., 2011; Petrovska 2012; Rahman et al., 2013; Harmony and Gayah, 2017; Islam, et al., 2017); however, this is not reviewed here because it does not explicitly pertain to passenger benefits.

The second and third dimensions are the ***mode*** of transit and the ***location*** where the study was conducted. Because different modes and geographic regions have varying levels of transit service and potentially varying preexisting perceptions of the transit system, the specific mode and location of the study is noted if an actual transit system was evaluated.

The fourth and fifth dimensions summarized for each study are the ***methodology*** used to evaluate the passenger impacts and the key ***findings***. Study methodologies are classified into three categories (surveys of individual travelers, simulation models, or aggregate-level econometric analyses), and further analysis details are given. The majority of prior studies utilized survey-based methods, and for these, the sample size of individuals participating in the survey and the statistical method utilized were noted. Regarding the findings, numerical values or ranges to quantify changes in passenger behavior or perception are presented whenever possible.

4. Findings from the Literature Review

Studies presented below are summarized based on their key impacts on passenger behavior and perception: decreases in wait times, decreases in overall travel time because of changes in path choice, increases in use of the transit system (or ridership), increases in satisfaction with transit service, increases in perceived levels of personal security, and other benefits.

4.1 Decreased Wait Times

The impacts of RTI on passenger wait times are the most common positive finding in the literature. Accessing RTI at a passenger's place of origin (e.g., home or work) enables the rider to "time" his or her arrival to a stop to reduce his/her *actual wait time*. Additionally, RTI may reduce a passenger's *perceived wait time* after reaching a stop because s/he is can check the status of the vehicle, which can reduce the uncertainty in a passenger's wait time (Mishalani et al., 2006).

[Table 1 near here]

4.1.1 Synthesis of Wait Time Studies

Specific studies that have examined the impact of RTI on wait times are summarized chronologically in Table 1. In the first study, an employee survey at the University of Michigan revealed that the disutility of wait times decreases with the provision of information (Reed, 1995). The second study was conducted in the Hague by surveying passengers on a tramline before and after RTI signage was installed (Dziekan and Vermeulen, 2006), and the average self-reported wait times of survey respondents decreased by 1.3 minutes (or 20%) from the before to the after survey. Third, a web-based survey of bus riders using RTI provided via personal devices was conducted in Seattle, Washington (Ferris et al., 2010), and 91% of respondents self-reported spending less time waiting for the bus. In the next study shown in Table 1, a simulation model of the Clemson area bus system was created to estimate the passenger wait time impacts prior to deployment of RTI (Fries, Dunning & Chowdhury, 2011), and the model results suggest that pretrip travel time savings (which are part wait time) are likely to be small.

Perhaps the most cited study on the relationship between RTI and passenger wait times shown in Table 1 was conducted in Seattle, Washington (Watkins et al., 2011). In this study, both non-users and users of RTI were surveyed at bus stops and self-reported average *perceived wait times* were 7.5 minutes for RTI users versus 9.9 minutes for non-users; additionally, observers timing how long those passengers were waiting at the bus stop found that the *actual wait times* of RTI users were almost two minutes less than non-users.

The sixth study shown in Table 1 was a behavioral experiment involving some bus riders with RTI and a control group without RTI in Tampa, Florida (Brakewood et al., 2014), and the results revealed a significantly larger decrease in self-reported "usual" wait times for the RTI user group (-1.79 minutes) compared to the control group (-0.21 minutes) from the before survey to the after survey. The next study in Table 1 utilized a dynamic transit model known as BusMezzo (Cats & Gkioulou, 2014), and the findings suggest that passengers will adapt their behavior to shorten wait times based on prior knowledge of the transit system, accumulated experience riding transit, and RTI.

The eighth study shown in Table 1 evaluated the wait time impacts of in-station RTI signage in a before-after survey of heavy rail riders in Boston, Massachusetts (Chow et al., 2014), and the results suggest that, after RTI signage was installed, passengers reduced their wait time estimates by 0.85 minutes on average. The ninth study was an onboard survey of both RTI users and non-users on the commuter rail in Boston (Brakewood, Rojas, et al., 2015), and the self-reported "usual" wait times were almost one minute less for RTI users than for non-RTI users (mean of 7.87 minutes for RTI users versus 8.45 minutes for non-users).

The tenth study shown in Table 1 aimed to understand the effects of amenities at transit stops in the Twin Cities, Minnesota; self-reported passenger wait times were used as the dependent variable in a regression model in which RTI signage was not significant (Fan et al., 2016). Next, a small number (n=15) of bus riders in rural Scotland were interviewed before the availability of RTI and an RTI app was installed on participants' phones; a key finding was that self-reported wait times decreased over the course of the study (Papangelis et al., 2016). The twelfth study shown in Table 1 surveyed passengers in Nanjing, China, and the results of a structural equation model of wait times revealed that RTI signage decreases the perception of wait times; specifically, shorter wait times (5 minutes) decreased 15.6% and longer wait times (10 minutes) decreased 30.6% (Ji et al., 2017). Last, a stated preference survey of tourists in Chengde, China was used to create a mixed ranked logit model, and a key finding was that tourists perceive longer wait times if bus RTI is not available (Liu et al., 2017).

In summary, wait times have been studied extensively on both RTI signage and personal devices over the past two decades. Many of the initial studies evaluated RTI provided on bus systems; however, in the last five years, researchers have evaluated RTI on numerous other modes, including light rail, heavy rail, and commuter rail. In terms of study locations, most of the earlier research was conducted in metropolitan areas in the United States and Europe; in the last few years, additional studies have been conducted in Asia. Methods for assessment include surveys of riders, in some cases paired with observations of actual wait times for comparison to stated wait times, as well as simulation models. The findings provide strong evidence that RTI displayed on signage decreases perceived wait times because this media type (signage) impacts passengers as they are waiting at the stop or station. Similarly, this body of research demonstrates that RTI provided via personal devices (the other media type) decreases both actual and perceived wait times because it can impact passengers before they leave their point of origin (reducing actual wait times) as well as at the stop or station (decreasing perceived wait times). Subsequently, reductions in wait times may be the most valuable benefit of providing RTI to passengers. In most studies, there was a statistical difference in perceived wait times, with a typical reduction of 20% to 30% or approximately 2 minutes.

