Impact Assessment of Integrated Dynamic Transit Operations

Final Report

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16. Abstract

This document details the impact assessment conducted by the Volpe Center for the Integrated Dynamic Transit Operations (IDTO) prototype demonstrations in Columbus, Ohio and Central Florida. The prototype is one result of the U.S. Department of Transportation's Dynamic Mobility Applications (DMA) program which seeks to enhance and transform future surface transportation systems management. The set of IDTO impacts were evaluated based upon a series of hypothesis tests governing travel behavior and strategies enacted by participating organizations. These tests related to usage of the IDTO technological bundle, changes in travel demand, changes in travel time, changes in operational costs, and changes in inter-organizational cooperation. Each of the hypotheses was tested based upon information provided by the prototype developer and participating organizations as well as analysis conducted by the IA team.

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Executive Summary

Purpose of the Impact Assesment

The United States Department of Transportation (U.S. DOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) has been working to transform the future of surface transportation systems management through the use of connected vehicles and other innovative technologies and systems. To this end, the ITS JPO has developed the Dynamic Mobility Applications (DMA) Program which features technologies, including the Integrated Dynamic Transit Operations (IDTO) bundle of three applications. This IDTO Impacts Assessment (IA) and associated prototyping activity encompass an effort to assess data and communications needs, collect relevant data, and inform the DMA Program on potential impacts of the IDTO bundle.).

The U.S. DOT wished to advance the IDTO bundle from concept formulation to prototype demonstration and test if the IDTO bundle worked as envisioned. The data and information that came out of the test will help relevant stakeholders and program leadership make more informed decisions regarding IDTO technical feasibility and potential IDTO value.

Program Description

A two-site prototype demonstration of the Connection Protection (T-CONNECT) and Dynamic Transit Operations (T-DISP) IDTO mobility applications was conducted in Columbus, Ohio and Central Florida. The Columbus deployment occurred over approximately seven months and included live users from the general public. The Central Florida deployment was closed to the general public and consisted of a proof-of-concept demonstration. This work was performed in cooperation with an IDTO Prototype Development (PD) task to conduct a small-scale demonstration test.[1] While the system architecture was developed for the third application, Dynamic Ridesharing (D-RIDE), the application was not tested in practice due to a partner agency withdrawing from the demonstrations.

Methodology

The Volpe Center completed an evaluation plan, in consultation with the ITS JPO, Battelle, and Noblis. Volpe then monitored the progress of the PD team and the demonstrations. In order to augment the analysis of the demonstrations, Volpe conducted multiple in-depth interviews with entities providing unique demand-response transportation services to learn more about the impacts of their services. Volpe also developed an analytical statistical tool, known as the Integrated Dynamic Transit Operations – Bundle Evaluation Tool (IDTO-BET), that simulates the functions of IDTO.

The Volpe Center identified and evaluated six key impact areas for the IDTO demonstration. These impact areas were determined through analysis of DMA and IDTO documentation, analysis of Battelle's Project Management and Work Plan, and quantitative and qualitative analysis of the planned demonstrations. These impact areas broadly encompass what the Volpe Center assessed, and consist of:

- Travel Times
- User Demand

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[1] The PD task is being conducted by the Battelle Memorial Institute under contract to the ITS JPO.

- Behavioral Change
- Functionality of the IDTO Bundle
- Strategies of IDTO Bundle Usage
- Inter-Agency Cooperation

The full methodology is described in Section Chapter 2 of this report. Additionally, the Volpe Center developed an addendum to the evaluation plan which outlines specific changes that occurred based on the outcome of the demonstrations.

Findings

The IA confirmed the majority of the evaluation hypotheses, including the central hypotheses relating to the benefits and cost-effectiveness of IDTO. A subset of the hypotheses was confirmed through user satisfaction and post-trip survey data provided by IDTO bundle users. The most notable hypothesis confirmed by IDTO bundle users is that the predicted travel and wait time information provided by the IDTO application improves users' ability to manage their trips.

Another subset of hypotheses were confirmed through in-depth interviews with representatives of participating agencies. The interviews confirmed both that IDTO is a cost-effective tool for improving services and supporting intermodal transportation, and that the IDTO bundle stimulated increased coordination to enhance effectiveness among transit agencies and other stakeholders.

Due to a lack of demonstration data, the IA team developed IDTO-BET to test the evaluation hypotheses. Assumptions seeding IDTO-BET were informed by available demonstration data and in-depth interviews with demonstration participants and demand-response service providers. Conditional on these assumptions, IDTO-BET confirmed several key hypotheses relating to the effectiveness of the IDTO bundle in improving service quality and system efficiency, and stimulating transit demand.

The scenarios investigated in IDTO-BET confirmed that the IDTO bundle reduces travel time for bundle users. For T-CONNECT users, the travel time reductions represent reductions in waiting time when making connections; the confirmation of reduced waiting time when making connections also confirms the hypothesis that T-CONNECT increases the likelihood of making successful transfers. For T-DISP users, the travel time reductions represent improved alternatives to satisfy trip needs (i.e., streamlined travel to satisfy origin-destination pairs) and reductions in waiting time at the origin.

For most scenarios investigated in IDTO-BET, T-CONNECT was projected to provide net travel time savings after accounting for delay accruing to passengers on board vehicles held during a protected connection; net travel time savings were projected to be low (or even negative) for connections to high-frequency services and services with a high volume of passengers on board.

Volpe applied IDTO-BET to identify the maximum level of delayed passengers (i.e., riders on board the outbound vehicle, and equivalent downstream passengers delayed by a vehicle hold triggered by T-CONNECT) that would result in net travel time savings per T-CONNECT user for connections to outbound vehicles with service frequencies between 5 and 60 minutes. The IDTO-BET analysis confirmed that the maximum ridership on outbound vehicles involved in protected connections rises linearly with outbound vehicle headway, at a rate of approximately 0.7 riders per minute of vehicle headway. That is, for all combinations of outbound vehicle headway and ridership on outbound vehicles (within the green shaded area in Figure ES1), the travel time savings experienced by a T-CONNECT user are projected to exceed the delay experienced by all riders on board the outbound vehicle (or equivalent downstream passengers).

The maximum net-beneficial ridership shown in Figure ES1 grows linearly with the number of T-CONNECT users. For example, if a given protected connection for one T-CONNECT user would be net-beneficial for an outbound vehicle with a 15-minute headway and up to 10 riders, the protected connection would also be net-beneficial for two T-CONNECT users and up to 20 riders.

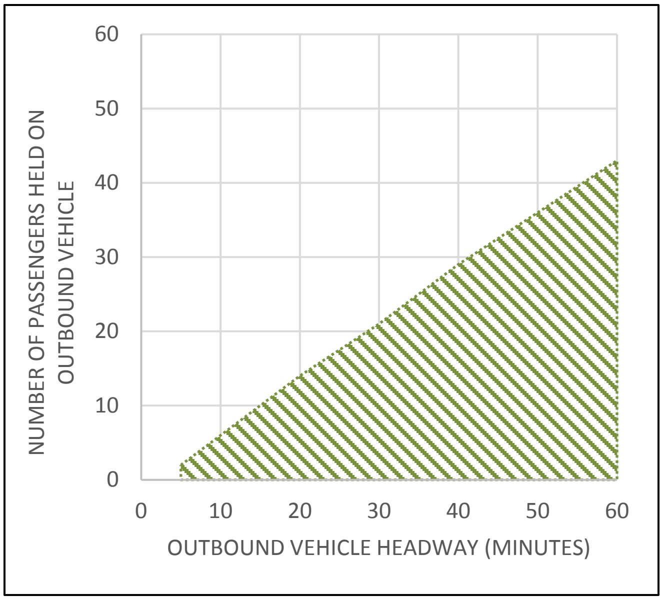

Figure 0-1. Maximum Ridership on Outbound Vehicles per T-CONNECT User to Yield Positive Net Travel Time Impacts, by Outbound Vehicle Headway (Source: Volpe Center)

The confirmation of net reductions in travel time under T-CONNECT also confirms the hypothesis that T-CONNECT improves system efficiency (i.e., T-CONNECT enables the system to carry an increased volume of passengers over a given interval). In the base T-DISP scenario, the net travel time impact was neutral (i.e., the travel time savings accruing to T-DISP users were closely offset by delay accruing to passengers on board).

IDTO-BET also confirmed that the IDTO bundle improves travel time reliability for bundle users. Improved reliability was represented in IDTO-BET as reductions in buffer time (i.e., 95th-percentile travel time). The projected improvements in travel time reliability increase as variability in trip time increases. Travel time reliability benefits were projected to represent approximately ten percent of total net benefits for the T-CONNECT scenarios investigated in IDTO-BET; due to the neutral projected net impacts of T-DISP on travel time, reliability benefits represent the lone source of projected benefits provided by T-DISP.

An additional hypothesis confirmed by IDTO-BET is that IDTO bundle usage stimulates transit demand. Conditional on an assumption that transit demand is sensitive to the generalized price of transit travel (i.e., travel time costs, reliability costs and fare), the projected reductions in generalized price arising from IDTO usage stimulate additional transit trips by IDTO users.

The remainder of the hypotheses were not confirmed. Post-trip survey data provided by IDTO bundle users indicated users did not identify value from the bundle in mitigating the effects of service disruptions. Interviews with demand-response providers indicated that T-DISP would not influence strategies relating to dynamic routing, dynamic scheduling and active fleet size. However, the effectiveness of T-DISP in supporting dynamic routing and scheduling is likely to be dependent upon the specific needs and capabilities of agencies that may choose to adopt T-DISP. Limited usage of the IDTO application inhibited the ability to confirm meaningful usage patterns by bundle users. Similarly, low usage rates inhibited the ability to observe variability in the usage of IDTO with respect to personal needs and the level of service of the network.

Recommendations

Based on the analysis conducted within this IA, the following recommendations were developed for the ITS JPO:

- Consider strategies of bundle implementation within different contexts;
- Encourage and ensure partner buy-in;

- Encourage flexible demand-response services within the context of T-DISP and D-RIDE;
- Consider scenarios where T-CONNECT is feasible and applicable; and
- Consider and be cognizant of data limitations.

These recommendations are expanded upon within Section Chapter 4 of this report.

Conclusion

The primary themes determined through the course of the IA and expanded upon within this report are as follows:

- The IDTO bundle is easily transferable to new cities and regions;
- The IDTO bundle can improve mobility and trip reliability;
- The net impacts of IDTO may vary critically with respect to service and demand characteristics;
- The IDTO bundle can enhance coordination and cooperation amongst transit agencies and partners;
- The demonstration experienced low demand based on limited capability and usability of the smartphone application; and
- The demonstration was hindered by the lack of demonstration partners, hampering the evaluation of the prototype.

In summary, despite the challenges experienced during the course of the demonstration, a functional prototype was developed and several valuable outcomes were learned regarding its use and potential impacts. In terms of implementing IDTO, the process is relatively straight-forward and the bundle can be adapted to the specific needs of the agencies involved. Separate tablets can be used or the software can be integrated directly into existing systems. Additionally, the three applications are not interdependent and can be adopted separately. The bundle does appear to improve mobility and can enhance the coordination and cooperation of transit agency partners. By providing transit alternatives to riders and supplying access to non-traditional services, particularly demand-response style services meeting niche demands, the bundle improves mobility using transit service. Agencies could also use this tool to communicate the effectiveness of their unique or non-traditional services and better integrate those services with those offered by other agencies in their area. While the advantages of T-CONNECT may not be as robust as originally perceived, there exists a small sub-group of riders who could benefit from using it, depending on the scale of the implementation and the characteristics of the particular transportation network.

The demonstration also led to lessons learned regarding the user interface of the bundle and the need to have buy-in from various partner agencies. Users have grown accustomed to Google and other existing transit applications. If a new, user-facing application is developed that incorporates IDTO, its functionality and usability is of critical importance. Additionally, if transit agencies do not buy-in to the process and agree to integrate, the system will not function. While it is possible to operate systems within one large agency that provides multiple services, the bundle will be most effective when integrating multiple agencies.

Chapter 1 Introduction

1.1 Integrated Dynamic Transit Operations Impact Assessment

This report itemizes and describes research activity that the Volpe Center conducted to address the Impact Assessment of the Integrated Dynamic Transit Operations (IDTO) prototype bundle of applications, and extrapolates observed findings. Also included is a projection of the effectiveness and impacts of a full IDTO operational deployment in Columbus, where the small-scale demonstration occurred. Along with the small-scale demonstration, a proof-of-concept demonstration was completed by the prototype development (PD) team in central Florida. Both demonstrations, as well as additional work conducted by the IA team, are described and evaluated in this report.

1.2 The U.S. DOT DMA Program

The United States Department of Transportation (U.S. DOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) has been working to transform the future of surface transportation systems management through the use of connected vehicles and other innovative technologies and systems. To this end, they have developed the Dynamic Mobility Applications (DMA) Program which features four environments with several activity clusters in each, including the IDTO bundle of three applications within the Corridor (Control) data environment.

The objective of this program is to “improve the capability of the transportation system to provide safe, reliable, and secure movement of goods and people.”[2] This report describes and summarizes the worked conducted to complete Track 5, evaluation and performance measures, for the IDTO bundle. The research tracks and program description can be found on the DMA Fact Sheets website.[3]

In 2011, the DMA Program concluded a first phase of activity focused on foundational research and then engaged in a second phase focused on applications development and testing, which initiated coordinated research activities on a portfolio of high-priority mobility applications. A description of all the high-priority applications and the process through which they were selected and grouped can be found on the Mobility Program website.[4]

As a first step, the DMA Program partnered with the research community to further develop these high-priority transformative concepts and to refine data and communications needs. These data and communication needs will inform related efforts in the Real-Time Data Capture and Management (DCM) Program in support of application development to collect, assemble, and provide relevant data resources integrating data from wirelessly connected vehicles, travelers, and roadside/wayside infrastructure. This IDTO IA and associated

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[2] DMA Research Description and Scope (http://www.its.dot.gov/dma/)

[3] http://www.its.dot.gov/factsheets/dma_factsheet.htm

[4] http://www.its.dot.gov/press/2011/mobility_app.htm

prototyping activity are examples of the effort to assess data and communications needs, collect relevant data, and inform the DMA program on potential impacts. In later phases of the DMA Program, selected mobility applications will be identified for further research and refinement, and for benefits assessment utilizing these open data environments (see the DMA Program Roadmap website[5]).

The U.S. DOT wished to advance the IDTO bundle from concept formulation to demonstration and test if the IDTO bundle worked as envisioned. The data and information that came out of the test, described in detail within this report, will help relevant stakeholders and program leadership make more informed decisions regarding IDTO technical feasibility and potential IDTO value.

1.3 The U.S. DOT IDTO Program

The U.S. DOT defines the IDTO bundle to be the following three mobility applications.

- Connection Protection (T-CONNECT) is designed to increase the likelihood that a traveler makes a successful transfer, particularly when transferring between transit modes or agencies.
- Dynamic Transit Operations (T-DISP) involves two components: real-time trip planning information and demand-responsive transportation. The real-time trip planning component gives a traveler the ability to obtain real-time information on available transit options for a desired trip, including cost and predicted time. The demand-responsive component enables travelers to gain access to transit vehicles whose schedules or routes are modified dynamically to satisfy travel needs.
- Dynamic Ridesharing (D-RIDE) provides an efficient ridesharing network to travelers by quickly communicating needs (passengers) or available space (drivers) to others.

A two-site prototype demonstration of T-CONNECT and T-DISP was conducted in Columbus, Ohio and Central Florida. The Columbus deployment occurred over approximately seven months and included live users from the general public. The Central Florida deployment was closed to the general public and consisted of a proof-of-concept demonstration. This work was performed in cooperation with an IDTO PD task to conduct a small-scale demonstration test.[6] Both prototype demonstrations differed in scope from what was originally planned, as described in section 1.3.3 below.

1.3.1 Columbus

The Columbus, Ohio test site covered the areas surrounding the Ohio State University (OSU) main campus and the Defense Supply Center Columbus (DSCC) for T-CONNECT and T-DISP. The baseline evaluation period began in March 2014, and the prototype went live in May 2014. The evaluation lasted ten months, concluding in December 2014.

The Central Ohio Transit Authority (COTA) is the primary transit provider in the region. Two additional providers took part in the demonstration: OSU's Campus Area Bus Service (CABS) and DSCC's Capital Transportation. The OSU campus is located north of downtown Columbus. CABS and COTA provide fixed-route transit to students, faculty, staff, and visitors. The DSCC campus is east of downtown Columbus. Capital Transportation

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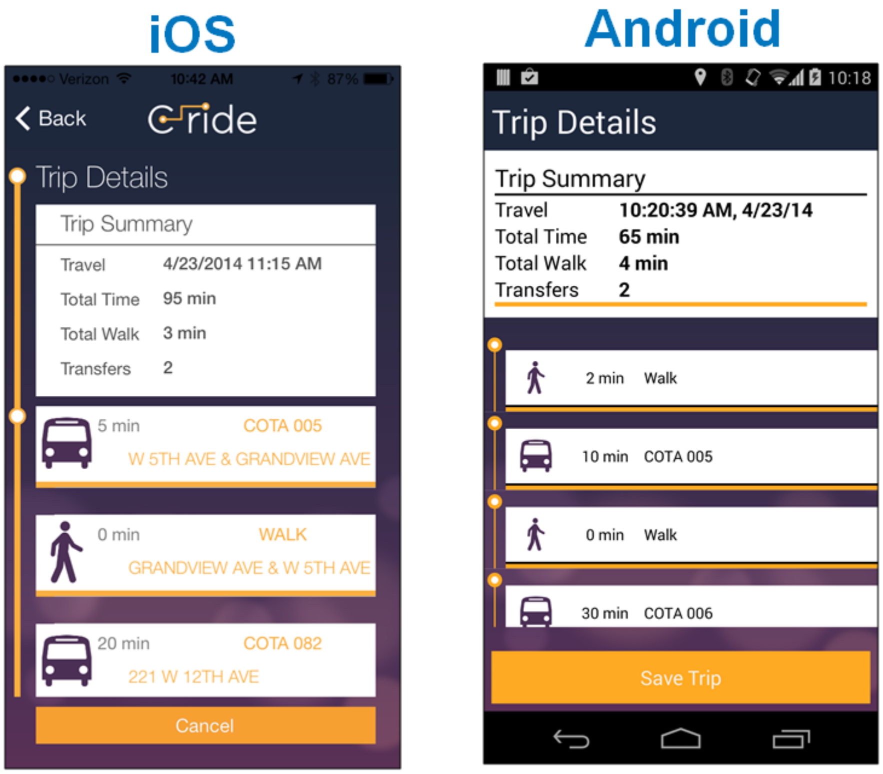
[5] http://www.its.dot.gov/roadmaps/dma_roadmap.htm

[6] The PD task was conducted by the Battelle Memorial Institute under contract to the ITS JPO.

provides on-demand, flex-route service between DSCC campus locations and base security gates adjacent to COTA bus stops.

Within the demonstration, T-CONNECT opportunities were provided from CABS to COTA and from Capital Transportation to COTA. In both cases, constraints were put into place that a vehicle would hold for a maximum of one minute if it was running less than five minutes late and if the bus had not already been held during the same route.

T-CONNECT could feasibly be provided between all combinations of agencies, except from CABS to Capital Transportation as those systems do not intersect. The real-time trip planning component of T-DISP was demonstrated through the smartphone app developed by Battelle Memorial Institute: C-Ride. Figure 1-1 contains sample images of the interfaces for C-Ride for iOS and Android versions.



Trip Details

Trip Summary

Travel	4/23/2014 11:15 AM
Total Time	95 min
Total Walk	3 min
Transfers	2

5 min COTA 005 W 5TH AVE & GRANDVIEW AVE

0 min WALK GRANDVIEW AVE & W 5TH AVE

20 min COTA 082 221 W 12TH AVE

Trip Details

Trip Summary

Travel	10:20:39 AM, 4/23/14
Total Time	65 min
Total Walk	4 min
Transfers	2

2 min Walk

10 min COTA 005

0 min Walk

30 min COTA 006

Figure 1-1. Examples of C-Ride Interface (Source: Battelle)

The level of automation and coordination of various IDTO transactions depended on the participating partners and the varying types of users. Users of the system in the campus-area were able to use automated features available via C-Ride to view and “book” various transportation options. Riders in the DSCC area were supported by the operators of the on-base shuttle, Capital Transportation.

When a passenger (or surrogate) entered his or her desired trip, the software package displayed this information to riders, who were then able to respond to a request. After a COTA dispatcher responded, the software package sent confirmation to the passenger. Figure 1-2 is an example image of the COTA dispatcher interface. The green check mark and red x mark represent the options for the COTA dispatcher to either accept or deny the T-CONNECT request.

