Transportation Research Part A 69 (2014) 409–422

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

An experiment evaluating the impacts of real-time transit information on bus riders in Tampa, Florida

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A R T I C L E I N F O

Article history:
Received 7 February 2014
Received in revised form 29 July 2014
Accepted 15 September 2014

Keywords:
Real-time information
Wait times
Before–after control group research design
Behavioral experiment
Mobile applications
Public transit

A B S T R A C T

Public transit agencies often struggle with service reliability issues; when a bus does not arrive on time, passengers become frustrated and may be less likely to choose transit for future trips. To address reliability issues, transit authorities have begun to provide real-time information (RTI) to riders via mobile and web-enabled devices. The objective of this research is to quantify the benefits of RTI provided to bus riders. The method used is a behavioral experiment with a before–after control group design in which RTI is only provided to the experimental group. Web-based surveys are used to measure behavior, feeling, and satisfaction changes of bus riders in Tampa, Florida over a study period of approximately three months.

The results show that the primary benefits associated with providing RTI to passengers pertain to waiting at the bus stop. Analysis of "usual" wait times revealed a significantly larger decrease (nearly 2 min) for RTI users compared to the control group. Additionally, RTI users had significant decreases in levels of anxiety and frustration when waiting for the bus compared to the control group. Similarly, they had significant increases in levels of satisfaction with the time they spend waiting for the bus and how often the bus arrives at the stop on time. Taken together, these findings provide strong evidence that RTI significantly improves the passenger experience of waiting for the bus, which is notoriously one of the most disliked elements of transit trips. The frequency of bus trips and bus-to-bus transfers were also evaluated during the study period, but there were no significant differences between the experimental and control groups. This is not surprising since the majority of bus riders in Tampa are transit-dependent and lack other transportation alternatives.

The primary contribution of this research is a comprehensive evaluation of the passenger benefits of RTI conducted in a controlled environment. Moreover, this research has immediate implications for public transit agencies – particularly those serving largely transit-dependent populations – facing pressure to improve service under tight budget constraints.

1. Introduction

Public transit plays a vital role in urban transportation systems. Transit helps to reduce carbon dioxide emissions, decrease gasoline consumption, and combat roadway congestion in metropolitan areas (Schrank et al., 2012). It is one of

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http://dx.doi.org/10.1016/j.tra.2014.09.003
0965-8564/Published by Elsevier Ltd.

the safest modes of passenger transport, as evidenced by low passenger fatality rates (Neff and Dickens, 2013). Other benefits of transit include providing personal mobility options for those who cannot or choose not to drive (e.g., American Public Transportation Association, 2014) and positive public health impacts associated with active lifestyles (e.g. Besser and Dannenberg, 2005).

Despite its benefits, transit agencies in many American cities struggle to compete with other modes of passenger transportation, especially single-occupancy motor vehicles. To be a viable option when compared to alternatives, transit service must be fast, frequent, and reliable, among other things (Walker, 2012). Reliability can be improved in many ways, including: increasing levels of right of way, such as providing a dedicated lane; using service planning approaches, such as adding slack to scheduled running times; or implementing control strategies, such as holding vehicles that are ahead of schedule. While these supply-side strategies can be effective at improving reliability, they often come at a substantial cost.

Recently, a demand-side strategy has emerged that can improve the perception of reliability: providing real-time vehicle location and/or arrival information helps passengers adapt to unreliability of transit service (Carrel et al., 2013). Moreover, real-time information (RTI) can be provided to passengers in an increasingly cost-effective manner, particularly when agencies take an "open data" approach. "Open data" means that the transit authority makes their service information freely available to the general public in a computer-readable format (Barbeau, 2013; Wong et al., 2013). This information can be used by third-party software developers to create transit "apps," often at little-to-no additional cost to the agency. The rapid adoption of mobile devices makes this third-party information dissemination channel directly accessible to an increasing number of riders (Schweiger, 2011). This trend has occurred so rapidly in the United States that, in December of 2012, the president of the American Public Transportation Association said that "the proliferation of transit apps is one of the most exciting things to happen to this industry" (Mann, 2012). In light of this, decision-makers at the country's transit providers want to understand the impacts of RTI. This research aims to provide a comprehensive study of the benefits of providing RTI to riders via web-enabled and mobile devices. To do this, a controlled behavioral experiment, which is an established methodology in the social sciences (Campbell and Stanley, 1963), was conducted to evaluate the impact of RTI on bus riders.

This paper proceeds as follows. First, prior research about real-time transit information is reviewed and hypotheses about the benefits of RTI are presented. The next section provides detailed information about the methodology used to conduct the controlled behavioral experiment. This is followed by the results, the limitations of the study, and the conclusions.

2. Literature review

There is a growing body of research that aims to understand the rider benefits of RTI. An early segment of this research focused on the impacts of RTI displayed on signage at stops or in stations (e.g., Hickman and Wilson, 1995; Dziekan and Kottenhoff, 2007; Politis et al., 2010). Recently, the literature has expanded to include the provision of RTI through web-enabled and/or mobile devices. Many of the initial studies of RTI provided via personal devices relied heavily on stated preference and/or simulation methods to evaluate possible impacts (e.g., Caulfield and Mahony, 2009; Tang and Thakuriah, 2010). Given the recent widespread availability of RTI applications throughout the country, there is a growing subset of the literature that uses actual behavioral data to understand rider benefits, and it is the focus of this review. Based on prior behavioral studies, the following key benefits of RTI were identified: (1) decreased wait times, (2) increased satisfaction with transit service, and (3) increased ridership. It should be noted that there may be other rider benefits associated with the use of RTI (e.g. route choice to minimize travel time), but prior research has largely relied on stated preference or simulation methods (e.g., Cats et al., 2011; Fonzone and Schmöcker, 2014). Therefore, this study focuses on the benefits grounded in actual behavioral studies to provide a framework for evaluation of RTI in a controlled environment.

The following review includes discussion of each one of these impacts (decreased wait times, increased satisfaction, and increased ridership), as well as related benefits.

2.1. Decreased wait times and feelings experienced while waiting

When passengers utilize RTI, they can time their departure from their origin to minimize their wait time at stops or stations; moreover, RTI can reduce their perception of the length of wait times. In Seattle, Washington, a recent study found that bus riders with RTI had actual wait times that were almost two minutes less than those of non-users, and perceived wait times of RTI users were approximately 30% less than those who did not use RTI (Watkins et al., 2011).

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 panel study conducted at the University of Maryland measured changes before and after the implementation of a RTI system on the university shuttle bus network, and the results revealed that passengers reported increased levels of perceived personal security at night attributable to RTI (Zhang et al., 2008). Two web-based surveys of RTI users conducted in Seattle, Washington provide additional evidence that RTI may increase self-reported levels of personal security. In the first survey, conducted in 2009, 18% of respondents reported feeling "somewhat safer" and another 3% felt "much safer" as result of using RTI (Ferris et al., 2010). In 2012, a follow-up web-based survey in Seattle found over 32% of RTI users had a positive shift in their perception of personal security (Gooze et al., 2013).