4.1.2 Areas for Future Research on Wait Times

Future research should make use of location-aware technologies in smartphones or other proximity detecting technologies such as Bluetooth to measure wait times because prior research primarily asked respondents about wait times using manual data collection methods, which are time consuming and expensive. Furthermore, although the average impact of RTI on wait times is well understood, the variance is not. Future research should differentiate wait time perceptions based on differing headways and differing levels of reliability. Finally, the most substantial gap in knowledge related to these reductions in perceived and actual wait times is the overall impact on riders' decisions. Travel demand models consistently penalize wait times as approximately 1.5 to 2 times the value of in-vehicle travel times. However, this research points to wait times with RTI being weighted approximately equally to in-vehicle travel time. Future research is needed to improve the prediction of demand models based on a more accurate understanding of wait times, which could have important implications for the overall flow of passengers in the transit network (e.g., Larsen and Sunde, 2009).

4.2 Decreases in Total Travel Times

This section summarizes the impacts of RTI on passenger path choice because transit riders are likely to choose the route that minimizes their travel time, which could vary based on RTI. RTI is particularly important when transit service does not follow the posted schedule, as passengers can check RTI and adapt their behavior to choose an alternative mode or route of transit (Carrel et al., 2013).

[Table 2 near here]

4.2.1 Synthesis of Total Travel Time Studies

Studies that have examined the impact of RTI on path choice and corresponding travel times are summarized chronologically in Table 2. An early study of RTI on passenger path choice and travel times created a simulation model of a single corridor in Boston, Massachusetts (Hickman and Wilson, 1995), and after modeling numerous scenarios, the results suggest that potential travel time savings under perfect information scenarios were only about 3% of the total trip times, which were 34-35 minutes. A second study utilized a dynamic transit model known as BusMezzo applied to Stockholm's metro (Cats et al., 2011), and the model results demonstrate that providing a comprehensive, system-wide RTI has the potential to lead to shifts in path choice and travel time savings. A third study created an algorithm for dynamic transit assignment that was applied to a fictitious, congested bus network to evaluate the impacts of RTI at stops; however, the results suggest that RTI does not lead to “a remarkable decrease in total travel time, with the exception of some particular instances” (Trozzi et al., 2013). The fourth study used Monte Carlo simulation in two fictitious transit networks with different passenger strategies to reduce travel times (Fonzone & Schmöcker, 2014), and the results suggest that RTI can reduce travel times by about 20%. Fifth, a discrete event simulation model was applied to the transit network in the small city of Rivera, Uruguay (Estrada, et al., 2015), and the results suggest that, compared to no available timetables, having static information can reduce total travel times by approximately 29% and RTI can reduce total travel times by 45%. The most recent study used a multiagent simulation platform to evaluate scenarios with varying percentages of riders having personalized RTI, and the results suggest that average travel times decreased until 50% of travelers are connected to RTI but travel times increased when 80% or more of passengers were connected (Zargayouna et al., 2015).

In summary, total travel time has relatively few studies compared to the number of wait time studies. All studies examining this relationship used simulation modeling techniques, and the results were varied substantially, with studies showing total travel time savings of 3% to 45%.

4.2.2 Areas for Future Research on Total Travel Times

Based on the previous synthesis, additional research is needed to better understand how RTI impacts path choice and travel time. First, future studies could consider minor differences in the media providing RTI; for example, there could be a comparison of travel time savings for apps that only provide RTI versus apps for real-time trip planning. Importantly, future research should consider use of passenger observations, surveys, and/or other methods to measure actual behavioral changes in addition to the simulation models that have been used to date. Future research could also consider travel time savings when there are varying levels of transit service coverage, e.g., dense networks versus sparser transit networks with fewer routing options. Similarly, RTI impacts on travel time should be tested with varying levels of transit service frequency and reliability. Finally, similar to previous studies that distinguished between actual and perceived changes in wait time, RTI could influence perceived travel times as well as actual travel times, and survey-based research in this area could help travel demand modeling processes that take travel time into account.

4.3 Increased Transit Use

If passengers spend less time waiting and/or decrease their overall travel time by choosing a shorter path, then the provision of RTI may also cause an increase in the frequency of transit trips by existing riders or potentially attract new riders to transit.

[Table 3 near here]

4.3.1 Synthesis of Transit Use Studies

Specific studies that have examined the impact of RTI on transit use are summarized chronologically in Table 3. The first study surveyed more than 1,000 residents in the Chicago metropolitan area, including both transit users and non-users, and asked if the availability of RTI would increase their transit use; 67% of all respondents stated that they would increase their use of transit if RTI became available at stops and stations (Tang & Thakuriah, 2007). The second study was performed on the University of Maryland shuttle bus network before and after the implementation of a RTI system (Zhang et al., 2008), and the use of RTI was not statistically significant in two fixed effects models of individual travelers' monthly shuttle bus use. A third study was conducted in Thessaloniki, Greece by surveying passengers at bus stops with RTI signage (Politis et al., 2010), and a total of 59 respondents (19.7% of the overall sample) stated that they made 103 new trips as a result of the recently installed RTI system. A previously mentioned survey of RTI users conducted in Seattle, Washington also examined self-reported changes in bus trips, and over 30% of RTI users reported increases in non-commute trips (Ferris et al., 2010); a follow-up web-based survey of 5,074 RTI users found similar results (Gooze et al., 2013), which is shown later in Table 3. The fifth study in Table 3 is a previously discussed study of the Clemson area bus system (Fries, Dunning & Chowdhury, 2011), with model results that suggest there would be limited if any changes in mode attributable to RTI.

The sixth and seventh studies shown in Table 3 were both conducted in Chicago, Illinois (Tang and Thakuriah, 2011; Tang and Thakuriah, 2012). One used a stated preference survey, and 76.1% of the 92 respondents stated they would increase transit use if RTI were available (Tang and Thakuriah, 2011). The other evaluated the gradual launch of bus RTI using an econometric analysis (Tang and Thakuriah, 2012), and the results of a linear mixed model show an increase of 126 average weekday bus trips per route associated with RTI, or 1.8% to 2.2%. Next, the previously mentioned behavioral experiment conducted in Tampa, Florida assessed changes in transit use by asking survey participants to self-report the number of bus trips that they made in the last week, and the results revealed that the change in trips from the before to the after survey was not significantly different between the RTI and non-RTI groups (Brakewood et al., 2014). The tenth study of transit use and RTI is the previously mentioned survey of riders in Boston (Chow et al., 2014); automated fare collection data was used in a fixed effects regression model that showed a 1.7% ridership increase as a result of RTI signage in rail stations.

The eleventh study evaluating the impacts of RTI on transit use was an econometric analysis of bus ridership in New York City (Brakewood, Macfarlane and Watkins, 2015), and the preferred model specification revealed an increase of 118 bus trips per route per weekday (or 1.7%) associated with RTI while a second model suggested that ridership increases may only be occurring on larger routes. The next study used web-based survey responses from university students in Brazil and Denmark in structural equation models of transit use, and a key finding was searching for RTI is associated with transit trips at night and to unfamiliar places, which is non-routine transit use (Kaplan et al., 2016). Last, a before-after survey of employees in three office buildings in Seattle (one with RTI signage and two without) examined commuter mode choice, and the percentage of respondents using transit increased for both the treatment group in the building with RTI signage and the control groups in the two buildings without; however, an additional regression model of drive alone versus other mode choices did not show a significant effect for the RTI treatment (Ge, et al., 2017).

