Executive Summary

Transit service in suburban regions can be costly and transit agencies face various challenges for providing desirable and responsive operations, especially from the perspective of connectivity and service frequency. Suburban transit operation typically uses fixed-route scheduled based operations with large headways. If a traveler miss a bus, they have to wait for an extended period of time for the next bus, This is inconvenient and wastes time for commuters. These issues have significant effects on transfer, first mile, and last mile connectivity. The lack of real-time information from both travelers and transit agencies presents a challenge for both stakeholders to obtain necessary and adequate traffic and transit information.

UC Berkeley PATH, in partnership with Tri Delta Transit, Contra Costa County Transportation Authority (CCTA), and the California Department of Transportation (Caltrans) havedeveloped an Integrated Dynamic Transit Operation (IDTO) system that enables D-RIDE service as well as real-time information for transit operations and travelers. As shown in Figure 1-1, The Tri Delta Transit provides on-demand shuttle services, called Tri-MyRide, in the cities of Antioch, Pittsburg, Brentwood, Oakley and Bay Point.

Figure 1-1. Tri-MyRide service zone at Tri Delta Transit

The development of an Integrated Dynamic Transit Operation (IDTO) and real-time information about the overall transportation systems (both transit and highway networks) has begun to make dynamic transit operation feasible. One of the dynamic operations, Dynamic Ridesharing (D-RIDE), can substantially improve transit service quality by providing faster, more convenient, and more cost effective trips to the traveling public. D-RIDE offers travelers the choice of micro-transit, ridesharing, or paratransit to connect to/from mass transit.

This project is Phase II+ of the IDTO system research, which focuses on the development and evaluation of the D-RIDE application at the Tri Delta Transit service zones. The D-RIDE function enables travelers to submit their connection and ridesharing request to the IDTO Server, which in

turn automatically forwards the request to the Demand Responsive Transit (DRT) application at a strategic time point in time. Then, the travelers are able to seamlessly arrange their successive trip directly with the on-demand service provider.The operation data and the field test demonstrates the benefit of notable time saving for both the travelers and the transit operators.

The tangible benefits of implementing the dynamic, real-time IDTO system was successfully proven in project phase I and II. Additionally, the research provides informative references and innovation practice for policy makers and stakeholders to develop new transit services operated in suburban American cities.

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Acronyms and Definitions

AVL	Automatic Vehicle Location
BART	San Francisco Bay Area Rapid Transit
Caltrans	California Department of Transportation
D-RIDE	Dynamic Ridesharing
DRT	Demand Responsive Transit
FOT	Field Operational Test
GTFS	General Transit Feed Specification
IDTO	Integrated Dynamic Transit Operation
PATH	California Partners for Advanced Transportation Technology
T-CONNECT	Connection Protection

1 Introduction

1.1 Overview of this Report

The purpose of this project is to develop and evaluate the D-RIDE component of the Integrated Dynamic Transit Operation (IDTO) system. The goal is to deliver significant and sustainable improvements to suburban transit services including transferring, ride-sharing and time-saving commutes.

The IDTO system developed under this project is built upon the IDTO framework and prototype systems developed under the previous phase including the IDTO server, the Mobile App, and the Driver-Vehicle Interfaces (DVI). The IDTO server hosts the decision support tool, data collection and database, and the messaging interfaces. The Mobile App interacts with travelers to obtain trip information and requests. The DVI communicates with transit operators to accommodate the requests from travelers and dispatch centers.

The D-RIDE application is the on-demand ridesharing option that incorporates the existing DRT services (e.g. Tri-MyRide at Tri Delta Transit). The D-RIDE function enables travelers to submit their connection and ridesharing requests to the IDTO Server, which in turn forwards the requests to the DRT application at a strategic timing automatically. Then the travelers are able to arrange their successive trip directly with the on-demand service provider seamlessly.

The key features of D-RIDE as described below:

A Train-to-DRT linkage model was developed to analyze mass transit to DRT connection needs with the objective to reduce the wait time of transfer passengers, as well as the total travel time of all passengers that use the D-RIDE application. Methodologies for real-time adjustments in response to the changing dynamics of the routes has been explored.

A function component of the mobile app has been designed to enable travelers to input their travel needs (e.g., plan a trip, request a service for D-RIDE, monitor the trip, and the connection status), and to receive trip status notifications.

A booking-by-prior-trip algorithm has been developed to enable a D-RIDE strategy that saves time for passengers and also provides reliable rider information to DRT operators.

With the integrated functions and features, the D-RIDE application has been tested and demonstrated at the Tri Delta Transit agency during this phase of the project. Under the sponsorship of Caltrans, the PATH project team, Tri Delta Transit, and the Contra Costa Transportation Authority have been devoting efforts investigating the benefits of D-RIDE.

The combination of innovative real-time data capture and data management methodologies has been shown to improve dynamic transit applications, expand the horizon for public transit management, and facilitate better operational and planning decisions

1.2 Project Objectives

The project objectives are listed below:

- Develop seamless trips connecting mass transit and on-demand shuttle services (aka DRT), that demonstrate how an optimized on-demand service and IDTO can enable an efficient operation strategy for suburban transit operations.
- Further develop the IDTO system to implement the D-Ride pilot application and conduct simulation analysis and field operational tests at the Tri Delta Transit serviced region.
- Facilitate the deployment and wide-spread implementation of dynamic transit operations as an essential component of MaaS.

1.3 Organization of the Report

This report is organized as follows: Chapter 2 describes the background of the project. Chapter 3 documents the framework of the D-RIDE system including the system structure, the database structure, and the overall workflow. Chapter 4 presents the system development and describes the functional components of the backend server, decision support engine, and booking interfaces. Chapter 5 is devoted to the field test with Tri-MyRide, and summarizes the test methodology and results. Chapter 6 focuses on the D-RIDE application performance evaluation from the perspective of transit operators and travelers. Chapter 7 summarizes the project and results, and provides recommendations for future research and implementations.

2 Background

2.1 Concept of the IDTO System

The PATH team has developed three phases of the Integrated Dynamic Transit Operations (IDTO) system.. The IDTO system aims to enable enhanced connectivity, reduced travel time, and improved transit operations by providing transit connection protection, dynamic dispatch, and dynamic ride-sharing applications.

A transit commuter can choose several options for their first/last mile trip through the IDTO applications. The T-CONNECT application aims to guarantee the local bus ride, while D-RIDE is expected to save time for the DRT ride. The multi-modal mobility scenarios are outlined in Figure 2-1.

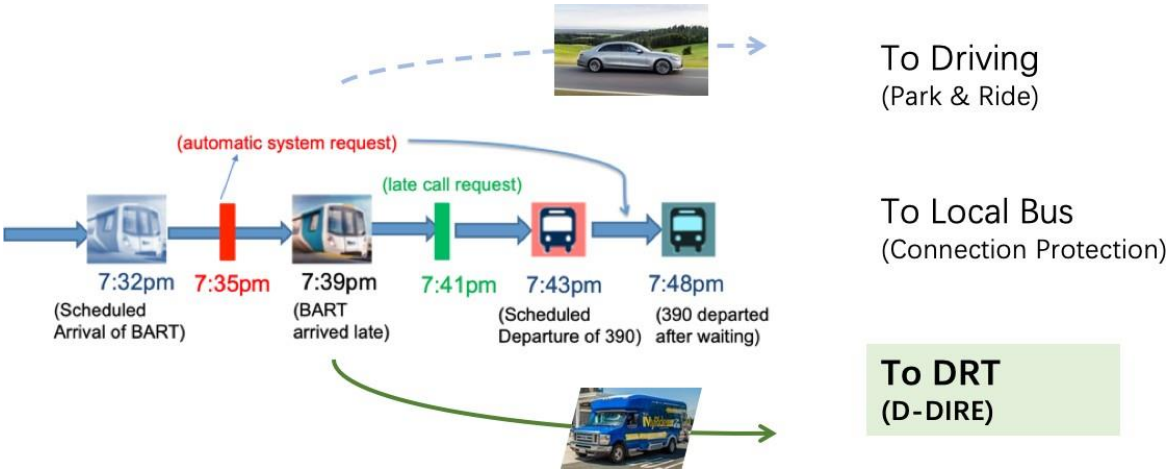


Figure 2-1. Connection Options for First/Last-Mile Transit

The PATH project team started the investigation of dynamic transit operation system in 2015 and developed the prototype of the IDTO from 2015 to 2018 in the IDTO Phase I project. The first phase proposed the architecture and system designs of the IDTO system, including a dynamic operation server, a mobile interface, and a dispatch center interface. As shown in Figure 2-2, the IDTO system allows the traveler and dispatch center to communicate through dynamic operation servers, that provide real-time information and operation status. In Phase I, the IDTO used an interface located at the Tri Delta Transit operation center that enabled transit operation staff to receive requests from the IDTO Server. They were able to successfully communicate with bus drivers through a radio communication channel to advise drivers to implement Connection Protection or dynamic operation.

The first phase has conducted several case studies to evaluate how Connection Protection can provide benefits for transit operations. For instance, the waiting time for transfer passengers can be significantly reduced at Tri Delta Transit's Hillcrest Park & Ride bus station by adjusting the schedule time of the connecting bus routes to meet the main bus route.. The study shows that a large number of schedules can be adjusted, resulting in a considerable benefit for all passengers. For another example, if the schedule of the connecting buses can be optimized at Hillcrest Park & Ride bus station, 13 hours can be saved for all transfer passengers per day.

The Phase I project concluded that T-Connect can significantly improve connections between transit routes, thus offering substantial reduction of travel time for transfer passengers. T-DISP and D-RIDE combined can offer travelers with connectivity and convenience, thus have potentials to attract choice riders.