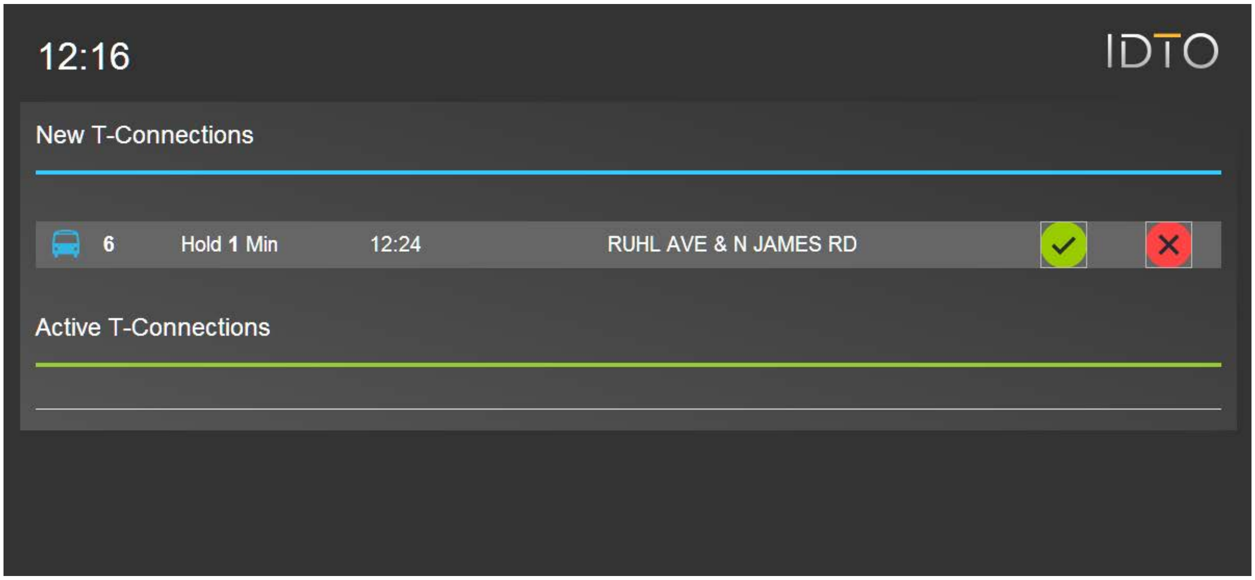


Figure 1-2. Example of COTA Dispatcher Interface (Source: Battelle)

1.3.2 Central Florida

The Central Florida proof-of-concept prototype demonstration occurred on November 5th, 2014. The demonstration centered on the LYNX bus system. LYNX serves the greater Orlando region, including the University of Central Florida (UCF).

T-CONNECT was demonstrated between the UCF campus shuttle system, LYNX bus routes, and the SunRail commuter rail service, which is operated by Veolia Transportation. The real-time trip planning component of T-DISP was demonstrated through the smartphone app C-Ride.

1.3.3 Key PD Challenges that Impacted the IA

The PD team experienced numerous challenges throughout the course of their work in developing and testing the IDTO prototype. Most notably, several agencies who had agreed to participate in the demonstration were unable to do so for various reasons. The lack of participation by these agencies greatly reduced the scope and altered the functionality of the bundle and the demonstration. The agencies who did not participate, the reason they withdrew from the demonstration, and the resulting impact is as follows:

- **FlexBus:** This service was designed by Lynx to be a demand-response shuttle service within the central Florida region. However, the launch of the service was delayed based on operational challenges and the service was not available for the demonstration. The PD team had hoped to use this service to test the dynamic rideshare component of T-DISP in central Florida; however, they were unable to do so. No other dynamic-response service was available in the area to fill that role.

- **TaxiCABS:** This service was designed by OSU CABS to be a demand-response shuttle service that would operate on OSU's campus and serve OSU faculty and staff. However, based on budget constraints, the service was never initiated by OSU. The PD team had hoped to use this service to test the dynamic rideshare component of T-DISP in Columbus; however, they were unable to do so. No other dynamic-response service was available in the area to fill that role.
- **Zimride:** This rideshare service agreed to participate in both the Columbus, Ohio and central Florida demonstrations. However, after being purchased by Enterprise Rent-a-Car, the service withdrew from the demonstrations for legal reasons. The PD team had hoped to use this service to test D-RIDE in both Columbus and central Florida; however, they were unable to do so. No other rideshare service was available in either area to fill that role.

Based on the lack of participation of these agencies, the dynamic rideshare component of T-DISP and the D-RIDE application were untestable in both demonstrations. This greatly reduced the scope of the demonstrations and led to the decision to deploy the bundle in Central Florida as a proof-of-concept only, rather than a live demonstration with users.

Along with the limited scope of the demonstrations, a second major challenge that impacted the IA was the lack of user participation in the Columbus demonstration. Due to the small number of users, the data required to evaluate the bundle in practice were incomplete. Critical limitations included small numbers of relevant trips, T-CONNECT opportunities, and protected connections. The demonstration also yielded an insignificant number of user satisfaction and post-trip survey responses. Using the data that were available, the IA team was able to draw some inference regarding the bundle; however, findings that centered on limited data were largely inconclusive.

While less significant, additional challenges related to limited data availability also hindered the demonstrations and led to changes to the planned IA. Specifically, user position data was unavailable based on privacy concerns. As a result, tracking users through the transportation network as they undertook their planned trips was not possible.

1.3.4 Additional Analyses beyond Demonstrations

The live demonstration in Columbus and proof-of-concept demonstration in Central Florida both experienced partner agencies dropping out, lack of overall demand, and various other unforeseen data challenges, as described in Section 1.3.3 above. As a result, in order to evaluate the impacts of the IDTO bundle, Volpe took five analytical steps:

- Interviews of participating agencies were conducted in order to assess their attitudinal perceptions of the demonstrations and the IDTO bundle. This was because Volpe required information directly from participating agencies that could not be observed independently.
- Interviews with entities who are utilizing unique demand-response services were conducted in order to assess the impacts of those services. This was done to supplement for the lack of dynamic services and demand-response component of T-DISP within the demonstrations and to gain information and lessons learned relating to demand-response services.
- Post-trip surveys were developed by Volpe and administered by Battelle (13 post-trip survey

responses were received).This was done because some hypotheses required users' perceptions. However, as noted in Section 1.3.3 , a limited number (17) of user satisfaction surveys were also collected.

- Battelle's developer database was received and analyzed. While the analysis of IDTO transactions was feasible, the data available based on the reduced scope of the demonstration was limited.
- An analytical spreadsheet tool, the Integrated Dynamic Transit Operations Bundle Evaluation Tool (IDTO-BET) was developed utilizing data received from participating transit agencies. This was done based on the insufficient volume of activity and missing demonstration components (particularly T-DISP). The tool also provides a usable and customizable template for organizations considering IDTO as well as a method for interested stakeholders to assess policy scenarios.

Table 1-1, llsts the agencies interviewed, their role, and the interview frequency:

Table 1-1. Interviewees

Agency	Role	Interview Frequency
128 Business Council	Demand-Response Agency	Once for demand-response discussion
Battelle	PD	Twice during demonstration
Bridj	Demand-Response Agency	Once for demand-response discussion
CABS	Columbus Demonstration Participant	Three times during demonstration
Capital Transportation	Columbus Demonstration Participant	Twice during demonstration
COTA	Columbus Demonstration Participant	Three times during demonstration
Lynx	Central Florida Demonstration Participant and Demand-Response Agency	Once during demonstration and once for demand-response discussion
Middlesex County Area Transit	Demand-Response Agency	Once for demand-response discussion
Montachusett Regional Transit Authority	Demand-Response Agency	Once for demand-response discussion
San Joaquin Regional Transit District	Demand-Response Agency	Once for demand-response discussion
SunRail	Central Florida Demonstration Participant	Once during demonstration
UCF	Central Florida Demonstration Participant	Once during demonstration
Utah Transit Authority	Demand-Response Agency	Once for demand-response discussion

IDTO-BET includes all three specific applications of the bundle: T-CONNECT, T-DISP, and D-RIDE. The tool was informed by actual data from Columbus transit agencies in order to project travel time, reliability and demand impacts of IDTO usage across the network. IDTO-BET was designed not only to enable the evaluation of IA hypotheses, but also to project impacts of full-scale deployment of IDTO and to support evaluations of additional hypothetical scenarios both within and outside the scope of the IDTO demonstration (i.e., scenario testing that can be customized to any specific application).

The central mechanisms in IDTO-BET involve the estimation of impacts on average travel times, average changes in buffer time (i.e., 95th-percentile travel time) for IDTO users and other travelers, and transit demand. Each target impact is projected in IDTO-BET through statistical representations of transit service performance calibrated with respect to: observed data from the demonstration, supplementary data provided by demonstration participants, and analyst-controlled assumptions. In the analysis of T-CONNECT scenarios, IDTO-BET incorporates information on (parameters used in the specification of the main T-CONNECT analytical scenario, and associated sources, in parentheses):

- Trip frequency for outbound vehicles (15, 25 and 40 minutes; source: COTA);
- Schedule adherence for inbound and outbound vehicles (mean arrival time of 2.5 minutes behind schedule, standard deviation of arrival time of 2.2 minutes; source: COTA);
- Average ridership on outbound vehicles (7 passengers; source: COTA);
- Maximum holding time for outbound vehicles (3 minutes; source: discussions with participating transit service providers and Battelle);
- Maximum allowed interval between arrival of the inbound vehicle and scheduled departure of the outbound vehicle (projected arrival 2 minutes ahead of outbound vehicle; source: discussions with participating transit service providers and Battelle);
- T-CONNECT demand (normalized to one request per day);
- Effectiveness of T-CONNECT transactions (90 percent effective; source: minimum standard as informed by the DMA evaluation);
- Annualized T-CONNECT service costs ($3,500; source: Battelle);
- Transit fares ($2 per trip; source: COTA);
- Overall transit demand for T-CONNECT users (4 trips per day; Volpe assumption of two connecting trips per day); and
- Generalized price elasticity of transit service demand (-0.63, based on Litman (2015)).

In the analysis of T-DISP scenarios, IDTO-BET incorporates information on (parameters used in the specification of the main T-DISP analytical scenario in parentheses):

- Average waiting time for demand-response and conventional vehicles (5 and 15 minutes, respectively);
- Mean travel time for demand-response and conventional vehicles (45 minutes and 60 minutes, respectively);
- Standard deviation of travel times for demand response and conventional vehicles (4.5 minutes and 6 minutes, respectively);
- Average ridership on demand-response vehicles during route deviations (5 passengers);
- Average deviation duration (5 minutes);
- T-DISP demand (normalized to one request per day);
- Effectiveness of T-DISP transactions (90 percent effective);
- Annualized T-DISP service costs ($6,000);

- Transit fares ($2 per trip);
- Overall transit demand for T-DISP users (2 trips per day); and generalized price elasticity of transit service demand (-0.63, based on Litman (2015))

Sensitivity analyses were conducted both to examine the sensitivity of T-CONNECT and T-DISP findings to analytical assumptions, and to investigate specific scenarios that were distinct from the general relationships represented by the above assumptions (e.g., peak-period ridership versus average ridership). The roles of each of the above inputs within IDTO-BET are summarized as follows:

Information on trip frequency and schedule adherence forms an essential component of calculations of travel time savings, reliability impacts, and T-CONNECT service effectiveness. Trip frequency constrains both the range of feasible connections and the travel-time-related impacts of protected connections. Information on schedule adherence, used in concert with trip frequency assumptions, was also a central factor in establishing the projected proportion of desired connections that both would be missed but could be protected via T-CONNECT. No demonstration data were available to allow the direct observation of the volume of missed connections. Rather, projected distributions of times of arrival for connecting passengers relative to outbound vehicles were used to estimate the rate of beneficial (i.e., cases in which users would arrive at a connection point after the outbound vehicle would leave) and feasible (i.e., cases in which the outbound vehicle could be held to complete a protected connection) T-CONNECT transactions. For all simulated T-CONNECT transactions, IDTO-BET incorporates schedule adherence and outbound vehicle frequency assumptions to calculate: the amount of travel time saved for the user (zero when no connection is feasible or required), the amount of travel time added to riders on board the held vehicle, and the amount of buffer time reduction when using T-CONNECT.

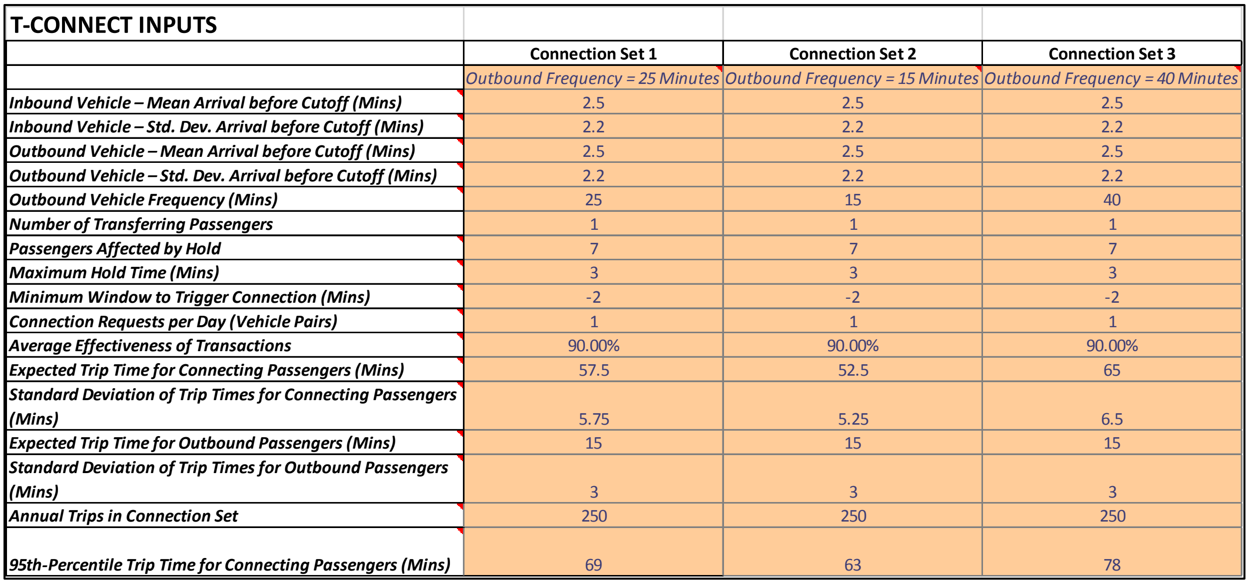
Information on ridership on outbound and deviating vehicles serves to identify the negative travel time impacts associated with T-CONNECT and T-DISP (i.e., delay of riders on vehicles held for T-CONNECT users, delay of riders on vehicles deviating to satisfy a T-DISP request). The effectiveness of processing transactions is a limiting factor in the effective demand for T-CONNECT and T-DISP, and, in turn, all impact estimates.

Constraints on feasible connections are a limiting factor in the effective demand for T-CONNECT and, in turn, all impact estimates.T-CONNECT and T-DISP costs are compared with monetized impact estimates to generate estimates of annualized return on investment; monetized impacts are projected by multiplying travel time and reliability impacts by corresponding values that were informed by U.S. DOT guidance and a literature review. Transit demand and revenues are interdependent, and are direct or indirect functions of the generalized price of transit travel. The generalized price of travel is estimated based on assumed and projected transit fares, travel time costs and travel time reliability costs.

For D-RIDE scenarios, IDTO-BET focuses on a demand-supply equilibrium model that is supplemented by assumptions on: waiting time for first-mile- and last-mile ridesharing trips coordinated via D-RIDE; effectiveness of D-RIDE transactions; D-RIDE system costs; and incremental transit demand for D-RIDE users. Due to a lack of both a D-RIDE component within the demonstration and supplementary data from stakeholders that could inform analyses of D-RIDE, analysis in IDTO-BET was unable to identify D-RIDE-specific outcomes relevant to the evaluation hypotheses.

The estimated travel time and buffer time savings determined through IDTO-BET map directly to impacts and the projected effects of full-scale implementation of the IDTO bundle. Furthermore, IDTO-BET allows for a comparison of travel time savings by application, which illuminates the degree to which particular components of the bundle have relatively high impacts on travel times.

To illustrate how IDTO-BET was applied in the analysis, consider an example investigating the net impacts of T-CONNECT for one-passenger connections to outbound vehicles with headways of 15, 25 and 40 minutes (the three headways considered within the analysis in this report, segmented in this example as “Connection Set 1”, “Connection Set 2” and “Connection Set 3”). IDTO-BET enables the analyst to specify assumptions across the range of inputs and scenarios summarized above. In this example, the analyst specifies the following values into the IDTO-BET T-CONNECT user input worksheet (all values used with Volpe's analysis), as shown in Figure 1-3:



T-CONNECT INPUTS			
	Connection Set 1	**Connection Set 2**	**Connection Set 3**
	Outbound Frequency = 25 Minutes	*Outbound Frequency = 15 Minutes*	*Outbound Frequency = 40 Minutes*
Inbound Vehicle – Mean Arrival before Cutoff (Mins)	2.5	2.5	2.5
Inbound Vehicle – Std. Dev. Arrival before Cutoff (Mins)	2.2	2.2	2.2
Outbound Vehicle – Mean Arrival before Cutoff (Mins)	2.5	2.5	2.5
Outbound Vehicle – Std. Dev. Arrival before Cutoff (Mins)	2.2	2.2	2.2
Outbound Vehicle Frequency (Mins)	25	15	40
Number of Transferring Passengers	1	1	1
Passengers Affected by Hold	7	7	7
Maximum Hold Time (Mins)	3	3	3
Minimum Window to Trigger Connection (Mins)	-2	-2	-2
Connection Requests per Day (Vehicle Pairs)	1	1	1
Average Effectiveness of Transactions	90.00%	90.00%	90.00%
Expected Trip Time for Connecting Passengers (Mins)	57.5	52.5	65
Standard Deviation of Trip Times for Connecting Passengers (Mins)	5.75	5.25	6.5
Expected Trip Time for Outbound Passengers (Mins)	15	15	15
Standard Deviation of Trip Times for Outbound Passengers (Mins)	3	3	3
Annual Trips in Connection Set	250	250	250
95th-Percentile Trip Time for Connecting Passengers (Mins)	69	63	78

Figure 1-3. Example T-CONNECT User Input Worksheet (Source: Volpe Center)

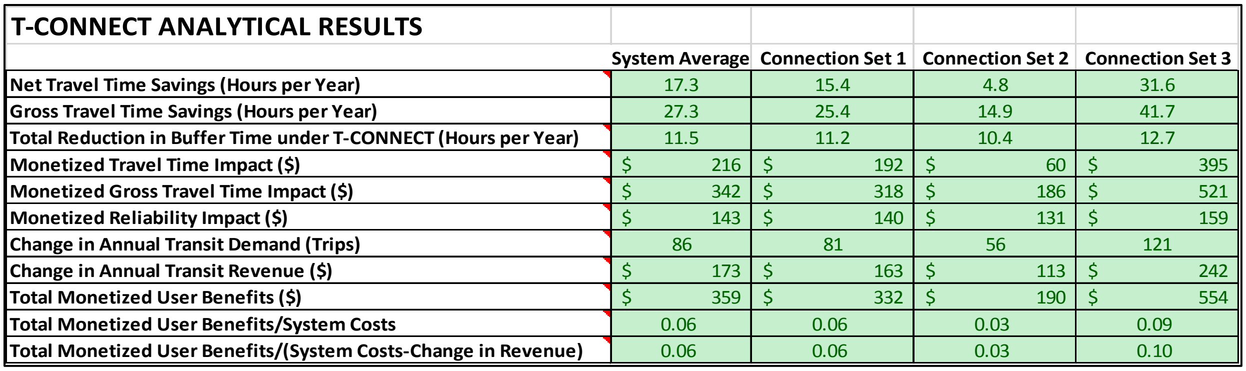
- Mean arrival time of the inbound and outbound vehicles before T-CONNECT cutoff = 2.5 minutes (i.e., maximum schedule delay for outbound vehicle of five minutes, minus average schedule delay for all vehicles of 2.5 minutes, from COTA schedule adherence data);
- Standard deviation of the arrival time of the inbound and outbound vehicles = 2.2 minutes (from COTA schedule adherence data);
- Outbound vehicle frequencies (one per scenario) = 15 minutes, 25 minutes, and 40 minutes (i.e., the headways in the analysis);
- Number of transferring passengers = 1;
- Passengers affected by the outbound vehicle hold = 7 (mean ridership in the COTA data, assumes no downstream delay or, alternatively, assumes loading below mean and some downstream delay);
- Maximum hold time = 3 minutes (based on the demonstration design);
- Minimum window to trigger connections = 2 minutes before scheduled departure from the connection point (based on the demonstration design);

- Connection requests per day = 1 (to normalize to quantify the net impacts per T-CONNECT user);
- Average effectiveness of transactions = 90 percent (based on the national DMA evaluation objectives);
- Expected trip time for connecting passengers on board the outbound vehicle = 45 minutes (selected as an example of a T-CONNECT user with a long expected total trip time);
- Standard deviation of trip times for connecting passengers on board the outbound vehicle = 10 percent of the expected trip time (selected for consistency with the relationship between mean and standard deviation of schedule adherence, with some allowance for interactive delay effects);
- Annual trips in each scenario = 250 (1 per business day); and
- 95th-percentile trip time for connecting passengers = expected trip time multiplied by two multiplied by the standard deviation of trip times.

IDTO-BET simulates a series of over 65,000 T-CONNECT requests calibrated with respect to the transaction-level assumptions entered by the analyst, and calculates average impacts across the simulated T-CONNECT requests. The projected average impacts are then used within calculations of annual T-CONNECT impacts, calibrated with respect to the annual-level assumptions entered by the analyst. IDTO-BET projects the impacts of each simulated T-CONNECT request based on the projected feasibility of the request (i.e., whether the outbound vehicle could be held long enough to satisfy a T-CONNECT request, and whether holding the outbound vehicle is necessary), conditional on the projected arrival times of the inbound and outbound vehicles and analyst-specified constraints on acceptable intervals for holding outbound vehicles.