In summary, numerous studies suggest that RTI may cause passengers to increase transit use. More than half of the studies, including many of the earliest ones, used survey methods to assess changes in transit use by individual riders, with the caveat that many of these studies are self-reported estimates of trips. More recently, researchers have used econometric methods to isolate aggregate changes in ridership on systems while controlling for other factors impacting ridership. These econometric studies were often conducted in large American cities with high levels of transit service (e.g., New York and Chicago), and ridership was estimated to increase approximately 2%, a substantial increase in locations where transit ridership is already quite high before RTI was introduced.

4.3.2 Areas for Future Research on Transit Use

Further research is needed using aggregate methods to assess both additional trips by existing riders and new riders in small to medium size cities to validate results obtained in larger cities. In addition, ridership studies should consider extended periods of analysis to assess long term changes in transit use, which has had some limited treatment in the literature (Wang & Wu, 2013), but could be due to more permanent choices such as automobile ownership. Furthermore, variation in ridership impacts based on the level of transit service provided (e.g., frequencies, service area) should be considered in cities of varying sizes. Similar to the wait time impacts, the variation in ridership increases with these service levels and varying levels of service reliability are critical to understand for travel demand models, as such models are used in the industry to predict future transit ridership.

4.4 Increased Satisfaction with Transit

If transit passengers spend less time waiting and/or adapt their travel choices to reduce their travel time, they may become more satisfied with overall transit service.

[Table 4 near here]

4.4.1 Synthesis of Satisfaction Studies

Specific studies that have examined the impact of RTI on satisfaction are displayed chronologically in Table 4. First is the previously mentioned study on the University of

Maryland campus (Zhang et al., 2008), in which the results of a random effects ordered probit model show that RTI use was associated with a significant increase in overall satisfaction level. Second, the previously discussed survey of RTI users conducted in Seattle showed 48% of respondents were “much more satisfied” and 44% of respondents were “somewhat more satisfied” with public transit as a result of using RTI (Ferris et al., 2010). Next is a follow-up survey in Seattle in which 51% of RTI users stated that they were “much more satisfied” with transit and 38% said they were “somewhat more satisfied” (Gooze et al., 2013). Fourth is the formerly cited behavioral experiment in Tampa, Florida, and two satisfaction-related indicators (satisfaction with “how long you have to wait for the bus” and satisfaction with “how often the bus arrives at the stop on time”) increased significantly from the before to the after survey between the control group and the experimental group (Brakewood et al., 2014). Next, the survey of heavy rail riders in Boston mentioned in the previous section also examined passenger satisfaction with system-wide transit service, and the results show that after RTI signage was available, passengers had a higher overall rating of the transit agency (3.46 compared to 3.41); however, this difference was not statistically significant (Chow et al., 2014). Last, a before-after survey of employees in three office buildings in Seattle (one with RTI signage and two buildings without) examined satisfaction with overall transit service on a 10-point scale; however, satisfaction ratings for employees in both the buildings with and without RTI decreased slightly from the before survey to the after survey (Ge et al., 2017).

In summary, transit riders who are provided RTI are generally more satisfied with the overall transit service than passengers without RTI. Although most studies showed an increase in the level of satisfaction, the methods used are entirely self-reported data and often used a sample of only those who use RTI. Presumably, those who did not find it useful would discontinue RTI use and not be included in the survey.

4.4.2 Areas for Future Research on Satisfaction

Future studies of passenger satisfaction should be done on a traditional experimental design basis with a treatment and control group before and after implementation. This will allow comparison between satisfaction scores of those with RTI and without. In addition, research may be needed to understand the ranking of RTI in terms of importance among other transit components such as increased service or stop amenities. Many agencies ask such questions in their passenger surveys, but the reports are not widely circulated in the industry or compared for universal understanding of customer preferences.

4.5 Increased Perception of Personal Security

Because passengers spend less time waiting at stops and stations, RTI may increase passenger perceptions of personal security when riding transit, particularly at night. A rider facing an unknown wait time may feel vulnerable without knowledge of when the vehicle will arrive.

[Table 5 near here]

4.5.1 Synthesis of Personal Security Studies

A synthesis of perceived personal security literature is displayed chronologically in Table 5. First, the previously mentioned survey in the Hague, Holland examined perception of security of passengers waiting at tram stops on a scale from 1 (very bad) to 10 (very good); the average security experience went from 7.9 to 7.6 from the before to the after survey, but this difference was not significant (Dziekan and Vermeulen, 2006). Second, the survey conducted on the University of Maryland campus also examined perceptions of personal security on a five point scale, and the results of two random effects ordered probit models show that RTI use had a positive effect on feelings of security at night (significant at the 0.1 level) but did not have a significant effect on feelings of security during the daytime (Zhang et al., 2008). Third, the results of the web-based survey conducted in Seattle, Washington that was previously mentioned revealed that 18% of respondents reported feeling "somewhat safer" and 3% reported feeling "much safer" as a result of using RTI; interestingly, this study found a strong correlation between feeling safer and gender (Ferris, Watkins, & Borning, 2010). The follow-up survey in Seattle found that 32% of RTI users reported feeling somewhat or much safer as a result of using RTI (Gooze, Watkins, & Borning, 2013). Last, in the previously mentioned behavioral experiment conducted in Tampa, Florida, feelings of "safety" during the daytime significantly increased for the RTI user group compared to the control group from the before to the after survey; however, there was not a significant difference regarding safety at night (Brakewood et al., 2014).

In summary, although personal security at transit stops is often considered an important issue, most studies did not find substantial perceived improvements. About half of the studies used self-reported survey ratings asking respondents if they felt safer as a result of having RTI. In these cases, only a small percentage of riders reported feeling safer (about 20%). In other studies with before and after ratings of feeling of safety, most did not find a statistical difference between RTI users and riders without RTI or between before and after situations once RTI was implemented. Riders with RTI have the option to leave a stop that feels unsafe until they know a vehicle is coming; however, these situations are likely rare on most systems and may therefore be difficult to identify in the study results.