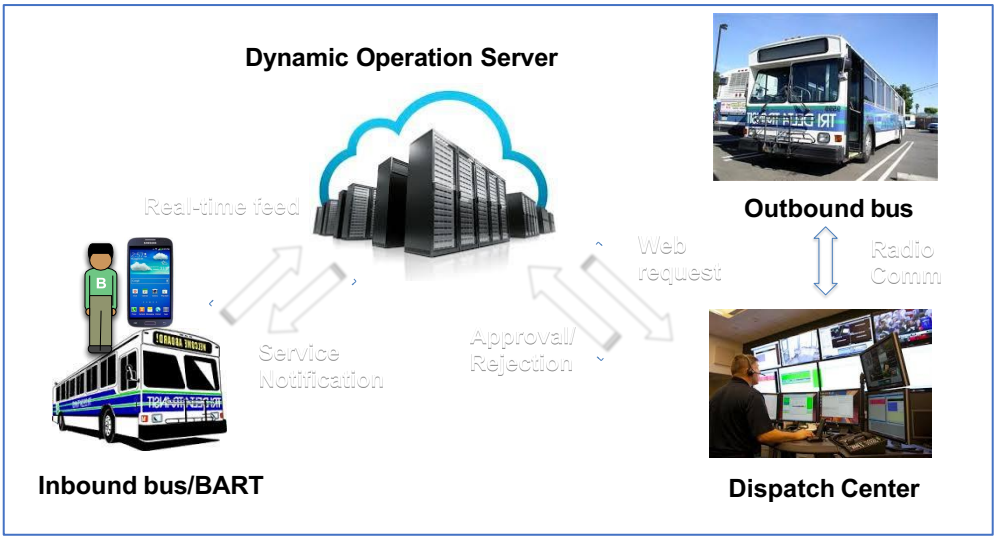


Figure 2-2. Use Case of IDTO Phase I system

In Phase II, lasting from 2018 to 2020, the PATH team further developed a fully functional IDTO system that delivered large improvements to suburban transit services. The overall goal of the project was to revolutionize suburban transit operation through deployment of IDTO. While the Phase I project was dedicated to the concepts and developing the IDTO system prototype, the Phase II project focused on the full scale implementation and field operation tests, successfully creating the following services:

1. Trip planning and communications with travelers through the mobile applications;
2. Real-time communications between IDTO and transit operators through driver-vehicle interfaces; and
3. Dynamic operation strategy optimization and decision support in the backend server.

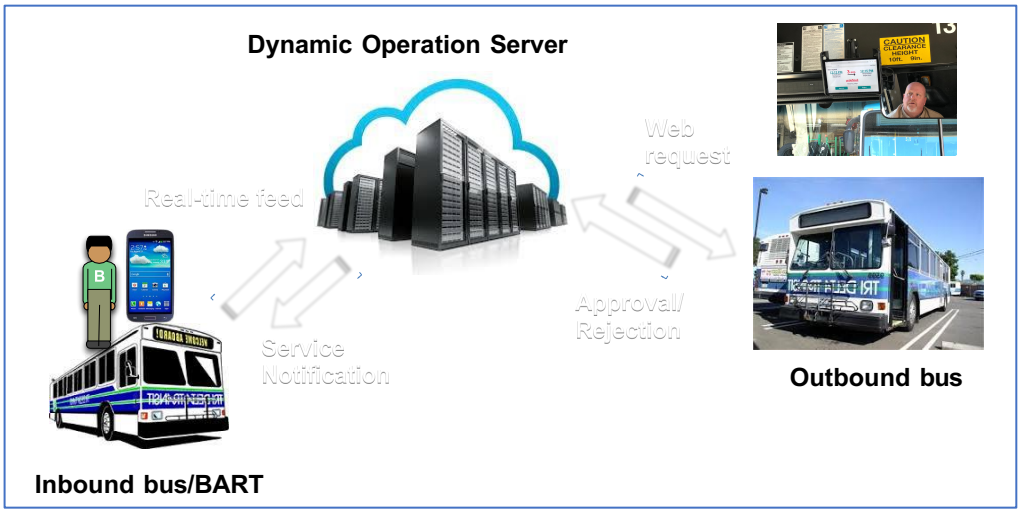


Figure 2-3. Use Case of IDTO Phase II system

In Phase II+ from 2020 to 2022, the PATH team added the D-RIDE function to the established system, which utilizes the transit real-time data to enable a booking-by-prior-trip strategy. The scenario is demonstrated in Figure 2-4 . The benefit of saving travel time caused by the overlap of BART trip time and DRT dispatch time has been evaluated and verified.

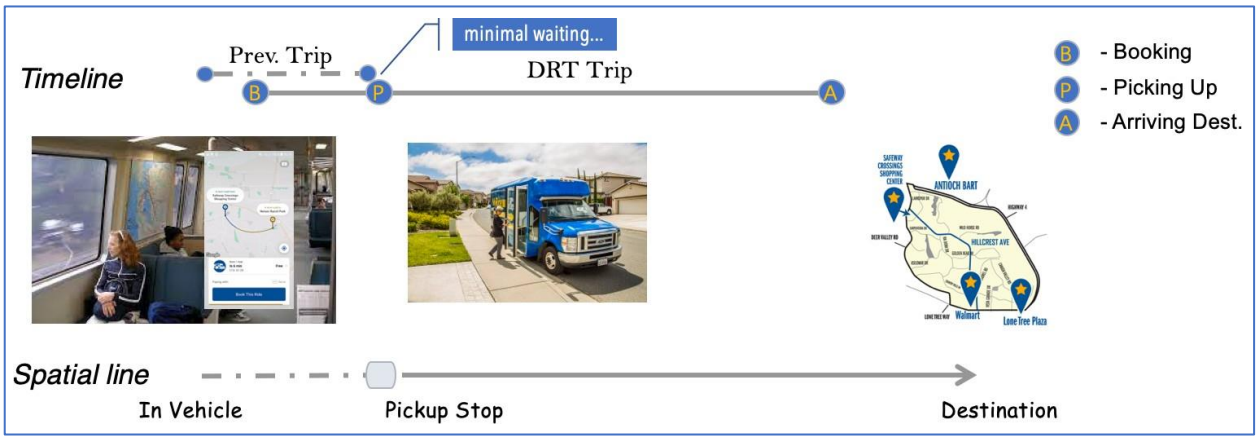


Figure 2-4. Use Case of IDTO Phase II+ system

The successive phases established a framework of transit operation being adaptive, dynamic, on-demand responsive, and traveler centric, and proved that future deployment can be achieved in a promising and reliable way.

2.2 Goal and Concept of D-RIDE

The objectives of D-RIDE (for IDTO Phase II+) are:

1) Develop seamless trips connecting mass transit and on-demand micro-transit (aka DRT), and to demonstrate how an optimized on-demand service and IDTO will enable an innovative and efficient operation strategy for suburban transit operations.
2) Further develop the IDTO system to implement the D-RIDE pilot application and conduct simulation analysis and field operational tests at the Tri Delta Transit serviced region.
3) Facilitate the deployment and wide implementation of dynamic transit operations as an essential component of MaaS.

The goals and objectives of this project directly address the needs of suburban transit agencies in California and across the country. This research best serves three of Caltrans' Goals -Flexibility, Reliability, and Performance. For Flexibility, the strategic focus is to enable transit as a solution to congestion; and for Reliability and Performance, the strategic focuses are operation and reliability improvements.

PATH applied a system engineering approach to the project management, system requirements, and implementation in the previous project phases. The Concept of Operation for the IDTO system and detailed system requirements have been defined collaboratively with Tri Delta Transit and Contra Costa Transportation Authority. We continued to follow the systems engineering approach during this project phase to update the system developments, the system requirements, the system designs, and for the project management aspect, and also incorporated the following concepts:

The D-RIDE application developed under this project is built upon on the IDTO framework and prototype system developed in Phase I & II and the details are described in the following sections. The system is designed to support a bundle of IDTO applications. These applications support integrated transit operation and provide travelers with a true "one-stop shop" for gathering multimodal travel information, making smarter trip planning, interacting with transit operators to improve successful transfers, informing their needs to transit operators in real-time for innovative demand responsive transit service, and potentially integrating with ride-sharing first-and-last mile services to supplement transit service.

The central element of IDTO system developed in this project is comprised of the IDTO Server that hosts Data Collection and Aggregation, a Travel Choice Tool (TC), a Decision Support Engine (DS), and Messaging Interfaces (MI). The DC acquires transit information from BART and the Tri-MyRide dispatch system and provides these data to the TC and DS. The TC tools interact with travelers to take O/D inputs, calculate feasible travel options, present the options to the traveler, take traveler's decision confirmation, and submit specific requests to the IDTO DS tools when this request involves transit buses. The responsibility of the DS tool is to evaluate the feasible strategies (i.e., T-CONNECT and D-RIDE) that will accommodate the request from the travelers. Once a feasible D-RIDE strategy is found, it will be submitted to transit dispatchers and drivers for

confirmation and execution. The MI is responsible for managing the interaction with travelers and operators to provide trip status updates.

The study of a new strategy led to a booking-by-prior-trip approach to enable time-saving. Train-to-DRT connections are built upon the schedules that enable the connecting shuttles to arrive in time. In IDTO Phase II+, we further developed the dynamic ridesharing service in designated stations and involved the engagement of multi-stakeholders including travelers, bus drivers, and transit agencies. The integration of the IDTO system and transit planning provides an adequate success rate of connectivity of transit transfer, and improves the overall efficiency and effectiveness of transit operation. Consequently, these improvements could encourage more passengers to use transit.

3 Framework of D-RIDE

3.1 System Structure

The Integrated Dynamics Transit Operation System considers the real-time transit and traffic condition information with the goal to provide successful connectivity between multiple transit modes (BART to bus, bus to micro-transit) and between different bus routes of an individual agency that can plan a trip that best fits the traveler's needs.

The system consists of four modules inclusive of the frontend and backend for both IDTO and Tri-MyRide system, whose relations and dependencies are shown in Figure 3-1.

- **IDTO Trip planner**: provides the travel information of travelers (e.g., trip information, requests a service for D-RIDE, acquires transit information and status of IDTO service request), and delivers travelers' requests to backend and receives real-time trip and service notifications.
- **DRT app**: the Tri-MyRide mobile app receives the booking requests for on-demand shuttle rides and delivers the pick-up information of the upcoming vehicle.
- **IDTO Backend**: hosts Data Collection and Aggregation, the Travel Choice Tool, the Decision Support Engine, and the Messaging Interfaces.
- **DRT Backend:** the existing backend of the DRT service provider; which needs to be modified to be able to process the new requests sent by a D-RIDE application.