For each simulated feasible protected connection, IDTO-BET calculates the travel time savings experienced by the T-CONNECT user (equal to the difference between the projected trip without and with connection protection), along with the corresponding delay to riders on the outbound vehicle (equal to the effective number of delayed riders and downstream passengers multiplied by the duration of the vehicle hold).

For all simulated infeasible protected connections, IDTO-BET specifies no impact on travel times or delay. IDTO-BET calculates the impact of T-CONNECT on travel time reliability as the difference between the baseline 95th-percentile travel time and the average 95th-percentile travel time across the simulated T-CONNECT requests. Figure 1-4 presents the summary outputs for this example, as reported in the IDTO-BET T-CONNECT results worksheet:



T-CONNECT ANALYTICAL RESULTS	System Average	Connection Set 1	Connection Set 2	Connection Set 3
Net Travel Time Savings (Hours per Year)	17.3	15.4	4.8	31.6
Gross Travel Time Savings (Hours per Year)	27.3	25.4	14.9	41.7
Total Reduction in Buffer Time under T-CONNECT (Hours per Year)	11.5	11.2	10.4	12.7
Monetized Travel Time Impact ($)	$ 216	$ 192	$ 60	$ 395
Monetized Gross Travel Time Impact ($)	$ 342	$ 318	$ 186	$ 521
Monetized Reliability Impact ($)	$ 143	$ 140	$ 131	$ 159
Change in Annual Transit Demand (Trips)	86	81	56	121
Change in Annual Transit Revenue ($)	$ 173	$ 163	$ 113	$ 242
Total Monetized User Benefits ($)	$ 359	$ 332	$ 190	$ 554
Total Monetized User Benefits/System Costs	0.06	0.06	0.03	0.09
Total Monetized User Benefits/(System Costs-Change in Revenue)	0.06	0.06	0.03	0.10

Figure 1-4. Example T-CONNECT User Input Worksheet (Source: Volpe Center)

The analytical results worksheet reports estimates for each scenario (connection set) in the analysis, along with system averages that apply weights across the scenarios (in this example, all scenarios are weighted equally, at one transaction per day). Net travel time savings are reported in hours per year, and are estimated as the number of annual T-CONNECT transactions (transactions per day multiplied by days per year) multiplied by the estimated net travel time savings per average T-CONNECT request (travel time savings for T-CONNECT users, less delay to riders on outbound vehicles). In this example, the projected net travel time savings range from 4.8 hours (for connections to services with 15-minute headways) to 31.6 hours (40-minute headways). The total reduction in buffer time under T-CONNECT is reported in hours per year, and is estimated as the estimated reduction in buffer time (difference between the baseline 95th-percentile travel time and the 95th-percentile travel time when making a T-CONNECT request) multiplied by the annual number of T-CONNECT requests. In this example, the projected reduction in buffer time has a relatively narrow a range of 10.4 hours to 12.7 hours across scenarios.

The estimated annual travel time and reliability impacts are multiplied by the user-specified values of travel time savings and reliability gains to yield monetized estimates of T-CONNECT travel time and reliability impacts in dollars (travel time benefits of $60 to $395, and reliability benefits of $131 to $159). The total monetized user benefits is specified as the sum of the monetized travel time and reliability benefits ($190 to $554).

1.4 Purpose of the Impct Assesment

This project was intended to comprise a subset of the inputs used in a national-level DMA evaluation, conducted by Booz Allen Hamilton. The DMA evaluation will include a benefit-cost analysis of DMA technology bundles that are being demonstrated at multiple sites. The benefit-cost analysis will compare monetized improvements to transit system productivity and traveler mobility at the national level. Specifically, this IA supports the national-level DMA evaluation through:

- The projection of estimated impacts of the IDTO demonstration at the regional level
- Assistance in identifying means of converting impacts to monetized benefits (e.g., converting travel time savings in minutes per use of a technology within the demonstration to dollars' worth of travel time savings from using the technology across the regions where the demonstration takes place).

Coordination meetings between the Volpe Center and the ITS JPO, Battelle, and Noblis guided the IA and the development of IDTO-BET to determine regional-level benefit-cost inputs for use within the national-level evaluation.

1.5 Report Structure

This report discusses the analytical approach that was used to evaluate the IDTO bundle, the key findings from that analysis, and recommendations for next steps. Section 2 describes the full approach with hypotheses, measures of effectiveness (MOEs), and data sources. Section 3 describes the evaluation findings, by hypothesis. Section 4 builds from the findings and incorporates the recommendations developed by the evaluation team. Finally, Section 5 summarizes the findings and highlights the key themes from the evaluation.

Chapter 2 Evaluation Design

This section describes the evaluation that was conducted in order to complete the IA. The Volpe Center first completed an evaluation plan, in consultation with the ITS JPO, Battelle, and Noblis. Volpe then monitored the progress of the PD team and the demonstrations in Columbus and the Central Florida region. In order to augment the analysis of the demonstrations, Volpe conducted multiple in-depth interviews with entities providing unique demand-response transportation services to learn more about the impacts of services and also developed an analytical statistical tool that simulates the functions of IDTO. The text below describes the potential impacts of IDTO and the methodology which Volpe used to assess those impacts. For further detail regarding the methodology and approach, please see the IDTO IA Evaluation Plan Addendum.

The Volpe Center identified and evaluated six key impact areas for the IDTO demonstration. These impact areas were determined through analysis of DMA and IDTO documentation, analysis of Battelle's Project Management and Work Plan, and analysis of the planned demonstrations themselves. These impact areas broadly encompass what the Volpe Center measured and assessed. The impact areas, and the specific impacts and testing approach relevant to each area, are listed in Table 2-1.

Table 2-1. Description of Impact Areas

Impact Area	Description	Specific Impacts	Approach
Travel Times	How the bundle affects user travel time and user travel reliability	User travel time savings User reliability gains	Analysis using IDTO-BET
User Demand	The extent to which transit users ultimately use the software package and specific IDTO applications to improve their travel alternatives	Changes in travel and transit demand accompanying bundle usage Differences in bundle usage across trip contexts	Analysis using IDTO-BET Analysis of Battelle's developer database Demonstration partner interviews
Behavioral Change	The extent to which users develop a reliance on the bundle to improve their travel alternatives, independent of demand	Software package use is higher during disruptions Software package is relied on habitually	Analysis of Battelle's developer database Demonstration partner interviews User satisfaction surveys Demand-response agency interviews

Impact Area	Description	Specific Impacts	Approach
Functionality of the IDTO Bundle	The multidimensional functionality of the bundle covering the experiences of both travelers and transit agencies	Increased passenger throughput Increased fleet efficiency Increased rate of multi-modal transfers Increased rate of multi-agency transfers Benefits of software package exceed costs	Analysis using IDTO-BET Analysis of Battelle's cost data Post-trip surveys Demonstration partner interviews
Strategies of IDTO Bundle Usage	The specific strategies employed by travelers and transit agencies to improve their decision making	Increased scheduling flexibility for transit agencies and users Increased routing flexibility for transit agencies Reduced effect (travel time loss) of disruptions on users and reduced burden of disruptions on transit agencies	Post-trip surveys Demonstration partner interviews Demand-response agency interviews
Inter-Agency Cooperation	The changes resulting from inter-agency cooperation	Increased levels of inter-agency communication, stream-lined improvements, and mitigated confusion, disruption, and operational inefficiencies	Demonstration partner interviews

Each of these specific impacts is discussed below. The discussion includes a description of the hypotheses relevant to each impact area, the specific tests conducted for each of the hypotheses, and the data used.

2.1 Impacts Relating to Travel Times

This impact area centers on travel time, which is arguably the most direct means of mapping outcomes onto quantifiable and expandable impacts. Travel times inherently represent a large contributing factor in determining the effectiveness of the IDTO bundle and ultimately how helpful the bundle is for users. This impact area is also related closely to others, specifically the functionality and strategies of usage for the bundle. By evaluating the impact of the IDTO bundle on travel times, and scaling accordingly, the Volpe Center is able to determine how effective the bundle is in a full-scale implementation. The specific impacts assessed in this area are:

- User travel time savings
- User reliability gains

The hypotheses used to evaluate this impact area intuitively focus on individual traveler efficiency. The specific hypotheses Volpe planned to test are as follows:

- Hypothesis 1: The software package and IDTO applications enable users to reach target destinations in less travel time compared to the baseline or non-users.
- Hypothesis 2: The software package and IDTO applications enable users to reach target destinations with less variation in travel time compared to the baseline or non-users.
- Hypothesis 3: Passenger wait time (at the origin) is reduced.

The evaluation of Hypothesis 1 helps to determine whether the software package or applications will lead to user travel time savings. The evaluation of Hypothesis 2 helps to determine whether the software package or applications lead to improvements in travel time reliability. Both hypotheses were tested using the analytical tool developed by Volpe, which was informed by data from the Columbus demonstration. While assumptions can be made regarding Hypothesis 3, the hypothesis was untestable as no testable data related to passenger wait times (at the origin, distinct from transfer time when connecting to a service) was available for collection.

Impacts of the IDTO bundle on travel times represented a critical set of measures to identify, both directly and as inputs into related impact measures discussed elsewhere in this report. The Volpe Center’s broadest planned travel time outcome to measure involved changes in travel times for users of the IDTO software package overall, regardless of the specific applications (T-CONNECT, T-DISP, D-RIDE) used (if any). That is, Volpe planned to compare the full set of travel times for those who consulted the software package relative to travel times before the demonstration, after accounting for primary external factors that could influence system performance. These external factors included, but were not limited to, demand and schedule variations. In doing so, Volpe had planned to utilize logs of user trips, including location and travel time, to determine if utilizing the bundle aided users in reaching their destinations faster than non-users.

However, based on data limitations and low usage rates of the bundle, this approach was not possible. As a result, Volpe tested travel times when utilizing the IDTO bundle through the use of IDTO-BET. IDTO-BET simulates a series of over 65,000 T-CONNECT requests calibrated with respect to the transaction-level assumptions entered by the analyst, and calculates average impacts across the simulated T-CONNECT requests. The projected average impacts are then used within calculations of annual T-CONNECT impacts, calibrated with respect to the annual-level assumptions entered by the analyst. IDTO-BET projects the impacts of each simulated T-CONNECT request based on the projected feasibility of the request (i.e., whether the outbound vehicle could be held long enough to satisfy a T-CONNECT request, and whether holding the outbound vehicle is necessary), conditional on the projected arrival times of the inbound and outbound vehicles and analyst-specified constraints on acceptable intervals for holding outbound vehicles.

For each simulated feasible protected connection, IDTO-BET calculates the travel time savings experienced by the T-CONNECT user (equal to the difference between the projected trip time for the T-CONNECT user without and with connection protection), along with the corresponding delay to riders on the outbound vehicle (equal to the effective number of delayed riders and downstream passengers multiplied by the duration of the vehicle hold). For all simulated infeasible protected connections, IDTO-BET specifies no impact on travel times or delay. IDTO-BET calculates the impact of T-CONNECT on travel time reliability as the difference between the baseline 95th-percentile travel time and the average 95th-percentile travel time across the simulated T-CONNECT requests.

A numerical example of how IDTO-BET was applied to generate estimates of travel time and reliability impacts is offered in Section 1.3.4.

2.2 Impacts Relating to User Demand

With this impact area, the Volpe Center attempted to determine the extent to which the software package and IDTO applications were used. The use of the software package and individual IDTO applications has significant implications not only to determine the level of demand for the bundle, but also to determine how useful and necessary the bundle is. By measuring the level of bundle demand, the Volpe Center planned to determine which groups were more likely to use the software package, including the individual applications within it, and how the bundle changes travel demand. Volpe planned to use these results to project the impact the bundle would have on transportation network capacity under a full-scale implementation scenario.

Unfortunately, this analysis was difficult to carry out based on the lack of demand for the bundle within the demonstration. While information can be gleaned from the low usage, the original planned analysis did not take full shape. Interviews with transit agency representatives helped to confirm the implications of the level of bundle usage in the demonstration and provided some insight, particularly as the bundle relates to a potential full-scale implementation. The specific impacts assessed in this area are:

- Changes in travel and transit demand accompanying bundle usage
- Differences in bundle usage across trip contexts
- The hypotheses used to evaluate this impact area focus on the level of use of the software package itself, and the different IDTO applications individually, as they relate to transit demand overall. The specific hypotheses Volpe planned to test are as follows:
- H4: The IDTO bundle was consulted and utilized at a meaningful level overall, and for trips originating from, or destined to, specific locations.
- H5: Transit demand is a positive function of IDTO bundle usage.

The primary impact evaluated within Hypotheses 4 and 5 is the degree to which the presence of the bundle influences transit demand. Based on this, the Volpe Center attempted to determine whether people who use T-CONNECT increase their transit trip volumes. Within this broad impact, Volpe evaluated the extent to which the bundle's influence on transit demand varied across trip contexts. For example, the Volpe Center attempted to determine whether trips to a major activity center involving the bundle are linked to increased transit demand overall.

The Volpe Center's preferred means of assessing demand for the IDTO bundle involved the quantification of usage levels and a comparison with overall trip levels and frequencies. This was done by determining the shares of trips where the bundle played a role. Interviews with transit agency representatives confirmed whether the usage patterns were meaningful. Rather than testing only general demand for the bundle, the analysis was disaggregated to assess demand for: the user application (separate to specific choices to use a particular IDTO application) and T-CONNECT. Unfortunately, the flexible service component of T-DISP and D-RIDE were not available the demonstration participants and could not be tested.

The central input data for the hypothesis tests included user logs for the software package (to gauge demand for consulting the software package itself), transaction-level data for each of the applications, and transit agency interviews. Based on the overall low demand for the bundle, impacts related to whether travel demand is a function of IDTO bundle demand were not possible to isolate. IDTO-BET was applied to identify links between bundle use and travel behavior, with analysis centering on the link between projected impacts on the generalized price of travel (estimated as the change in travel time and reliability costs relative to a baseline) and the assumed generalized price elasticity of transit demand. The IDTO-BET analysis was supported by qualitative interviews with Battelle and transit agencies.

Continuing from the example presented in Section 1.3.4 , additional analytical inputs are required to generate estimates of the transit demand impacts of T-CONNECT and T-DISP. For T-CONNECT (the bundle component within the example), the additional analytical inputs include:

- Annualized system cost = $6,000 (based on the demonstration design);
- Generalized price elasticity of demand = -0.63 (based on a literature review of transit demand elasticities with respect to transit price, travel time and service quality);
- Value of travel time savings = $12.50 per hour (based on U.S. DOT guidance);
- Value of reliability gains = $0.21 per minute (based on U.S. DOT guidance on travel time savings and a literature review comparing estimated values of travel time savings and values of reliability);
- Days effective per year = 250 (all weekdays, less holidays);
- Annual affected ridership = 3,000 (four transit trips per day per T-CONNECT user across scenarios);
- Annual incremental revenue per trip = $2.00 (COTA fare); and
- Average generalized price of travel per trip = $14.15 (calculated based on the COTA fare, expected travel time, expected buffer time, and specified values of travel time savings and reliability gains).

The change in annual transit demand is estimated as the percentage change in the generalized price of transit travel (equal to the monetized reduction in travel time and reliability costs divided by the analyst-specified baseline generalized price of travel) multiplied by the analyst-specified baseline number of affected annual trips and the analyst-specified generalized price elasticity of transit demand. For the example presented in Section 1.3.4, the projected annual change in transit demand associated with 250 annual T-CONNECT transactions ranges from 56 to 121. The change in annual transit revenue is estimated as the estimated change in annual transit demand multiplied by the analyst-specified incremental revenue per new transit trip ($113 to $242) While not directly in line with what was originally planned, the steps taken were sufficient to test the hypotheses. The evaluation plan addendum describes the changes from the evaluation plan to the steps taken.

2.3 Impacts Relating to Behavioral Change

With this impact area, the Volpe Center planned to investigate whether participants grow to depend on the software package and individual applications. The Volpe Center planned to do this by focusing on behavioral change based specifically on the IDTO bundle; that is, independent of the degree of demand. While limited user satisfaction survey data evidence from users was available to determine this, qualitative data from interviews conducted with transit agencies has helped to augment the analysis. Using this information, the

Volpe Center investigated the extent to which users developed a reliance on the bundle to improve their travel alternatives particularly during periods of disruption. The extent of reliance would create widespread implications for transit agencies and transportation network planning overall. The specific impacts assessed in this area are:

- Software package use is higher during disruptions
- Software package is relied on habitually

The hypotheses used to evaluate this impact area focus first on isolating the portion of demand for the software package or IDTO applications which acts as a function of one-time or individual circumstances, and second on determining continual or habitual use of the software package or applications. The specific hypotheses Volpe planned to test are as follows:

- H6: Demand for the IDTO bundle is a function of personal needs and traffic conditions.
- H7: The IDTO bundle is utilized by individual users on a continuous or repeated basis.

The evaluation of Hypothesis 6 supports the analysis of impacts on users, by disaggregating overall impacts on travel time by travel time savings and reliability gains. This was intended to be done with respect to systematic influences including travel conditions, such as relatively high congestion levels, and trip constraints, such as commutes to and from work. In turn, it was intended to help identify whether a disproportionate share of impacts accrue under primary contexts (e.g., that the bundle offers particularly high travel time savings under high congestion), which may improve the projection of impacts under full-scale implementation. While some information was available for analysis regarding these topics, the overall low usage of the bundle made the results less useful.

The analysis was designed to include a focus on service disruptions, such as incidents and accidents, inclement weather, or other unusual delays. While the Volpe Center did not assume that most IDTO users will only use the bundle during an incident, it is feasible that a disproportionate amount of the value offered by the bundle could manifest itself during disruptions. A reasonable and testable base expectation was that bundle use would be more likely under time constraints, such as commutes, and deteriorated traffic conditions or service disruptions.

Limited user satisfaction survey data from 17 respondents regarding application usage and satisfaction was gathered by Battelle and is presented in Section 3.3.1 for context. Information related to basic application usage was available from Battelle’s developer database and has been augmented by interviews conducted with Battelle and the transit agencies involved in the demonstration. However, based on the limits of the demonstration as well as data limitations, overlaying the trips logged with traffic network data would not have provided any additional value. To correct for these limitations, the interviews conducted with entities providing unique demand-response services addressed how these services, potentially used in coordination with IDTO, can be utilized to enhance mobility for travelers, particularly during service disruptions. This analysis is included in Section 3.3 of this report. A description of each entity can be found in Table 2-2 below.

Table 2-2. Description of Demand-Response Service Interviewees

Agency	Location	Description
128 Business Council	Greater Boston, Massachusetts	Transportation Management Association providing shuttle service to businesses along the Route 128 corridor of the MetroWest Boston area. Currently exploring filling excess capacity with demand response service.
Bridj	Washington D.C. Metro Area; Greater Boston, Massachusetts	Private transportation service using data-driven process and user demand to set origin-destination pairs for riders.
LYNX	Greater Orlando, Florida	Transit agency in Orlando, Florida operates NeighborLink, a flex-service designed to provide riders access to specific neighborhoods based on demand.
Middlesex County Area Transit	Middlesex County, New Jersey	Transit agency operates a route-deviation service which allows riders to deviate within two-blocks from a fixed route upon request.
Montachusett Regional Transit Authority	North Central Massachusetts	Transit agency operates a shuttle service from rural communities to metro areas based on demand. Destinations in metro areas are determined by riders.
San Joaquin Regional Transit District	Greater Stockton, California	Transit agency operates a route-deviation service called the Metro Hopper which allows for deviations of up to one mile from the normal fixed route.
Utah Transit Authority	Greater Salt Lake City, Utah	Transit agency operates a route-deviation service called Flex Routes which allows for deviations of up to ¾ of a mile from the normal fixed route.

The evaluation of Hypothesis 7 was intended to confirm the extent to which user demand became habitual, however, based on the low overall demand this impact was difficult to isolate. Transaction-level and software package usage information was used to test whether individual usage rates or levels (on an interval basis) were consistent with habitual or continuous use. This information was augmented by interviews conducted with Battelle to gain context. However, more complex analysis related to travel demand based on habitual and non-habitual usage was not possible because of the low overall demand for the bundle. Despite this, qualitative evidence was learned through interviews and various inferences have been made, as seen in Section 3.3.2 .

2.4 Impacts Relating to the Functionality of the IDTO Bundle

This impact area centers on the functionality of the IDTO bundle; that is, is the technology working? This impact area is inter-connected with several others because if the functionality of the bundle is inconsistent or inconclusive, then there is likely to be a ripple effect across several other impacts, such as demand, and the error bars around other impact estimates would need to be adjusted (up) accordingly. Based on the demonstration, this is deemed to have been the case to some degree.

This impact area is multidimensional, covering the experiences of both travelers and transit agencies. By determining the bundle's functionality, the Volpe Center first diagnosed if the software package and applications performed in the manner intended, and then, determined how practical the applications are, through a form of abbreviated benefit-cost analysis focusing on cost-effectiveness.

