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16. ABSTRACT

The objective of Interactive Transit Station Information System (ITSIS) is to better inform transit travelers during their trips and to enable dynamic transit operations to better serve travelers. The ultimate goal is to make transit more friendly and attractive to the traveling population such that transit will become a viable choice for travel and an integrated part of the solution for congestion relief. This report documents a research effort to develop and test a ITSIS prototype that uses Connected Vehicle technologies to enable the real-time interaction between passengers and transit systems at bus stations. The reports summarizes the findings from passenger surveys conducted through field testing at two transit stops.

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Acknowledgements

Acronyms and Definitions

APTA	American Public Transportation Association
AVL	Automatic Vehicle Location
BSM	Basic Safety Message
CAD	Computer-Aided Dispatch
CONOPS	Concept of Operations
DMS	Dynamic Messaging Sign
DPI	Dynamic Passenger Information
DRI	Caltrans Division of Research and Innovation
DSRC	Dedicated Short-Range Communication
DVI	Driver Vehicle Interface
FTA	Federal Transit Administration
FAVL	Fused Automatic Vehicle Location
GPS	Global Positioning System
GUI	Graphical User Interface
I2S	Infrastructure to Station
ICM	Integrated Corridor Management
ITS	Intelligent Transportation System
ITSIS	Interactive Transit Station Information System
JPO	Joint Program Office
NT-T/SP	Networked Traveler – Transit and Smart Parking
OBE	On-Board Equipment
O-D	Origin-Destination
PATH	California Partners for Advanced Transportation Technology
PFT	Prototype Field Test
RFS	Richmond Field Station (PATH Headquarters)
RSU	Roadside Unit
SIH	Station Interactive Hub
TSP	Transit Signal Priority
TRB	Transportation Research Board
USDOT	United States Department of Transportation
VRM	Vehicle Revenue Miles
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle

1.0 Introduction

This study aims to develop and test an innovative Interactive Transit Station Information System (ITSIS) that uses Connected Vehicle technologies to enable the real-time interaction between passengers and transit systems at bus stations. The objective of ITSIS is to better inform transit travelers during their trips and to enable dynamic transit operations to better serve travelers. The ultimate goal is to make transit more friendly and attractive to the traveling population such that transit will become a viable choice for travel and to integrate a part of the solution for congestion relief. The intention of this project is to generate findings from that can provide valuable stepping stones to incorporate and deploy broader interactive information into our transit ITS systems and operations.

1.1 Statement of Problem

Although public transit is an important means of transportation for many American travelers, it is still largely underutilized. Encouraging greater transit use is seen as part of the integrated solution to the congestion problem in metropolitan areas and has been a major objective for transportation innovations such as Integrated Corridor Management (ICM). The real-time transit traveler information system has been one of the key innovations to enhance the user experience and to encourage mode shifts. Effective TTIS solutions have already been implemented worldwide and are providing essential core travel information to users, empowering them to make better transportation choices. While this information is typically provided to travelers using dynamic messaging signs (DMS) at fixed locations, it becomes more common to provide real time traveler information through the internet (website) and personal mobile devices (e.g., smartphones) with enhanced connectivity applications installed on them (FTA, 2011). In some cases, real-time information is simply "pushed" to interested individual users without the need for significant user input. However, there have been significant efforts in developing interactive information system for transit stations in the United States. As we look at moving to a more robust interactive system, there exist several technical gaps in the current implementation of TTIS that must be overcome. These can generally be grouped into three major categories.

Limited coverage

The use of Computer Aided Dispatching (CAD) and GPS-based Advanced Vehicle Location (AVL) systems is now well-established in transit bus and light rail networks. By 2010, 60.1% of buses and 55.3% of light rail vehicles were implemented with CAD/AVL systems (APTA, 2011). However, only about half of these installations have been used to provide transit traveler information (RITA, 2010).