The four modules manage a series of algorithms, interfaces, and demonstration programs which ensure the effective and efficient operations of the services. Details of the components for each module are illustrated in Section 4.

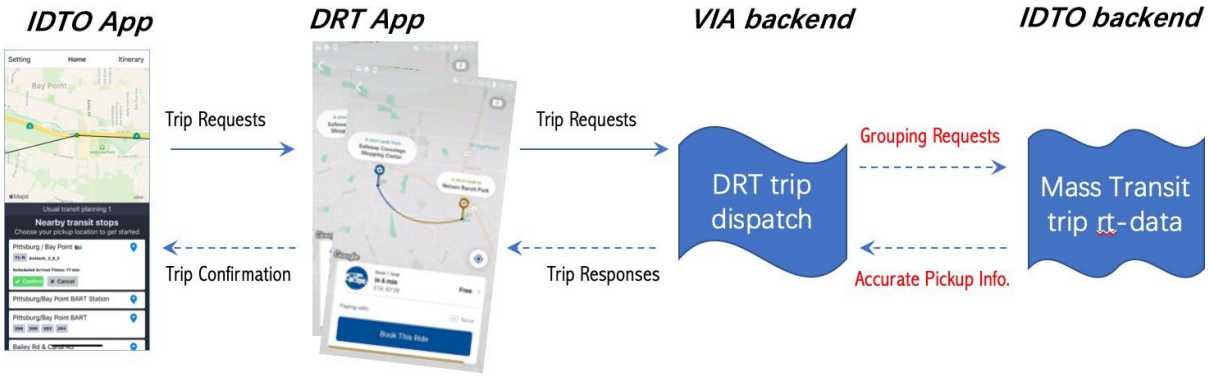


Figure 3-1. System Diagram of D-RIDE Application

3.2 Database Structure and Data Management

We have established an integrated IDTO database running on a backend server which collects, produces, and maintains transit and traveler data by manipulating a number of tables as shown in Figure 3-2. The database covers most of the transit agencies with an existing automatic vehicle location (AVL) system, and has stored the comprehensive data of transit agency operation (e.g. BART, Tri-Delta Transit, Tri-MyRide) and trip information, including:

- **Transit Agencies Data Feed**: static stops, routes, trips, schedule and real-time locations which are fetched from agencies server center.
- **Traveler-customized Demand**: first & last mile travel demand, real-time multi-modal connection request, and user account and preferences which are associated with the module "Trip planner"
- **Service Event Status**: tracking how a request has been approved or rejected, whether a demand has been satisfied.
- **Driver-Vehicle Interface Activities**: DVI device login and logoff time, button press time, driver ID and driver responses which are associated with the module "Driver-Vehicle Interface"

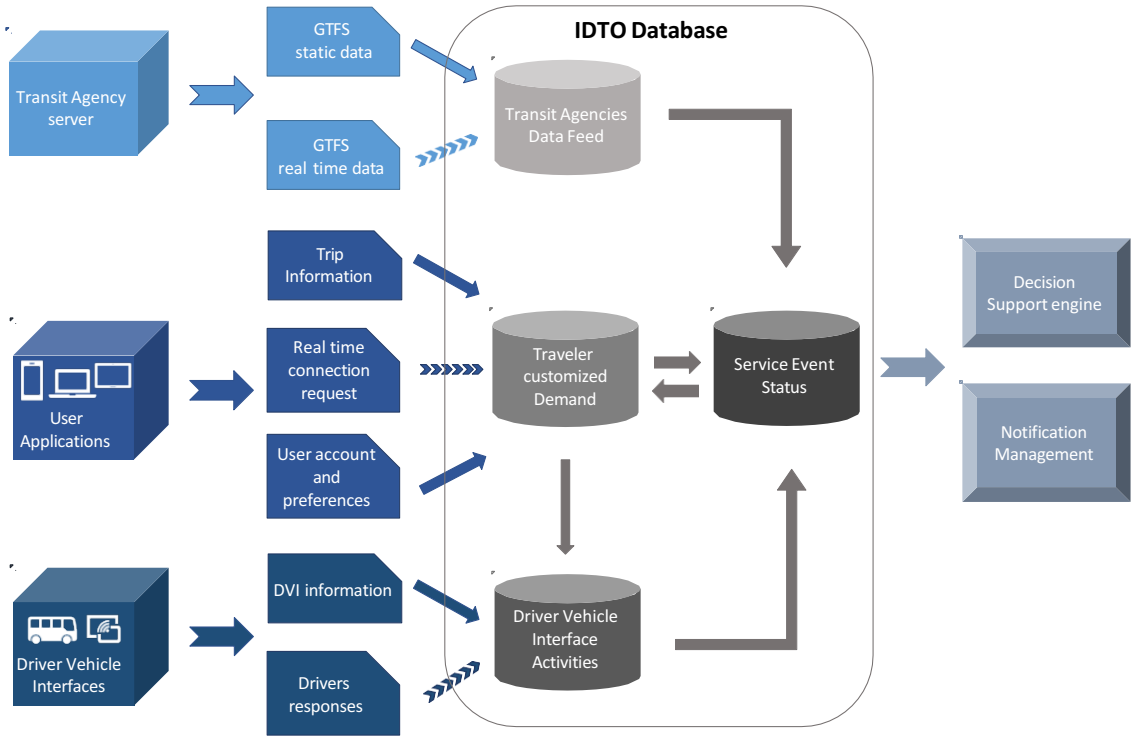


Figure 3-2. IDTO Database Structure and Data Management

One of the key data sources is the GTFS data feed which includes a static GTFS feed and a GTFS real-time feed, and their update frequencies are shown in Figure 3-3.

Figure 3-3. The GTFS data feed

3.3 D-RIDE Workflow

The IDTO system monitors the real-time transit operation (e.g. delays, schedules and transfer information) and plans a trip that best fits the traveler's needs. The planned trip could consist of several segments, with each segment representing a different transportation mode which is transit or transit-related. Once the traveler has confirmed the planned trip (including a last-mile trip demand after debarking BART) the system will track the user throughout the planned trip. The system will keep an update on the status of the traveler and the corresponding trains/buses, and automatically submit trip requests to the Tri-MyRide app in order to make a seamless connection between the BART trip and the DRT trip. The traveler will also be informed of updates or status changes during the entire trip. The D-RIDE operation can also be regarded as a Mobility-as-a-service application which provide a one-shop transit service by combining and connecting all trip segments automatically.

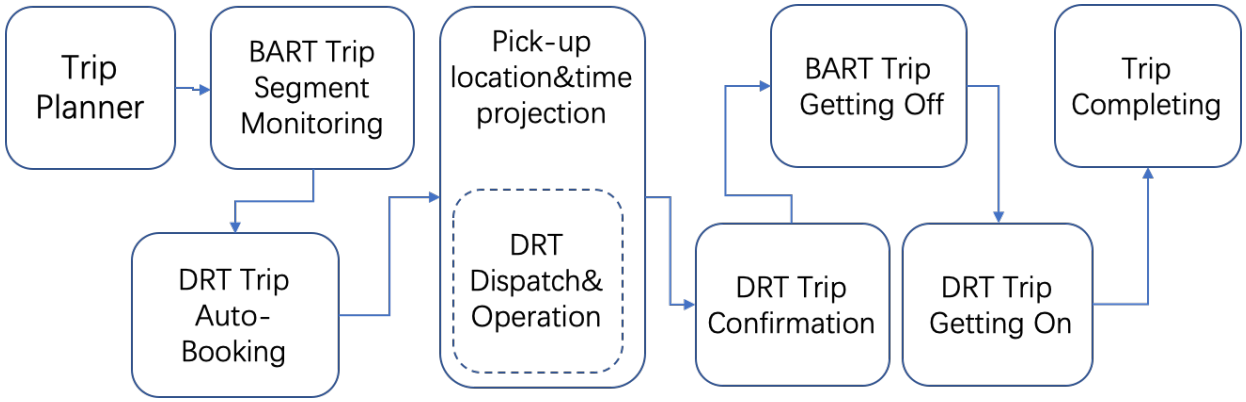


Figure 3-4. Workflow of D-RIDE Operation

The workflow of the IDTO server system consists of the following components that support the train-to-DRT connection service:

- **The mobile app**delivers and receives information related to travelers, trip information, and real-time event status.
- **The database on server:** updates and archives all the static and real-time data from external feed (public GTFS and agency dispatch data) and internal activities (mobile app requests, event records)
- **The application on server** provides the application programming interfaces between mobile app and database to retrieve saved trips, obtain real-time information, as well as send notifications.

4 Development of D-RIDE

4.1 Overview of Operations

This project aims to deploy and implement the key functions of the IDTO system including the Connection Protection service, T-CONNECT, from the previous project phases and the train-to-DRT service D-RIDE for this project phase. The IDTO system serves as a bridge between individual travelers and the public mobility suppliers as well as mass transit and micro transit.

From the perspective of transit operation, The D-RIDE intends to facilitate first-mile and last-mile shared riders by connecting riders from mass transit to DRT trips in real-time. The D-RIDE application is implemented through dynamic operation supporting tools for real-time on-demand shuttle operation based on predetermined operation rules. The on-board transit operators are able to receive real-time operation advice and adjustments via interfaces and management systems through the IDTO server. The D-RIDE system is implemented in the Tri-MyRide service zone within the Tri Delta Transit area. The field tests conducted prove the time-saving performance for both the transit rider and operator.

From the perspective of traveler trip planning, IDTO provides transparent information to travelers in an on-demand manner, but there are some conditional cases where buses may or may not be available. A traveler can input the transit trip (bus or BART) she is currently taking (or can automatically set the current location using GPS on a mobile device), the trip she is planning to take the transfer, and the transfer points (e.g. bus stops or BART stations). The IDTO server, upon receiving the request confirmation, will identify the real-time transit and traffic conditions and make the decisions of whether to trigger the traveler's requests or not. Once the requests are triggered, the server will send the information to the transit operator and obtain the response. The IDTO will update the real-time response from the operators to travelers and display the response within the mobile interfaces.

During the entire process, the IDTO system will keep updates on the status of the mass transit vehicles. After the trips are completed, the system automatically archives daily historical logs, trip information, and bus operation information.