In addition, prior studies have aimed to assess changes in other feelings while waiting for the bus, including aggravation, anxiety and relaxation. The previously mentioned University of Maryland panel study evaluated levels of anxiety while waiting for the bus but did not find a significant decrease associated with the use of RTI (Zhang et al., 2008). Similarly, the Seattle study of wait times evaluated passenger levels of aggravation and relaxation while waiting, but the results showed no significant difference between the RTI users self-reported aggravation levels and that of those without RTI (Watkins et al., 2011).

2.2. Increased satisfaction with transit service

In theory, if transit passengers spend less time waiting (or perceive waiting time to be less), it follows that they may feel more satisfied with overall transit service. The University of Maryland study found a significant increase in overall satisfaction with shuttle bus service attributable to RTI (Zhang et al., 2008). Additionally, in the 2009 web-based survey of RTI users in Seattle, 92% of respondents stated that they were either "somewhat more" satisfied or "much more" satisfied with overall transit service, and the follow-up 2012 survey of RTI users found similar results (Ferris et al., 2010; Gooze et al., 2013).

2.3. Increased ridership and transfers

If passengers spend less time waiting and/or are more satisfied with overall transit service, 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. In Seattle, the two web-based surveys of RTI users previously discussed found that approximately one third of riders reported an increase in the number of non-work/school trips per week made on transit because of RTI (Ferris et al., 2010; Gooze et al., 2013). On the other hand, the University of Maryland study also evaluated frequency of travel on the university shuttle bus system but concluded that RTI did not cause an increase in shuttle bus trips (Zhang et al., 2008). Last, an empirical evaluation of Chicago bus ridership found a "modest" increase in overall route-level ridership (precisely 126 rides per route per day, which is 1.8–2.2% of average route-level weekday bus ridership) attributable to real-time bus information (Tang and Thakuriah, 2012).

If passengers take more trips on transit, they may also increase the number of transfers they make between transit routes. Similarly, if RTI reduces the perception of the length of wait times, it could also reduce the perception of transfer times, potentially leading to an increased willingness to transfer. In a follow-up study in Chicago, the impacts of bus RTI on rail ridership were evaluated, and the results showed a small increase in rail ridership (0.3% of the average weekday train station-level ridership) attributable to bus RTI. The authors argue that this increase in rail ridership may be due to increased intermodal transfer efficiency between buses and trains, which suggests a complementary effect of the provision of bus RTI on connected rail service (Tang et al., 2012).

Last, it should be noted that most of these RTI studies were conducted in two large American cities (Seattle and Chicago) that have extensive bus systems. The Chicago Transit Authority and King County Metro in Seattle operate the second and seventh largest American bus systems, respectively, based on passenger miles (Neff and Dickens, 2013). Given the sheer size of these networks, they differ from many other American bus systems in their level of service provision (namely frequency of service and/or origin–destinations served), as well as the demographics of transit riders that include relatively high levels of "choice" riders (ORC, 2011; Zhao et al., 2014). Evaluation of the benefits of RTI in a mid- or small-sized transit system may find different levels of benefits.

3. Hypotheses

Based on this literature review of studies evaluating transit rider behavior, the following hypotheses about the benefits of RTI have been developed. First, it is hypothesized that RTI is associated with a decrease in the wait times (either actual and/or perceived) of riders. Second, riders using RTI may report increased levels of personal security while riding transit, likely because they can reduce their wait times at bus stops. Third, RTI use may be associated with decreases in levels of aggravation and anxiety or increases in levels of relaxation while waiting for the bus, although most prior studies have not found significant changes in these feelings. RTI use may also result in higher levels of satisfaction with overall transit service. Last, RTI users may increase their frequency of transit trips, as well as their frequency of transferring.

4. Methodology

A controlled behavioral experiment was conducted in Tampa, Florida to evaluate the benefits of providing RTI to transit riders. Tampa was selected as the location for this study for two reasons. First, the transit provider in Tampa, Hillsborough Area Regional Transit (HART), operates a bus service of approximately 27 local and 12 express bus routes (HART, 2013a) and had a FY2013 annual ridership of approximately 14.6 million bus trips (HART, 2013b). Therefore, this small-sized transit system differs from the prior studies of larger systems (Seattle and Chicago). Notably, the demographics of HART's ridership are largely transit-dependent users; their most recent system-wide survey showed that 56% of riders do not have a valid driver's license and 66% live in households without cars (Tindale-Oliver et al., 2010).

More importantly, Tampa offered a unique opportunity to provide RTI to only a controlled subset of transit riders. HART outfitted all of their buses with automatic vehicle location (AVL) equipment in 2007, but initially implemented the system

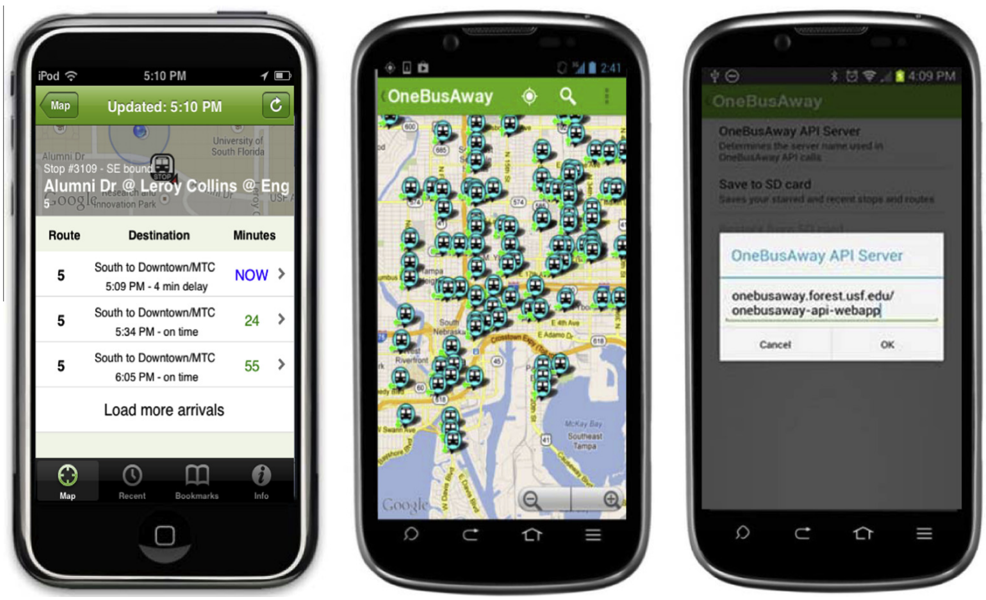

Fig. 1. Screenshots of the OneBusAway Tampa iPhone application, Android application, and setting changes to limit access (shown for Android).

for operational purposes only and did not share RTI with riders. In 2012, the agency granted the authors special access to their real-time bus data in order to develop a RTI system for riders. Since there were no other means for HART riders to access RTI, a controlled environment was available for experimentation.[3] The transit agency and the authors decided to pursue a small-scale launch of the RTI system, which provided a limited time to conduct a research study that restricted access of RTI to a small group of participants. In light of the opportunity to expose a controlled population to RTI without other interference (i.e. the launch of other transit agency developed applications or the public release of open real-time data), a behavioral experiment was selected as the methodology for this study.