Low update rate

Real-time information collected by CAD/AVL systems is of particular relevance to TTIS. For the state-of-the-art CAD/AVL systems, the polling interval to get a transit vehicle's location update is generally between 60 and 120 seconds (TRB, 2008). This long polling interval makes it difficult to generate accurate vehicle arrival predictions when transit stations/stops are closely

located, as is the case in most metropolitan transit systems. It also makes it difficult to provide timely departure information. The built-in delay in transmission of information packets clearly impacts the accuracy of information presented to travelers in metropolitan areas.

Lack of "personalized" information

The information displayed on a Dynamic Message Sign located at a transit station or stop typically shows the predicted arrival(s) (or countdown) of the next transit vehicle(s). Although this type of information has proven to produce significant passenger benefits in generating higher passenger satisfaction levels (Dziekan & Kottenhoff, 2007), it does not include other valuable information for passengers, such as the transfer and connection information (40% of transit trips involve at least one transfer between transit vehicles (APTA, 2007)). Connected Vehicle technologies can potentially offer solutions to fill these gaps.

1.2 Overview of this Research Project

This project is to develop and field test a ITSIS prototype using Connected Vehicle technologies to research three important questions:

- Can the Connected Vehicle and Infrastructure technologies envisaged by the USDOT enable more timely and accurate passenger information, and an interactive transit station information process?
- Can ITSIS benefit passengers by allowing them to interact with transit systems for obtaining 'personalized' information?
- Can ITSIS enable a more efficient operation of transit?

In this project, we stress using a combination of innovative real-time data capture and data management methodologies to enable improved dynamic mobility for transit and intermodal applications. ITSIS provides for the next jump in improving the level of service to passengers and supporting future enhanced transit operations by enabling travelers to *interact* with transit systems on their current trip plans and real-time needs. The hypothesis is that ITSIS would result in a better passenger information service for passengers and an improved origin-destination (O-D) data collection for transportation providers. The addition of real-time interactive sessions with travelers expands the horizon for public transit management, offering them the opportunity to both improve the service level and facilitate better operational and planning decisions.

The ITSIS system has been field tested at the California Connected Vehicle test bed in Palo Alto, California. This Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) test bed, implemented by Caltrans and California PATH, is comprised of 11 signalized intersections two-miles in length along State Highway 82 (also known as El Camino Real). Roadside units (RSU) units have been installed on the test bed with up-to-date software and hardware packages that meet the Connected Vehicle standards. The initial plan was to develop a backhaul network to transport data to/from RSUs and centralized systems. As the project evolve, it was determined that, though a DSRC based ITSIS is technically feasible, it is difficult to conduct field testing

with such system as it is not practical to instrument a large number of buses with DSR receivers under a research project with limited funding. During the course of the project, VTA has implemented an updated communication network that supports second by second AVL updates. The research team therefore decided to use the second by second AVL to emulate a DSRC based communication system for the ITSIS-based prototype.

The Santa Clara Valley Transportation Authority (VTA) is a perfect partner in this project since they operate in the California Connected Vehicle test bed area. VTA operates two bus routes that travel along the El Camino Real test bed, the conventional bus service Route 22 and a bus rapid transit service Route 522. Appendix A provides route maps for these two bus routes. Route 22 makes 88 trips every weekday in both northbound and southbound directions, and Rapid 522 operates at 15-minute headways in both directions. Twenty-eight bus-stops on Route 22 and four on Rapid 522 are within the coverage of Dedicated Short-Range Communication (DSRC) to a nearby RSU. In addition, VTA has deployed the Computer-Aided Dispatch (CAD) and Global Positioning System (GPS)-based Automatic Vehicle Location (AVL) system on its bus fleets. A selected bus station along VTA Route 22 within the Connected Vehicle testbed has been selected as an ITSIS case study test site.