4.5.2 Areas for Future Research on Personal Security

There are numerous potential avenues for future research regarding personal security and RTI. As mobile RTI becomes more prevalent, the reductions in actual waiting time at stops described previously will reduce the exposure to potential crimes at stops; however, having less presence on the streets may increase crime as the street becomes less active and stops become more isolated. Similarly, using a mobile phone (even briefly) may make passengers more likely to be the victim of theft; stealing mobile phones has become sufficiently widespread that is has given rise to the colloquial term "apple picking." In light of these different possibilities, further study of actual crime rates would be a useful addition to the perception studies previously conducted.

4.6 Other Impacts

The literature includes other possible benefits of RTI, including (1) walking speeds in the vicinity of transit stations, (2) distance walked to access transit stops, (3) transfers between different modes of transit, and (4) perceptions of environmental and traffic impacts of transit service.

[Table 6 near here]

4.6.1 Synthesis of Other Studies

The other possible benefits of RTI are summarized chronologically in Table 6. First, RTI signage in or around transit stations may impact passenger's ***walking speed***, particularly when signage says that a transit vehicle will soon arrive (Dziekan and Kottenhoff, 2007). A study of the subway in Stockholm, Sweden observed passengers entering subway stations and counted the number of passengers running and walking when RTI signage outside the subway station was on, and the results reveal that significantly more people run when the RTI signage was on rather than when the signage was off.

Second, RTI provided on mobile devices may impact a passenger's decision of where to board the transit vehicle, which would impact the passenger's ***walking distance*** to access transit (Ferris et al., 2010). On the previously mentioned survey of RTI users conducted in Seattle, Washington, 78% of respondents reported they were more likely to walk to a different stop based on RTI (Ferris et al., 2010).

Third, RTI may influence a passenger's decision to ***transfer between different transit modes***, and a study of Chicago, Illinois used econometric techniques to investigate the impacts of bus RTI on train ridership (Tang, Ross & Han, 2012). The model results suggest that there was an increase of 9.8 train rides per day, or 0.3% of the average weekday train station ridership, for every additional connected bus route that is provided with bus RTI, which may be due to increased intermodal transfer efficiency.

Last, a new direction of research suggests that availability of RTI might also lead ***nonusers of the transit system to have more positive perceptions*** of the transit provider. The results of a survey of transits users and nonusers at Ohio State University suggests that those respondents who noticed the RTI system had a higher probability of having positive attitudes towards the environmental and traffic-related impacts of the local shuttle bus system, regardless of their usage of the shuttle bus (McCord et al., 2015).

In summary, additional studies addressed walking speed and distance, transfers, and perceptions of environment and traffic impacts. However, with only one study looking at each impact, few broad conclusions can be drawn.

4.6.2 Areas for Future Research on Other Benefits

All four areas could benefit from additional study. In particular, the relationship between walking and transit is not often studied and additional research could be conducted to better understand the personal trade-offs between a walk trip and a transit trip that RTI allows, such as deciding to walk to the next stop for exercise to make use of a delayed bus. Furthermore, RTI may substantially change the burden of transferring from one transit mode to another or from one route to another, making grid-type transit networks rather than those designed around one-seat services more convenient. Further research is also needed to differentiate between changes in transfer behavior on the same transit mode, which would result in different passenger flow distributions but not ridership, versus transfers to other transit modes and potentially other transit providers, which would result in ridership differences by mode and/or provider.

4.7 Summary and Comparison of Impacts

Table 7 shows the five most common passengers benefits identified in the literature; other impacts (such as walking distance) are not included in this table due to the limited literature. In Table 7, a filled circle represents a positive finding in that study, a half-filled circle signifies a finding that is sometimes positive, and an empty circle implies that the study investigated the passenger impact but the results were null, negative, or not statistically significant. A dash means that the study did not investigate that passenger impact. Table 7 also shows the year of publication of each study.

Of the twenty-eight studies evaluating the five primary benefits of RTI, twenty-three were published in 2010 or later, which demonstrates that this is a rapidly evolving area of research. Thirteen of the twenty-eight studies examined the wait time implications of RTI, and twelve of these studies found positive results. This implies that wait times are thoroughly studied and have the most supporting evidence of the various impacts. Only six of the twenty-eight studies examined travel time implications from path choice, meaning this is a field ripe for further research. Also from Table 7, thirteen of the twenty-eight studies evaluated the impacts of RTI on transit use, and nine of them found positive results. Notably, many of the studies that found positive results were conducted in large cities with high levels of preexisting transit service. Six of the twenty-eight studies examined satisfaction and of those, only three found fully positive results. Similarly, five of the twenty-eight studies examined perceived personal security and of those, only two found fully positive results. Satisfaction, though not discussed as frequently in academic studies, is often addressed in agency reports; personal security, however, is another area where future research could address impacts more thoroughly.

[Table 7 near here]

5. Conclusions and Future Research

This study compiled a literature review of the passenger benefits of real-time information (RTI) provided via signage at transit stops or personal devices. Three key behavioral impacts of RTI were identified: reductions in passenger wait times, reductions in overall travel time due to changes in path choice, and increases in transit use. Additionally, two important changes in passenger feelings were identified: increases in perceptions of personal security and increases in satisfaction with overall transit service.

Of the passenger impacts that were identified, the evidence suggests that the primary benefit to passengers is reductions in wait times associated with using RTI. Early studies of signage at transit stops found a reduction in ***perceived wait times***, or how long passengers think they have been waiting, on the order of 1.5 minutes. A recent study of RTI provided via mobile devices found a reduction of observed ***actual wait times*** of approximately 2 minutes. Similarly, another recent study of mobile RTI found a reduction of self-reported "usual" wait times of nearly 2 minutes. Taken together, there is now strong evidence that RTI significantly decreases the perceived and actual wait times of passengers, which is particularly important given that passengers generally dislike the waiting segment of transit trips more than being in the transit vehicle.

Numerous areas for future research were also identified throughout the paper and a few key areas are highlighted here. Although passenger wait times have been studied in numerous real-world environments, there has been limited research pertaining to the total travel time impacts of RTI in actual transit systems. Simulation models suggest that RTI provides possible travel time savings because of changes in passenger path choices; however, identifying effective methods to capture this in real world environments is a key challenge for future research. A second noteworthy area for future research pertains to the impacts of RTI on overall transit use; specifically, a handful of prior studies evaluating aggregate ridership impacts found increases in bus ridership of approximately 2%. However, these studies were conducted in large cities with vast transit coverage and predominantly high frequency service. Future research is needed to better understand the impacts of RTI in situations with varying levels of service frequency and availability.

Given the many benefits of RTI discussed in this paper, another important area for future research is comparing these passenger benefits to the transit operator costs of providing RTI. This has had some treatment in the literature, including cost-benefit analyses (Lehtonen & Kulmala, 2002; Cham et al., 2006; Nuworsoo et al., 2009; Welde et al., 2011) and other economic evaluations (Chen, 2012). However, there is room for additional research compiling system-level capital and operating costs of RTI systems after implementation. Similarly, future research could compare the benefits of RTI to other policy or operational improvements, which has had limited treatment in the prior literature (Whitelegg, 2016).