4.1. Experimental design

The specific method utilized was a before–after control group research design (Campbell and Stanley, 1963). The treatment in this experiment was access to RTI over a study period of approximately three months. The method of measuring rider behavior, feeling, and satisfaction changes was two web-based surveys: one administered before RTI and another after the completion of the study period. The reason for using a web-based survey (as opposed to paper or telephone surveys) was because RTI was only accessible via web-enabled devices; therefore, in order to assure that each study participant could use the treatment, the survey was conducted online.

4.2. Treatment

The treatment in this experiment was exposure to RTI. RTI was provided to riders through a transit traveler information system known as OneBusAway. OneBusAway was originally developed in 2008 at the University of Washington to provide real-time bus arrival information for riders in greater Seattle. Over its five years in existence in the Puget Sound region, OneBusAway has increased in utilization to become a proven platform, currently hosting more than 100,000 unique users per week. More importantly, OneBusAway was developed as an open-source system, which allows others to adapt the code for their own transit systems.

Five OneBusAway interfaces were developed for Tampa and made available to the experimental group: a website, two mobile websites for internet-enabled mobile devices (one text-only and the other optimized for smartphones), a native Android application, and a native iPhone application (see screenshots in Fig. 1). For the three websites, access was limited by only providing the web address to the experimental group. For the two smartphone applications, participants in the experimental group were instructed to download the OneBusAway application from Seattle and change the settings for the OneBusAway server application programming interface (API) from Seattle to Tampa. An example of the setting change is shown in the rightmost screenshot in Fig. 1.

[3] In 2012, HART installed a small LED sign system for estimated arrival information that was intermittently functional. To the best of the authors' knowledge, the LED signs were only operational at one stop (Marion Transit Center) during the experiment.

4.3. Recruitment

The ‘‘before’’ survey was conducted in February 2013 during a two week period. HART bus riders were recruited to participate in the study through a link posted on the homepage of the transit agency website, as well as through the transit agency email list and other local email lists. The recruitment materials stated that participants would be enrolled in the ‘‘OneBusAway Tampa pilot program and research study’’ and would be ‘‘testers’’ of OneBusAway, meaning that they had early access to OneBusAway until May 2013. Participants were not directly informed that this study would be evaluating the impacts of RTI. Interested riders could enter a publically accessible link to the web-based survey software, and on the pre-wave survey, all respondents were asked to provide an email address in order to contact them for follow-up and the ‘‘after’’ survey. An incentive of a free one day bus pass was provided to all pre-wave survey participants to help increase the response rate.

After the pre-wave survey was completed, respondents were randomly assigned to the control group and the experimental group. Then, the experimental group was emailed instructions explaining how to use RTI, and they were instructed not to share RTI with anyone during the study period. After approximately three months, the ‘‘after’’ survey was administered during the last two weeks of May 2013. A second incentive of a free one day bus pass was provided to all participants (both the control and experimental groups) to help increase the response rate of the post-wave survey.

4.4. Survey content

To measure behavior, feeling, and satisfaction changes, the survey instruments contained identical questions in the pre-wave and the post-wave surveys for both the control and experimental groups. Transit travel behavioral questions included the number of trips on HART buses in the last week and the number of transfers between HART bus routes in the last week. To assess wait times, respondents were asked about their ‘‘usual’’ wait time on the route that they ride most frequently. Participants were also asked questions about eight feelings while waiting for the bus, and they rated them on a five point scale. Specifically, they were asked about three feelings discussed in the prior literature (relaxed, anxious and safety at night and during the daytime), and a minor alteration was made to a fourth (aggravation was changed to frustration). Additionally, three feelings were included that could change due to the availability of RTI: bored, productive and embarrassed. It was hypothesized that riders may feel bored or unproductive while waiting for the bus, but those who checked RTI could experience decreases in these feelings; similarly, passengers might be embarrassed to stand on street corners waiting for the bus for extended periods of time and, if this were the case, those who use RTI may experience a decrease in this feeling. To assess satisfaction, all participants were asked to rate their level of satisfaction with overall transit service on a five point scale. Because the transit customer research literature typically breaks down satisfaction ratings into specific elements of service provision (e.g., Eboli and Mazzulla, 2007), five indicators of certain elements of transit service were also included. One of these indicators was specifically targeted at passenger wait times: ‘‘how long you have to wait for the bus.’’ Two indicators aimed to capture reliability of the transit service: ‘‘how often the bus arrives at the stop on time’’ and ‘‘how often you arrive at your destination on time.’’ The last two indicators represented frequency of service and transferring, respectively: ‘‘how frequently the bus comes’’ and ‘‘how often you have to transfer buses to get to your final destination.’’

In addition to the questions that were asked of both the control and experimental groups in the before and after surveys, a series of questions was added to the post-wave survey of the experimental group to assess if RTI users perceived a change in their travel behavior, satisfaction, and feelings. This was specifically done because two prior studies in the Seattle area asked RTI users to self-report changes (Ferris et al., 2010; Gooze et al., 2013), and asking these perception questions allows for comparison with the previously mentioned questions asked on both the pre-wave and post-wave surveys.

It should also be noted that standard socioeconomic characteristics were asked to understand the representativeness of the survey participants of HART bus riders. Respondents were also asked about their use of information and communication technologies (e.g. smartphones and computers).

The survey instruments were pre-tested on a group of a dozen students and staff at Georgia Tech and reviewed by customer research employees at HART before dissemination.

4.5. Sample size

The sample sizes for the before and after surveys are shown in Table 1. A total of 534 people initially entered the link to the survey software, and of these, 452 responses included a unique email address, which was necessary to contact participants for the post-wave survey. These 452 usable responses were then divided into the control and experimental groups using a random number generator. 59% of the usable experimental group and 60% of the usable control group sufficiently completed the post-wave survey, which resulted in a final sample size of 268 participants.

A key challenge to conducting this controlled behavioral experiment was limiting access of OneBusAway to only the experimental group. As can be seen in Table 1, some contamination of the control group occurred because 24 participants figured out how to access OneBusAway, mostly by searching the internet sufficiently to find the website (14/24) or receiving instructions from family/friends (8/24). Similarly, there were some members of the experimental group (27 total) that never used OneBusAway during the study period. The most common reason for not using OneBusAway was not having a smartphone (12/27), and other common reasons included not riding the bus, not needing it, and not having time to read instruc-

Table 1
Sample size.