The field test was conducted along the California testbed and the VTA's bus system, which provided a real-world operational environment for the development and testing of this proposed research. The closely spaced transit stops and frequent transit services of Route 22 and Rapid 522 present an optimal situation for testing ITSIS applications. The development and testing of effective mobility and convenience transportation applications that make the use of available V2V/V2I test beds are among the core focus areas of Connected Vehicle research. The findings from this project provide opportunities for building valuable stepping stones to incorporate and deploy this technology into our transportation system.

1.3 Document Overview

This report describes the development of field testing of an innovative Interactive Transit Station Information System (ITSIS). This report is organized as follows:

- **Section 1.0, Introduction** provides the background and context for the ITSIS project.
- **Section 2.0, Current Condition** reviews state-of-the-art practices of bus stop operations and existing deployments of traveler information systems.
- **Section 3.0, Concept of ITSIS** describes the key concepts of operation for ITSIS, including a proposed system architecture, the operational scenarios, information needs, and functionalities associated with the ITSIS, the needs for ITSIS, and how ITSIS addresses these needs.
- **Section 4.0, Development of an ITSIS** summarizes user interfaces that support designed ITSIS use cases and the functional elements of an ITSIS-based prototype.
- **Section 5.0, Field Operational Test of ITSIS** described the field testing of ITSIS at transit stations, the surveys conducted with passengers, and the analysis of the survey results.
- **Section 6.0, Conclusion and Recommendation** provides a summary of findings and recommendations.

2.0 Current Conditions on Information at Transit Bus Stops

A comprehensive study on Advanced Bus Stops for Bus Rapid Transit (Dehlgren 2002) provides insights of the current situation for bus stops. Notably, it investigated, from the perspectives of travelers and operators, the statuses of, and needs for, information at bus stops. While the study was conducted 10 years ago, the characteristics of bus stop operations remain the same and the technological status has not advanced substantially. This report adopts the findings from the PATH project report on Advanced Bus Stops for Bus Rapid Transit. Relevant sections from the Advanced Bus Stops for Bus Rapid Transit PATH report are included in the ITSIS Concept of Operations (this document) verbatim in italics.

2.1 Overview of Bus Stop Operation

The bus stop operation was studied extensively under this PATH study (Dehlgren 2002). Literature on bus stop amenities and technologies that could be employed at bus stops are reviewed. Field surveys of bus stops along VTA Route 22, field observations of bus operations (including 300 stop operations), and observations of passenger activities at bus stops are conducted. An on-board survey of 300 passengers on Route 22 was carried out. Key VTA staff involved in Bus Rapid Transit (BRT) plans and bus stop facilities, VTA trainers and supervisors are interviewed. Bus stop information and products are reviewed.

2.1.1 What Passengers Do at Bus Stops

Passengers waiting for buses were observed at the most highly used bus stop in downtown San Jose during the late morning and early afternoon on 4 weekdays and a Saturday in January 2001. This stop is served by 3 routes, with headways of 10, 15, and 30 minutes. The stop is in front of the VTA customer service center, which has an overhanging roof that shelters those waiting. There are four benches that can each accommodate three to four people. One schedule is posted. On the days of the observations, a security officer who was stationed inside the VTA office came outside periodically to patrol the area. Of the 876 people observed, 68% were male, 6% appeared to be high-school age, 10% college age, 18% over 60, and 66% between college and retirement age. Only 1% had children with them. There were always 2 or 3 people who did not get on any bus and appeared to be homeless. Over 90% of the passengers arrived at the bus stop on foot, 4% transferred from another bus, 3% rode bicycles or skate boards.

Most people just stand and wait for the bus. They may be reluctant to read or leave the stop because they do not know when their bus will arrive. Although the average time between buses matched the scheduled frequency, the buses often bunched leaving unpredictable intervals between buses.