This impact area differs from system acceptance tests in that it is less detailed or rigorous and measures only what is necessary to demonstrate that changes in traveler behavior can be traced to software that functions as expected. The specific impacts assessed in this area are:

- Increased passenger throughput
- Increased fleet efficiency
- Increased rate of multi-modal transfers
- Increased rate of multi-agency transfers
- Benefits of software package exceed costs

There are several hypotheses used to evaluate this impact area. These hypotheses focus on user experience, the likelihood of making transfers and completing trips successfully, the applications' cost-effectiveness, and whether the applications function as they are designed to function. The specific hypotheses Volpe planned to test are as follows:

- Hypothesis 8: Predicted travel and wait time information from T-DISP improves users' ability to manage their trips.
- Hypoethesis 9: The IDTO bundle increases system efficiency.
- Hypothesis 10: T-CONNECT increases the likelihood of making successful transfers.
- Hypothesis 11: T-CONNECT and T-DISP are cost-effective applications for improving services and intermodal transportation.

These hypotheses link to the IDTO bundle's functionality by helping the Volpe Center to determine whether the software package adds value to users. The hypotheses also serve to determine if the IDTO applications represent tools to decrease overall and unit (i.e., passenger-level) costs, through both cost savings arising from improved vehicle utilization and passenger throughput. This analysis was augmented by cost discussions with entities who are utilizing unique demand-response services. Finally, these hypotheses incorporate post-trip survey respondent's opinions of the usability of the applications and software package and if the software functions as expected and whether or not that functionality affects their demand or usage.

An important component of the analysis for Hypothesis 9, 10, and 11 involved generating a simulated profile of trips within IDTO-BET. This included the representation of travel demand by users and non-users of the software package. The analysis included parameterized assumptions about general user behavior for transit trips, such as vehicle occupancy and distributions of expected trip times. Data on vehicle position, headways and ridership during the demonstration period supported the parameterization of trip details within the tool.

The Volpe Center's preferred means of assessing the degree to which the functionality of the bundle impacted system performance included one set each of behavioral outcomes, operational outcomes, and technical outcomes. The set of behavioral outcomes involved impacts on users' travel experiences, including the ability to manage trips, and the relative ease of making transfers. The Volpe Center assessed impacts on travel experiences through stated information from the limited post-trip surveys received (13 responses received total). In assessing impacts, the role of significance testing of post-trip survey responses was limited to confirming subjective views regarding the bundle's ability to improve users' ability to manage their trips and minimize travel time in trips involving transfers. Using IDTO-BET, a simulated comparison of observed trips by users relative to representative trips by non-users offered tangible evidence of value offered by the bundle in improving users' travel experiences. This analysis includes distributions of travel time savings for trips involving connections, by service type.

The set of operational outcomes focuses on passenger throughput and transit agency cost-effectiveness measures. Passenger throughput (by service type, measured in passengers per vehicle-hour or hour) was analyzed using IDTO-BET. It is not technically necessary to increase passenger throughput for the bundle to offer value to agencies, but changes in efficiency are a critical component of operational impacts represented in the analysis. This measure is also useful in determining the effect of idling vehicles due to T-CONNECT holding the vehicle for incoming passengers. Transit agency cost-effectiveness represents the broadest operational-level outcome evaluated; if the bundle does not yield cost-effective solutions to agencies, it could be difficult to justify investments in full-scale implementations of the bundle.[7] This topic is explored in Section 3.4.4 . The Volpe Center assessed cost-effectiveness through both qualitative (i.e., stakeholder interviews) and quantitative (i.e., estimates of cost per unit system improvement) means. Information from stakeholder interviews helped to identify both overall attitudes of stakeholders toward the value offered by the bundle, and specific areas where the bundle performs strongly or weakly.

The set of technical outcomes are chiefly diagnostic in nature. Significance tests of technical outcomes reveal how well T-CONNECT and T-DISP could perform given certain parameters. These tests were performed within IDTO-BET. The performance of T-CONNECT was evaluated to confirm the effectiveness of the system when T-CONNECT requests are honored at or above a target rate of 90 percent. The sample size of T-CONNECT transactions within the demonstration was insufficient to enable a direct test of the 90-percent effectiveness threshold.

2.5 Impacts Relating to Strategies of Usage

This impact area centers on specific strategies employed by travelers and transit agencies to improve their decision making. In other words, the Volpe Center attempted to determine how the technology was being

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[7] It is possible that this small-scale demonstration may have different cost-effectiveness than a full-scale roll-out due to economies of scale.

used. While a typical transportation network likely operates effectively under normal circumstances, problems may arise in cases of disruption or incidents that require one or multiple agencies to adapt. Measuring how effectively the IDTO bundle manages these scenarios and improves decision making, for both users and transit agencies, provides information on how significant the impact of the bundle is. By monitoring these scenarios, the Volpe Center would be able to determine the bundle's usefulness. The specific impacts assessed in this area are:

- Increased scheduling flexibility for transit agencies and users
- Increased routing flexibility for transit agencies
- Reduced effect (travel time loss) of disruptions on users and reduced burden of disruptions on transit agencies

The hypotheses used to evaluate this impact area focus on T-DISP's ability to support dynamic routing and scheduling and the ability of the software package and individual applications to mitigate the effect of and improve the reliability of travel alternatives under disruptions. The specific hypotheses Volpe planned to test are as follows:

- Hyopthesis 12: T-DISP extends demand response services to support dynamic routing, scheduling, and changing number of vehicles in service.
- Hypothesis 13: The IDTO bundle improves users' ability to mitigate effects of disruptions to the network.

The evaluation of Hypothesis 12 offers insight into the degree to which scheduling and routing flexibility improve users' transit experiences. This information was considered in concert with users' changes in transit demand to gauge the impact of demand-response services on overall transit ridership and trip quality improvements. Hypothesis 12 also enabled an analysis of the extent to which T-DISP impacts operational decisions, such as the share of vehicle trips that are impacted by T-DISP transactions, and costs. Hypothesis 13 links to the strategies of bundle usage impact area by allowing Volpe to determine the level of flexibility that the bundle adds to the transportation network and as an indicator for whether the software package or individual applications are used by travelers to mitigate the effect of disruptions.

The Volpe Center's preferred means of assessing the degree to which users and agencies use the bundle strategically included behavioral outcomes for users and agencies. The user-specific set of outcomes focused on the use of the bundle as a strategic tool for mitigating the effects of disruptions to the travel network or transit system. That is, separate to analyses of overall bundle use, this set of outcomes relates to strategic use of the bundle to minimize effects of reduced levels of service due to unusual traffic congestion or transit service disruptions. Consistent with the approach to assessing user-centered impacts relating to the functionality of the bundle, the Volpe Center assessed strategic use of the bundle by travelers through analyses of information from post-trip surveys.

In assessing user-centered impacts, the role of significance testing of post-trip survey responses was limited to confirming subjective views that the bundle improves users' ability to mitigate the effects of disruptions to the traffic network or transit system. Based on the limited sample size of post-trip survey responses (13 received in total), this analysis is not as robust as was originally planned.

As a result, the analysis was augmented by data collected from in-depth qualitative interviews conducted with transit agencies, both those who participated in the demonstration and agencies who were interviewed based on the unique demand-response services they operate. The information collected in these interviews was then inputted and used to conduct tests within IDTO-BET.

The agency-specific set of outcomes focuses on the role of T-DISP in influencing operational decisions for demand-response services. During in-depth interviews with providers of demand-response services, the Volpe Center investigated hypotheses that dynamic demand-response leads to significant levels of route variations, schedule variations, and changes in active fleet size. Variations in schedule refer to cases where vehicles are held to pick-up a rider. Variations in route refer to cases where demand-response vehicles change course to pick up a rider. Variations in the fleet size were listed in previous bundle documentation, although it is unclear if transit agencies intend on making such adjustments. These tests were based on the qualitative transit agency interviews conducted both from agencies involved with the demonstrations and with agencies conducting other demand-response services.

The degrees to which T-DISP added flexibility in routing and scheduling demand-response vehicles is reflected as a relatively intangible impact in the analysis. Changes in active fleet size involves two distinct, tangible impacts: changes to operating costs, such as product of net change in vehicle-hours and cost per vehicle-hour, and impacts on travel times and wait times arising from changes in active fleet size.

2.6 Impacts Relating to Inter-Agency Cooperation

The final impact area centers on transformative operational changes in inter-agency cooperation. Many of the benefits of the IDTO bundle - and T-CONNECT, in particular – can be increased through higher levels of collaboration between agencies. Volpe believed that establishing strategies to support the success of transfers involving transportation provided by multiple agencies, such as transfers between Capital Transportation and COTA services, may improve the effectiveness of T-CONNECT transactions involving multiple agencies, relative to purely arms-length operations. Furthermore, Volpe expected that the presence of the bundle itself could reduce barriers to cooperation between agencies by placing attention on the interdependence of transit services across agencies and on specific high demand transfers. Viewing the impact of the bundle more broadly, Volpe sought to determine if the presence of the software package stimulated increased cooperation between agencies, by framing otherwise independent transit alternatives as part of a cohesive unit. The specific impact assessed in this area is:

- Increased levels of inter-agency communication, stream-lining improvements and mitigating confusion, disruption, and operational inefficiencies

Similar to the travel times hypotheses, these hypotheses focus on capturing the change in coordination between different agencies which already communicate to varying degrees. The specific hypothesis Volpe planned to test is as follows:

- Hypothesis 14: The IDTO bundle stimulated increased coordination to enhance effectiveness among transit agencies and others.

The evaluation of this hypothesis helped to gauge the extent of any observed improvement in inter-agency cooperation, both in general and for the purpose of improving service. Changes in inter-agency coordination were likely the least tangible outcome to link to impacts, but they do serve to frame the scope for broader improvements to service quality arising from implementing the bundle.

The Volpe Center's preferred means of identifying impacts relating to inter-agency cooperation was qualitative, focusing on insights gained from stakeholder interviews. Interviews were conducted with demonstration participants in Columbus throughout the demonstration and on a one-time basis with agencies in Central Florida, after the proof-of-concept demonstration, as described in Table 1-1. Volpe collected and analyzed stated attitudes toward inter-agency cooperation through Likert-scale responses, in conjunction with responses to open-ended interview questions on the subject. The stakeholder interviews were designed to elicit views on the role of the bundle in improving both coordination between agencies and overall service quality, along with views on the extent to which agencies have worked together to enhance the effectiveness of T-CONNECT. Volpe explored two directions of causality: whether the bundle increases cooperation, and whether cooperation increases the effectiveness of the bundle and its components.

Chapter 3 Impact Assesment Findings

This section described the findings of the IA by impact area and hypothesis. Findings are based on the analysis and evaluation steps described in Section Chapter 2 above.

3.1 Findings Relating to Travel Time Impacts

3.1.1 Hypothesis 1: The IDTO bundle enables users to reach destinations faster compared to the baseline or non-users

Based on tests via IDTO-BET, the IDTO bundle enables users to reach destinations faster compared to non-users.

IDTO-BET was applied to evaluate the extent of travel time savings that could be realized by IDTO bundle users, relative to non-users. T-CONNECT scenarios comprised the focus of the analysis, due to the relatively large set of T-CONNECT-related data collected during the demonstration. T-DISP and D-RIDE scenarios were also evaluated; due to the lack of T-DISP and D-RIDE activity in the demonstration, the scenarios were calibrated with respect to assumptions based on in-depth interviews and data sources external to the demonstration.

The base-case scenarios examined for T-CONNECT centered on travel time and reliability impacts for individual T-CONNECT transaction requests for three predominant service headways, as identified in COTA service data (15-minute-, 25-minute and 40-minute headways). Within the base-case scenarios, COTA vehicle schedule adherence data were used to represent the likelihood that connecting vehicles would be within sufficient windows to activate a protected connection (represented as means and standard deviations of schedule adherence). COTA data on passenger counts were applied to represent the average number of on-board passengers that would be negatively affected by vehicle holds. The constraints set within the demonstration regarding holding time and schedule adherence described in Section 1.3.1 were applied to represent the feasibility of a given simulated T-CONNECT request (i.e., designating whether a given request was necessary and allowable).

Across the base-case scenarios, IDTO-BET indicated that T-CONNECT would offer clear travel time reductions for IDTO bundle users. The key estimated impacts are summarized in 3-1:

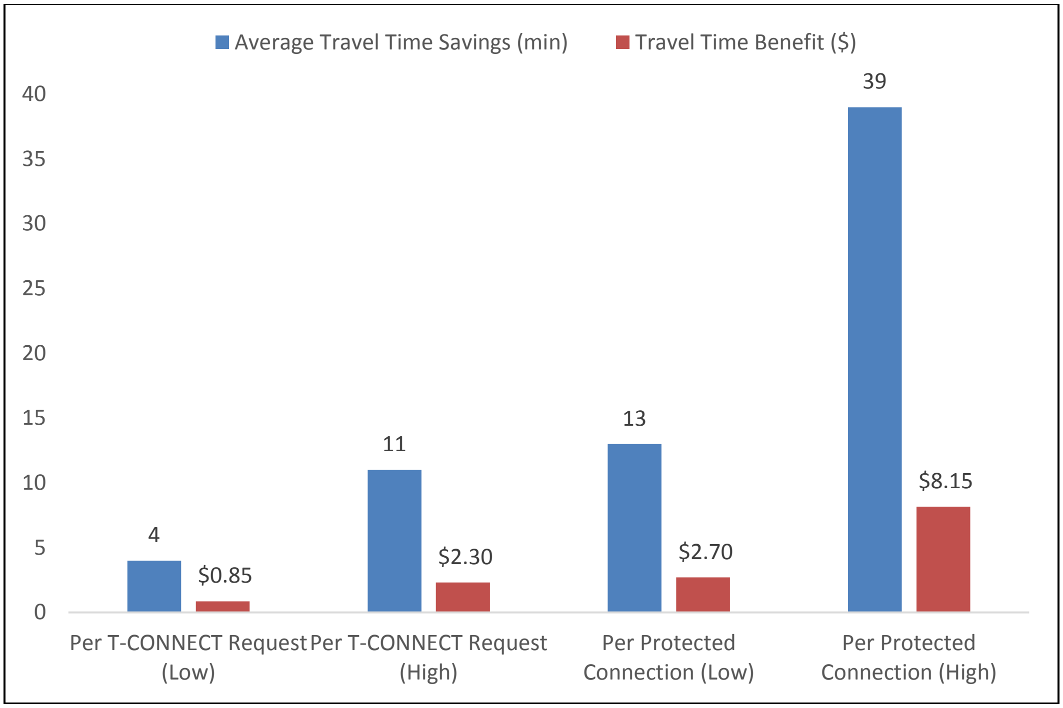

Figure 3-1. Estimated T-CONNECT Impacts (Source: Volpe Center)

The average travel time savings associated with a T-CONNECT request was projected to range from approximately 4 minutes (for connections to services with 15-minute headways) to approximately 11 minutes (for connections to services with 40-minute headways). IDTO-BET indicated that only 29 percent of simulated T-CONNECT requests would be both necessary (i.e., the incoming vehicle is expected to arrive with insufficient time to ensure that a connection to an outgoing vehicle is made) and feasible (i.e., the incoming vehicle is expected to arrive within an interval that will not cause the delay of the outgoing vehicle to exceed a specified threshold). This indicates average travel time savings per successful (i.e., enacted) connection protection via T-CONNECT of between 13 and 39 minutes (i.e., 4 to 11 minutes, divided by 29 percent); applying the value of personal travel time savings from USDOT guidance, the average monetized value of travel time savings per successful T-CONNECT transaction was projected to range between around $2.70 and $8.15. The expected level of travel time savings was projected to be invariant to the factors investigated within sensitivity analyses (see the discussion of Hypothesis 2 below).

The scenarios evaluated for T-DISP indicated the potential for users to experience considerable travel time savings, due to reductions in both travel time and waiting time (an average of approximately 22 minutes in total, per transaction). However, the speculative nature of the T-DISP scenarios, which represented transactions that did not occur within the demonstration, limits the extent to which the findings may be representative. The D-RIDE scenarios were designed to incorporate (unavailable) information on the supply and demand relating to first-mile and last-mile ridesharing transactions. Although it is reasonable to expect that D-RIDE would offer travel time savings to users, there were no sufficient data available to quantify the extent of travel time savings. Rather, the primary quantifiable result associated with D-RIDE was an increase in transit demand, reflecting a hypothesized relationship in which dynamic ridesharing would link users to transit trips that would be otherwise impractical.

3.1.2 Hypothesis 2: The IDTO bundle enables users to reach destinations more reliably compared to the baseline or non-users

Based on tests via IDTO-BET, the IDTO bundle enables users to reach destinations more reliably compared to non-users.

The base-case T-CONNECT scenarios indicated that users would experience reliability improvements, on average. The tool projected a narrower range of impacts on buffer time (i.e., 95th-percentile trip time) across connecting service headways than for travel time, with average buffer time reductions of around two minutes for 15-minute and 25-minute headways, and around 2.5 minutes for 40-minute headways per T-CONNECT request. These values could feasibly be scaled up by 3.44 (1/0.29) to account for the frequency with which T-CONNECT holds were projected to be necessary and feasible. However, the trip planning aspect associated with buffer time (i.e., involving a decision on how early to depart) is more closely aligned with the choice whether to make a T-CONNECT request than with whether a given T-CONNECT hold was enacted.

Estimated monetized values of reliability gains were identified by applying the value of time savings from U.S. DOT guidance to estimates of buffer time reductions, as indicated in research by Ubbels, et al. (2005) and Fowkes, et al. (2015). The average estimated monetized values of reliability gains per T-CONNECT transaction range from $0.38 (for 15-minute headways) to $0.51 (for 40-minute headways). This range is much narrower than the corresponding range for user travel time benefits, due to a lower projected sensitivity of buffer time to service frequency compared to the sensitivity of travel time benefits.

The expected level of reliability benefits was sensitive to a range of factors, as investigated in sensitivity analysis:

- As trip time on board the connecting vehicle increases, reliability benefits increase (representing proportional impacts of missing connections to longer trips);
- As variability of trip time on board the connecting vehicle increases, reliability benefits increase (representing proportional impacts of missing connections to trips of relatively uncertain length); and, deterministically
- As the value of reliability gains increases, reliability benefits increase (representing uncertainty in the specific values that users would place on reliability, as supported by ranges of estimates in the literature).

The scenarios evaluated for T-DISP indicated the potential for users to experience considerable reliability gains (an average of around 13 minutes per transaction, or a monetized value of $2.71 per transaction). However, the speculative nature of the T-DISP scenarios, which represented transactions that did not occur within the demonstration, limits the extent to which the findings may be representative.

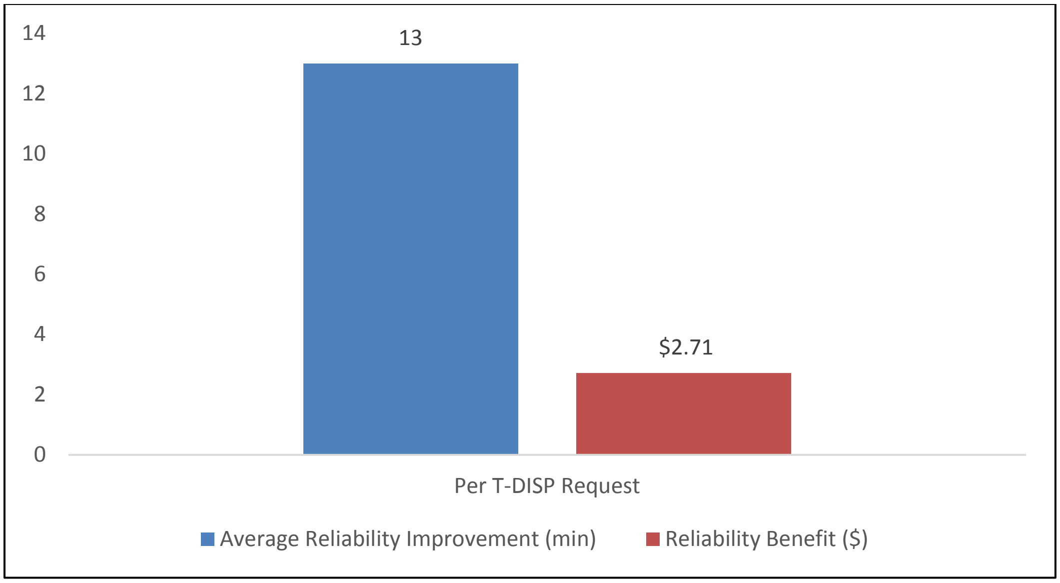

Figure 3-2. Estimated T-DISP Impacts (Source: Volpe Center)

3.1.3 Hypothesis 3: The IDTO bundle reduces passenger wait times at the origin and during transfers

Based on tests via IDTO-BET and the results of Hypothesis 1, the IDTO bundle reduces passenger wait times.

The data available from the demonstration limit the extent to which impacts on waiting time can be evaluated within the tool (in particular, no data were available on waiting time at the origin). However, the travel time benefits projected for T-CONNECT transactions represent reductions in waiting time at the connection point. Hence, the full set of T-CONNECT travel time benefits reported for Hypothesis 1 also apply to Hypothesis 3.

Furthermore, the T-DISP scenarios include assumed reductions in waiting time under demand-response service. However, the speculative nature of the T-DISP scenarios, which represented transactions that did not occur within the demonstration, limits the extent to which the findings may be representative.

3.2 Findings Relating to User Demand Impacts

3.2.1 Hypothesis 4: The IDTO bundle was consulted and used at a meaningful level

Based on usage rates, the IDTO bundle was not consulted or used at a meaningful level.