	Before survey[a]		After survey[b]			
	Began survey	Usable sample size	Sample size of OneBusAway users	Sample size of non-users	Sample size total	Percent of before survey usable sample (%)
Experimental group	534	229	110	27	137	59
Control group		223	24	107	131	60
Total	534	452	134	134	268	59

[a] Only participants who provided a unique email address and were 18+ years of age were deemed usable.
[b] Only participants responding to at least 50% of the questions were included in the final sample.

Table 2
Socioeconomic characteristics of the control and experimental groups.

Category	Variable	Control group		Experimental group		Total	
		#	%[a]	#	%[a]	#	%[a]
Total	All respondents	107	100	110	100	217	100
Age	Age 18–24	10	9	11	10	21	10
	Age 25–34	24	22	23	21	47	22
	Age 35–44	24	22	29	26	53	24
	Age 45–54	27	25	30	27	57	26
	Age 55–64	16	15	15	14	31	14
	Age 65–74	5	5	1	1	6	3
	Age 75 and over	1	1	0	0	1	0
	No answer	0	0	1	1	1	0
		Wilcoxon sum rank test: $W = 6124.5$, p-value = 0.514					
Annual household income	Under $5000	9	8	10	9	19	9
	$5000–$9999	9	8	11	10	20	9
	$10,000–$19,999	23	21	13	12	36	17
	$20,000–$29,999	14	13	28	25	42	19
	$30,000–$39,999	13	12	14	13	27	12
	$40,000–$49,999	8	7	10	9	18	8
	$50,000 or more	27	25	18	16	45	21
	No answer	4	4	6	5	10	5
		Wilcoxon sum rank test: $W = 5599$, p-value = 0.568					
Household car ownership	No cars	53	50	59	54	112	52
	1 car	30	28	27	25	57	26
	2 cars	19	18	18	16	37	17
	3 or more cars	4	4	6	5	10	5
	No answer	1	1	0	0	1	0
		Wilcoxon sum rank test: $W = 5971.5$, p-value = 0.737					
License	Has a valid license	71	66	83	75	154	71
	No license	35	33	27	25	62	29
	No answer	1	1	0	0	1	0
		Kruskal–Wallis test: Chi-squared = 1.885, p-value = 0.170					
Gender	Male	53	50	45	41	98	45
	Female	54	50	64	58	118	54
	No answer	0	0	1	1	1	0
		Kruskal–Wallis test: Chi-squared = 1.475, p-value = 0.225					
Employment status	Employed full time	57	53	63	57	120	55
	Employed part time	17	16	14	13	31	14
	Not employed	7	7	11	10	18	8
	Retired	6	6	4	4	10	5
	Student	13	12	13	12	26	12
	Other (disabled, etc.)	4	4	2	2	6	3
	No answer	3	3	3	3	6	3
		Kruskal–Wallis test: Chi-squared = 0.377, p-value = 0.542					
Ethnicity	White	75	70	54	49	129	59
	Black/African American	19	18	26	24	45	21
	Hispanic or Latino	5	5	19	17	24	11
	Asian	0	0	1	1	1	0
	Other[b]	8	7	9	8	17	8
	No answer	0	0	1	1	1	0
		Kruskal–Wallis test: Chi-squared = 9.546, p-value = 0.002					

[a] Figures rounded to the nearest percent.
[b] Multiple ethnicity selections included in other.

tions. Due to their deviation from random assignment, the contaminated control group and experimental non-user group were not given the complete post-wave survey. Therefore, the results presented in the following sections include only the clean control group (107) and the clean experimental group (110).

Last, the socioeconomic characteristics of the clean control and experimental groups were compared to assure that the usable sample remained equivalent after attrition. As shown in Table 2, the groups were not statistically different in age, annual household income, gender, employment status, household car ownership, and having a driver's license, but they differed in ethnicity ($p = 0.002$).

5. Results

The results of this behavioral experiment are divided into four sections. The first three sections evaluate changes in behavior, feeling, and satisfaction using identical questions posed on both the pre-wave and post-wave surveys. The fourth section assesses the questions that were only asked of the experimental group in the post-wave survey.

5.1. Behavior changes

Three measures of behavior change were evaluated: trip frequency, transfer frequency and wait time. To measure differences in transit trip frequency associated with RTI use, all respondents were asked how many trips on HART buses they made in the last week. Similarly, to measure changes in transit transfer frequency, respondents were asked how many of their trips in the last week included a transfer from one HART bus route to another bus route. Both questions (number of trips and number of transfers in the last week) were posed as multiple choice questions in which the respondent could select a whole number ranging from no trips (zero) to ten trips with an additional choice of eleven or more trips/transfers. Riders were also asked which HART bus route they traveled on most frequently and what their "usual" wait time was on that route. The usual wait time question was phrased with whole number multiple choice responses ranging from one minute to fifteen minutes with additional choices "less than one minute" and "more than fifteen minutes."

For each of the three measures of behavior change, the gain score, or difference (D), from the before survey (Y_1) to the after survey (Y_2) was calculated for each individual as follows: $D = Y_2 - Y_1$. The mean (M) and standard deviation (SD) of the before survey, the after survey, and the gain scores for the number of trips per week, number of transfers per week, and "usual" wait times are shown in Table 3 for the control group and the experimental group. All three variables had, on average, a decrease from the before to the after survey for both the control and experimental groups. The difference in the mean gain scores between the control group and the experimental group was not significant for bus trips per week ($t = 0.66$, $p = 0.512$) nor was it significant for transfers per week ($t = 0.37$, $p = 0.715$). On the other hand, the mean gain score of the usual wait time for the experimental group (−1.79 min) was significantly different ($t = 2.66$, $p = 0.009 < 0.01$) from the control group (−0.21 min). This implies that the experimental group experienced a decrease in "usual" wait times approximately 1.5 min greater than they would have without RTI. The decrease of −1.79 min in usual wait time experienced by the experimental group represents a 16% decrease from their average wait time (11.36 min) from the pre-wave survey.

In theory, the research design should control for other changes affecting travel behavior, since such changes could be expected to occur similarly for members of both the experimental and control groups. This assumption was directly investigated to understand potential threats to internal validity. Differences in the frequency of transit trips and transfers may be caused by changes in automobile ownership, availability of a driver's license, household and work location, among other things. Therefore, all participants were asked if they bought/sold a car, got/lost a driver's license, moved household locations, or changed work/school locations during the study period. A total of 50 participants (24 in the control group; 26 in the experimental group) had one or more of these socioeconomic changes during the study period. Then, participants who had these changes (plus 3 who did not answer the questions) were removed from the calculations. The difference of mean gain scores between the remaining participants in the control group and experimental group was again not significant for bus trips per

Table 3
Mean (M), standard deviation (SD), and difference of mean gain scores for trips, transfers, and wait time.