2.1.2 Bus Passenger Survey 2002

Passengers on twenty-four Route 22 runs and twelve Route 300 (a limited stop version of Route 22) runs were surveyed in May and June of 2002. The runs were at all times of day on weekdays and weekends in both directions. Thus the responses were more representative of Route 22 and 300 passengers than the bus stop observations. Questionnaires were offered in either English or Spanish as passengers sat down on the bus and collected as they left. A fair number of passengers did not appear to speak or read either of these languages. Sixty percent of the 958 completed surveys were in English and 40% in Spanish. The age, gender, trip frequency proportions of survey respondents were similar to those found in bus passenger surveys that VTA had conducted in previous years.

Passengers were asked where they boarded the bus, how useful they found various types of information, if they felt safe at the bus stop, what would make them feel safer, what they liked to do while waiting for the bus, if various types of bus stop amenities would make waiting more pleasant, and if they would take more bus trips if the stop had more information, was safer, or was more pleasant. They were also asked if they owned a cell phone, pager or personal digital assistant or if they had access to the internet at work or at home. Over 50% of people responding to the question regarding electronic devices had one or more. Sixty-three percent of people responding to the internet question had access to the internet, 40% at home, 32% at work, and 17% at other locations. Many had access at more than one location. The percentages were much lower among Spanish speakers than among English speakers.

Even though 78% of those surveyed rode the bus four or more days a week, they still found many types of information useful, as shown in Table 1. Schedule information was by far the most useful; 62% found it very useful and almost 80% found it very or somewhat useful. Next most useful was the time when the next bus will arrive. Route maps, connecting routes and transfer points, and the current time of day were judged very useful by over 40% of riders and very or somewhat useful by about 60%. Less useful, but still somewhat useful for a majority of riders, were service updates, fares, and the customer service telephone number. The survey asked if people were interested in a map of activities close to the bus stop. About half felt this would be very or somewhat useful. More people were interested in information about health services, businesses, and parks and recreation, less in movies and entertainment, family activities and government services. People were also asked "What other information would you like to have at this bus stop?" The most common response was schedule information, indicating some lack of understanding of the survey, but also reinforcing the importance of schedules to bus patrons.

These findings are consistent with studies elsewhere. *Bus stop real-time information systems appear to be very popular with riders. A survey of London bus passengers six months after the Countdown signs were installed found that they were reliable and accurate and that 90% of riders looked at them at least once during their wait for the bus. Over 2/3 of passengers felt that they waited for a shorter time (perceived wait time dropped from 11.9 to 8.6 minutes) and that service reliability had improved since Countdown was implemented even though reliability had actually declined. Passengers valued Countdown at an average of more than 31 cents*

(Schweiger, 2003). The bus arrival time display, if visible to passersby, serves the added function of informing people who do not use transit about the frequency of the bus service.

2.1.3 How Useful Is Bus Stop Information?

Of 761 responses, 78% said they would take more bus trips if the bus stops had more information. The percentage was the same regardless of whether the stop at which passengers boarded had a shelter or not or whether it was a heavily used stop. Fifty-five percent of 762 respondents said they would take more bus trips if bus stops had information in another language beside English. Of the 217 people who named another language, 84% named Spanish, 3% Chinese, 2% Tagalog, 1% Vietnamese, 1% Japanese, and less than 1% named each of 10 other South Asian, European, and African languages.

Table 1-1 *Information useful to Travelers* (Dehlgren 2002)

Information type	Very useful to me		Very or somewhat useful to me	
	Number	Percent of all surveyed	Number	Percent of all surveyed
Schedule	598	62%	753	79%
Time when the next bus will arrive	474	49%	646	67%
Route maps	402	42%	605	63%
Connecting routes and transfer points	392	41%	574	60%
Current time of day	379	40%	558	58%
Updates on bus services	326	34%	545	57%
Fares	325	34%	496	52%
Customer service phone number	310	32%	500	52%
Map of activities close to the bus stop	277	29%	468	49%
• Medical and health services	360	38%	551	58%
• Shops and businesses	330	34%	492	51%
• Parks and recreation	309	32%	488	51%
• Movies and entertainment	256	27%	445	46%
• Activities for children and families	248	26%	443	46%
• Government services	243	25%	422	44%
Information about other transit agencies	265	28%	477	50%
Bus web address	211	22%	406	42%