Overall, generating demand and usage for the IDTO bundle was a considerable challenge for the PD team. As a result, the bundle deployed in Columbus that incorporated T-CONNECT and the trip planning component of T-DISP was not consulted or used at a meaningful level. The application was downloaded by 1,174 users over the course of the demonstration and only 1,097 trips were logged. Those trips were logged by 189 users or

16% of the individuals who downloaded the application. While 386 T-CONNECT opportunities were created on these trips (i.e. the trip included a T-CONNECT applicable transfers from CABS to COTA or Capital Transportation to COTA), only 11 T-CONNECT requests were actually sent to COTA. Of those, four were accepted and enacted. These figures reflect two possible findings: Demand for the bundle itself was low or users did not find the application useful (i.e., the bundle did not meet user demand).

Interview responses from Battelle and participating transit agencies indicated that, despite what they believed to be a valuable tool, there was an apparent lack of demand among riders. One interviewee from CABS stated that she was surprised by the lack of demand. Despite social media outreach, marketing efforts, and outreach and incentives for student groups at OSU, particularly when more students returned for the Fall semester, demand did not increase as the demonstration progressed. There are several possible reasons for this, one of which could be related to the user interface of the application described in Section 3.3.1 below. Another could be related to the fact that the application itself, as well as the marketing efforts, did not appear to clearly communicate the connection protection feature of T-CONNECT and the application appeared to users as a traditional planning app. As application downloads occurred throughout the course of the demonstration in both the summer and fall months, the IA team does not feel that the limited overall demand was the result of the calendar timing of the demonstration.

3.2.2 Hypothesis 5: Transit demand is a positive function of IDTO bundle usage

Based on usage rates and interviews, the IDTO bundle did not lead to increased transit demand. Based on tests via IDTO-BET, transit demand could increase with IDTO bundle usage, through reductions in the generalized price of transit travel.

Based on the overall lack of demand for the application, as well as interview responses from transit agencies, there was no evidence from the prototype demonstration that the IDTO bundle led to an increase in demand for transit. Agencies felt that, through the demonstration, transit demand was relatively constant and the bundle would simply enhance value for existing transit riders. However, attitudinally, transit agencies interviewed speculated that if the bundle were deployed in a broader setting there would be a positive impact on transit demand. In addition, IDTO-BET includes components that project changes in transit demand with respect to changes in the generalized price of transit travel. Changes in the generalized price are measured as changes in travel time and reliability costs, and are calibrated with respect to an assumed generalized price elasticity of transit demand.

One interviewee from CABS stated that if, the bundle were rolled out simultaneously with other network changes or transit alternatives, she would expect an increase in demand for both transit and the application. One interviewee from UCF described a complicating factor related to access: because IDTO could be used to integrate open (public transit) and closed (private services such as the UCF shuttle available only to students and staff) systems, this dynamic option could be limited to a subset of users. In other words, not all riders would have access to all transit systems or bundle components within the application. This could have the effect of limiting demand for the application for certain users and also lead to equity and access concerns depending on the transportation network the system is being implemented in. Ultimately, care should be exercised when including functionality to an application of IDTO that may not be available to all users. Although this limitation was present in the planned demonstration, this limitation may not be typical of settings where the IDTO bundle may be enacted.

The T-CONNECT and T-DISP scenarios investigated in IDTO-BET included components that projected changes in transit demand due to changes in the generalized price of transit travel. For both T-CONNECT and T-DISP, changes in the generalized price of transit were calculated as the monetized value of reductions in travel time and buffer time, relative to an assumed base generalized price of travel that represented baseline travel time and buffer time. The assumed value of travel time savings was taken from USDOT guidance ($12.50 per hour), and the same value was applied for reliability gains, as indicated in research by Ubbels, et al. (2005) and Fowkes, et al. (2015).

Projected percentage changes in generalized prices of travel were multiplied by an assumed generalized price elasticity of transit demand of -0.63, based on recommendations from Litman (2015); the value of -0.63 represents the implied generalized price elasticity based on the recommended transit service quality elasticity (0.5) and the share of travel time and reliability costs within the generalized price (the only other component of generalized price is the fare).

In the main T-CONNECT analytical scenario, IDTO-BET indicated that the use of T-CONNECT would stimulate an increase in transit demand ranging from around six percent (for users connecting to services with 15-minute headways) to around 15 percent (for users connecting to services with 40-minute headways). The projected impacts on transit demand were larger for T-DISP than for T-CONNECT (an increase of around 32 percent). The projected monetized travel time and reliability impacts were larger for T-DISP than for T-CONNECT, leading to a stronger response. This is also an intuitive result, in that demand-response service would improve transit system access, stimulating demand. Furthermore, a new demand-response service may attract additional riders that would not otherwise use transit; IDTO-BET assumed that each use of T-DISP by a user that did not formerly use transit would be associated with an additional 0.5 new transit trips.

3.3 Findings Relating to Behavioral Change Impacts

3.3.1 Hypothesis 6: Demand for the IDTO bundle is a function of personal needs and level of service

Based on usage rates and interviews, demand for the IDTO bundle was not a function of personal needs and level of service, however, in the future the bundle could fill that role.

Based on the limited demand for the IDTO application within the demonstration, it is difficult to determine what drove bundle usage by individual users. After assessing the application usage information within Battelle’s developer database, there is no clear trend or discernible pattern that indicates reasons for usage, such as commutes. One possibility of usage was that users downloaded the application and used it for its trip planning features; however, users did not tend to save or log their planned trips, making it infeasible to confirm trip planning activity. *Notably, this saving action was required in order to initiate a trip and generate a T-CONNECT request. That fact was not made clear within the application.* The conclusion that the application was potentially used for planning purposes and trips were simply not “saved” is purely circumstantial, however, and based on the fact that 1,174 users downloaded the application but of those only 189 initiated or “saved” trips.

While not specifically relating to personal needs or level of service, Battelle administered a user satisfaction survey that in part addressed the demand for the application. 17 users responded to that survey. When asked how many times they had planned a trip using C-Ride, five respondents had not planned a trip, 9 had planned one to two trips, two had planned three to five trips, and one had planned more than five trips. Ten respondents felt that the application was not easy to use and the remaining seven felt that it was. When asked to indicate components that need improvement:

- 7 of 17 felt that the user experience needed to be improved,
- 6 of 17 felt that the bus schedule options needed to be improved,
- 6 of 17 felt that the time and location entry needed to be improved,
- 6 of 17 felt that the account creation needed to be improved,
- 2 of 17 felt that the notifications and reminders needed to be improved, and
- 2 of 17 felt that nothing needed to be improved.

Based on these responses, despite the small sample size, it is clear that the majority of users found the application difficult to use and that improvements were possible and necessary. These user-interface and functionality problems may have contributed to the lack of demand for the application and the bundle.

When asked their overall level of satisfaction using C-Ride, seven respondents were very dissatisfied, seven respondents were dissatisfied, one respondent was satisfied, and two respondents were very satisfied. When asked what has caused them to not use the app, one respondent took another form of transportation, eight respondents stated using another app for transportation planning, and eight respondents stated that the app wasn’t useful. Finally, when asked how likely they were to use C-Ride again, four respondents were very unlikely, six respondents were unlikely, six respondents were likely, and one respondent was very likely.

Based on these responses, the responses to the open-ended question within the user satisfaction survey, and the overall usage of the IDTO bundle, demand for the application appeared to be low based on a lack of usefulness and usage of other transportation planning applications such as Google. Additionally, it is unclear if users were able to distinguish the application from a more traditional transit planning app. Based on this, it is unclear what the level of demand was, or would be, for the IDTO bundle and the concepts employed by T-CONNECT, T-DISP, and D-RIDE.

Of the demand that did exist for the application, Volpe observed little evidence of variability in usage based on personal needs and level of service. Instead, usage of the bundle appears to have been driven by: incentives provided to sub-groups of students at OSU; and Capital Transportation drivers building it into their operating procedure. This is consistent with the interviews conducted with demonstration transit agencies, who viewed application demand as generally lacking, and who did not see a connection to riders’ personal needs or level of service.

In fact, one interviewee from COTA noted something along the lines of the opposite occurring. He stated that COTA doesn’t currently connect with CABS very often based on CABS having generally less frequent service. This indicates a lack of personal need for T-CONNECT and IDTO, based on the levels of service, which could have contributed to the lack of demand for the application and the bundle.

Interestingly, the entities providing unique demand-response services highlighted a strong connection between personal needs and level of service and demand for their services. Agencies noted that their services are particularly effective at connecting riders to activity centers or specific areas that traditional transit services may not serve as well. These areas specifically included hospitals and VA facilities, or in the case of the Montachusett Regional Transit Authority, court houses and legal offices. These activities typically require appointments. As a result, riders placed a premium on effective and reliable transit services that would meet their needs and get them to their appointments on time. A more general example came from the 128 Business Council, an entity that connects employment centers in the suburban belt around Boston to public transit. This service fills a niche demand for riders in an area that is underserved by traditional transit. This finding indicates that if the IDTO demonstration had incorporated a demand-response service component, demand for the bundle, and consequently the application, may have been a positive function of personal needs.

3.3.2 Hypothesis 7: The IDTO bundle is utilized by individual users on a continuous or repeated basis

Based on usage rates, there was little overall evidence of continuous or repeated use of the IDTO bundle.

There was limited evidence of repeated application usage. The 1,097 trips that were logged during the Columbus demonstration were created by 189 travelers, including three tablets installed on Capital Transportation vehicles at DSCC. Capital Transportation tablets accounted for 410 or 37% of all trips logged; however, it is unknown how many travelers requested those trips. Of the remaining 63% of trips, a small group of 11 users logged ten or more trips, including one user who logged 100 trips. In total, the three tables at Capital Transportation and the 11 users who logged ten or more trips accounted for 64 percent of all trips.

These figures indicate a degree of repeated usage among a small group of travelers. However, the motivation for this usage is unclear. Capital Transportation drivers were given discretion to request T-CONNECTS (i.e., log trips) based on their vehicle position in relation to COTA vehicles, and it is unclear how many of the 410 trips logged were driven by traveler request or input. Additionally, incentives were provided and offered to sub-groups of students at OSU. As a result, the identified repeat users could have been responding to those incentives, rather than a desire to continue using the bundle on a habitual basis. Of the 11 repeat users, five provided OSU e-mail addresses. Overall, those using the application were likely to be part of the student population at OSU, as non-campus origins were outliers.

3.4 Findings Relating to Functionality Impacts

3.4.1 Hypothesis 8: Predicted travel and wait time information from T-DISP improves users' ability to manage their trips

Based on limited user survey information, using T-DISP helped users manage their trips.

As noted in Section 2.4, the limited number of post-trip survey responses makes testing this hypothesis difficult. However, as can be seen in the table below, of the responses received the majority of respondents feel that using the bundle did help to improve their ability to manage their trips.

The question posed to respondents appears in the left-hand column and the possible responses are listed along the top row. The figures within the table represent the number of respondents corresponding with each answer.

Table 3-1. User Post-Trip Survey Responses Related to Hypothesis 8

Question:	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	N/A
Predicted travel and wait times from C-Ride improve my ability to manage my trips	1	1	2	0	4	3	1	1

3.4.2 Hypothesis 9: The IDTO bundle increases system efficiency

Based on tests via IDTO-BET, the IDTO bundle may increase system efficiency, conditional on ridership volumes and service frequencies.

IDTO-BET represents changes in system efficiency through net impacts on travel time across all riders. That is, to gain insight into the efficiency of the transit system, hypothesized impacts on passenger throughput are investigated through projected impacts on average travel times for all riders. The key distinction is that other hypotheses centering on travel time impacts focus on how travel times for IDTO bundle users change.

However, offering travel time savings to bundle users through connection protection and route deviation comes at a cost (of delay) to other riders. To gauge impacts on passenger throughput (i.e., how many passengers the system can move over a given interval), it is necessary to gauge the extent to which user benefits are offset by non-user disbenefits.

The base-case T-CONNECT scenarios indicate improvements in system efficiency, with an average net travel time savings of between approximately four minutes (for connections to services with 15-minute headways) and 27 minutes (for 40-minute headways) per successful T-CONNECT. This represents average non-user delay disbenefits of around 8.5 minutes per T-CONNECT request.

Sensitivity analysis confirmed that increases in system efficiency would not be universal under T-CONNECT. With sufficiently high passenger loadings and low service headways, the net impact of an average T-CONNECT becomes negative; delays to passengers on board were projected exceed travel time benefits to T-CONNECT users connecting to services with 15-minute headways and with 15 passengers on board.

Hence, T-CONNECT may not offer system efficiency gains when applied to connections to high-demand vehicles, especially when those vehicles operate with low headways. Ultimately, T-CONNECT appears to offer system efficiency gains for services where relatively few riders would be disadvantaged, and when users stand to yield a relatively large travel time benefit. Volpe conducted a sensitivity analysis to identify thresholds within which T-CONNECT offers system efficiency gains; the results, which include combinations of ridership levels and service frequencies defining such thresholds, are presented in Section 4.4.

The base T-DISP scenario indicated a neutral net impact on travel times. Based on the assumptions seeding the analysis (which are speculative), the key system-wide benefits yielded by T-DISP are restricted to reliability gains; T-DISP would not impact passenger throughput meaningfully.

3.4.3 Hypothesis 10: T-CONNECT increases the likelihood of making successful transfers

Based on tests via IDTO-BET, T-CONNECT increases the likelihood of making successful transfers.

IDTO-BET offered clear evidence that T-CONNECT would increase the likelihood of making successful transfers, conditional on the set of constraints establishing which connections are eligible for protection. Using the parameters on connection protection applied within the demonstration, along with COTA data on bus arrival times, IDTO-BET indicated that 29 percent of T-CONNECT requests would result in protected connections that mitigated missed connections (i.e., with vehicle holds enacted). Hence, T-CONNECT usage under the assumed set of parameters and vehicle activity would increase the likelihood of making successful transfers. This result is borne out by the projected travel time savings for T-CONNECT users, which would be comprised specifically of mitigated transfer time.

Table 3-2. User Post-Trip Survey Responses Related to Hypothesis 10

Question:	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	N/A
The Connection Protection feature of C-Ride helps me make transfers between different types of transportation	0	2	3	0	1	0	1	6
The Connection Protection feature of C-Ride improves my ability to make transfers between different transit services providers (e.g. COTA, Taxi company)	0	3	2	0	0	1	1	6

3.4.4 Hypothesis 11: T-CONNECT and T-DISP are cost-effective applications for improving services and intermodal transportation

Based on cost information, interviews, and tests via the IDTO-BET, T-CONNECT and T-DISP are cost-effective applications.

Overall, agencies involved in the demonstration found that operating T-CONNECT and T-DISP was a cost-effective way to improve their services and provide additional value to their riders. Attitudinal responses from agencies concluded that the value of the connection protection and other features would be greater than the costs of the bundle, particularly if a large implementation was adopted that included increases in transit use. When asked if “T-CONNECT is a cost-effective application for improving transit services,” respondents from COTA, UCF, and LYNX all either somewhat agreed or agreed. Similarly, when asked if “T-CONNECT is a cost-effective application for improving intermodal transportation,” respondents either somewhat agreed, agreed, or strongly agreed. Battelle estimated the costs that could be attributed to each agency for the Columbus demonstration and determined the following:

Table 3-3. Bundle Implementation Costs per Agency

Agency	Cost
CABS	$6,000
Capital Transportation	$6,280
COTA	$3,500
Total	$15,780

These cost estimates include the resources required to convert data into usable GTFS format in order to operate the bundle, labor spent on other data filtering activities, operator training, and hardware. The hardware included the tablets installed at COTA’s center of operations and on the Capital Transportation vehicles. The only recurring cost was the monthly data plans purchased for the data terminals operating on the Capital Transportation vehicles ($40 per month per terminal).

If IDTO were to be implemented in the future by other agencies, costs would vary based on several factors. The quality and compatibility of existing data feeds would likely determine the amount of time level of effort required to implement the system. Additionally, depending on the nature of the implementation, hardware may be purchased and installed or the entire bundle could be implemented utilizing software and existing data terminals and communication equipment. Interview participants also confirmed that additional staff could be required if bundle usage exceeded a certain threshold (and if automation were not a sufficient strategy to address high bundle demand with a given staffing constraint), which could increase costs substantially.

IDTO-BET indicated that there is a broad range of achievable outcomes in which T-CONNECT would be cost-effective. The average monetized user benefit per T-CONNECT request projected by IDTO-BET ranges from around 60 cents to over two dollars (around $1.30 per request across all scenarios). At an annualized cost of $3,500 (see Table 3-3 above) and 250 days of service per year (i.e., business days), aggregate net benefits would exceed system costs when at least seven to 23 T-CONNECT requests were made per day; this corresponds to a range of approximately two to seven implemented vehicle holds per day. Furthermore, IDTO-BET projected increases in transit demand – and hence revenue – associated with reductions in the generalized price of travel when using T-CONNECT. If the increase in transit revenue is greater than the associated increase in transit operating costs, one may apply the projected increase in revenue net of operating costs as a rebate against T-CONNECT system cost. IDTO-BET projected increases in transit revenue ranging from around $0.50 to $1.20 per T-CONNECT request; the corresponding lower bound volume of daily T-CONNECT requests when applying new transit revenue as a rebate to T-CONNECT system costs ranges from four to 13.

IDTO-BET did not indicate a clear case of cost-effectiveness for T-DISP, driven chiefly by neutral net effects on travel time. However, the scenario specified in the tool was speculative; system designs limiting delays to passengers on board and offering sufficient service improvements to users would be cost-effective.

3.5 Findings Relating to Strategies of Usage Impacts

3.5.1 Hypothesis 12: T-DISP extends demand-response services to support dynamic routing, scheduling, and changing number of vehicles in service

Based on interviews, T-DISP does not extend demand-response services to support dynamic routing, scheduling, and service changes.

As noted in Section 2.5 above, this hypothesis was not fully tested as no demand response service was involved in the demonstration. However, based on interviews with transit agencies, attitudinal responses indicate that the overall bundle of applications would not have an impact on operations related to routing, scheduling, or the number of vehicles in service. Agencies involved in the demonstration viewed the bundle as a tool that could provide value to customers and would minimally impact service (i.e., when a vehicle is held to protect a connection) but there would not be a major impact on operations or a change in scheduling or level of service.

It is likely that these responses were influenced to some degree by the fact that there was no dynamic or demand-response service involved in the demonstration. For this reason, unique demand-response service providers were also contacted and interviewed to gain their opinion on how their services support dynamic routing, scheduling, and service.

The demand-response service providers we contacted were pleased with their ability to implement systems that provide dynamic routing that meets the demand of niche riders in a way that traditional fixed-route service do not. Route-deviation services in San Joaquin, California (the Metro Hopper), Middlesex County, New Jersey (Community Shuttle), and Salt Lake City, Utah (Flex-Routes) field requests from their riders on certain fixed routes and allow those routes to deviate based on the request. For example, the Flex Routes in Utah travel a fixed route and allow for deviations of ¾ of a mile to either pick up or drop off passengers.[8] Agencies feel that these services help to meet demand for riders by incorporating dynamic routing and scheduling, without

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[8] UTA: Flex Routes. http://www.rideuta.com/uploads/FLEX_factsheet_january2015.pdf

negatively impacting operations. Agencies operating these services feel that they are cost-effective because some riders who previously required comparatively more expensive paratransit services can shift to the route-deviation service. The initial demand-response services operated by San Joaquin Regional Transit District cost over $50 per trip to operate, however, the Metro Hopper service now averages $19 per trip with five to seven cycles per day.

Overall, the agencies we spoke to do not change the number of vehicles that they operate based on demand. They have created demand-response services where riders can interact with dispatchers or drivers and fluctuations and variations may exist within the parameters of the system created. However, these systems do not require day-to-day operational changes in the level of service provided.

One unique example was from a small suburban agency, Montachusett Regional Transit Authority, which operates a purely demand driven shuttle system that will only operate if a request has been made in advance. However, this system still operates by coordinating with the dispatcher as described above. Based on the operational conversations with these agencies, Volpe concluded that IDTO, and T-DISP in particular, could be built into the existing systems of these agencies and riders could use IDTO to make demand-response requests.

3.5.2 Hypothesis 13: The IDTO bundle improves users' ability to mitigate effects of disruptions to the network

Based on limited user survey information, the IDTO bundle did not clearly improve users' ability to mitigate effects of disruptions to the network.

As noted in Section 2.5 above, a limited number of post-trip survey responses are the only data that was available and useful regarding how IDTO helps users when there are disruptions to the transportation network. Unfortunately, based on the small sample size, the information presented in the table below does not provide much information regarding how IDTO helps travelers during periods of traffic or disruption.

As seen in Section 3.4.3 , a large portion of the 13 post-trip survey respondents answered “not-applicable,” indicating that they either did not understand the technology driving IDTO, or more likely, they did not utilize the application to make transfers. Of the remaining respondents, the majority appeared to either disagree or were neutral with the questions regarding the role that C-Ride played in providing travel alternatives and avoiding disruptions.