Finally, as transit information provision continues to evolve based on the availability and adoption of new technologies, many additional areas for related research are likely to emerge. For example, some RTI systems collect records of user interactions with smartphone apps; if these RTI apps are "location aware", then backend server records can provide data about the real-time location of RTI users and their transit travel patterns (Brakewood et al, 2017). Additionally, transit providers are beginning to provide customized information about other attributes of the transit system, such as real-time crowding information, which is an interesting area for future study (Kim et al., 2009; Yu et al., 2015; Zhang, 2015). Similarly, the integration of fare media and trip planners into real-time information apps allow passengers to consult one app for all their transit needs. Multimodal information – including private and public transportation options – in real-time trip planners is another interesting area for future research (Gkiotsalitis and Stathopoulos, 2015; Zhang et al., 2011; Zhang et al., 2013). As transit agencies look toward the service provided by transportation network companies such as Uber and Lyft with seamless integration of all aspects of the service (location data, payment, ratings) in one location, it is clear that high quality information will be important to passengers. The impacts of the evolution of transit apps into this one-stop shop for passenger information will be a fruitful area for future study.

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FIGURES AND TABLES

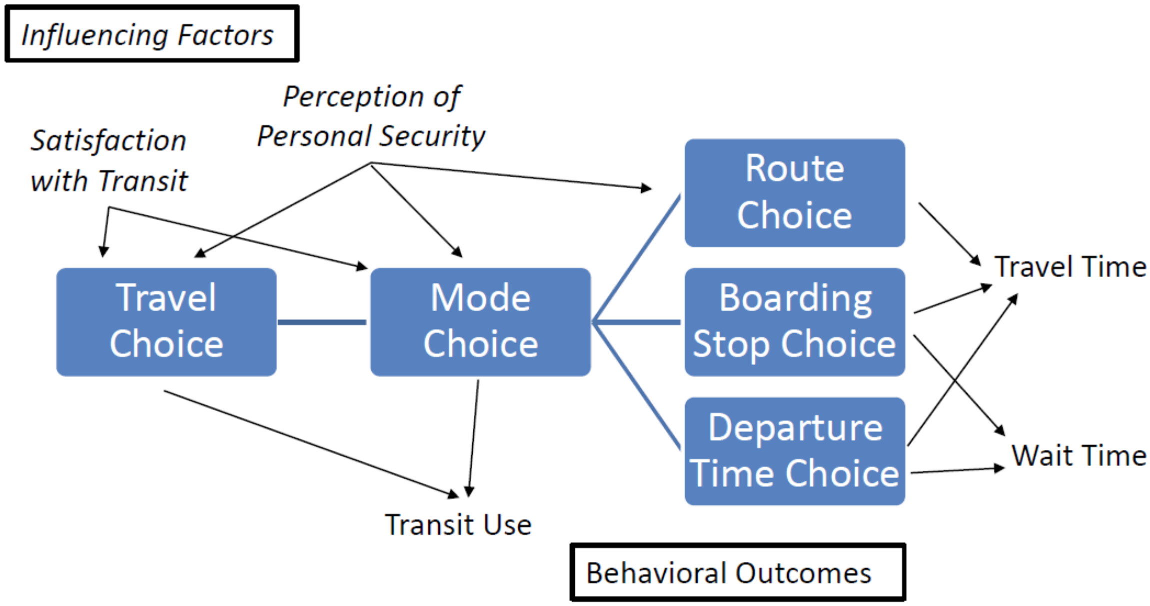

Figure 1: Theoretical diagram of passenger choice impacts of real-time information

Table 1: Impacts of real-time information on passenger wait times

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	Analysis	
1	1995	Reed	Signage and Telephone	Bus	University of Michigan, USA	Survey-based method (n=295)	A series of hypothetical scenarios were used in a conjoint analysis to assess the impact of RTI on the disutility of wait times for bus trips	The disutility of wait times decreases with the provision of information; RTI via a telephone message had a greater influence than RTI via signage at stops and both forms of RTI were preferable to printed schedules
2	2006	Dziekan & Vermeulen	Signage	Tram	The Hague, Holland	Survey-based method (n=53)	Before-after passenger surveys asking passengers to self-report their average wait time on both surveys	Average perceived wait time decreased from 6.3 minutes before to 5.0 minutes after, which is a difference of 1.3 minutes or 20%
3	2010	Ferris, Watkins & Borning	Personal Devices	Bus	Seattle, USA	Survey-based method (n=488)	Web-based survey of RTI users asking if their (self-reported) wait time has changed since they began using RTI	91% of RTI users self-reported spending less time waiting for the bus since they began using RTI, 8% reported no change, and less than 1% reported an increase in wait times
4	2011	Fries, Dunning & Chowdhury	Signage & Personal Devices	Bus	Clemson University, USA	Simulation model	A simulation model was created to assess potential impacts of deploying RTI; pretrip time savings and anxiety levels while waiting were evaluated	Pretrip travel time savings (part of wait time) were small; reduction in anxiety levels while waiting were the most significant benefit of RTI
5	2011	Watkins, Ferris, Borning, Rutherford & Layton	Personal Devices	Bus	Seattle, USA	Survey-based method (n=655)	In-person survey of bus riders asking how long they have been waiting at the stop to measure perceived wait times; Observations of actual wait times	Self-reported average perceived wait times were 7.5 min versus 9.9 min for RTI users versus non-users (approximately 30% difference); RTI users had average actual wait times approximately 2 min less than non-users
6	2014	Brakewood, Barbeau & Watkins	Personal Devices	Bus	Tampa, USA	Survey-based method (control group n=107; RTI users n=110)	Behavioral experiment with a before-after control group design; both groups were asked to self-report their "usual" wait times on the route that they ride most frequently	Self-reported "usual" wait times for the RTI user group (average decrease of -1.79 minutes) decreased by approximately 1.5 minutes more than the control group (average of -0.21 minutes) from the before to the after survey; this is a 16% decrease from their average wait time (11.36 minutes) on the before survey