2.2 Overview of State-of-the-Art Bus Stop Information Systems

Real-time information system systems have been employed throughout Europe. London's Countdown system began operation in the early 1990s. In Lyon, France, 500 bus stops are equipped with LCD displays for displaying estimated waiting times. Such systems in the United States began to be deployed in the 2000s. The early deployment includes real-time information systems at Los Angeles Metro Rapid transit bus stops, at bus stops in Portland, at stops on San Francisco's Muni first and then other Bay Area transit systems, and at bus stops on other smaller systems, such as San Luis Obispo.

The arrival information is generally displayed on LED dynamic message signs. They display the route and either the number of minutes until the next bus or the arrival time of the next bus. The method by which expected arrival time is estimated varies depending on the communications and vehicle tracking equipment available and the nature of the bus operations. Some systems, such as those used in Seattle and Portland, have been developed by the transit agencies. Other agencies use proprietary systems, such as NextBus.

Elsewhere, interactive bus stop information has been explored. *The Kowloon Motor Bus Company (KMB) in Hong Kong has developed a Cyber Bus Stop equipped with a touch screen linked to a microcomputer that is linked to the KMB homepage. Passengers can use KMB's point-to–point route search and other information on the KMB website. A web-camera at the bus stop allows management to monitor the bus stop remotely.*

While real-time bus arrival information have become available on the Internet and through mobile applications, the arrival information at bus stops provides additional benefits, including improved customer service, increased customer satisfaction and convenience, and improved visibility of transit in the community.

3.0 Concept of Operation of an Intelligent Transit Stop Information System

The ITSIS concept is motivated by a number of key factors, including: (1) bus stops have largely remained the same as their initial forms despite the fact that substantial technological changes have been made in the transportation industry during the past 20+ years; (2) although the 'nextbus' information becomes available at some BRT bus stops, the accurate prediction of transit arrival has been challenging because of the low sampling rate; and (3) there is little effort in developing interactive bus stop information products and services.

This section, Concept of ITSIS, includes efforts to define the ITSIS and the development of the Concept of Operation. The ConOps describes the goals, functions, key concepts, architecture, operational scenarios, operational policies, and impacts of interactive transit station information systems. A summary of benefits and costs follows the ConOps description. This document follows the outline provided by IEEE Standard 1362-1998, with small variations to reflect the nature of the specific system under study.

The ConOps is a basis for the research, development and field testing of ITSIS. The ConOps has been updated throughout the duration of the research project.

3.1 Addressing Stakeholders' Needs

The PATH study on advanced bus stops concluded that among the technological products and services offered for bus stops, real-time bus arrival information systems were rated highest, followed by electronic fare cards, interactive information displays, solar-powered lights, beacons and information panels. Other studies of bus stop behaviors indicated that passengers perceive waiting times to be greater than actual waiting times at a bus stop and real-time passenger information systems can reduce their perceived waiting time for buses when providing accurate information. Interactive and personalized transit information provided by ITSIS can further alter their perception of transit routes, travel times, waiting times, and service reliability.

Transit agencies such as VTA have found that passengers care more about frequency and reliability of service than about bus stops themselves. While it is critical for transit agencies to focus on providing more frequent, reliable and direct service, how much improvement can be done is constrained by the available resources. VTA and other transit agencies have learned from recent experience that real-time information can reduce perceived waiting times and compensate for some of the service uncertainties and deficiencies. This change of perceptions could potentially be translated into reduced operating costs (e.g., through efficiency of on-demand service) or increased passenger satisfaction and, ultimately, into increased ridership for public transit. Transit agencies are interested in exploring further applications of real-time information including ITSIS.