Table 3-4. User Post-Trip Survey Responses Related to Hypothesis 13

Question	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	N/A
The Trip Planning feature of C-Ride allows me to FIND travel alternatives during heavy traffic or other disruptions	0	4	1	2	0	0	2	4
The Trip Planning feature of C-Ride allows me to USE travel alternatives during heavy traffic or other disruptions	0	4	0	2	0	1	1	5
C-Ride reduces the impact that heavy traffic or other disruptions have on my trips	1	3	0	2	2	2	0	3
The Connection Protection feature of C-Ride allows me to FIND travel alternatives during heavy traffic or other disruptions	0	3	0	2	0	0	1	7
The Connection Protection feature of C-Ride allows me to USE travel alternatives during heavy traffic or other disruptions	0	3	0	2	0	0	1	7
The Rideshare feature of the C-Ride application allows me to FIND and USE travel alternatives during heavy traffic or other disruptions	0	3	1	0	1	0	0	8

3.6 Findings Relating to Inter-Agency Cooperation Impacts

3.6.1 Hypothesis 14: The IDTO bundle stimulated increased coordination to enhance effectiveness among transit agencies and others

Based on interviews, the IDTO bundle stimulated increased coordination among transit agencies.

Based on interviews with transit agencies who participated in the demonstration, implementing the IDTO bundle did increase coordination between agencies and entities and enhanced their overall effectiveness. When asked if "organizations increased coordination to enhance the effectiveness of T-CONNECT," respondents from CABS, Capital Transportation, and COTA all either agreed or strongly agreed when queried multiple times throughout the demonstration.

When asked if "organizations increased coordination to enhance the effectiveness of T-DISP," respondents either somewhat agreed, or agreed when queried multiple times throughout the demonstration. When asked if "the presence of the IDTO bundle motivated an increase in coordination across organizations," respondents either somewhat agreed, agreed, or strongly agreed when queried multiple times throughout the demonstration.

Attitudinally, agencies felt strongly that the formal implementation of the bundle led to much desired integration and interaction between agencies. In particular, CABS as a college-area service greatly appreciated the opportunity to interact with COTA, the regional transit agency, and felt that both agencies could benefit from increased communication as their services evolve. Specifically, as the agencies planned to redesign their service schedules, they intended to communicate their plans with each other to ensure that the systems interface in the most efficient way possible.

Another example of the impact of the enhanced coordination between agencies relates to the link between COTA and Capital Transportation on DSCC's campus. During the course of the demonstration, COTA's paratransit service, Mainstream, would change their operations and would no longer bring riders directly to their destination within DSCC. Instead, Mainstream would pick-up and drop-off riders at one central location and Capital Transportation would operate as the only transportation service on the base. Based on the interactions developed during the demonstration, this policy change and the interface between the two agencies was improved.

3.7 Summary of Findings

The table below summarizes the findings and resulting conclusions for each hypothesis.

Table 3-5. Summary of Findings

Hypothesis	Finding
1	The IDTO bundle enables users to reach destinations faster compared to non-users
2	The IDTO bundle enables users to reach destinations more reliably compared to non-users
3	The IDTO bundle reduces passenger wait times
4	The IDTO bundle was not consulted or used at a meaningful level
5	The IDTO bundle did not lead to increased transit demand; however, transit demand could increase with IDTO usage, through reductions in the generalized price of transit travel
6	Demand for the IDTO bundle was not a function of personal needs and level of service, however, in the future the bundle could fill that role.
7	There was little overall evidence of continuous or repeated use of the IDTO bundle
8	Using T-DISP helped users manage their trips
9	The IDTO bundle may increase system efficiency, conditional on ridership volumes and service frequencies
10	T-CONNECT increases the likelihood of making successful transfers.
11	T-CONNECT and T-DISP are cost-effective applications
12	T-DISP does not extend demand-response services to support dynamic routing, scheduling, and service changes
13	The IDTO bundle did not clearly improve users' ability to mitigate effects of disruptions to the network
14	The IDTO bundle stimulated increased coordination among transit agencies

Chapter 4 Recommendations

Based on the findings described in Section Chapter 3 above, the Volpe Center has several recommendations for the ITS JPO that may provide value regarding the continued development of the IDTO bundle as well as its place within the broader DMA program. These recommendations will focus on considerations to keep in mind as the bundle is incorporated into future research as well as aspects for stakeholders and adopters to be cognizant of when implementing the bundle. These recommendations are as follows:

- Consider strategies of bundle implementation within different contexts
- Encourage and ensure partner buy-in
- Encourage flexible demand-response services within the context of T-DISP and D-RIDE
- Consider scenarios where T-CONNECT is feasible and reduces net travel time
- Consider and be cognizant of data limitations

The sections below describe each of these recommendations in detail.

4.1 Consider Strategies of Bundle Implementation Within Different Contexts

As designed and developed by Battelle, the IDTO bundle is easily adoptable and transferable. While originally implemented with agencies in Columbus, Battelle's proof-of-concept demonstration in the Central Florida region showed that the bundle can be easily implemented with new agencies in a new city or region. Along these lines, the demonstrations also showed that each application within the bundle can be operated and utilized independently from the others. As a result, when marketed to potential agencies, Volpe recommends that the ITS JPO emphasizes this flexibility within the bundle. The fact that agencies can selectively apply the technology, and if they desire only implement one or two of the components, provides additional value for agencies who can determine which components suit their needs the most and also allow them to be more cost-effective in their decision-making. This process would be facilitated by the fact that the ITS JPO promotes open standards and information related to the technical operability of the bundle is publicly available.

Another consideration within this context is the fact that, while possible to implement a trip planning smartphone application that allows for users to access and use the IDTO applications, it is also possible to implement the applications internally within the transit agencies. This would eliminate the need to engage riders directly and still allow agencies to capture the value of the bundle. This can be done most readily with: (1) T-CONNECT, which can be handled and administered by integrating and monitoring vehicle position and dispatcher communications with drivers;[9] and (2) T-DISP, assuming demand-response services and the

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[9] This would likely require an understanding of how routes or agencies interface and a historical determination of popular or common transfers. However, rider intent could also be determined through an on-board passenger request to the driver.

communications required to operate them are already in place. While not impossible, implementing D-RIDE without the smartphone application would be more difficult and would require agencies to work with a ride share operator that is willing to modify its system and the options it presents to its customers. Along these lines, there is nothing within the IDTO bundle that inherently requires multiple agencies or agency-to-agency transfers. If an agency chose, it would be possible to implement the IDTO application in an intra-agency setting. The specific applications needed would depend on the types of services the agency offered.

Based on this flexibility in terms of both application components and the methods for operating and using the technology, Volpe recommends that the bundle be marketed accordingly and that the various implementation strategies be made clear to potential users of IDTO.

4.2 Encourage and Ensure Partner Buy-In

One of the key challenges from the demonstration was a lack of demonstration partners. In Columbus, the demand-response service that was planned by OSU, TaxiCABS did not materialize and was therefore unavailable for the T-DISP component of the demonstration. In Central Florida, NeighborLink, a similar demand-response service that would allow for the testing of T-DISP, was not yet ready at the time of the demonstration and was also not available. Zimride, a ride share operator, was purchased by Enterprise and the new ownership decided to withdraw from the demonstrations in both Columbus and Central Florida, which eliminated Battelle’s ability to demonstrate D-RIDE.

While integrating agencies and services is a strong concept in theory, in practice it can be challenging to gain traction and ensure buy-in from particular partners. This can be for controllable reasons such as lack of commitment or follow-through, or for uncontrollable reasons such as changes in external factors. Based on the genuine challenge of getting partners involved and following through on their commitments that was experienced during the demonstrations, it is possible that this scenario could manifest itself in other cities and implementations of the bundle. As a result, Volpe recommends that the ITS JPO and relevant stakeholders promoting the technology emphasize this challenge, and that any future implementations of the bundle plan accordingly. This could include developing a risk management and assessment strategy that will allow for partners to monitor internal and external risks that would lead to a lack of engagement or complete withdrawal from the IDTO bundle. In short, if agencies are going to integrate together, all relevant agencies need to be able and willing to do so for an agreed upon period of time. Otherwise, the applications will not function effectively; if a participating agency withdraws, certain applications may not be able to function at all.

4.3 Encourage Flexible Demand-Response Services Within the Context of T-DISP and D-RIDE

A key finding of the demonstration was that, given certain conditions, the range of unique demand-response services currently being developed by public and private agencies have the ability to improve mobility for riders and meet a niche demand for certain customers. As agencies continue to innovate and enhance efficiency, these services are valuable and are of immense interest to both agencies and riders. Given these findings, Volpe recommends that the ITS JPO encourage the application of T-DISP and D-RIDE to help to facilitate these demand-response services.

One area of potential technological improvement regarding the identified demand-response services is the logistics of riders requesting service. The specific nature of the service and communication structure in place varies based on the type of service and the technological capabilities of the agency. In some cases discussed by interview participants, service needs to be requested up to 24 hours in advance; in other cases riders can board a vehicle and make a request. Some systems allow for smartphone communication, while others require requestors to make phone calls or send e-mails to the transit agency. Given these factors, T-DISP and D-RIDE could potentially fill a need by allowing for more efficient communication between riders and agencies when requesting and confirming services. Volpe recommends that the ITS JPO highlight this value when promoting IDTO.

4.4 Consider Scenarios Where T-CONNECT Is Feasible and Reduces Net Travel Times

The demonstration showed that T-CONNECT opportunities and requests can be limited depending on the network and parameters involved. If two services with coordinated schedules operate effectively, provide sufficient service to mitigate the potential for long waiting times at transfer points, and maintain schedule adherence, transfers between the services may be accommodated easily and hence connection protection may not offer strong value. However, if internal (e.g., uncoordinated schedules, long headways, poor schedule adherence) and external (e.g., recurrent severe traffic congestion, network disruptions) factors limit services' effectiveness, connection protection could reduce net travel times and improve reliability considerably. In addition to schedule coordination, service frequency and schedule adherence, lower-level operational constraints influence the potential extent of T-CONNECT utilization.

Key constraints include the degree of flexibility for holding outbound vehicles and the interval between the projected arrival of inbound vehicles and projected or scheduled departure of outbound vehicles; limited flexibility and shorter intervals will lead to fewer T-CONNECT opportunities.

Given these factors, Volpe recommends that prior to T-CONNECT being implemented, the scale, parameters, and feasibility of connection protection be fully evaluated and considered. The application is only worthwhile to implement if there is sufficient need and opportunities for connection protection to benefit riders making transfers. Some factors could be modified after implementation in order to continue to improve the application for a given network. In short, these considerations and continued monitoring are necessary to enhance the application's effectiveness.

The findings of IDTO-BET summarized in Section Chapter 3 indicated that T-CONNECT would tend to reduce net travel times across users, but that some applications of T-CONNECT could result in net increases in travel times. After identifying the main findings, Volpe conducted a sensitivity analysis to identify representative thresholds within which T-CONNECT may offer value (i.e., net improvements in travel time and travel time reliability), conditional on a subset of the demonstration-based assumptions used to evaluate the hypotheses (i.e., holding all assumptions fixed except for one at a time).

The sensitivity analysis indicated that T-CONNECT would offer net benefits as long as the following criteria were satisfied:

- Service headways for outbound vehicles are longer than ten minutes;
- The maximum hold time for outbound vehicles does not exceed five minutes; and
- The ratio of ridership on outbound vehicles that are held to protect a connection to service headway for the outbound vehicle does not exceed 0.7. That is, conditional on the assumptions seeding the main demonstration analysis in IDTO-BET, the net travel time impact of T-CONNECT was beneficial as long as no more than:
    - 7 passengers were delayed on services with 10-minute headways (ratio of 0.70);
    - 10 passengers were delayed on services with 15-minute headways (ratio of 0.67);
    - 17 passengers were delayed on services with 25-minute headways (ratio of 0.68); and
    - 28 passengers were delayed on services with 40-minute headways (ratio of 0.70).

The sensitivity analysis indicated that net impacts of T-CONNECT on travel times were insensitive to other assumptions, including the spread of arrival times around the mean, the arrival time threshold for triggering connection protection, and the expected total trip time for connecting passengers. These assumptions do impact buffer time savings, total travel time savings, transit demand impacts and return on investment, but large ranges of plausible values for these assumptions did not influence whether T-CONNECT provided net travel time savings or buffer time reductions.

Broader sensitivity analysis in IDTO-BET confirmed that three predominant constraints limit the effectiveness of T-CONNECT:

- The number of riders on board or waiting downstream for a vehicle held for a T-CONNECT user;
- The frequency of the service to which a T-CONNECT user is connecting; and
- The time spent by the T-CONNECT user traveling on board the held vehicle.

Riders on board a vehicle that is held for a T-CONNECT user experience travel time *increases* that are potentially offset by the travel time *savings* accruing to the T-CONNECT user. Likewise, downstream riders that would be delayed by a vehicle hold also would experience travel time increases (the IDTO-BET analysis normalized the impact of a vehicle hold to the *effective* number of passengers delayed, accounting for downstream effects). When calculating the net travel time impacts of T-CONNECT for all transit users, it is necessary to subtract the total amount of delay experienced by riders on the outbound vehicle from the travel time savings experienced by the T-CONNECT user. Although the level of delay experienced by an individual rider under a T-CONNECT may be low relative to the T-CONNECT user's travel time savings, the delay is additive across the number of riders impacted.

Consider a case in which a T-CONNECT transaction reduces a user's travel time by 20 minutes, while holding the outbound vehicle for 2 minutes. If there are 11 or more riders on board the held vehicle, and assuming no offsetting impacts (e.g., the driver is able to increase travel speed downstream to make up for lost time) the T-CONNECT transaction would cause net travel time to *increase* (i.e., the 20-minute savings for the T-CONNECT user is offset by at least 22 minutes in additional travel time for riders delayed by the vehicle hold). Delays of downstream riders, if any, would add to the total amount of delay caused by the vehicle hold.

Hence, as confirmed by the IDTO-BET analysis, T-CONNECT offers the strongest net travel time benefit under connections that delay the fewest riders. Furthermore, T-CONNECT cannot offer a net travel time benefit under a given service configuration when the number of delayed riders exceeds a given level.

As noted above, the IDTO-BET analysis normalized the impact of a vehicle hold to the *effective* number of passengers delayed. The normalization represents the average delay experienced by all non-T-CONNECT users due to a vehicle hold, which is represented within IDTO-BET as the number of passengers on board the outbound vehicle multiplied by the duration of the vehicle hold.

The frequency of the service to which a T-CONNECT user is connecting is the central factor in determining the travel time savings experienced; in turn, service frequency is critical in determining the travel time reliability benefits experienced (i.e., reductions in travel time lead to reductions in the 95th-percentile travel time). As the interval between services grows, the travel time savings experienced by a T-CONNECT user due to a protected connection likewise grows. Indeed, the expected amount of travel time savings from a successful protected connection is roughly equivalent to the service frequency (variability in arrival times for subsequent vehicles and vehicle holds that are on the margin of being necessary influence the result to some degree).

Hence, as confirmed by the IDTO-BET analysis, T-CONNECT offers the strongest travel time benefit under connections to low-frequency (i.e., long headway) services, and offers the weakest travel time benefit under connections to high-frequency services.

Lastly, the time spent by the T-CONNECT user traveling on board the held vehicle is a factor in determining the travel time reliability benefits experienced. The variability in trip time increases with the duration of a trip (under an assumption that the schedule adherence test data from COTA, used in the analysis, are representative). Thus, travel time savings for longer trips are associated with greater decreases in 95th-percentile travel times. However, this relationship is weaker than the corresponding relationship between service frequency and travel time reliability.

Volpe analysis in IDTO-BET identified a frontier of combinations of travel demand characteristics and outbound vehicle service frequencies that meet one of two strategic objectives for T-CONNECT: (1) a positive net travel time impact; and (2) a positive impact on the sum of net travel time and reliability. The frontier was developed with a focus on the above bulleted key factors, holding all other input values at their base levels from the IDTO-BET analysis (see Section 1.3 for a review of analytical assumptions). 4-1 presents the maximum count of riders on held outbound vehicles for which T-CONNECT yields at least a neutral net travel time impact, per T-CONNECT user, by headway:

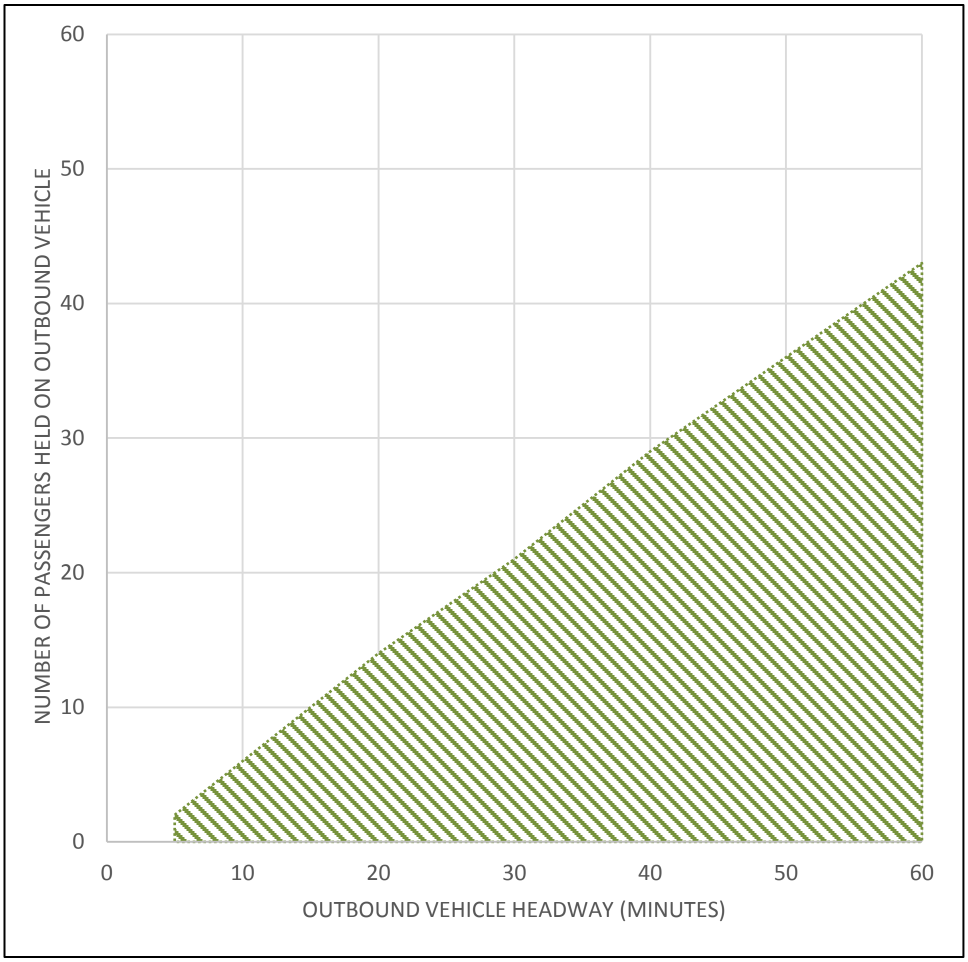

Figure 4-1. Maximum Ridership on Outbound Vehicles per T-CONNECT User to Yield Positive Net Travel Time Impacts, by Outbound Vehicle Headway (Source: Volpe Center)

IDTO-BET projects T-CONNECT to yield positive net travel time impacts for all levels of riders on board outbound vehicles within the green shaded area. That is, within the shaded area, the travel time benefits experienced by a T-CONNECT user exceed the sum of the delay across all riders onboard the outbound vehicle (or equivalent delayed downstream riders). The maximum net-beneficial ridership on outbound vehicles rises linearly with headway (i.e., it is feasible to reduce net travel time with more riders on board outbound vehicles), at a general rate of around 0.7 riders per minute of headway.