	Control group				Experimental group				Difference in gain scores	
	Sample *n*	Before *M* (SD)	After *M* (SD)	Difference *M* (SD)	Sample *n*	Before M (SD)	After M (SD)	Difference M (SD)	Two-tailed *t*-test *t*-Stat	*p*-value
Trips/Week	107	7.03 (3.79)	6.63 (4.09)	−0.40 (2.63)	110	7.09 (3.94)	6.40 (3.71)	−0.69 (3.76)	0.66	0.512
Transfers/Week	88	4.53 (4.15)	4.35 (3.90)	−0.18 (3.77)	94	4.26 (3.93)	3.87 (3.33)	−0.38 (3.63)	0.37	0.715
Usual wait time (minutes)	102	10.71 (3.88)	10.50 (4.25)	−0.21 (4.42)	107	11.36 (4.06)	9.56 (4.68)	−1.79 (4.21)	2.66	0.009***

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

week ($t = -0.37$, $p = 0.712$) or transfers per week ($t = 0.36$, $p = 0.721$). These results support the previous analysis shown in Table 3.

Similarly, prior transit research has shown that expected wait times are a function of the frequency and reliability of the transit service (Furth et al., 2006). Therefore, participants were asked what bus route they ride most often. A total of 38 participants (20 in the experimental group; 18 in the control group) reported changing their usual route during the study period. When the participants who changed bus routes were removed from the usual wait time calculations (plus 9 who did not answer the question), the difference between the mean gain scores of the usual wait time for the experimental group (−1.97 min) and the control group (−0.01 min) was nearly 2 min and was significantly different ($t = 3.02$, $p = 0.003 < 0.01$).

Additionally, regression models of the gain scores of the trips per week, transfers per week, and usual wait time were created to understand the extent to which the experimental design "controlled" for other factors. The results do not differ substantially from the simple *t*-statistics. The regression models can be found in Brakewood (2014).

A few caveats about this analysis should be made. First, the one positive finding (usual wait time) relied completely on self-report data, but prior research has shown that self-reported wait times may not align with actual wait times due to the perception of time (Watkins et al., 2011). Accordingly, the finding that the usual wait times of RTI users were less than the usual wait times of non-users could be interpreted as either a change in actual wait time or a change in the perception of wait time associated with RTI. If a RTI user checks the real-time vehicle location/arrival time when s/he is still at his/her origin, s/he can "time" his/her arrival at the stop to minimize his/her wait time, which would be an reduction in "actual" waiting time. However, if a RTI user is only checking for information once s/her arrives at the bus stop, then this would be a reduction in his/her perceived waiting time. To explore this in the survey, each RTI user was asked how often s/he check RTI before leaving for the bus stop (when still at home/work/school); 35% of RTI users "always" check and another 29% "frequently" check RTI before leaving to go to the bus stop. Similarly, 27% of RTI users "always" check and another 34% "frequently" check RTI once they have arrived at the bus stop. In light of this, the proportion of the reported change attributed to perceived or actual changes in wait time is not known from this study and should be determined with independent observations of passenger wait times.

Also, it should be noted that the use of the word "usual" in the wait time question was specifically included to encourage respondents to report their perceived wait times; however, the travel survey literature has found that the use of the word "usual" may cause inaccurate or unreliable responses (Stopher, 2012, p. 182).

Finally, the difference of means test assumes that the variables (difference in trips/week, transfers/week, and usual wait time) are continuous. To lessen the burden of survey participation on the respondents, these questions were posed with multiple choice answers that were capped on the high end (trips/week ranged from 0 to 11 or more trips; transfers/week from 0 to 11 or more transfers; usual wait time from 0 to more than 15 min). Therefore, this analysis decreases the impact of extreme values (trips/transfers more than 12 per week and usual wait times above 15 min).

5.2. Feelings experienced while waiting

Identical questions were posed to participants in the pre-wave and post-wave surveys to evaluate potential changes in feelings while waiting for the bus. These questions quantify the frequency that a respondent experienced specific feelings while waiting for the bus on the following five-point scale: never, rarely, sometimes, frequently, and always. Eight different indicators were used: bored, productive, anxious, relaxed, frustrated, embarrassed, safe at night and safe during the day. Similar to the previous section, the gain score, or difference (D), from the before survey (Y_1) to the after survey (Y_2) was calculated for each individual as follows: $D = Y_2 - Y_1$. Since each feeling was rated on a five-point scale, the differences ranged from −4 to 4. The gain scores were then used in a Wilcoxon rank sum test to evaluate any differences between the control group and the experimental group, and the results are shown in the rightmost column of Table 4. Additionally, the percent of

Table 4
Percent frequently or always and Wilcoxon rank sum test for change in feelings while waiting for the bus.

	Control group			Experimental group			Difference in gain scores	
	Sample *n*	Before % Frequently + always	After % Frequently + always	Sample *n*	Before % Frequently + always	After % Frequently + always	Wilcoxon test *W*	*p*-value
Bored	103	49%	45%	107	31%	30%	4864	0.112
Productive	102	11%	10%	106	10%	17%	6201	0.051*
Anxious	99	18%	19%	106	26%	25%	4547.5	0.082*
Relaxed	101	34%	34%	105	27%	25%	5518	0.592
Frustrated	103	24%	26%	104	25%	18%	4240.5	0.006***
Embarrassed	100	3%	7%	103	3%	7%	4808.5	0.346
Safe at night	97	36%	35%	105	24%	24%	5104.5	0.976
Safe during the day	103	73%	67%	104	72%	73%	6185	0.035**

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

respondents experiencing these feeling more than average (either "frequently" or "always") for the control group and the experimental group on the before survey and the after survey is shown in Table 4.

Table 4 shows that four feelings (productive, anxious, frustrated, and safe during the day) had significant differences from the pre-wave to the post-wave survey between the control group and the experimental group. Feeling "productive" while waiting for the bus increased from 10% of the experimental group in the pre-wave survey to 17% in the post-wave survey (combined total of "frequently" and "always"), and this was significantly different from the control group ($p = 0.051$). This may be because RTI users have better knowledge of how long they will be waiting, which helps them to choose an activity (e.g. reading, sending emails) that is a good fit for the amount of time they will be waiting, as opposed to simply passing the time idly. Second, the experimental group had a small decrease in the frequency with which they feel "anxious" while waiting for the bus, which was somewhat different from the control group ($p = 0.082$). Providing RTI to passengers may help them to feel as if they have more control over their trip (Watkins et al., 2011) and reduce their level of anxiety when waiting for the bus. Notably, the experimental group decreased their frequency of feeling "frustrated" when waiting for the bus (from 25% to 18%; combined total of "frequently" and "always"), and this was significantly different from the control group ($p = 0.006$). One possible explanation of this is that RTI decreases the perception of unreliability of transit service and enables riders to adjust their behavior when service is delayed. This may be particularly important for riders who are dependent on the transit system and do not have other alternatives readily available.