ITSIS offers a combination of innovative real-time data capture and data management methodologies to enable improved dynamic mobility for transit and intermodal applications. ITSIS provides for the next jump in improving the level of service to passengers and supports future enhanced transit operations by enabling travelers to *interact* with transit systems on their current trip plans and real-time needs. This results in better passenger information services for passengers and better origin-destination (O-D) data collection for transportation providers. The addition of real-time interactive sessions with travelers will expand the horizon for public transit management, offering the opportunity to both make improvements at the service level and facilitate better operational and planning decisions.

Specifically, VTA is interested in this study to examine: (1) how advanced communication means such as DSRC can improve the quality of real-time data and the application and services powered by real-time data (e.g., improved resolution and information accuracy); (2) how ITSIS can provide additional information such as bike loading conditions on upcoming buses, service breakdown, etc. that will affect passengers' trip decisions; (3) how interactive traveler information can further help passengers travel by transit and improve users' appreciation of reasonableness of transit services; and (4) how ITSIS can enable real-time dynamic transit operations.

3.2 The Concept of an ITSIS

A desirable transit real-time information system at a bus stop provides not only real-time 'next arrival' information but also interactively determines the best possible use of the transit network for travelers. This is focused on finding the "best" travel itinerary from the current station/stop to the final destination station/stop using the most up-to-date transit network status information, including detailed connectivity information about transfer points, out-of-vehicle travel instructions and total trip duration. The system also provides customers with information about real-time vehicle load factors (i.e., the ratio of actual passengers to capacity), the availability of bike racks or wheelchair spaces of the upcoming bus, bus service disruptions along the trip route, and other information that allows them to make their trip in a timely, comfortable and easy manner.

3.2.1 ITSIS Goals

The goal of the Connected Vehicle technologies-based ITSIS is to support a new passenger experience and improve transit service. More specifically, ITSIS may:

- Enable more timely and accurate passenger information: A typical transit management system has a 60 sec to 120 sec pooling cycle, which often creates errors for bus arrival prediction. ITSIS bus-to-station communication can facilitate buses to provide accurate arrival and departure information to correct the prediction error by the transit management system. This could eliminate the possibility for inaccurate information that

informs passengers of a bus arrival when no bus is visible or a bus has already left the station.

- Benefit passengers by enabling them to interact with transit systems through 'personalized' information: ITSIS could provide certainties to all transit passengers and assist passengers who are unfamiliar with the transit system to navigate to their destination.
- Enable a more efficient operation of transit. This passenger waiting information could help bus operators to prepare for the next stop and potentially enable on-demand transit service to reduce costly, unnecessary stops, thereby speeding up transit operations and enhancing transit rider satisfaction levels.

3.2.2 Functions of ITSIS

It is envisioned that ITSIS has the following primary functions:

- Enables passengers waiting near transit stations to receive "personalized" real-time trip information about transit vehicle arrivals at their current stop locations and at future stations (i.e., "downstream" stations) on their planned travel route. The improved vehicle's arrival prediction accuracy is enabled by the DSRC V2I communication between the arriving bus and the station ITSIS.
- Provides real-time information regarding the current status of transit vehicles, including service disruption notices, bike rack availability on the upcoming bus, etc.
- Provides trip-specific modal and intermodal connectivity options to passengers "on-demand" and before passengers reach their transfer stations and stops.
- Communicates passenger waiting data and trip data to the transit operation center to enable transit dynamic operation.
- Collects passenger O-D data to provide transit agencies an opportunity to improve transit operations and planning.