4.2 Scenarios of the operation

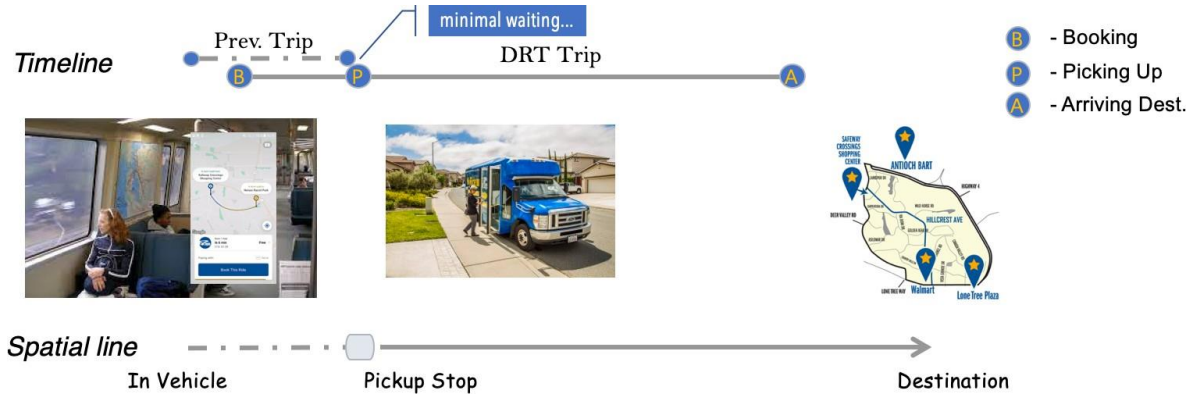
The scenario of D-RIDE application can be described as the following use case and shown in Figure 4-1:

- First, a passenger initiated a transit trip including a transfer from BART to a Tri-MyRide ride. The trip information, including the origin, destination, and transfer location was

submitted to the server through the user interface (e.g. mobile app). The trip information was sent at 4:30 pm, indicating he will exit BART (scheduled at 5:05 pm) and take the Tri-MyRide shuttle upon its arrival. The walking time between the BART station and the shuttle stop is 4 minutes.

- The server therefore obtained the trip schedule activities and tracked the BART estimated time of arrival (ETA). At 4:58 pm, the server engine sent a booking request to the Tri-MyRide app to request a shuttle ride to pick the passenger up at the BART get-off station and at 5:09 pm. The Tri-MyRide app verified that a shuttle was available and the ETA was 5:10 pm.
- The passenger exited BART and got to the pick-up stop at 5:09 pm, so the passenger waited for the pick-up shuttle for 1 minute.
- If a number of passengers on the same BART vehicle sent their requests through the D-RIDE application, the DRT shuttle could respond quicker.

(a) Current approach of booking-upon-arrival



(b) New approach of booking-by-prior-trip

Figure 4-1. Example of D-RIDE Scenario

The IDTO system will offer faster and better transportation services that attract travelers, reduce the transit operation costs, and allow public transit to assume a greater role in the overall solution in reducing transportation congestion, increasing safety, and improving air quality.

4.3 The Backend Server

The IDTO backend server monitors the real-time information of the travelers' requests, gathers DRT dispatching data serving the connection point, and triggers bookings of successive DRT trips using a variety of optimization algorithms as described in the following sections.

4.3.1 Decision Support Engine

The decision support engine contains an ETA-based algorithm to monitor the BART and Tri-MyRide operation, process travelers' requests, and provide a book-in-advance decision. The core function of the decision support engine is to effectively and efficiently decide the Connection Protection events and manage the notifications.

The booking-by-prior-trip algorithm is the core algorithm in the backend server that checks trigger conditions and timing to send the DRT booking request. The request time is the time point when the backend server begins to make trigger decisions of the events. We use the following notation to denote the passenger's ETA at the transfer stop:

$$ETA_psg = current\ time + remaining\ BART\ time + transfer\ walking\ time$$

The confirmation of successful booking-in-advance will be returned when:

$$ETA_psg < ETA_drt,$$

which means the passenger must show up before the pick-up shuttle arrivals. This criterion sets up a protection mechanism for the DRT operation since the shuttle location can be tracked by the passenger app while it's not the case the other way around. When the aforementioned criterion is not satisfied, the DRT will be at the pick-up location before the passenger shows up, possibly wasting time. Therefore, the system will reject the first booking request and submit a second request 2 minutes later. Eventually the last-mile DRT trip will be dispatched to save the train-to-DRT connection time.

We also considered the conventional way of dispatching where the DRT operation does not support an in-advance booking method.

4.3.2 Real-time Monitoring of Trip Updates

The D-RIDE application aims to provide real-time on demand service for connectivity improvement and travel time saving. To obtain and monitor the real-time transit schedules and delays, the server first generates static transit operation data and the pre-defined transfer routes from the static General Transit Feed Specification (GTFS) feed and then continuously fetches the real-time vehicle locations and trip time updates from the GTFS-rt to monitor the pre-defined trip pairs as shown in Figure 4-2.

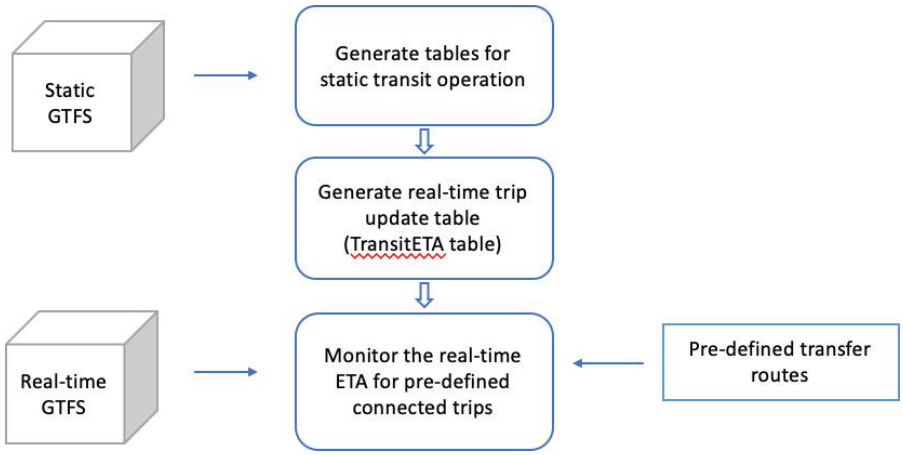


Figure 4-2. Diagram of real-time monitoring of trip-updates

The IDTO server uses static GTFS feed to generate transit operation tables and uses the real-time GTFS feeds to monitor transit delays. From the static GTFS feed, the server generates the tables of selected stops, schedules, and other fix-route based information. From the real-time GTFS feed, the server generates the TransitETA table which contains the ETA records for all trips under investigation. Transit agencies typically use GTFS-flex to standardize the DRT service zone and route data, but Tri-MyRide has not adopted these data feed or their extension yet.

4.3.3 Booking-by-Prior-Trip API

The DRT dispatch vendor VIA offers two booking approaches by calling a simple URL (which any rider can access using VIA's app) and receive a VIA proposal with a predefined origin & destination.

- Approach 1: booking right at the pickup location

baseurl/proposal?referrer=Via&passengers_count=1&destination=<destination address>

- Approach 2: booking at a remote location (but within the service zone)

baseurl/proposal?referrer=Via&origin_lat=<origin latitude>&origin_lng=<origin longitude>
&destination=<destination address>

Beyond the above conventional approaches, the booking-by-prior-trip API should include the inputs of pick-up location (other than the passenger's real-time location), the time, and the new endpoint recommended to serve as an extendable API to allow in-advance and remote booking requests.

- New Approach:

baseurl/proposal?referrer=Via&origin=<pickup_location>&destination=<destination_address>&p
*ickup=<a_later_pickup*_time>

Note that this API has not been officially implemented in the Via system.

4.4 IDTO Mobile App (Path2Go)

The IDTO mobile app has been developed during the three phases of the IDTO project, and acts as the first transit app to impact the transit operation beyond the conventional transit information services (lines, stops, and ETAs). For the D-RIDE function, we designed an interface to an in-app linkage to invoke the VIA app for booking a successive Tri-MyRide trip. We have designed the conceptual workflow and interfaces for this function component, but no real app development has been made.

4.4.1 Mobile App Interface Framework and Components

The applicaiton has three main functions:

- Account: the account function allows passengers to register and set their commuting routes and stations
- Trip information: the trip information function allows passengers to select a specific route, origin, destination and transfer station.
- Itinerary: the itinerary information shows the current status of passenger's route and the status of D-RIDE.

The mobile app interface for trip information contains the trip origin and the transfer information.

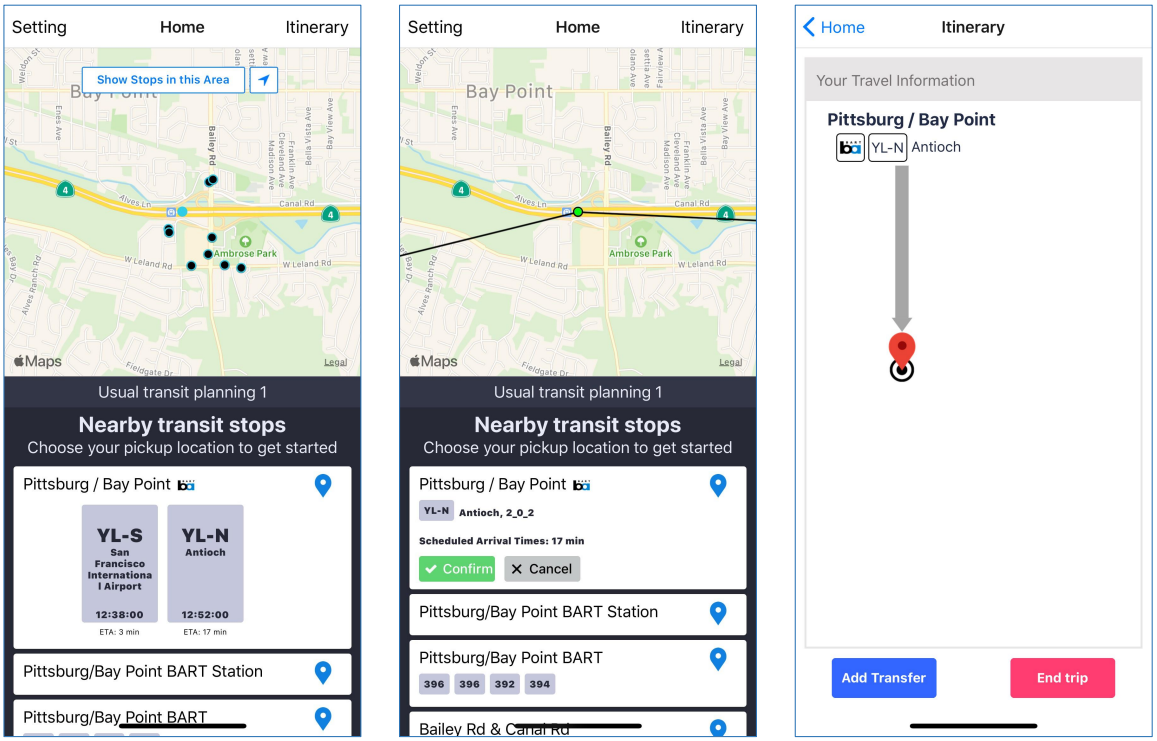


Figure 4-3. The Mobile App Interface Demo

After obtaining the trip information, the mobile app generates the itinerary for the specific trip and displays it.