Additionally, feelings of safety during the daytime significantly increased for the experimental group compared to the control group ($p = 0.035$). This may be because passengers spend less time waiting on street corners where they feel exposed to passing traffic or personal crime. Furthermore, at less popular stops, passengers may find themselves waiting alone, and feel unsafe compared to when they are on a transit vehicle with other passengers. It is interesting to note that changes in feelings of safety at night did not have a significant difference between the two groups. There are two likely explanations for why this may not have occurred. First, the pre-wave survey was conducted in February, when daylight hours are short, whereas the post-wave survey was conducted in May, when days are much longer and the evening peak commute occurs in daylight. Because of the seasonal differences, regular commuters may not have experienced many (or any) trips during darkness after beginning to use RTI, and therefore may not have had the opportunity to perceive a change in feelings of safety at night from the pre-wave survey period. An alternative explanation is that most RTI users are carrying a smartphone, which is a common item targeted by thieves (even resulting in the term "Apple-picking" as a common crime in most transit systems). Therefore, RTI users may feel more susceptible to petty theft if they use their smartphones to check RTI, particularly at night.

The three remaining feelings (bored, relaxed and embarrassed) did not have a significant difference between the mean gain scores of the control and experimental groups. Regarding levels of relaxation, it was originally hypothesized that those who decreased their levels of frustration or anxiety would have similar increases in levels of relaxation while waiting, but this did not occur.

5.3. Satisfaction

Six indicators asked about specific aspects and overall service of HART buses, and each indicator was rated on the following five-point scale: very dissatisfied, somewhat dissatisfied, neutral, somewhat satisfied, and very satisfied. Again, the gain score, or difference (D), from the before survey (Y_1) to the after survey (Y_2) was calculated for each individual as follows: $D = Y_2 - Y_1$. Since the indicators were rated on a five-point scale, the differences ranged from −4 to 4. The gain scores were then used in a Wilcoxon rank sum test to evaluate any differences between the control group and the experimental group, and the results are shown in the rightmost column of Table 5. Additionally, the percent satisfied (either "somewhat" or "very") for the control group and the experimental group is shown for the before survey and the after survey in Table 5.

Two of the variables (how long you have to wait for the bus and 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. This may be because RTI users are able to time their arrival at the bus stop to decrease how long they have to wait for the bus, which may also lead to increased levels of satisfaction with how long they have to wait for the bus. Additionally, RTI may also change a passenger's perception of a vehicle arriving on time at the stop. Because passenger with RTI know when the vehicle is running late, they may not perceive the bus as being "late" and may be more satisfied with how often the bus arrives at the stop according to the posted schedule. These two variables directly support the "usual" wait time analysis discussed in a previous section.

Both the indicators for frequency of service and arriving at a final destination on time did not have significant changes between the experimental group and the control group. Since the frequency of HART bus service did not change over the study period, it is reasonable that there were not changes in satisfaction with frequency. Similarly, RTI should not, in theory, impact the final time that passengers arrive at their destination, unless they change routes/paths, which is unlikely in a sparse transit network like Tampa's. It is therefore logical that this indicator did not change. Similarly, there was not previously a difference in the number of transfers associated with using RTI, and therefore, it also is reasonable that satisfaction with the number of transfers did not change.

Finally, it was surprising that the analysis of overall HART bus service did not show a significant change between the control and experimental groups. It was envisioned that since passengers are more satisfied with waiting times – which are notoriously one of the most onerous parts of riding transit (e.g., Hess et al., 2004) – their overall ratings of service might increase. Similarly, since HART is piloting a new technology and catering to the changing demographics of transit riders, this could reinforce their overall satisfaction with transit. The results of the Wilcoxon rank sum test did not support this hypoth-

Table 5
Percent satisfied and Wilcoxon rank sum test for changes in satisfaction.

	Control group			Experimental group			Difference in gain scores	
	Sample	Before	After	Sample	Before	After	Wilcoxon rank sum test	
	n	% Satisfied	% Satisfied	*n*	% Satisfied	% Satisfied	*W*	*p*-value
How frequently the bus comes	103	37%	41%	107	40%	44%	5812	0.459
How long you have to wait for the bus	103	39%	34%	106	36%	46%	6425	0.020**
How often the bus arrives at the stop on time	103	54%	45%	107	45%	59%	7094	0.0001***
How often you arrive at your destination on time	101	57%	53%	106	55%	63%	5835	0.236
How often you transfer to get to your final destination	100	44%	42%	106	38%	36%	4916	0.342
Overall HART bus service	102	63%	59%	106	57%	58%	5717	0.410

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

esis. One possible reason why this may be the case is that a five-point scale is a very simple approximation for levels of satisfaction, and if the changes were slight, then the unit of measurement may not have been sufficient to capture it. Similarly, calculating the difference in ordinal scales may not accurately represent changes in satisfaction because these scales are not absolute measurements.

5.4. Perceived changes

In addition to the measures of behavior, feeling, and satisfaction discussed above, the post-wave survey included questions to the experimental group to directly measure perceived changes due to using RTI, including three questions about behavior (frequency of HART bus trips, frequency of making transfers, and wait time), three questions about feelings while waiting (relaxed, safety at night, and safety during the day), and one question about overall satisfaction with transit service. These questions were specifically included to help assess if participants perceived changes and to test if these perceived changes aligned with the actual (self-reported) differences from the before survey to the after survey. Additionally, these questions were similar to two prior studies of RTI users in Seattle, which also relies on OneBusAway for transit traveler information (Ferris et al., 2010; Gooze et al., 2013), so responses between the two studies could be compared. It is important to note that these questions were placed after all of the previously discussed questions (but prior to questions on changes in demographics) to avoid influencing the responses to the other post-wave survey questions.

Fig. 2 shows that 39% of the experimental group reported that they make HART bus trips more often (combined total of "somewhat" or "much" more often), while the majority (60%) stated that they ride HART buses "about the same" amount. To compare this question with the results of previous analysis of gain scores from the pre-wave to post-wave surveys, each gain score of self-reported trips per week was categorized as an increase, decrease, or no change, and the correlation coefficient with perceived changes (more often, the same, less often) was calculated. The results indicate that there was limited correlation between the perceived change in trips and actual difference in self-reported trips per week over the study period (Pearson's $R = 0.129$). Additional analysis comparing the perceived changes with the self-reported questions can be found in Brakewood (2014).