3.2.3 Key Concepts

The concept of ITSIS using Connected Vehicle technologies can be implemented in a number of approaches. One approach is to use DSRC-based communication links. When Connected Vehicle-equipped transit vehicles travel through RSU-equipped intersections, the real-time information about departure time, location and speed of transit vehicles is transmitted to downstream RSUs and to the passenger information server. DSRC provides a reliable way to quickly update the status of transit vehicles as they progress towards the downstream stations. Its high update rate makes it possible to more accurately predict a transit vehicle's arrival at stations near RSUs and to even extend that accuracy to stations much farther downstream than is possible with the update methods currently utilized in CAD/AVL systems. At transit stations near RSUs, the ITSIS that facilitates DSRC communication allows customers to query real-time transit information, plan a transit trip, and transmit O-D data to the dispatch center for cost-effective dynamic transit operations. Figure 3-1 illustrates a DSRC-supported ITSIS.

Another approach is to implement ITSIS using a cellular communication link that transit agencies have already deployed between transit centers and buses. This approach will require certain data samplings or pulling rates in order to achieve accurate arrival predictions to bus stops. The ITSIS prototype system developed under this project uses this approach.
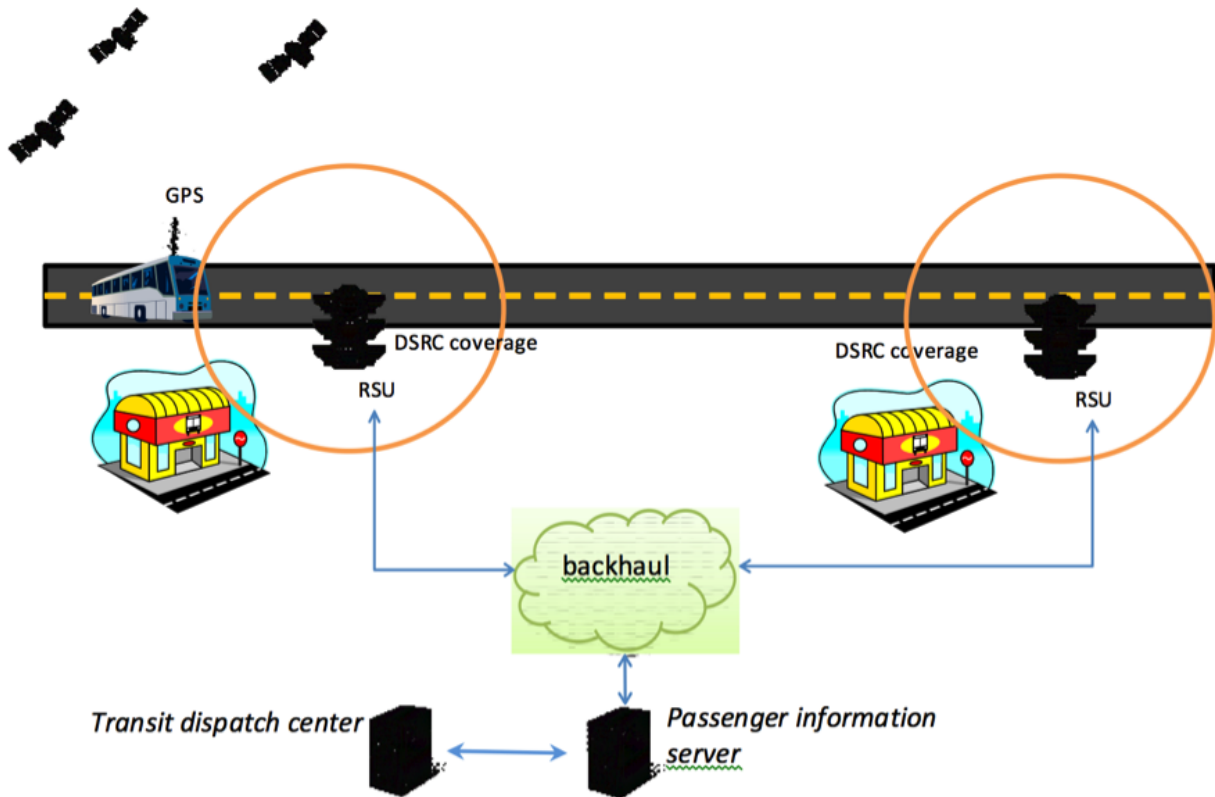

Figure 3-1 DSRC Link and AVL

3.3 ITSIS Operational Scenarios

This section provides scenarios that show how ITSIS could help transit passengers on deciding and making trips, as well as facilitating dynamic operations by transit operators. Each scenario may include a number of use cases.