4.4.2 D-RIDE Interface Design

To enable the mass transit to DRT connection, the mobile app provides the spatial and temporal transit information and real-time schedule information by the following core functions:

- **Identify valid transfer stations** corresponds to the Transfer Information function. After the traveler selects the departing transit stop of the incoming trip, the APP will send the station information through an API and obtain the possible transfer transit stops and the subsequent trip information arriving at the given transit stop.
- **Identify spatial and temporal information** is in accordance with Trip Origin function. When a traveler opens the application, the APP will display a regional map view where the traveler is located. The app recognizes the latitudes and longitudes of the region, the traveler's location, and the current time. Through an Application Programming Interface (API), the app sends a request with spatial and temporal information to obtain the return of nearby route, stop, and schedules.

- **Send ride request to DRT app,** to encode the spatial and temporal information into the endpoint parameters, then call the endpoint to send the booking request to the DRT backend.
- **Monitoring itinerary and providing real-time updates**, for the rest of the mass transit trip, the app continuously monitor the status of both the ongoing BART and upcoming DRT. The confirmed DRT booking will be cancelled if the current BART trip experiences significant delay which is very not likely to happen but should be considered for the service design.

5 Field Operation Test

5.1 Baseline Data Analysis

To analyze the D-RIDE function, we collected the demand data of Tri-MyRide service via mobile from 09/2019 to 02/2020. Tri-MyRide is the on-demand micro-transit service provided by Tri Delta Transit. It has two service areas including Antioch BART and Pittsburg/Bay Point BART, operating every weekday from 5:00 am to 9:00 pm.

5.1.1 Demand patterns

In total there are 19132 rides during the period using TriMyRide service. The types of the rides are categorized by From/To Home for Antioch BART (ANTC), From/To Home for Pittsburg/Bay Point BART (PITT), and From/To other locations. It is noted that rides are concentrated for BART stations which is 73.46%, as shown in Table 5-1.

Table 5-1. Number of rides with different origins and destinations

	ANTC	PITT	Other
From Home	5166 (21.55%)	3496 (14.58%)	722 (3.01%)
To Home	4606 (19.21%)	4344 (18.12%)	537 (2.24%)
Other	0.00%	0.00%	261 (1.09%)

In addition, the demand is geographically concentrated in residential areas as shown in Figure 5-1, where the size of the circle indicates the amount of the demand.

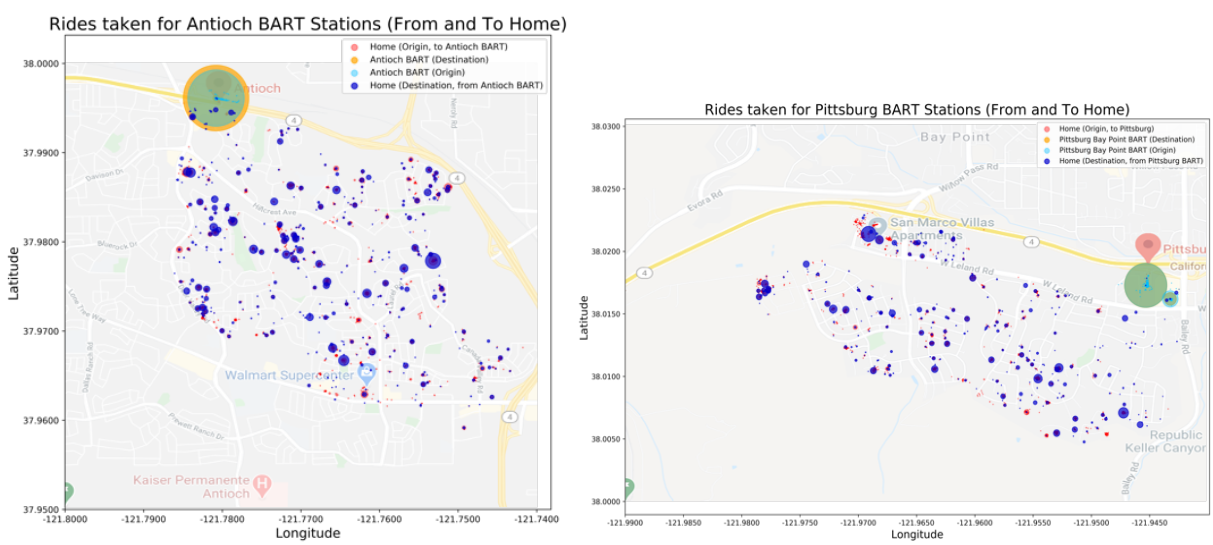


Figure 5-1. Geographical distribution of demand for the two BART station are

On average there are 3188 rides in a month with the lowest record of 2822 rides and the highest record of 3476 rides, as shown Figure 5-2. The demand also shows the commuting trend of travelers where a large number of rides are taken during the morning and evening peak hours as shown Figure 5-3.

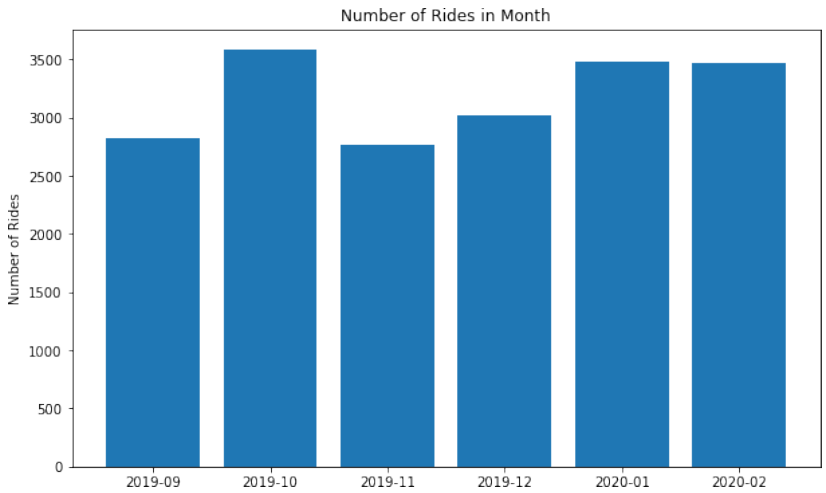


Figure 5-2. Number of rides in month

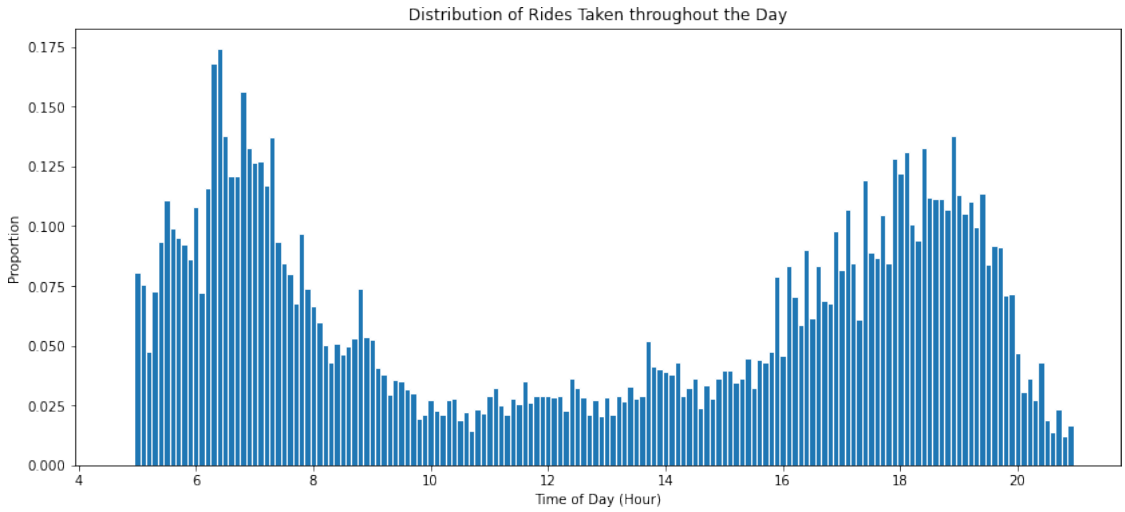


Figure 5-3. Distribution of rides with respect to the time of day

5.1.2 Issues of waiting time

It is noted that travelers need to wait at the location to get picked up by the micro-transit service. To analyze the waiting time, we focused on the rides from the two BART stations to home which are matched with the BART schedules.

As shown in Figure 5-4, travelers' average in-vehicle time is 11.12 minutes. However, travelers' waiting time is 10.38 minutes which is 48% of the total travel time. The waiting time is a total time loss which reduces both the efficiency of the operation and the traveler trip connectivity.