The maximum net-beneficial ridership also rises one to one with the number of connecting passengers; for example, if the maximum net-beneficial ridership on the outbound vehicle for one connecting passenger is four held passengers, the maximum net-beneficial ridership on the outbound vehicle for two connecting passengers is eight held passengers. Hence, as a general guideline, the IDTO-BET analysis indicates that, conditional on the assumptions within the analysis, each vehicle hold via T-CONNECT in the demonstration would yield net travel time savings as long as: # delayed passengers < headway of held vehicle * # connecting passengers * 0.7

An example of this relationship can be shown using routes operated by COTA. 4-2 expands on 4-1 by adding estimated passenger loads and vehicle headways averages for COTA routes in the OSU area:

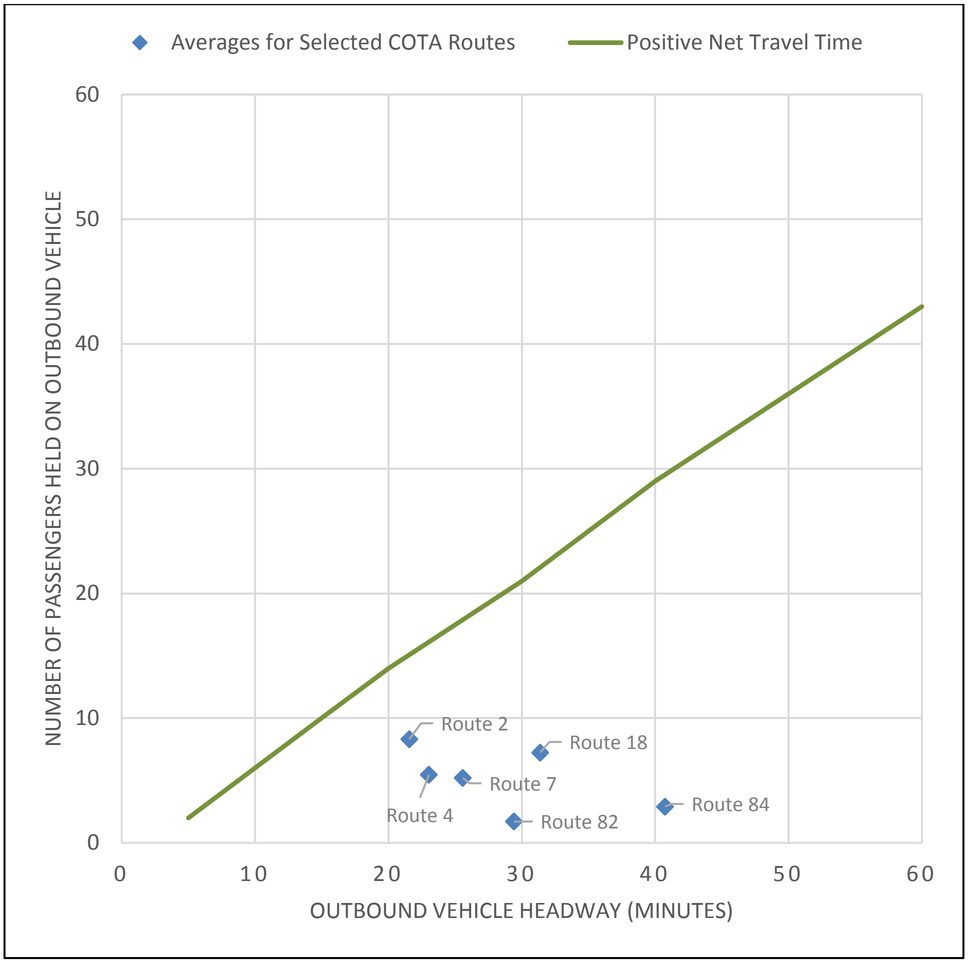

Figure 4-2. Maximum Ridership on Outbound Vehicles per T-CONNECT User to Yield Positive Net Travel Time Impacts, by Outbound Vehicle Headway with COTA Example Routes (Source: Volpe Center)

Figure 4-2 reveals that all COTA routes around the OSU area, on average, are projected to exhibit positive net travel time impacts per T-CONNECT user.

A direct implication of the general finding described above is that T-CONNECT is highly constrained in its ability to yield net travel time benefits for high-frequency services that are carrying moderate (or greater) passenger loads; T-CONNECT would only yield net travel time benefits for high-frequency, moderate-to-high demand services when *multiple* users would benefit simultaneously from a protected connection.

Consider 4-3 below, which expands 4-1 to include the corresponding maximum held passenger counts for T-CONNECT transactions for a group of five connecting passengers:

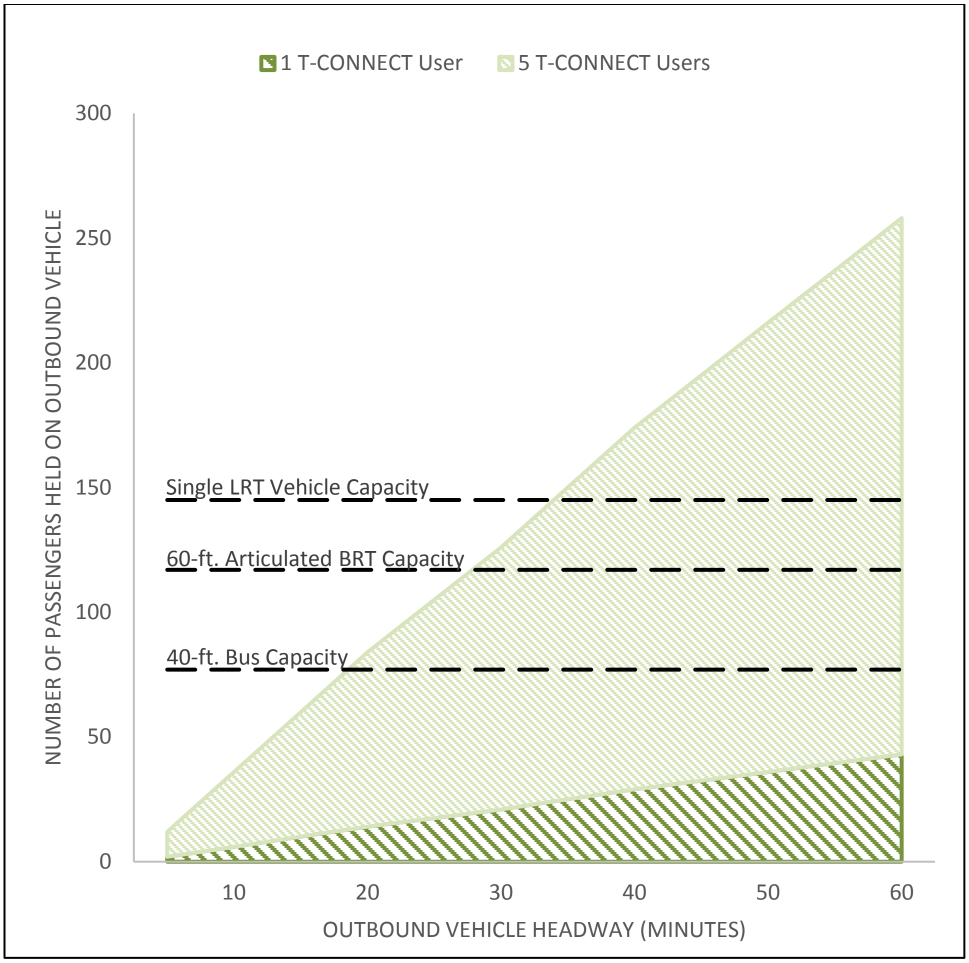

Figure 4-3. Maximum Ridership on Outbound Vehicles per T-CONNECT User to Yield Positive Net Travel Time Impacts, by Outbound Vehicle Headway (1 and 5 T-CONNECT Users) (Source: Volpe Center)

Figure 9 includes estimated capacities for three types of transit vehicles, to illustrate ranges of vehicle headways for which vehicles at or near capacity are projected to yield net travel time reductions when offering protected connections. The estimated 40-foot bus capacity is based on a standard, low-floor transit bus.[10] The estimated 60-foot articulated BRT capacity is based on a standard, low-floor articulated BRT service.[11] The estimated single light rail transit vehicle capacity is based on an assumed 1.5 passenger loading level per foot during peak periods and a maximum car length of 95 feet.[12]

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[10] TCRP: Transit Capacity and Quality of Service Manuel, Third Edition. Chapter 6: Bus Transit Capacity. Page 6-20. http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_165ch-06.pdf

[11] Ibid.

[12] TCRP: Transit Capacity and Quality of Service Manuel, Third Edition. Chapter 8: Rail Transit Capacity. Page 8-82. http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_165ch-08.pdf

For an outbound service with a five-minute headway, the IDTO-BET analysis indicated that no more than two riders on board outbound vehicles could be delayed per T-CONNECT user to yield a net travel time benefit. Hence, it would likely be ineffective to honor T-CONNECT requests involving single riders connecting to high-frequency services (i.e., net travel time would increase if more than two riders were on board the outbound vehicle). However, with five T-CONNECT users (e.g., connecting from a high-density service such as commuter rail), holding the outbound vehicle would yield net travel time savings with as many as 20 riders on board the outbound vehicle. Hence, it may be effective to honor T-CONNECT requests involving many riders, even when connecting to high-frequency, high-demand services.

4-3 indicates that, with multiple T-CONNECT users connecting to a single service, T-CONNECT could yield net travel time benefits for services with relatively short headways and ridership near capacity. Indeed, for connections involving five T-CONNECT users, protected connections are projected to yield net travel time reductions for at-capacity services with headways ranging from just under 20 minutes (for a 40-foot bus) to approximately 35 minutes (for a single light rail vehicle).

To that end, transit agencies already tend to identify opportunities to accommodate transfers of large groups of passengers, and hence the technology of T-CONNECT need not be necessary to ensure that such connections are protected optimally.[13] However, the IDTO-BET analysis confirms the presence of a range of less obvious situations where T-CONNECT could offer net travel time benefits; this information can be used by agencies to focus on providing T-CONNECT where net travel time benefits could be gained (and to restrict protection connection in situations where net travel time is likely to be increased).

Volpe repeated the frontier analysis for the less-restrictive case in which the sum of net travel time impacts and reliability benefits is positive (i.e., either net travel time decreases, or the reliability benefits more than offset the net travel time increase). Reliability benefits are a function of time on board the outbound vehicle; to incorporate this relationship, the analysis was repeated across 10-minute intervals ranging from 10 minutes to 60 minutes on board the outbound vehicle for T-CONNECT users.

4-4presents maximum counts of riders on board outbound vehicles for T-CONNECT to offer positive net travel time plus reliability benefits. The analysis revealed that the results were tightly clustered across intervals; 4-4reports the findings under only 10-minute and 60-minute trip times on board outbound vehicles:

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[13] For example, routes that begin at commuter rail stations and depart only when the passengers arrive accomplish the same task without the IT investment. Similarly, pulse schedules at transit centers allow starters or dispatchers to accomplish the task using low-tech means.

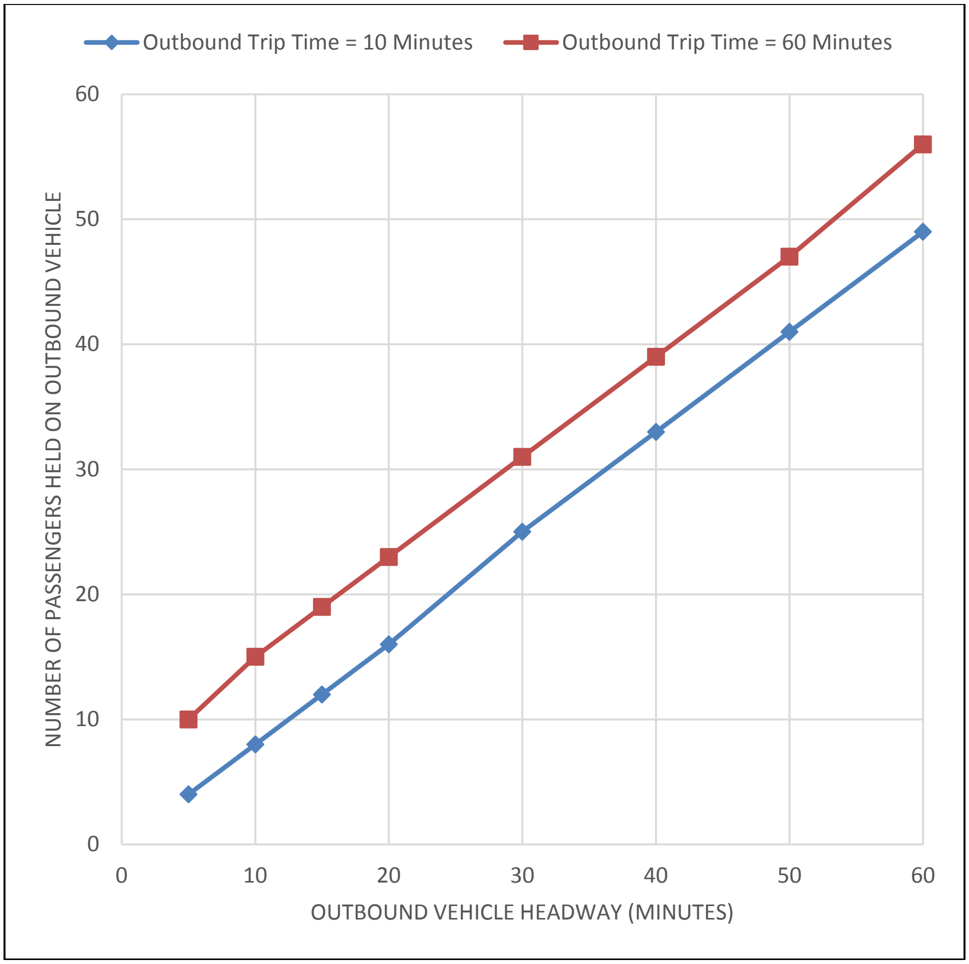

Figure 4-4. Maximum Ridership on Outbound Vehicles per T-CONNECT User to Yield Positive Net Travel Time plus Reliability Impacts, by Outbound Vehicle Headway(Source: Volpe Center)

For trips with T-CONNECT users traveling on the outbound vehicle for 10 minutes, T-CONNECT would yield positive net travel time plus reliability benefits in all cases where ridership on outbound vehicles is below the blue line (with diamond markers). Because reliability benefits increase with time on board the outbound vehicle, the maximum net-beneficial ridership on outbound vehicles is higher when T-CONNECT users travel on outbound vehicles for 60 minutes (orange line with square markers). For all cases represented in Figure 10, the maximum net-beneficial ridership on outbound vehicles is higher than the corresponding values in 4-1 and 4-2; outcomes on or near the lines are likely to indicate cases where net travel time increases, while the reliability benefit to T-CONNECT users nearly or exactly offsets the net travel time increase.

The duration of T-CONNECT users' trips on outbound vehicles is an important factor in determining the amount of acceptable delay to passengers. In general, Figure 4-4indicates that the maximum net-beneficial ridership for a given outbound vehicle when a T-CONNECT user will ride the vehicle for 60 minutes is roughly equivalent to the maximum net-beneficial ridership for a service with a headway that is ten minutes longer but only carries the T-CONNECT user for ten minutes. This finding indicates that agencies could optimize the effectiveness of T-CONNECT service if they had information on the general travel patterns (i.e., time on board connecting vehicles for linked trips) of passengers that transfer between services.

Based on the findings of the main scenario analysis and sensitivity analysis in IDTO-BET, Volpe recommends that agencies implementing T-CONNECT should focus on promoting the use of T-CONNECT to protect connections to vehicles with relatively long headways (to maximize travel time and reliability benefits per connection). Volpe also recommends the development of strategies to restrict connection protection that would involve holding a vehicle that is carrying a relatively large number of passengers (to mitigate total delay costs imposed upon riders on connecting vehicles). This strategy would result in a useful application of real-time passenger counts, as described in a related FTA Research report describing an Integrated Corridor Management Demonstration.[14]

4.5 Consider and Be Cognizant of Data Limitations

Similar to the recommendation related to partner buy-in described in Section 4.2, when integrating systems between separate agencies, various complications can occur. The primary example of this from the demonstration was related to data limitations, where some participating agencies did not have data available or did not track or maintain data in the same way as other agencies. This made integrating the systems between the two agencies complex or impossible. One example of this was the case of Capital Transportation, which did not track vehicle position. This was resolved by the installation of GPS-equipped tablet computers. Other data challenges related to updating schedules and network changes also occurred during the demonstration that required resolution.

Based on these challenges, Volpe recommends that agencies considering implementing IDTO be cognizant of any data limitations that may exist within their systems and the systems of their partner agencies. As agencies integrate, accounting for these limitations and discrepancies will make the implementation and maintenance of the bundle easier for all agencies. While the demonstration used a separable system of tablets both on Capital Transportation’s shuttles and in COTA’s dispatch radio room, it would also be possible to integrate IDTO directly into agency systems and dispatch prompts. As noted by the prototype development team, achieving standardization across bundle components would capture these gains. By establishing this full integration, some data limitations could be addressed automatically. In any case, planning and accounting for data constraints when implementing IDTO is a necessary step to ensure that the system operates in the manner that is designed. For some agencies, implementing IDTO could serve as an impetus for adopting FTA, other U.S. DOT, or third-party open technical standards.

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[14] Biernbaum, L., and Minnice, P. (2014). *Integrated Corridor Management Transit Vehicle Real-Time Data Demonstration: Dallas Case Study.* Prepared for Federal Transit Administration. FTA Report No. 0077. http://www.fta.dot.gov/documents/FTA_Report_No._0077.pdf

Chapter 5 Conclusion

5.1 Key Findings

Based on the research and IA conducted by Volpe, several key themes and trends emerged based on both the evaluation of the technology itself and the steps taken during the course of the demonstration. These themes include the following:

- The IDTO bundle is easily transferable to new cities and regions
- The IDTO bundle can improve mobility and trip reliability
- The net impacts of IDTO may vary critically with respect to service and demand characteristics
- The IDTO bundle can enhance coordination and cooperation amongst transit agencies and partners
- The demonstration experienced low demand based on limited capability and usability of the smartphone application
- The demonstration was hindered by the lack of demonstration partners, hampering the evaluation of the prototype

In summary, despite the challenges experienced during the course of the prototype demonstration, a functional prototype was developed and several valuable outcomes were learned regarding its use and potential impacts. In terms of implementing IDTO, the process is relatively straight-forward and the bundle can be adapted to the specific needs of the agencies involved. Separate tablets can be used or the software can be integrated directly into existing systems. Additionally, the three applications are not interdependent and can be adopted separately if necessary.

In terms of value from a transportation standpoint, the bundle does appear to improve mobility and can enhance the coordination and cooperation of transit agency partners. By providing different transit alternatives to riders and also supplying access to non-traditional services, particularly demand-response style services that can meet niche demand, the bundle satisfies a need of improving mobility using transit service. Agencies could also use this tool to communicate the effectiveness of their unique or non-traditional services and better integrate those services with the services offered by other agencies in their area. While the advantages of T-CONNECT may not be as robust as originally perceived, there exists a small sub-group of riders who could benefit from using it, depending on the scale of the implementation and the characteristics of the particular transportation network.

The demonstration also led to various lessons learned regarding the user interface of the bundle and the need to have buy-in from various partner agencies. Users have grown accustomed to Google and other existing transit applications. If a new, user-facing application is developed that incorporates IDTO, its functionality and usability is of critical importance. Additionally, if transit agencies do not buy-in to the process and agree to integrate, the system will not function as designed. While it is possible to operate systems within one large agency that provides multiple services, the bundle will be most effective when integrating multiple agencies.

5.2 Projected Impacts of Full-Scale Implementation

The analysis concludes with a projection of the impacts of full-scale implementation of the IDTO bundle, to help inform broader analyses of the DMA portfolio. The projection of full-scale implementation represents the application of IDTO for the Columbus area. The projection was informed by the results of scenarios investigated in IDTO-BET and plausible parameters indicated by interview participants; the specific assumptions seeding the calculations in IDTO-BET are itemized in Section 1.3.4 , in concert with IDTO demand assumptions itemized below. The focus of the projection is T-CONNECT, which was the only demonstration component for which detailed data were available to guide projections. A projection is also offered for T-DISP, but the projection is speculative due to a lack of demonstration data.

5.2.1 T-CONNECT

Interviews with COTA confirmed that dispatch staff would be capable of accommodating approximately 50 T-CONNECT holds per day. If demand were to exceed 50 holds per day, it would be necessary to allocate additional staff time to the coordination of T-CONNECT requests, which would increase the costs of maintaining T-CONNECT capability at a level that may not be justified by the net benefits offered by T-CONNECT. Based on the cost constraint on T-CONNECT volumes, the projection of full-scale implementation assumes a maximum of 50 T-CONNECT holds per day in Columbus, associated with daily transit travel demand of 200 trips for T-CONNECT users.

The tool indicated that T-CONNECT offers relatively strong benefits for connections to services with relatively long headways and limited passenger volumes on board connecting vehicles (i.e., T-CONNECT would be most effective when applied to corridors with lower demand and longer headways, rather than along corridors with high demand and short headways). Based on these findings, the projection assumes that participating agencies would calibrate T-CONNECT service to achieve a mix of protected connections that is weighted towards services with long headways with average-to-low passenger volumes (i.e., T-CONNECT requests would be more likely to be honored for connections to low-frequency services and away from demand peaks).

For the projection of full-scale implementation, the analysis assumes the specific mix of average service frequencies and average passenger volumes for connecting vehicles for T-CONNECT holds is:

- 10 T-CONNECT holds for outbound vehicles with 15-minute headways and 15 passengers on board (20 percent of daily T-CONNECT holds);
- 15 T-CONNECT holds for outbound vehicles with 25-minute headways and 7 passengers on board (30 percent of daily T-CONNECT holds);
- 25 T-CONNECT holds for outbound vehicles with 40-minute headways and 7 passengers on board (50 percent of daily T-CONNECT holds); and
- No holds for vehicles with headways below 15 minutes or more than 15 passengers on board.

Under the assumed values of travel time savings and buffer time savings ($12.50 per hour) and an assumed effectiveness of 250 days per year, the projected net benefits of T-CONNECT at full-scale implementation are:

Table 5-1. Projected Impacts of T-CONNECT under Full-Scale Implementation

Connection Type	Net Benefit per T-CONNECT	Net Benefit per Day	Net Benefit per Year
15-Minute Headway, 15 Passengers	$0.10	$1.05	$262
25-Minute Headway, 7 Passengers	$3.14	$47.03	$11,758
40-Minute Headway, 7 Passengers	$6.06	$151.62	$37,904
Total		$199.70	$49,924

The projected annual net benefit of T-CONNECT under full-scale implementation is $49,924 ($4.00 per T-CONNECT hold). This value includes a lower-bound assumption of reliability benefits, in which buffer time per T-CONNECT hold is reduced by the average buffer time reduction per T-CONNECT request; this assumption accounts for potential mitigations in buffer time reductions arising from cases where T-CONNECT requests do not result in vehicle holds. Under this assumption, approximately 90 percent of the net benefits provided by T-CONNECT represent net travel time impacts (3,610 hours of net travel time savings per year). The share of net benefits associated with net travel time reductions is relatively invariant across connection types, ranging from 87 percent to 92 percent.