Fig. 2 also shows that 16% of RTI users believe that they transfer more often (combined total of "somewhat" or "much" more often), whereas over three quarters (79%) of stated that they transfer "about the same" number of times. Again, there is

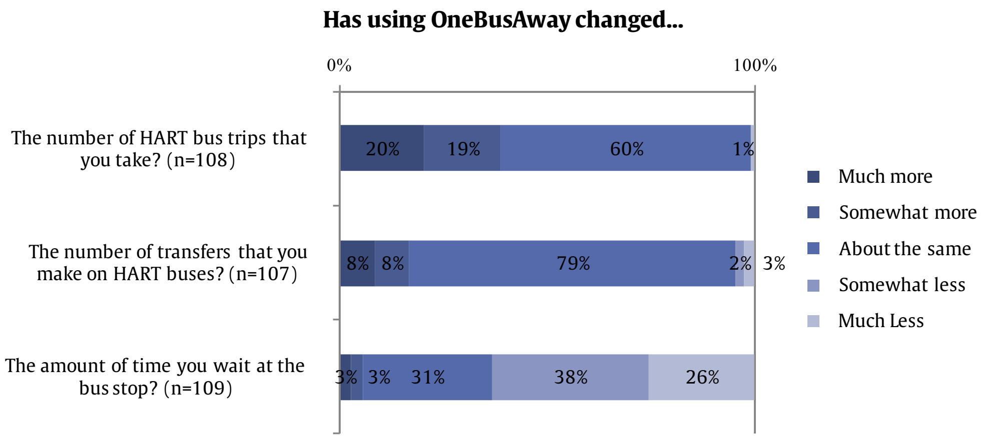

Fig. 2. Perceived behavior changes of RTI users.

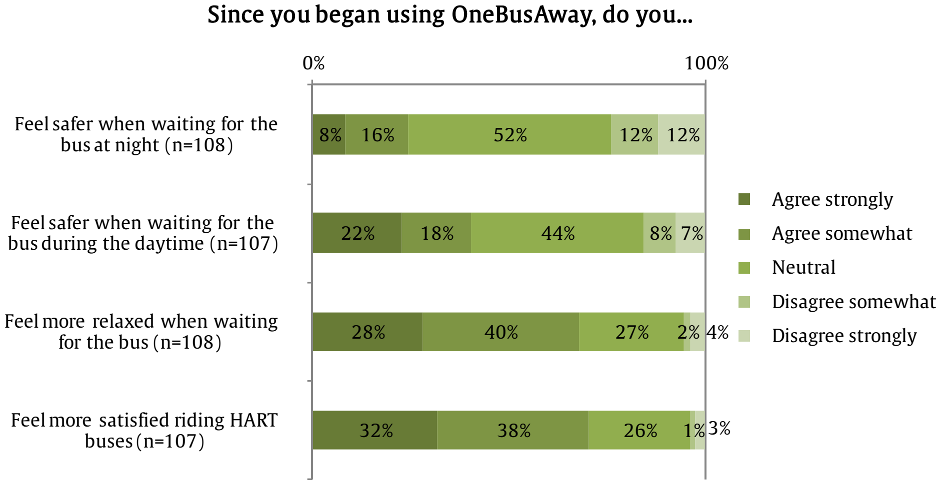

Fig. 3. Perceived feeling and satisfaction changes of RTI users.

limited correlation between the stated question and the actual change (increased, decreased or same number) in transfers per week from the before to the after survey (Pearson's $R = 0.138$).

Importantly, 64% of RTI users reported that they spend less time (combined total of "somewhat" and "much" less) waiting at the bus stop, which is in alignment with the previous analysis of "usual" wait times. This result is notably smaller than for a similar question posed of Seattle RTI users, which found that 91% reported spending less time waiting (Ferris et al., 2010). Also, when this question was compared to the change in self-reported usual wait times from the before to the after survey, there was very little correlation (Pearson's $R = 0.009$). This low level of correlation was likely due to two groups: one group who reported actual decreases in "usual" wait times but stated that they wait "about the same" (14% of the experimental group) and another group who reported identical "usual" wait times from the before to the after survey but stated that they wait less (21%). This may be caused by differences in the perception of wait time.

Members of the experimental group were also asked to agree or disagree (on a five-point scale from strongly disagree to strongly agree) with statements about increases in feelings of safety at night, safety during the day, and relaxation while waiting for the bus. Fig. 3 shows that 52% were "neutral" about feeling safer at night and the remainder was split almost equally between agreeing (strongly or somewhat) and disagreeing (strongly or somewhat). When asked about safety during the daytime, 40% agreed (strongly or somewhat) that they feel safer since they began using OneBusAway. However, while these results appear to support the previous analysis of changes in perceptions of personal security from the before to the after survey, the correlation between those who had changes in ratings of safety (net increase, decrease or same) with those who perceived that they did was very limited (Pearson's $R = 0.011$).

As can be seen in Fig. 3, 68% of the experimental group agreed (strongly or somewhat) that they feel "more relaxed" since they started using RTI. While the previous analysis of feelings did not reveal a statistically significant difference between the experimental group and the control group in relaxation, this could in part be captured by reductions in levels of frustration and anxiousness.

Last, members of the experimental group were asked (on a five-point scale from strongly disagree to strongly agree) about increases in their satisfaction with overall HART bus service. As can be seen in Fig. 3, 70% of the experimental group agreed (somewhat or strongly) with the statement that they are more satisfied with overall transit service since they began using RTI. This is notably less than the 2009 study in Seattle, which found that 92% of OneBusAway users were either somewhat or much more satisfied with overall transit service (Ferris et al., 2010). Comparing this question to the changes in ratings of overall satisfaction from the before to the after survey shows no correlation (Pearson's $R = -0.010$), but there is some limited correlation with the changes in satisfaction with "how long you have to wait for the bus" (Pearson's $R = 0.134$) and "how often the bus arrives at your stop in-time" (Pearson's $R = 0.100$).

The analysis discussed in this section presents mixed results, since many of the questions about user perceptions did not align with the self-reported changes from the before to the after survey. One possible reason for this discrepancy is that the questions posed on both the before and after surveys suffered from an insufficient scale of measurement. For example, the use of trips per week to measure transit travel frequency could be insufficient if a person only makes one or two additional trips per month attributable to RTI. A more reliable way to measure this would be to record trips over an extended period of time (e.g. respondents report their number of trips per week for all the weeks over the study period). It is also important to note that this question was a multiple choice question with answers that were capped on the high end (trips/week ranged from 0 to 11 or more trips). Many respondents (12% of the experimental group) selected the maximum category in the pre-wave survey (11 or more trips/week), and then stated that they increased their trips in the post-wave survey, but the surveys did not capture this change.

A second plausible explanation is bias on behalf of the survey respondents. The survey methods literature has shown that respondents often have an affirmation bias, also known as the demand characteristic, and will give the response that he or she thinks the researchers want to hear (Stopher, 2012, p. 149). When asked directly about changes (as opposed to those changes inferred from before and after self-reported measures), participants may have selected answers that they felt would make RTI or their participation in the study look more favorable.

6. Limitations

There are four notable caveats that may limit the results of this study: the length of time of the study, participant difficulties using the smartphone applications, representativeness of the sample, and applicability to a larger population beyond Tampa.