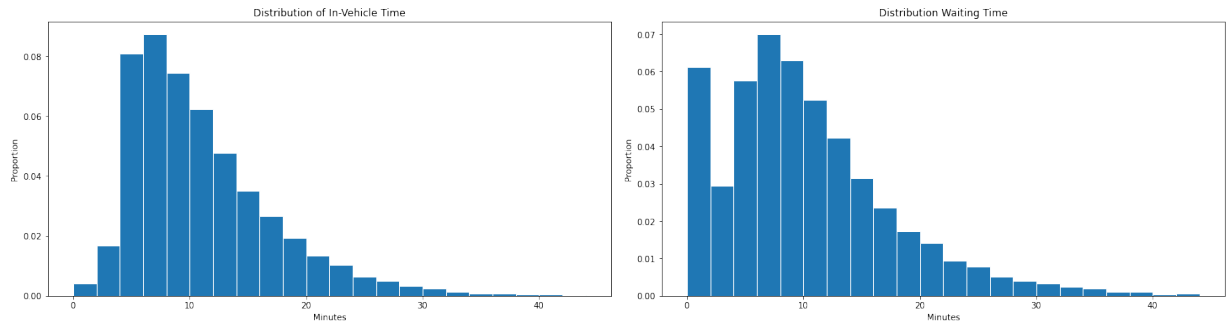


Figure 5-4. Distribution of in-vehicle time and waiting time

To specify the issues of the waiting time, we concluded the three types of the time loss:

Case 1: Short waiting time: this case refers to the situation where travelers are waiting for less than 15 minutes for boarding the Tri-MyRide vehicle after taking off from BART, as shown in Table 5-2. Such waiting time can be saved with the D-RIDE function where travelers can book the service in advance, (i.e., by taking the micro-transit after the BART) without waiting.

Table 5-2. Example of short waiting time case

service_name	origin_address	Date	BART_Time	Timestamp	Wait Time	Boarding time	Total Time
San Marco - To Home	Pittsburg Bay Point BART	2019-09-04	18:29:00	18:33:33	03:13.0	18:36:46	19:14.0
San Marco - To Home	Pittsburg Bay Point BART	2019-09-04	18:29:00	18:34:47	01:59.0	18:36:46	13:01.0
San Marco - To Home	Pittsburg Bay Point BART	2019-09-04	19:06:00	19:06:02	05:04.0	19:11:06	20:17.0
San Marco - To Home	Pittsburg Bay Point BART	2019-09-04	19:06:00	19:07:41	03:25.0	19:11:06	09:03.0

Case 2: Long waiting time and short BART headway: When two batches of travelers get off two consecutive BART trips, the second batch may have a longer waiting time even though the headway of the BART is short. This may be because the micro-transit operators lack travelers' demand information and pick up only the first batch of the travelers. Therefore, the second batch of travelers has to wait for a long time to board another vehicle. In the example shown in Table 5-3, the BART headway is 4 minutes but the waiting time of the second traveler batch is as high

as 22 minutes while the waiting time of the first traveler batch is only 3 minutes. With D-RIDE function of advanced booking, the operators are able to obtain the booking information in advance and can wait at the station for a few minutes and pick up both travelers.

Table 5-3. Example of long waiting time and short headway

service_name	origin_address	Date	BART_Time	Timestamp	Wait Time	Boarding time	Total Time
San Marco - To Home	Pittsburg Bay Point BART	2019-09-06	**18:06:00**	18:07:50	03:03.0	18:10:53	10:27.0
San Marco - To Home	Pittsburg Bay Point BART	2019-09-06	**18:10:00**	18:12:04	22:53.0	18:34:57	31:26.0

Case 3: Long waiting time and long BART headway: This case refers to a situation when travelers wait for a long time for the micro-transit service after getting off the BART. This is partially because of the dispatch time and fleet limitation. As shown in Table 5-4, both travelers have a long waiting time and the headway of BART is 20 minutes. In this case, providing D-RIDE service may not have a large effect since the waiting time is caused by the dispatch operation rather than pick-up arrangements. Therefore, in this section we will focus on the analysis of D-RIDE for Case 1 and Case 2.

Table 5-4. Example of long waiting time and long headway

service_name	origin_address	Date	BART_Time	Timestamp	Wait Time	Boarding time	Total Time
San Marco - To Home	Pittsburg Bay Point BART	2019-10-03	16:56:00	16:58:24	17:39.0	17:16:03	24:10.0
San Marco - To Home	Pittsburg Bay Point BART	2019-10-03	17:16:00	17:20:00	29:37.0	17:49:37	36:45.0

5.1.3 Potential Time Saving with D-RIDE

To assess the potential impacts of D-RIDE, we selected the trips from BART to home and matched them with BART schedules. The percentage of trips in each case is listed in Table 5-5. As mentioned above, we focus on the time saving in Case 1 and Case 2 which consists of 95.15% and 95.28% trips in Pittsburg/Bay Point (PITT) and Antioch Station (ANTC) respectively. For Case 1, D-RIDE can save 4.5 and 3.7 minutes waiting time per traveler in PITT and ANTC respectively. For the second case, it can save 4.3 and 3.5 minutes in PITT and ANTC.

Table 5-5. Overview of different cases for BART-to-Home trips

	Case 1	Case 2	Case 3
Trip Percentage - PITT	80.60%	14.55%	4.85%
Time saving per traveler – PITT (minutes)	4.5	4.3	n/a
Trip Percentage - ANTC	82.08%	13.20%	4.72%
Time saving per traveler - ANTC (minutes)	3.7	3.5	n/a

5.2 Test Methodology

The field test aims to the validate and verify the D-RIDE application in real world cases, including procedures for preparation, backend development, performance monitoring, and data collection and analyses. Working with Tri Delta Transit and their on-demand shuttle supplier VIA, the PATH project team conducted a two-stage quasi-simulated field operational test of the D-RIDE application at the Tri-MyRide Transit serviced zone.

The first stage is a simulation test. Since the real DRT operation cannot be interrupted during testing, the researchers developed a simulated DRT dispatch tool whose structure is presented in Figure 5-5 . The tool serves as a DRT simulator providing the information of vehicle availabilities and predicted pick-up times through the IDTO backend rather than a DRT operation backend.

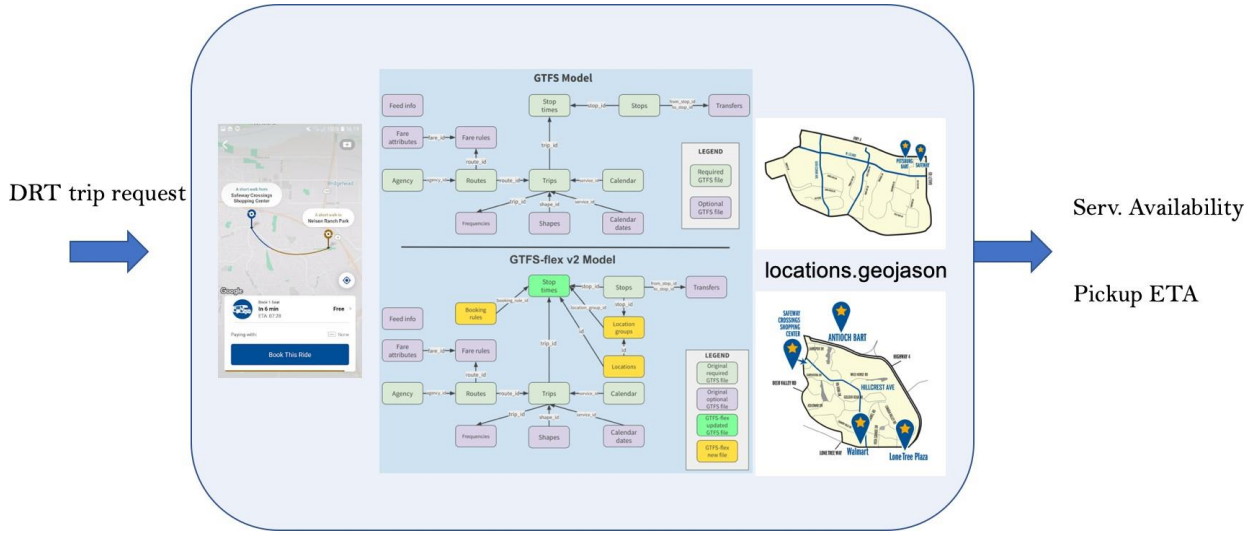


Figure 5-5. DRT Dispatch Simulator

The second stage is a field test including the real DRT dispatch responses. For the same reason of not influencing the real DRT operation, a quasi-simulated test methodology has been adopted and further designed. The Tri-MyRide app has an ETA inquiry step to provide the DRT availability information before a real trip request has been submitted, which was leveraged as a pre-booking request. A number of pre-booking requests were submitted remotely and in advance when the test travelers were on BART approaching the transfer stops, whose responses has been parsed to obtain the shuttle ETAs. The data collected are analyzed to obtain the performance of this booking-by-prior-trip strategy.

5.3 FOT Implementation

To study the connectivity between BART and Tri-MyRide which is inclusive of the Pittsburg/Bay Point BART Station and the Antioch BART Station, the PATH project team adopted a two-stage test including the simulation test and the field test. Theirdescriptions and features are outlined in Table 5-6.

Table 5-6. Timeline and Descriptions of FOT

Time	12/01/2021–12/10/2021	03/16/2022 – 03/31/2022	
FOT stage	Simulation test	Field test	Performance Evaluation
Approach	Using a DRT dispatch simulator	Integrating with Tri-MyRide mobile App	Data processing and evaluation
Data produced	Simulated trips, simulated events and timelines	Booking requests, BART and DRT trip timelines	valid trips and connections, time saving results

5.3.1 Simulation Test

A set of trips were virtually generated in the simulation test. The time duration was from 5am to 8pm each day. The trips were generated every 30 seconds. The dispatching time was calculated through the Google map Direction API (as below) by assigning the vehicle real-time origin to a random place within the Tri-MyRide service zone.

https://maps.googleapis.com/maps/api/directions/xml?origin=<origAddrUTF8>&
destination= <destAddrUTF8>&mode=driving&key=<GOOGLE_KEY>

The total 1,800 trips were simulated and were fed to the IDTO system to verify and evaluate the D-RIDE strategy.