Projecting COTA’s demonstration cost of $3,500 as the annual cost of providing T-CONNECT, the net benefits represent an annual return of $14.26 per dollar invested in T-CONNECT. Under a more restrictive assumption in which T-CONNECT holds are only provided for the first two connection types (i.e., no T-CONNECT holds are provided for the highest-return trips, and twice as many T-CONNECT holds are provided for services with average headways of 15 and 25 minutes), the projected annual net benefit of T-CONNECT under full-scale implementation would be $24,040 ($1.92 per trip, and 1,664 hours of travel time savings per year). This would represent an annual return of $6.87 per dollar invested in T-CONNECT.

Lastly, under the assumed generalized price elasticity of transit demand (-0.63), the calculated average change in the generalized price of travel for riders utilizing T-CONNECT holds (off of a base generalized price of $14.15) and an assumed average daily trip volume of four transit trips per day (i.e., two connecting trips), 178 new transit trips are projected per year; at an assumed revenue of $2 per additional trip, T-CONNECT is projected to generate an additional $356 in revenue per year, offsetting approximately ten percent of the assumed annual cost. Under the more restrictive assumption in which the highest-return T-CONNECT holds are not provided, T-CONNECT is projected to generate 86 new transit trips per year ($171 in revenue per year).

5.2.2 T-DISP

The base T-DISP scenario investigated in the tool represented a new dynamic demand-response service supported by T-DISP, in which shuttle vehicles were allowed to deviate freely within a designated service area. This specification was informed by the design of the NeighborLink service, as discussed in interviews with LYNX in Orlando. The new service was assumed to offer an average reduction of 15 minutes in total travel time for T-DISP users relative to their closest travel alternative. The relative reliability of status quo and T-DISP-supported trips was assumed to be the same (standard deviation equal to ten percent of the mean travel time).The T-DISP supported trip was assumed to offer an average reduction in waiting time of ten minutes, reflecting the benefits of predicted vehicle arrival time via the T-DISP application. An average of five passengers were assumed to be on board when a route deviation would be triggered by T-DISP, with an average route deviation lasting five minutes.

IDTO-BET indicated that, based on the above assumptions, the average T-DISP transaction would result in a neutral net impact on travel times; a large travel time savings per user (over twenty minutes per trip) would be offset by an approximately equal amount of increased travel time across passengers affected by a route deviation. However, reliability benefits accruing to T-DISP users were projected to be large, with an average reduction in buffer time of 13 minutes per trip. Under the assumed value of buffer time reduction ($12.50 per hour), the projected reliability impact (and hence the net benefit) is approximately $2.70 per trip.

Projecting CABS's demonstration cost of $6,000 as the annual cost of providing T-DISP, the net benefit per trip indicates that it would require 2,215 T-DISP-supported trips per year (approximately nine trips per day) to yield net benefits equal to the cost of offering T-DISP-supported demand-response service. However, this projection is speculative; for agencies that are considering implementing T-DISP, agency-specific data inputs could be applied within IDTO-BET to yield distinct projections. That is, the customizable nature of IDTO-BET enables agencies to utilize the tool to generate projections of impacts that are specific to the characteristics of dynamic demand-response under agencies' consideration, along with the characteristics of traditional services that would be alternatives to trips scheduled via T-DISP.

Of particular importance, the net benefits offered by T-DISP would increase with respect to the following changes, relative to the assumptions in the base scenario:

- Larger travel time improvements offered to users relative to the best alternative;
- Larger reductions in travel time variability offered to users relative to the best alternative;
- Fewer passengers on board on average during route deviations triggered by T-DISP; and
- Shorter average route deviations triggered by T-DISP.

Lastly, under the assumed generalized price elasticity of transit demand (-0.63), the calculated average change in the generalized price of travel for riders utilizing T-DISP (off of a base generalized price of $14.50) and an assumed average daily trip volume of four transit trips per day (i.e., two connecting trips), each use of T-DISP is projected to generate approximately 0.48 new transit trips. At an assumed revenue of $2 per additional transit trip, each T-DISP-supported trip is projected to generate an additional $0.96 in revenue. When applying the results of the T-DISP analysis to external analyses, it would be appropriate to add the projected $0.96 revenue increase per T-DISP transaction to the projected $2.70 reliability impact if transit revenue increases are categorized as a relevant impact.

The projected increase in revenue is equal to approximately one-third of the projected net benefits of T-DISP use. If agencies seek to increase ridership or choose to allocate incremental transit revenue as a rebate against T-DISP costs, the projected transit demand impacts of T-DISP could be an important factor supporting the implementation of T-DISP. Furthermore, if T-DISP is implemented in concert with an improved demand-response service, it is feasible that a significant amount of non-users of transit could switch travel mode to T-DISP-supported trips for some travel, leading to a stronger incremental impact on overall transit demand and revenue. In such a case, the joint impacts of increased transit demand for existing and new transit riders would reduce the volume of T-DISP demand required to achieve net benefits exceeding the annual cost of providing T-DISP.

Chapter 6 References

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Appendix A Abbreviations and Acronyms

Acronym	Definition
C-Ride	Software package
CABS	The Ohio State University's Campus Area Bus Service
COTA	Central Ohio Transit Authority
DCM	Data Capture and Management
DMA	Dynamic Mobility Applications
D-RIDE	Dynamic Ridesharing (IDTO Application)
DSCC	Defense Supply Center Columbus
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
IA	Impacts Assessment
IDTO	Integrated Dynamic Transit Operations
IDTO-BET	Integrated Dynamic Transit Operations – Bundle Evaluation Tool
ITS JPO	Intelligent Transportation Systems Joint Program Office
MOE	Measure of Effectiveness
OSU	The Ohio State University
PD	Prototype Development
T-CONNECT	Connection Protection (Application)
T-DISP	Dynamic Transit Operations (Application)
UCF	University of Central Florida
U.S. DOT	U.S. Department of Transportation

Appendix B Demand-Response Interviews

A.1 Introduction

Volpe's ability to evaluate hypotheses centering on demand-response (DR) service was restricted because several key participants were unable to participate in the demonstration, including DR agencies such as TaxiCABS and FlexBus. As an alternative approach to investigating the evaluation hypotheses, the IA team conducted a supplementary set of interviews with transportation entities to learn about their innovative DR services. The primary objective of these interviews was to learn how these DR agencies operate and how T-DISP would function if integrated into their systems. However, beyond the T-DISP related points, the discussion unearthed several valuable themes and lessons learned. The table below lists the agencies interviewed and describes the services they provide.

Table Appendix 1-1. Description of Demand-Response Service Interviewees

Agency	Location	Description
128 Business Council	Greater Boston, Massachusetts	Transportation Management Association providing shuttle service to businesses along the Route 128 corridor of the MetroWest Boston area. Currently exploring filling excess capacity with demand response service.
Bridj	Washington D.C. Metro Area; Greater Boston, Massachusetts	Private transportation service using data-driven process and user demand to set origin-destination pairs for riders.
LYNX	Greater Orlando, Florida	Transit agency in Orlando, Florida operates NeighborLink, a flex-service designed to provide riders access to specific neighborhoods based on demand.
Middlesex County Area Transit	Middlesex County, New Jersey	Transit agency operates a route-deviation service which allows riders to deviate within two-blocks from a fixed route upon request.
Montachusett Regional Transit Authority	North Central Massachusetts	Transit agency operates a shuttle service from rural communities to metro areas based on demand. Destinations in metro areas are determined by riders.
San Joaquin Regional Transit District	Greater Stockton, California	Transit agency operates a route-deviation service called the Metro Hopper which allows for deviations of up to one mile from the normal fixed route.

Agency	Location	Description
Utah Transit Authority	Greater Salt Lake City, Utah	Transit agency operates a route-deviation service called Flex Routes allowing for deviations of up to ¾ of a mile from the normal fixed route.

Each interview focused on four areas: the strategic goals of the DR service, the demand for the service, the operations of the service, and the evolution of the service over time. A description of the discussion and key findings for each agency follows below.

A.2 128 Business Council

The 128 Business Council is a Transportation Management Association which provides shuttle services to the route 128-corridor in the MetroWest Boston area. The shuttles primarily serve businesses and connect employment centers with public transportation hubs. The shuttles operate primarily during peak periods and there is excess capacity during non-peak periods. In order to fill this capacity, the council has explored using a Smart Bus which would consist of a vehicle routing dynamically in response to customer demand and requests. While the project is currently on hold based on funding constraints, the council plans to revisit the project in 2016.

A.2.1. Strategic Goals of DR Service

The agency had excessive capacity during non-peak periods where fixed-route vehicles do not operate. The agency believed that this excess capacity could be utilized within a DR system and that riders could make requests for transportation that they could use for lunch or appointments. While DR service was viewed as an alternative that can benefit riders in a way that traditional services cannot, the council did see certain limitations. The primary challenge is that the agency serves a large geographic area and, as a result, implementing a dynamic DR service within that area could be a challenge. The council was seeking to implement a system that maintained its dynamic routing flexibility but did not evolve into a taxi service.

A.2.2. Demand for DR Service

Demand for the shuttle service in general is generated by the structure of connecting employment centers with traditional transportation networks. For demand-response services such as the proposed Smart Bus, a similar demand is occurring where riders seek an alternative means of transportation to reach areas that are underserved by traditional transit. Ultimately, the feeling is that DR services can increase options for riders either by shortening travel time or reaching underserved areas. The hope for Smart Bus is that it will be an open-source software solution which will connect riders with multiple services or vendors to further fill those gaps.

A.2.3. Operations of DR Service

The Smart Bus would be operated through a traditional dispatcher system and some additional staff would be needed to oversee the transactions. The transaction process would be iterative where users would enter their request and receive options to choose from. Operationally, there would be no plan to alter the number of vehicles or level of service.

A.2.4. Evolution of the DR Service

The Smart Bus program is still under development with the next step being to move forward with a software solution that is either proprietary or readily available from third-party providers. As mentioned above the hope remains that the software will be open-source which will allow for a pool of vendors to access and utilize the system. Proprietary products can be expense and, as a result, the barrier to entry may be high. A goal of the 128 Business Council is to strengthen partnerships with other agencies and services as the program moves forward.

A.3 Bridj

Bridj is a private transportation service that provides data-driven transportation options to fill gaps that exist in traditional transit services. The trips are express-style and have 0 or 1 intermediate drop-offs between a rider’s origin and destination (O-D). The company feels that users prefer one-seat rides and the ability to work while in transit and the system caters to those needs by providing Wi-Fi, and by connecting origins and destinations appropriately using travel demand data.

A.3.1. Strategic Goals of DR Service

The strategic goal of the service is to fill a need for riders using a data-driven approach. The belief is that Bridj can use this approach to provide high levels of service at a lower cost than traditional transit. A primary limitation facing Bridj is the cost to operate the system as funding-mechanisms are currently constructed. Federal funding must come through cities, who can then issue performance-based contracts to Bridj, either through joint provision of funds and service, or separate provision of funds.

A.3.2. Demand for DR Service

Demand for the service is driven by connecting riders to employment centers and improving connections compared to traditional transit service. Additionally, the service provides an enhanced user experience both on vehicle and in terms of its adaptive nature. Because the network adjusts automatically based on demand, value is inherently provided to users.

A.3.3. Operations of DR Service

Bridj charges a flat fare and the average small-shuttle vehicle generates about $80 per hour against costs of $40 per hour. During peak periods, the service operates at around 98% capacity and as the service continues to expand, demand is growing. Vehicles are scheduled to depart every 10 minutes and the company estimates that trips are 30% faster compared to transit. Bridj contracts out vehicle operation and maintenance and focuses on the data portion of the operation.

A.3.4. Evolution of the DR Service

A major initial improvement was reducing vehicle sizes from 30-50 passengers down to 15 passengers. Operating smaller vehicles seems to fit the model better. Additionally, Bridj feels, now more than ever, that they are in the business of partnering with cities as research partnerships and city-based partnerships have helped to advance the service significantly. Along these lines, Bridj is looking to expand into several new cities. As Bridj continues to expand, the focus will be on improving booking effectiveness and avoiding denial of service based on capacity constraints.

A.4 LYNX

LYNX is a transit agency in Orlando, Florida which offers several types of services including NeighborLink, a flex-service that is limited to certain geographic areas with transfer connections to fixed route service.

A.4.1. Strategic Goals of DR Service

The initial goal of the service was to utilize DR service to take the place of underperforming fixed route services. The feeling is that DR service is less expensive than traditional transit while covering a broader area. While confining service to a limited geographic area is a limitation, it makes sense within the context of the areas and the structure of the overall service.

A.4.2. Demand for DR Service

NeighborLink operates in a niche where demand is present but insufficiently high to support fixed-route service. DR service also complements paratransit service at a lower cost, although it is not designed to replace paratransit service. Another key factor driving demand for the DR service is reliability. As long as it remains reliable, the service can shorten travel times and wait times for riders.

A.4.3. Operations of DR Service

Users can request a pick-up by calling a dedicated NeighborLink customer service line between two hours and seven days in advance of the requested pick-up. There are currently 3 call-takers for 13 routes with approximate wait times of up to 8 minutes with an average of about 4 minutes. The abandon rate for calls is fairly high. Based on these limitations, an application is being developed to allow automated reservations without the 2 hour advance requirement.

A.4.4. Evolution of the DR Service

The agency has made various modifications to the service over time such as operating times and establishing one route which solely connects a commuter rail station with an office park. Moving forward, LYNX hopes to continue to monitor areas of service needs as well as develop an application which will enable self-booking, vehicle monitoring, and minimizing the required lead time. While NeighborLink does service areas that enable transfers to other agencies, there are no plans at this time to coordinate directly with other entities.

A.5 Middlesex County Area Transit

Middlesex County Area Transit (MCAT) operates a 90-bus community transit fleet including 15 vehicles operating in deviated fixed route service. This route-deviation system is based on demand and allows for fixed route vehicles to deviate within two-blocks of the route as requested by riders at least a day in advance.

A.5.1. Strategic Goals of DR Service

The service hopes to meet a growing demand for service within the suburban county area without adding additional fixed routes. Funds that had been designated for elderly, disabled, and employment support were used to support the DR service. Along with filling this need, MCAT feels the route deviation is able to function as a front-door service connecting riders to activity centers, at a lower cost to users, in a way that could not be done through traditional transit service. A key challenge of the service was marketing and the perception of the system. The shuttles are body-on-chassis buses and there is a perception that these buses do not serve the general public.

A.5.2. Demand for DR Service

Demand factors for the service tend to vary by route. In urban areas, the service provides the ability to serve activity centers that weren't served by traditional transit. In short, the service is able to solve the "first-mile" problem for many users and the agency saw a notable shift away from car use in trips. Users rode the routes habitually, including for reverse commuting and as a rail feeder service. Based on these uses, the agency feels that riders appreciate the increased flexibility in trip timing, chaining, and destinations.

A.5.3. Operations of DR Service

Operationally, the routes require more recovery time compared to traditional transit in order to allow for deviation and slower passenger boarding speeds. Additionally, the service requires that deviations be booked a day in advance, with the exception of at activity centers, otherwise the routes have fixed stops and flag stops. In terms of day-to-day operations, the service runs efficiently with minimal alterations or changes.

A.5.4. Evolution of the DR Service

As the use of the service evolved, electronic destination signs and color coding was added and were seen as a major improvement. Based on the winding nature of the deviations, the signs were need in order to make it more clear which direction the vehicle was headed. In terms of next steps, continuing to determine funding methods and evaluating the fare structure will be major priorities.

A.6 Montachusett Regional Transit Authority

Among other services, the Montachusett Regional Transit Authority (MART)[15] offers DR style "out-of-town" shuttle service from a rural part of north-central Massachusetts, connecting to the cities of Boston and Worcester. The shuttles leave three times per day from Fitchburg, MA and riders can select their final destinations and pick-up times. Pick-up is purely demand driven. The urban destinations typically include medical facilities or legal offices.

A.6.1. Strategic Goals of DR Service

Based on MART's geographic position, connecting riders to urban centers through DR service adds significant value for the agency and for riders. MART feels that the DR service they operate allows for connections to other services and greater flexibility in terms of customized scheduling.

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[15] Transit vehicles are branded as "Montachusett Area Regional Transit."

A.6.2. Demand for DR Service

Ridership typically ranges between four and ten riders per day for both shuttles. Users typically utilize the Boston shuttle for medical appointments and the Worcester shuttle for medical facilities and legal services or purposes at the court house. Other uses include intercity travel, particularly by connecting to the train station in Worcester. Riders can book trips through the “United We Ride” mobility program as well as by calling MART directly.

A.6.3. Operations of DR Service

The “United We Ride” program software is directly linked to MART’s software so that the process is seamless and trip requests are logged automatically. Users can also ride without scheduling. From a day-to-day perspective, drivers determine the route based on their mobile data terminals and rider demand.

A.6.4. Evolution of the DR Service

The major adjustment made as the service has evolved was adjusting the departure times from Fitchburg so that riders will be able to make it to their destinations for typical appointment times. Future options include better utilizing the Massachusetts Bay Transportation Authority (MBTA) commuter rail services and possible connecting riders to commuter rail stations and then setting up transport for their “last mile” when in the urban center. A key to these options and future alternatives is the continued ability to secure funding.

A.7 San Joaquin Regional Transit District

Similar to the system that was described above for MCAT, San Joaquin Regional Transit District (SJRTD) provide a route-deviation service, known as the Metro Hopper, along with several other DR services. SJRTD has a service area of 1,500 square miles and as a result tries to optimize their service strategies over that large area. The Metro Hopper has eight routes, and buses can deviate up to one mile from the route. SJRTD also provides DR service in collaboration with the United Cerebral Palsy (UCP) center.

A.7.1. Strategic Goals of DR Service

SJRTD feels that DR service offers efficient, cost-effective transportation to customers. The routes have been designed around O-D pairs and centers of activity such as malls, the community college, and the downtown transit center. The Metro Hopper routes also serve neighborhoods that are underserved by traditional transit. SJRTD also provides shuttles for UCP; demand for that service is based on specific program and activities that occur at the center. SJRTD fuels and maintains the vehicles and UCP operates them. SJRTD feels these options and alternative services provide value that traditional transit service cannot.

A.7.2. Demand for DR Service

Demand for the service is based on the ability to have door-to-door service and providing greater flexibility for riders. These factors generally increase their satisfaction. The DR services provide rides for eight to ten passengers per hour, up from only one to two passengers initially.

A.7.3. Operations of DR Service

Metro Hopper rides can be conducted ad hoc if riders simply get on the shuttle. However, deviations must be requested through by calling at least a day in advance. The deviations are managed by a dispatcher. In establishing the system, a key challenge was determining the routes and headways in order to allot enough time for deviations, and to market the way that the service worked. SJRTD had experienced a fear of change amongst riders and it was important for the agency to communicate the advantages of the new service along with the similarities to traditional trips.

A.7.4. Evolution of the DR Service

Initially, SJRTD's DR services were very expensive to operate (over $50 per trip). However, the agency has worked hard to reduce costs (now $19 per trip). After initial changes, noted above, relating to adjusting headways and establishing service to the most beneficial areas, minimal alterations have been necessary.

A.8 Utah Transit Authority

Along with its traditional transit services, the Utah Transit Authority (UTA) offers flex routes, which are fixed routes services that are permitted to deviate up to three-quarters of a mile to either pick up or let off passengers. The 17 flex routes can make up to two deviations per trip, deviations can be scheduled in advance, and cost an additional fare ($1.25). Flex routes are part of UTA's special services unit along with various vanpool, ridesharing, and paratransit services.

A.8.1. Strategic Goals of DR Service

Flex route services began based on a desire to reduce the number of fixed routes during the recession in the late 2000's by linking peripheral communities to transit networks at a much lower cost. In short, Flex routes give UTA a way to provide solutions in a unique way by leveraging resources that already exist. As the landscape for non-traditional services changes, the objectives are also changing and in the next five years, UTA's special services unit will offer a wide range of service based on new and emerging technology.

A.8.2. Demand for DR Service

Flex routes provide service to communities and areas that are underserved and efficiently function as "the only game in town" for those communities. A key advantage is that flex routes help to solve the first/last mile problem for many riders. Typically, the routes are used by non-traditional riders making mid-day trips for errands or appointments at high-volume destinations. Flex-routes build in time for deviations and place limits on deviations where necessary in order to maintain a reliable schedule. Reliability versus efficiency represent trade-offs in terms of deviating from the route. As of summer 2015, there were approximately four to five requests per day for a deviation.

A.8.3. Operations of DR Service

Riders are able to hop on a flex route at any time, however, deviations must be requested a day in advance and occur by phone. Once trips are set up, scheduling and assignment is consistent with other services. The system works smoothly and does not require much maintenance. As with other route-deviation services, UTA notes that a key factor was determining the areas of service, scheduling, and building in time for deviations.

A.8.4. Evolution of the DR Service

Over time, some flex routes have been converted back into fixed routes based on demand. In general, areas of service have been tweaked and modified over time to maximize the benefit for riders and minimize costs. Primary next steps for the service include various developments regarding coordinated human services. This would include building flexible, dynamic, services such as coordinate ridesharing and integrating those services with existing DR services.

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