One important limitation of the study was the length of time the treatment (RTI) was applied to the experimental subjects before the post-wave survey was conducted. In June 2013, HART opened its first Bus Rapid Transit (BRT) route in central Tampa. Because this was a significant change to the transit network, the post-wave survey was conducted in May 2013, which was two weeks before the opening of the BRT route. This resulted in a total study period of slightly less than three months, which may not have been sufficiently long to capture changes in travel behavior, feelings, or satisfaction. In theory, the before–after control group design should mitigate such external events (e.g. opening of a new route/line) because the experimental group can be compared to the control group. However, the authors made the decision to conclude the study prior to the BRT launch to avoid any chance of potentially muddying the effect of the treatment by this significant change in transit service.

A second limitation pertains to the manner in which the treatment (access to RTI) was limited to only the experimental group. As was previously noted, in order to use the native smartphone applications for Androids and iPhones, participants were instructed to download the publically available Seattle OneBusAway smartphone applications and then change a setting to re-direct the application programming interface from Seattle to Tampa. In the post-wave survey, the experimental group was asked how difficult this setting change process was, and 64% stated that it was easy. However, 5% of the sample agreed with the statement that it was "so difficult that I did not use the Android/iPhone apps." Therefore, there could be a non-response bias in which those that found this process overly complicated dropped out of the experimental group. If this was the case, these participants were likely less tech-savvy or possibly less patient than remaining participants, which could, for example, bias feelings while waiting for the bus.

Since the use of a before–after control group research design helps to protect against many threats to interval validity, other noteworthy concerns include threats to external validity (Campbell and Stanley, 1963). First, the representative of the sample to overall bus ridership in Tampa could be a concern since non-probability sampling was used to recruit participants. To investigate this, socioeconomic questions were asked on the pre-wave survey, and whenever possible, questions were worded in an identical manner to the last system-wide HART bus ridership survey, which was conducted in 2009 (Tindale-Oliver et al., 2010). The participants in this study differed from the 2009 system-wide survey on three noteworthy socioeconomic characteristics: income, automobile ownership and ethnicity. This study had only 18% of respondents with annual household incomes less than $10,000, but the 2009 ridership survey found that 45% of riders had annual household incomes less than $10,000. Additionally, this study had 52% of respondents without cars in their household, whereas the 2009 survey had 66% of respondents without cars in their household. Last, this study had a total of 59% white participants and 21% African American respondents, whereas the 2009 system-wide survey had only 29% white respondents and 49% African Americans; it should be noted that the survey question in this study allowed respondents to select more than one ethnicity whereas the 2009 system-wide survey did not so the two ethnicity questions are not perfectly equivalent. Additionally, due to institutional review board regulations, participants under age eighteen were not included in this study, which biased the sample away from younger riders. Therefore, it appears that certain groups were oversampled, including those with slightly higher incomes, somewhat increased levels of automobile ownership, Caucasians, and older age groups. Despite these differences, this sample was primarily composed of transit-dependent, low-income participants.

A related concern is that those who were oversampled may be more likely to have higher levels of technology adoption (i.e. web-enabled and mobile devices). Unfortunately, prior survey data on transit rider use of information and communication technologies in Tampa were not available for comparison. Despite this, in the pre-wave survey, respondents were asked which information and communication technologies they use. A total of 78% of participants stated that they used smartphones, and the most commonly used smartphones were Androids (52% of all participants). Since the before and after surveys were conducted through web-based survey software, all participants had, at a minimum, a means to access the internet and could therefore try OneBusAway through the web or mobile web interfaces.

Finally, with respect to the limited gains in trips per week associated with RTI, there are two important notes. First, many bus riders in Tampa are dependent on transit and have limited ability to increase their trips, as they are already using transit for all or a majority of their trips. Also, the participants in this study were recruited from among people already in the sphere of influence of the transit provider; thus, there was no opportunity to analyze the potential of RTI for attracting entirely new riders. For these reasons, a substantial change in existing ridership associated with RTI was not anticipated in this study of Tampa, which may differ from previous research in transit-dense cities such as Seattle or Chicago. For these reasons, it is important to continue to use experimental studies to gauge the impacts of RTI in a variety of locations.

7. Conclusions

This study conducts a comprehensive analysis of the benefits of RTI provided to bus riders in Tampa, Florida. Based on the results of a before–after control group research design, the primary benefits associated with providing RTI to passengers pertain to waiting at the bus stop. A difference of means analysis of gain scores of ''usual'' wait times revealed a significantly larger decrease (nearly 2 min) for the experimental group than the control group. Moreover, analysis of the gain scores of feelings while waiting for the bus revealed significant decreases in levels of anxiety and frustration and increases in levels of productivity and safety during the daytime associated with the use of RTI. This is further supported by significant increases in satisfaction with ''how long you have to wait for the bus'' and ''how often the bus arrives at your stop on time'' for the experimental group compared to the control group. Taken together, these three analyses provide strong evidence that RTI significantly improves the passenger experience of waiting for the bus, which aligns with prior studies of RTI in other cities. Two respondents summed up these benefits in an open-ended question at the end of the post-wave survey by writing the following:

> ''Brilliant tool! ... Often when catching busses along their route, I felt like it was the 'wild, wild, west' with times, busses not showing, etc. OneBusAway helped make everything much more sensible and relaxing!!''

> ''Please put the OneBusAway program into affect as soon as possible. There is nothing more frustrating than waiting on a bus that is running real late or not going to show at all. And the whole time you're stuck out in the street just waiting and waiting.''

While the experience of waiting for the bus appears to have been significantly improved by using RTI, evidence supporting changes in the number of transit trips associated with RTI was limited for this sample of existing transit riders. The difference of mean gain scores in weekly trips showed that the experimental group did not have a significant change compared to the control group. A largely transit-dependent population of riders in Tampa could be contributing to this limited increase. Despite this, a sizable percentage (39%) of the experimental group stated that they ride the bus more frequently since they began using RTI. This is likely due to either an affirmation bias on behalf of the respondents and/or an insufficient scale of measurement used by the researchers.

In addition to these findings, a key contribution of this research is demonstrating that controlled behavioral experiments can be used to evaluate web and mobile applications used by transit travelers. This experiment was particularly distinctive in its ability to (largely) limit the use of the smartphone applications to the experimental group. Hopefully, the successful implementation of this behavioral experiment will lead to the increased use of before–after control group research designs to evaluate new information and communications technologies used by travelers in the future.

Acknowledgments

This work was funded by the National Center for Transit Research (NCTR), the National Center for Transportation Systems Productivity and Management (NCTSPM), and an US DOT Eisenhower Graduate Fellowship. The authors are very grateful to Hillsborough Area Regional Transit for their support of the OneBusAway project, particularly Shannon Haney. They would also like to thank the bus riders in Tampa who agreed to participate in this study. Finally, the authors owe a tremendous amount of gratitude to the many people who have contributed to OneBusAway open source project over the years, particularly Brian Ferris who created the original instance of OneBusAway in Washington.

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