5.3.2 Field Test

During the field test, we initiated 83 Tri-MyRide booking trips at the *Pittsburg/Bay Point* (41) and *Antioch* (42) BART Stations. Sixty trips are of conventional booking-upon-arrival at the stations, and 23 trips are the D-RIDE approach: booking-by-prior-trip on BART trips.

Figure 5-6. Real Scene of pick-up stop at BART station (left) and Tri-MyRide vehicle (right)

During the field test, The IDTO system collected and archived a set of data to support the evaluation of the D-DIRE application, as outlined below:

- Real-time and archived transit data, including those collected by Tri-MyRide dispatching system and BART.
- Traveler activities through mobile apps collected and archived at IDTO system server.

The data collected in the FOT period was used for the D-RIDE performance analysis as stated in Table 5-7. Pxxx and Axxx indicate the data collected at Pittsburg (P-station) and Antioch BART station respectively. The columns heads represent the data as:

- "Pbook": the in-advance booking time, independent with the BART schedule;
- "Parr": , the arrival of pick-up DRT shuttle;
- "Pdur": duration from booking to getting on DRT shuttle, on the BART of last run;
- "PBart": the BART scheduled arrivals.

Table 5-7. Time Dataset of Field Test Trips

Pbook	Parr	Ppick	Pdur	PBart		Abook	Aarr	Apick	Adur	ABart
10:11	10:20	10:13	00:09	10:05		10:13	10:25	10:14	00:12	10:10
10:17	10:26	10:19	00:09	10:05		10:19	10:31	10:20	00:12	10:10
10:39	10:53	10:46	00:14	10:35		10:41	10:56	10:46	00:15	10:40
10:56	11:07	11:00	00:11	10:50		11:03	11:15	11:06	00:12	10:55
11:55	12:04	11:57	00:09	11:50		11:09	11:21	11:12	00:12	11:10
11:59	12:08	12:01	00:09	11:50		12:37	12:52	12:41	00:15	12:38
12:45	13:06	12:58	00:21	12:35		12:44	12:57	/	00:13	12:38
13:03	13:22	13:15	00:19	12:50		13:15	13:28	13:16	00:13	13:08
13:30	13:40	13:32	00:10	13:20		13:20	13:57	13:45	00:37	13:08
14:41	14:51	14:44	00:10	14:35		13:35	14:03	13:53	00:28	13:23
15:37	15:45	15:38	00:08	15:35		15:35	16:08	15:55	00:33	15:20
15:47	16:09		00:22	15:35		15:45	16:09	15:56	00:24	15:35
15:52	16:14		00:22	15:50		15:53	16:10		00:17	15:50
15:58	16:19		00:21	15:50		15:59	16:15		00:16	15:50
16:05	16:19		00:14	16:05		16:05	16:22		00:17	16:05
16:10	16:32		00:22	16:05		16:10	16:25		00:15	16:05
16:16	16:33		00:17	16:05		16:16	16:51		00:35	16:05
16:20	16:30		00:10	16:20		16:20	16:49		00:29	16:05
16:26	16:42		00:16	16:20		16:26	16:50		00:24	16:20
16:32	16:57		00:25	16:20		16:32	17:04		00:32	16:20
16:40	17:11		00:31	16:35		16:40	17:12		00:32	16:35
16:45	17:10		00:25	16:35		16:45	17:10		00:25	16:35
16:50	17:07		00:17	16:50		16:51	17:15		00:24	16:50
16:55	17:09		00:14	16:50		16:55	17:24		00:29	16:50
17:00	17:10		00:10	16:50		17:01	17:24		00:23	16:50
17:05	17:24		00:19	17:05		17:05	17:24		00:19	17:05
17:10	17:33	17:17	00:23	17:05		17:11	17:26		00:15	17:05
17:16	17:35		00:19	17:05		17:16	17:31		00:15	17:05
17:20	17:38		00:18	17:20		17:20	17:35		00:15	17:20
17:25	17:33		00:08	17:20		17:25	17:40		00:15	17:20

6 D-RIDE Performance Evaluation

6.1 Framework of Performance Evaluation

The evaluation is conducted using three data sources including the IDTO dataset and the Estimated Time of Arrival (ETA) Dataset. As shown in Figure 6-1, the measures of the evaluation are from the perspective of real-time connectivity, the DRT dispatch operation, and the travelers' OD.

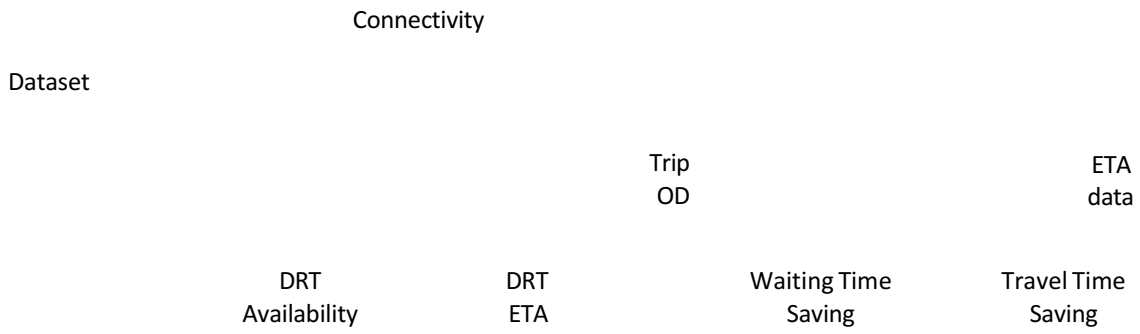


Figure 6-1. Framework of Performance Evaluation

In this project, we investigate the performances that are primarily the time saving for last-mile trip connections and eventually for the entire trips.

6.2 Performance of Simulation Tests

The Tri-MyRide trip times have been investigated by comparing the cases before and after a D-RIDE strategy has been virtually implemented. **The simulation tests show that the passenger transfer waiting time (for pickup) was saved by an average of 53%, while the number decreases to 22% for DRT travel time saving.** It's also shown that there is no notable difference between peak hours and off-peak hours, which can possibly be explained by a reduced amount of traffic in in the investigated area.

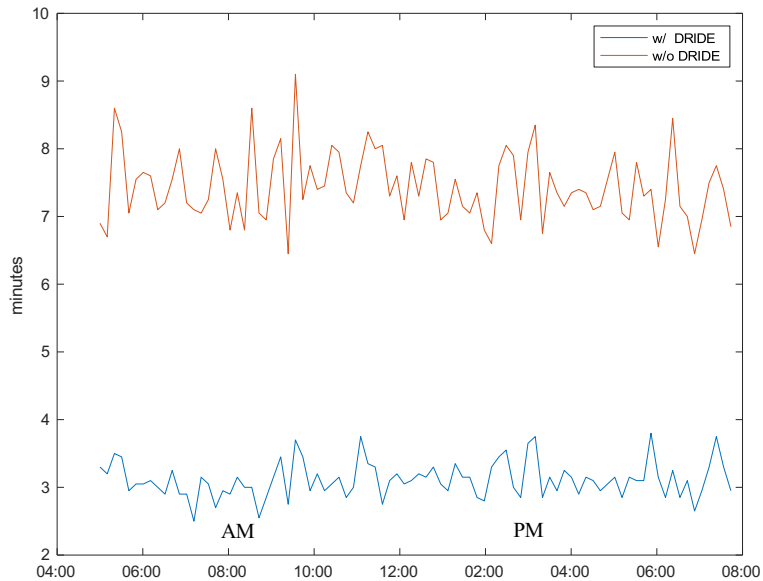


Figure 6-2. average waiting with respect to the time of day

Illustrated by Figure 6-3, the waiting time for pick-up at the shuttle stop of the Antioch BART station varies from 3-15 minutes if the riders choose to order the shuttle trip after getting off of their BART trip. In contrast, when the book-by-prior-trip function has been integrated into the DRT service, **most of the cases will result in a waiting-for-pickup time of 1-7 minutes.**

Figure 6-3. Waiting-time for a DRT shuttle, without D-RIDE (left) and with D-RIDE (right)

6.3 Performance of Field Test

From the analysis of the collected operational data of Tri-MyRide, the results show a self-organization pattern of the DRT operation which aligns with the mass transit schedule to serve the passengers for the last-mile trip. As shown in Figure 6-4, when the booking time is closer to the BART arrival, a shorter waiting time is expected. The pattern exposes a mechanism of the DRT drivers' behavior of picking up passengers that exit BART on time, which acts as an supportive evidence to implement the D-RIDE application.

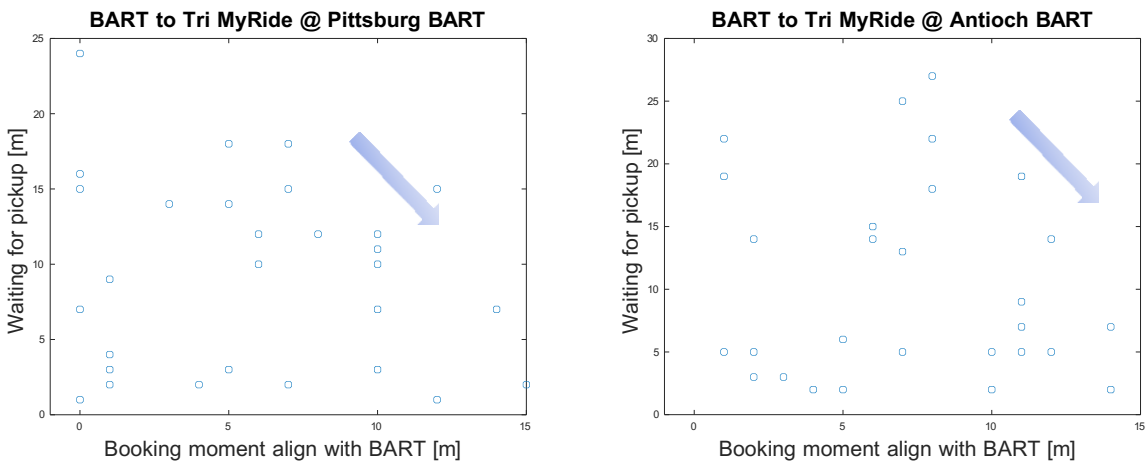


Figure 6-4. DRT waiting time when align with BART schedule

As shown in Figure 6-5, when the booking-by-prior-trip strategy was applied and tested, the saving of waiting-for-pickup time was achieved in coordination with the timing of booking.