Table 1 (continued): Impacts of real-time information on passenger wait times

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	Analysis	
7	2014	Cats & Gkioulou	Personal Devices	Subway, Bus and Light Rail	Stockholm, Sweden	Simulation model	Dynamic transit model (BusMezzo) considering RTI with varying levels of reliability	RTI users adapt their behavior to shorten their wait times
8	2014	Chow, Block-Schachter & Hickey	Signage	Heavy Rail	Boston, USA	Survey-based method (n=4,118)	Before-after passenger surveys conducted in heavy rail stations; passengers were asked to estimate how long they expected to wait for a train	After RTI, passengers reduced their wait time estimates by 0.85 minutes on average; after further controlling for service disruptions, wait time estimates were reduced by 1.3 minutes on average (17% of total wait times)
9	2015	Brakewood, Rojas, Zegras, Watkins & Robin	Personal Devices	Commuter Rail	Boston, USA	Survey-based method (n=868)	On-board survey of passengers who use RTI and those who do not; all respondents were asked to self-report their wait times on the day of the survey and their "usual" wait times	Wait times on the day of the survey did not have a statistically significant difference between RTI users and non-users; "Usual" wait times were almost one minute less for RTI users than for non-RTI users (mean of 7.87 minutes for RTI users versus 8.45 minutes for non-users)
10	2016	Fan, Guthrie & Levinson	Signage	Light Rail, Commuter Rail, BRT	Minneapolis and St. Paul, USA	Survey-based method (n=702)	On-board survey of passengers asking them to self-report their wait times; video footage of passengers waiting at stops/station to capture actual wait times; log-log regression model of self-reported wait time as the dependent variable	RTI signage was not significant as an independent variable in the wait time regression model
11	2016	Papangelis, Nelson, Sripada & Beecroft	Personal Devices	Bus	Rural Scotland	Survey-based method (n=15)	Interviews and observations of passengers riding the bus before and after the availability of RTI; respondents were asked to self-report how long they have been waiting for the bus	Self-reported wait times decreased from an average of 12 minutes (min 5, max 19) before RTI to an average of 5 minutes (min 4, max 6) after RTI
12	2017	Ji, Zhang, Gao & Fan	Signage	Metro, BRT, Bus	Nanjing, China	Survey-based method (n=1031)	Survey of passengers at stops/stations asking them to self-report their wait times; video footage of passengers waiting at stops/station to capture actual wait times; structural equation model of wait times	Results of the structural equation model suggest that RTI signage decreases the perception of wait times; shorter wait times (5 minutes) decreased 15.6%; longer wait times (10 minutes) decreased 30.6%
13	2017	Liu, Shi & Jian	Personal Devices	Bus	Chengde, China	Survey-based method (n=706)	Stated preference survey of tourists; real-time transit and traffic information considered in a mixed ranked logit model	Model results reveal that tourists perceive longer wait times for the bus if RTI is not available

Table 2: Impacts of real-time information on total travel time by changing passenger path choice

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	Analysis	
1	1995	Hickman & Wilson	Signage	Bus	Boston, USA	Simulation model	Dynamic path choice model with numerous scenarios	Travel time savings with perfect information were about 3% of the total trip times, which were 34-35 minutes; travel time savings under more realistic information scenarios were l-3% of the total trip times, which is a savings of 0.5 to 1.0 minutes
2	2011	Cats, Koutsopoulos, Burghout & Toledo	Signage & Personal Devices	Subway	Stockholm, Sweden	Simulation model	Dynamic transit model (BusMezzo) with three components: traffic dynamics, transit operations and passenger demand; Scenarios were evaluated with different levels of RTI provision and transit operations (including delays)	Comprehensive RTI systems have the potential to lead to shifts in path choice and travel time savings
3	2013	Trozzi, Gentile, Kaparias & Bell	Signage	Bus	Fictitious Network	Simulation model	Dynamic transit assignment model; compared scenarios with and without RTI and varying levels of passenger congestion	RTI does not lead to a remarkable decrease in travel times, except in some particular instances
4	2014	Fonzone & Schmöcker	Not specified	Not specified	Fictitious Network	Simulation model	Monte Carlo simulation model; passengers were assumed to have two different strategies: (1) arrive at their destination as soon as possible or (2) stay slightly longer at their current location to reduce their overall travel time	RTI access can reduce travel times by about 20%
5	2015	Estrada, Giesen, Mauttone, Nacelle & Segura	Signage & Personal Devices	Bus	Rivera, Uruguay	Simulation model	Discrete event simulation model; six variations of passenger behavior are evaluated	Publishing static timetables and encouraging their use can save total travel time (about 29%); RTI can result in greater total travel time savings (45%)
6	2015	Zargayouna, Othman, Scemama & Zeddini	Signage & Personal Devices	Bus	Toulouse, France	Simulation model	SM4T multiagent, multimodal simulation platform; six scenarios with different numbers of travelers and levels of information are evaluated	The scenario with no information provides the worst mean travel times; average travel times decrease until 50% of travelers are connected to personalized RTI; when 80-100% of travelers have RTI, mean travel times increase due to capacity constraints

Table 3: Impacts of real-time information on transit use (ridership)

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	Analysis	
1	2007	Tang & Thakuriah	Signage	Bus & Train	Chicago, USA	Survey-based method (n=1,020)	Survey of both transit riders and non-riders; Asked if availability of RTI would increase their transit use; Bivariate probit model estimated to explore simultaneous choice of transit use and RTI use relate to demographics, automobile availability, etc.	67% of all respondents stated that they would increase their transit use if RTI became available at stops/station; This was higher among current transit riders (70%) compared to non-riders (60%); Bivariate probit models showed some differences based on demographics, etc.
2	2008	Zhang, Shen & Clifton	Signage and Personal Devices	Shuttle Bus	University of Maryland, USA	Survey-based method (n=623)	Panel survey of shuttle bus riders before and after RTI implementation; Two fixed effects models; dependent variable in the first model is the natural log of monthly shuttle trips; dependent variable in the second model is the natural log of monthly campus-based shuttle trips; independent variables include demographics, automobile availability, etc.	Use of RTI was not statistically significant in either of the two models; One possible explanation from the authors is the number of shuttle trips was measured two weeks after an extensive marketing campaign of the new RTI system, which could have been insufficient time
3	2010	Politis, Papaioannou, Basbas & Dimitriadis	Signage	Bus	Thessaloniki, Greece	Survey-based method (n=300)	Surveys were conducted at bus stops with RTI signage, and passengers were asked if RTI inspired them to make additional bus trips	59 respondents (19.7% of the sample) stated that they have undertaken new trips as a consequence of RTI, which resulted in a total of 103 new trips
4	2010	Ferris, Watkins & Borning	Personal Devices	Bus	Seattle, USA	Survey-based method (n=488)	Web-based survey of RTI smartphone application users asking if their average number of weekly commute and non-commute trips has changed since they began using RTI	Over 30% of RTI users self-reported an increase of non-commute trips; Over 10% of RTI users self-reported an increase of commute trips
5	2011	Fries, Dunning & Chowdhury	Signage & Personal Devices	Bus	Clemson University, USA	Simulation model	A simulation model was created to assess potential impacts of deploying RTI; mode shift of bus riders was evaluated	Results of the simulation model suggest that mode shift changes are not significant.