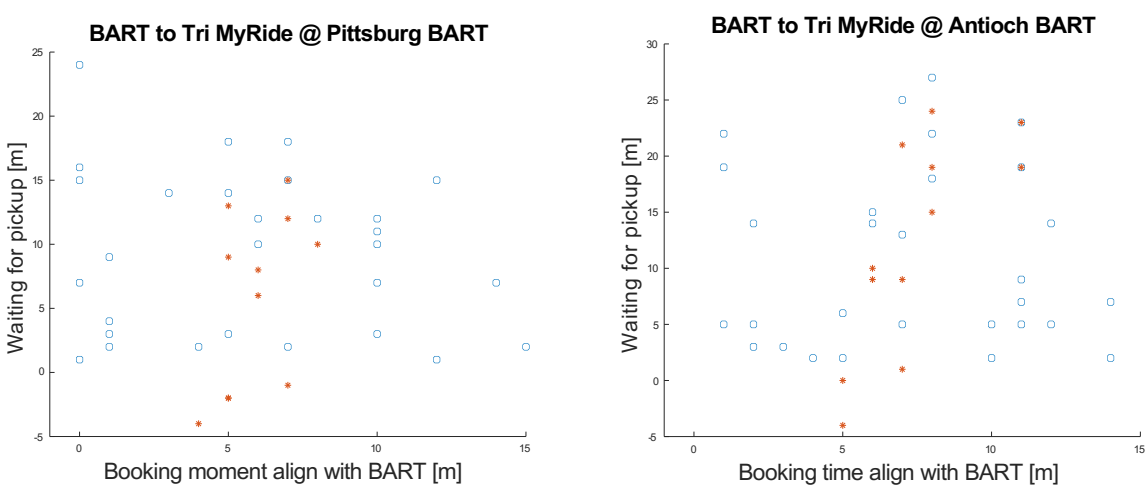


Figure 6-5. time saving by comparing w/o D-RIDE ('o') and with D-RIDE ('*')

The DRT trip booking timing has been categorized into three intervals. If there is a significant amount of time before a BART's trip end, (i.e., 12 minutes for Pittsburg and 11 minutes for

Antioch), the booking is too in-advance to receive an available and reliable DRT response. If the amount of time is close to the end of a BART trip, there is no additional time-saving benefit when using the in-advance booking strategy. For the booking time in between, **the saved waiting time are discovered to be 3~6 minutes**, which is consistent with the results concluded from the simulation test. Considering the entire last-mile DRT travel time, this performance of time saving is significant.

7 Conclusions and Future Research

7.1 Summary of accomplishments and findings

The IDTO project aims at developing and implementing a full-scale Integrated Dynamic Transit Operation (IDTO) prototype system that enables T-CONNECT and D-RIDE services. For the Phase II+ project, the project team has accomplished the following system integration and data analysis:

- The IDTO server hosts a trip planner, decision support engine, data collection and management, and acquires information of transit operations to communicate with transit agencies, operators, and travelers.
- The booking-by-prior-trip API with the DRT service supplier enables D-RIDE instructions to be communicated directly via communication link between the transit operation center and the buses. It establishes the communication between the IDTO and the DRT operation backend.
- The D-RIDE interfaces within the mobile app to enable travelers to input their travel needs (e.g., plan a trip, request a service for T-CONNECT and D-RIDE, acquire status of DRT service request), and to receive trip status notifications.

The research team has collected baseline and experimental data in the field test to evaluate the benefits and impacts of D-RIDE. An analysis on the new dynamic operation system and strategy is conducted for the evaluation of the system performance with discussions from transit agencies and stakeholders. The findings are listed below:

- The D-RIDE strategy works for different conditions of BART and DRT services. It can adapt to the BART schedules and the DRT dispatch capabilities by implementing a dynamic algorithm taking into consideration both the needs of travelers and operators.
- For a last-mile DRT trip of approximately 10-15 minutes, the simulation tests show that the D-RIDE strategy can lead to saving an average of 53% waiting (for pickup) time, while saving an average of 22% DRT travel time.
- In a real DRT operation site, the saved waiting time is 3~6 minutes, which is consistent with the historic operation data and the simulation test.

The analysis of test results demonstrates that D-RIDE application provides an effective and efficient service to DRT transit operators and travelers and supports dynamic transit operations by establishing communications and enhancing real-time operations. The IDTO has accommodated both the traveler's trip planning and agencies' on-demand operations which provide opportunities to improve the transit service quality and to facilitate better operational decisions. Moreover, the

integrated dynamic transit operation also proved to have significant benefits for travelers by reducing travel time and improving connectivity. It therefore has great potential to attract ridership and reduce operation costs.

7.2 Recommendations and Future Research

The IDTO projects have taken several yearlong efforts to address the inter-modal and inter-agency connection problems towards seamless trips. Most agencies provide the transit trip service for a local or regional area, and many resources have been utilized to improve the in-vehicle trip performances. However, the connection/transfer segments consume an average of 25% of the entire trip time and the related issues are more traveler specific than the in-vehicle segments. There is a strong need to conduct studies to address the following problems and limitations:

1. Lack of data tools to describe the connections/transfers between trip legs, especially at the transfer hubs, while the conventional OpenStreetMap is not adequate for reliable planning;
2. The current GTFS dataset doesn't support trips for inter-agency, inter-modal and inter-county (regional) activities;
3. The current transit operational data, including GTFS-RT, AVL and APC, do not contain or reflect the actual transfer demand and activities;
4. The cross-modal transfer data standards are not well-defined, for instance, how to define a transfer from the perspective of temporal-spatial reachability, how to describe a transfer from mass transit to paratransit or on-demand micro-transit, and so forth.

Considering these factors, there is a demand to use and extend the GTFS Dataset to standardize the transfer data feeds. The solution will be to create GTFS extensions for interagency and/or intermodal trips. The current GTFS is a data specification that allows public transit agencies to publish their transit data in a format that can be consumed by a wide variety of software applications. Figure 7-1 presents the limitation of GTFS based planning for a multi-segment trip. An extended data specification named Connected GTFS could be worked out to provide interagency and intermodal data at transit hubs to facilitate seamless trip planning and monitoring, as shown in Figure 7-2.

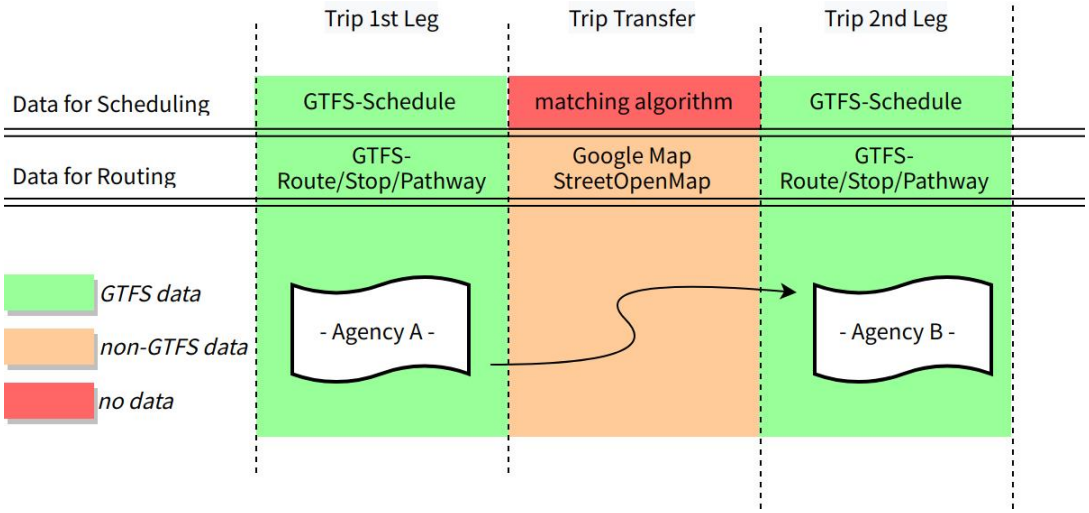


Figure 7-1. GTFS data utilization for multi-leg transit trip planning

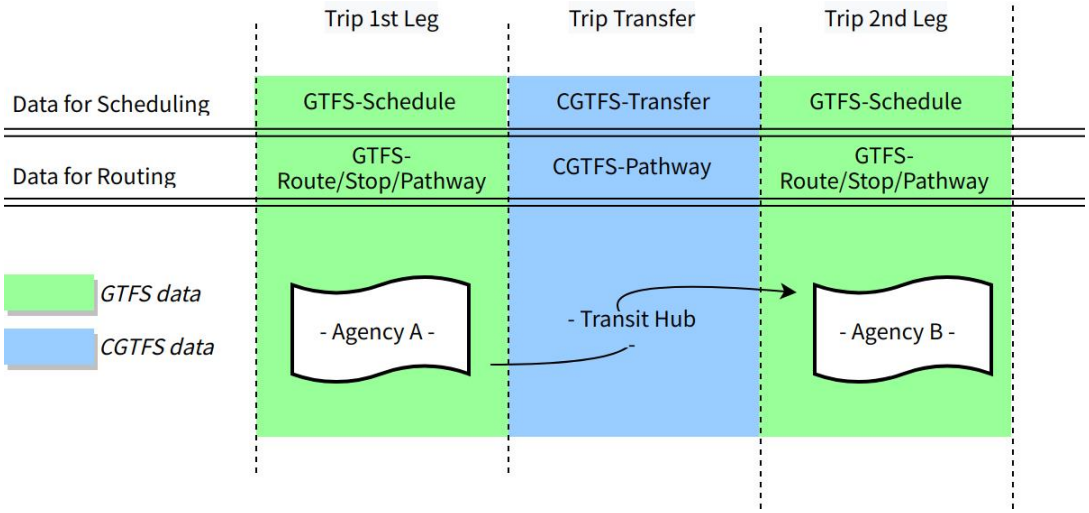


Figure 7-2. CGTFS data utilization for interagency transit trip planning