Table 3 (continued): Impacts of real-time information on transit use (ridership)

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	Analysis	
6	2011	Tang & Thakuriah	Not specified	Transit	Chicago, USA	Survey-based method (n=92)	Stated preference (SP) survey conducted before RTI was widely available; Path analysis with variables including behavioral intentions to use transit more if RTI were available	SP survey results suggest that 76.1% of the respondents stated they would increase transit use if RTI were available; Path analysis provides evidence that the psychological effects on commuters caused by providing RTI might lead to transit ridership increase
7	2012	Tang & Thakuriah	Personal Devices	Bus	Chicago, USA	Econometric analysis	Linear mixed model; dependent variable is average weekday route-level bus ridership; independent variables include unemployment levels, weather, gas prices, population, and transit service attributes (such as fares and frequency of service)	126 average weekday trips per route associated with RTI, which is 1.8-2.2% of route-level average weekday ridership
8	2013	Gooze, Watkins & Borning	Personal Devices	Bus	Seattle, USA	Survey-based method (n=5,074)	Web-based survey of RTI users asking if their average number of weekly commute and non-commute trips has changed since they began using RTI	Over 30% of RTI users reported an increase of non-commute trips; Over 10% of RTI users reported an increase of commute trips
9	2014	Brakewood, Barbeau & Watkins	Personal Devices	Bus	Tampa, USA	Survey-based method (control group n=107; RTI user group n=110)	Behavioral experiment with a before-after control group; both groups were asked to self-report the number of bus trips they made in the last week	No significant difference in bus trips/week from the before survey to the after survey between the RTI user group and the control group; the authors noted that many participants were transit-dependent and had limited ability to increase their trips
10	2014	Chow, Block-Schachter & Hickey	Signage	Heavy Rail	Boston, USA	Econometric analysis	Automated fare collection system data used in a fixed effects regression model; dependent variable is the log of boardings; independent variables included fare changes, station effects, line effects and seasonal effects	The model suggests that ridership increased by 1.7% as a result of RTI signage; however, the authors caution that these results should be treated as "preliminary" because of data limitations

Table 3 (continued): Impacts of real-time information on transit use (ridership)

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	Analysis	
11	2015	Brakewood, Macfarlane & Watkins	Personal Devices	Bus	New York City, USA	Econometric analysis	Two panel regression models presented; dependent variable is average weekday route-level bus ridership; independent variables include level of transit service, fares, weather, local socioeconomic conditions, and availability of RTI	Model 1 finds an increase of 118 trips/route per weekday associated with RTI (median increase of 1.7%); Model 2 finds an increase of 340 trips/route per weekday associated with RTI on the largest quartile of routes (median increase of 2.3%)
12	2016	Kaplan, Monteiro, Anderson, Nielsen & Santos	Signage & Personal Devices	Bus, BRT, LRT (Brazil) & Metro, Local/ Suburban/ Regional Trains, Buses (Denmark)	Recife/Natal, Brazil and Copenhagen, Denmark	Survey-based methods (total n=1123; 63% in Brazil; 37% in Denmark)	Web-based survey of university students in two regions (Brazil and Denmark); structural equation models (separate for Brazil and Denmark) to explain transit use	Results show that searching for real-time information is associated with trips at night and to unfamiliar places (non-routine transit use); there is a complex relationship between transit information and transit use
13	2017	Ge, Jabbari & MacKenzie	Signage	Transit (bus, streetcar), Carsharing, Ridesourcing, Bikesharing	Seattle, USA	Survey-based method (before n=550; after n=455)	Before-after surveys of employees in three office buildings; signage was installed in one building (treatment group) but not in the other two buildings (control group); respondents were asked about their commute mode	Percent of transit commuters increased for both groups from the before survey (control group = 62.1%; treatment group = 58.4%) to the after survey (control group = 66.2%; treatment group = 62.1%); an additional regression model of drive alone versus other modes did not show a significant treatment effect

Table 4: Impacts of real-time information on passenger satisfaction

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	Analysis	
1	2008	Zhang, Shen & Clifton	Signage & Personal Devices	Shuttle Bus	University of Maryland, USA	Survey-based method (n=482)	Panel survey of shuttle bus riders; Random effects ordered probit model; dependent variable is overall satisfaction with shuttle bus service on a five-point scale; independent variables include demographics, automobile availability, etc.	RTI use had a significant positive effect on shuttle riders' overall satisfaction level; RTI use increased the probability of Rating 5 (highest satisfaction level) by 0.071
2	2010	Ferris, Watkins & Borning	Personal Devices	Bus	Seattle, USA	Survey-based method (n=488)	Web-based survey of RTI users asking if their overall satisfaction with public transit had changed as a result of using RTI	48% of respondents stated that they were much more satisfied and 44% of respondents were somewhat more satisfied with transit as a result of using RTI
3	2013	Gooze, Watkins & Borning	Personal Devices	Bus	Seattle, USA	Survey-based method (n=5,074)	Web-based survey of RTI users asking if their overall satisfaction with public transit had changed as a result of using RTI	51% of respondents stated that they were much more satisfied with transit as a result of using RTI and 38% said they were somewhat more satisfied with transit
4	2014	Brakewood, Barbeau & Watkins	Personal Devices	Bus	Tampa, USA	Survey-based method (control group n=107; RTI user group n=110)	Behavioral experiment with a before-after control group; both groups were asked about six indictors pertaining to satisfaction with specific aspects and overall bus service	Satisfaction with two indicators (how long you have to wait for the bus & how often the bus arrives at the stop on time) increased significantly from the before to the after survey between the control group and the RTI user group; ratings of overall bus service did not show a significant change

Table 4 (continued): Impacts of real-time information on passenger satisfaction

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	Analysis	
5	2014	Chow, Block-Schachter & Hickey	Signage	Heavy Rail	Boston, USA	Survey-based method (n=4,118)	Before-after passenger surveys conducted in heavy rail stations; passengers were asked to rate the overall transit system on a scale from 1 (poor) to 5 (great)	After RTI signage was available, passengers had a higher overall rating of the transit agency (3.46 compared to 3.41); however, this difference was not statistically significant
6	2017	Ge, Jabbari & MacKenzie	Signage	Transit (bus, streetcar), Carsharing, Ridesourcing, Bikesharing	Seattle, USA	Survey-based method (before n=550; after n=455)	Before-after surveys of employees in three office buildings; signage was installed in one building (treatment group) but not in the other two buildings (control group); respondents were asked about satisfaction with public transit on a 10-point scale	Satisfaction with public transit decreased slightly for both the treatment and control groups from the before to the after surveys

Table 5: Impacts of real-time information on the perception of personal security

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	**Analysis**	
1	2006	Dziekan & Vermeulen	Signage	Tram	The Hague, Holland	Survey-based method (n=53)	Before-after passenger surveys asking passengers to rate their perceived security at a stop on a scale of 1 (very bad) to 10 (very good)	Average security rating was 7.9 on the before survey and 7.6 on the after survey; however, the difference was not significant
2	2008	Zhang, Shen & Clifton	Signage & Personal Devices	Shuttle Bus	University of Maryland, USA	Survey-based method (n=482)	Panel web-based survey of shuttle bus riders; Two random effects ordered probit models; dependent variable in the first model is feeling of security in the daytime; dependent variable in the second model is feeling of security at night; independent variables include demographics, automobile availability, etc.	RTI use had a positive effect on feelings of security at night (significant at the 0.1 level); RTI use did not have a significant effect on feelings of security during the daytime
3	2010	Ferris, Watkins & Borning	Personal Devices	Bus	Seattle, USA	Survey-based method (n=488)	Web-based survey of RTI users who were asked how their perception of personal safety had changed as result of using RTI	21% of RTI users reported feeling somewhat or much safer (18% somewhat safer; 3% much safer)
4	2013	Gooze, Watkins & Borning	Personal Devices	Bus	Seattle, USA	Survey-based method (n=5,074)	Web-based survey of RTI users who were asked how their perception of personal safety had changed as result of using RTI	32% of RTI users reported feeling somewhat or much safer
5	2014	Brakewood, Barbeau & Watkins	Personal Devices	Bus	Tampa, USA	Survey-based method (control group n=107; RTI user group n=110)	Behavioral experiment with a before-after control group; both groups were asked how safe they feel on a 5-point scale when waiting for the bus during the daytime and at night	Feelings of safety during the daytime significantly increased for the RTI user group compared to the control group from the before to the after survey; Not a significant difference in feelings of safety at night

Table 6: Other impacts of real-time information

#	Year	Authors	Media	Mode	Location	Method		Findings
						Classification	Analysis	
1	2007	Dziekan & Kottenhoff	Signage	Subway	Stockholm, Sweden	Passenger observations	Two observers counted the numbers of passengers running and walking in the station hall entrance when RTI signage outside the subway station was on; RTI displays were then turned off for one day and similar passenger observations were conducted	More people run when RTI displays are on; the highest percent of passengers running (14.5%) was observed when RTI signs displayed 1 minute, which compares to 2.6% running when signs were off
2	2010	Ferris, Watkins & Borning	Personal Devices	Bus	Seattle, USA	Survey-based method (n=488)	Web-based survey of RTI users, who were asked how likely they are to walk to a different bus stop based on RTI	78% of users were more likely to walk to a different bus stop based on RTI
3	2012	Tang, Ross & Han	Personal Devices	Bus RTI; Train Use	Chicago, USA	Econometric Analysis	Mixed linear model; dependent variable is monthly average weekday train ridership per station; independent variables include socioeconomic factors, transit service factors and weather conditions	An increase of 9.8 train rides per day per station (which is approximately 0.3% of the average weekday train station ridership) for every additional connected bus route that is provided with bus RTI
4	2015	Mishalani et al.	Signage & Personal Devices	Shuttle Bus	Ohio State University, USA	Survey-based method (n=4,399 on before survey; n=4,741 on after survey)	Binary logit models; dependent variables were respondents' attitudes toward the shuttle bus system helping to (1) promote a "green" campus and (2) reduce the amount of car traffic on campus; independent variables included if the respondent was a shuttle bus user, if they are familiar with the local transit system, and demographics	The models suggest that respondents who noticed the RTI system had a higher probability of providing a positive response for both the environmental and traffic related dimensions; the effect was equally great between shuttle bus users and nonusers in the environmental model; the effect was greater among non-users of the shuttle bus system in the traffic reduction model

Table 7: Summary of the passenger impacts of real-time information

#	Authors (Year)	Wait Time	Total Travel Time	Transit Use	Satisfaction	Perceived Security
1	Brakewood, Barbeau & Watkins (2014)	●	-	○	◖	◖
2	Brakewood, Macfarlane & Watkins (2015)	-	-	●	-	-
3	Brakewood, Rojas, Zegras, Watkins & Robin (2015)	◖	-	-	-	-
4	Cats, Koutsopoulos, Burghout & Toledo (2011)	-	●	-	-	-
5	Cats & Gkioulou (2014)	●	-	-	-	-
6	Chow, Block-Schachter & Hickey (2014)	●	-	●	○	-
7	Dziekan & Vermeulen (2006)	●	-	-	-	○
8	Estrada, Giesen, Mauttone, Nacelle & Segura (2015)	-	●	-	-	-
9	Fan, Guthrie & Levinson (2016)	○	-	-	-	-
10	Ferris, Watkins & Borning (2010)	●	-	●	●	●
11	Fonzone & Schmöcker (2014)	-	●	-	-	-
12	Fries, Dunning & Chowdhury (2011)	●	-	○	-	-
13	Ge, Jabbari & MacKenzie (2017)	-	-	○	○	-
14	Gooze Watkins & Borning (2013)	-	-	●	●	●
15	Hickman & Wilson (1995)	-	●	-	-	-
16	Ji, Zhang, Gao & Fan (2017)	●	-	-	-	-
17	Kaplan, Monteiro, Anderson, Nielsen & Santos (2016)	-	-	●	-	-
18	Liu, Shi & Jian (2017)	●	-	-	-	-
19	Papangelis, Nelson, Sripada & Beecroft (2016)	●	-	-	-	-
20	Politis, Papaioannou, Basbas & Dimitriadis (2010)	-	-	●	-	-
21	Reed (1995)	●	-	-	-	-
22	Tang & Thakuriah (2007)	-	-	●	-	-
23	Tang & Thakuriah (2011)	-	-	●	-	-
24	Tang & Thakuriah (2012)	-	-	●	-	-
25	Trozzi, Gentile, Kaparias & Bell (2013)	-	◖	-	-	-
26	Watkins, Ferris, Borning, Rutherford & Layton (2011)	●	-	-	-	-
27	Zargayouna, Othman, Scemama & Zeddini (2015)	-	◖	-	-	-
28	Zhang, Shen & Clifton (2008)	-	-	○	●	◖
● = positive finding; ◖ = sometimes positive finding; ○ = negative / not significant finding; - = did not consider						
Note: Studies pertaining to "other" miscellaneous benefits are not included in this table.						