3.3.1 Scenario 1: Acquiring Transit Service Information

ITSIS providestransitservice information, helping passengers to glance at service options before making their trip decisions.

1) Passengers use the SIH to inquire about route maps, schedules, real-time next bus arrival information, estimated arrival time at future (downstream) transit stations, available seating and available bike rack space information.
2) The query of real-time transit information is transmitted to the passenger information

server via the combination of DSRC and its backhaul.
3) The information returned by the server is presented to the customer via SIH.

3.3.2 Scenario 2: Acquiring Transit Trip Information

ITSIS assists travelers by interactively providing trip information at the station through the SIH or when approaching a station through mobile devices.

(a) Passengers acquire trip information at the station through the SIH

1) Passengers provide their destinations by either selecting a transit station/stop or inputting a street address using the SIH interactive interface.
2) The destination information is transmitted to the passenger information server where a transit trip itinerary is generated using the most up-to-date transit network status information;
3) The trip itinerary is returned and presented to passengers. The returned information includes the route, transit vehicle's ID, its arrival time at the current station and predicted arrival time at the destination or transfer station, if any, the connection information at transfer point(s) (e.g., transit vehicle route, transit vehicle's ID, arrival time of the connecting vehicle, walking distance between transfer stations/stops), the arrival time at the final destination station/stop, transit vehicle seating availability / passenger load information, and bike rack availability information.
4) Passengers can confirm the planned trip using the interactive interface, and the confirmation is communicated to the passenger information server through the nearby RSU.

(b) Passengers acquire trip information through a designated application

1) Passengers plan trip or activate a pre-stored trip plan prior to the trip through a web or mobile application that is linked with the passenger information server where a transit trip itinerary is generated using the most up-to-date transit network status information.
2) Passengers are provided trip information similar to scenario 2(a) with additional information about the trip segment between the origin and the first transit station. This transit data is updated.

3.3.3 Scenario 3: On-Demand Transit Station Operation

While scenarios 1 and 2 focus on the dissemination of transit traveler information to passengers, scenario 3 aims to enhance transit operations by providing bus operators with real-time 'passenger waiting' information. The information enables the bus operators to prepare for picking up passengers at stations. This function is particularly useful at night and when visibility is poor. The passenger waiting call is also critical for dynamic transit operation. When passengers are familiar with the passenger waiting call function, the same way they are used to

pedestrian request button at signalized intersections, transit operators can achieve dynamic operation by determining which stop to serve based on the station passenger waiting call information.

(a) Passenger requests transit service using the SIH

1) Passengers use the SIH to request transit service at the current station either by pushing a 'waiting for route X' button on the interactive interface or by confirming a planned trip.
2) The 'passengers waiting' information is communicated with the OBE on transit vehicles and presented to the bus operator via an on-board driver vehicle interface (DVI).
3) The bus operator makes an early lane change, if not already in the curb lane, to prepare for a stop, or deviates from the route for flex-route operations.

(b) Passenger requests transit service using a mobile device

1) When approaching a station, the mobile device carried by a passenger automatically communicates 'passenger waiting' and pre-selected destination information to transit vehicles through wireless means via Interactive Passenger Information Server.
2) The passenger waiting information is presented to the bus operator via a DVI. Similar to scenario 3(a), this information is relayed to the bus but without passengers' interaction with any SIH.

4.0 Development of ITSIS

4.1 Proposed ITSIS Architecture

California PATH has developed a system architectural framework for an integrated transit information/management system, shown in Figure 4-1. This open architecture includes the basic functions for the proposed ITSIS.
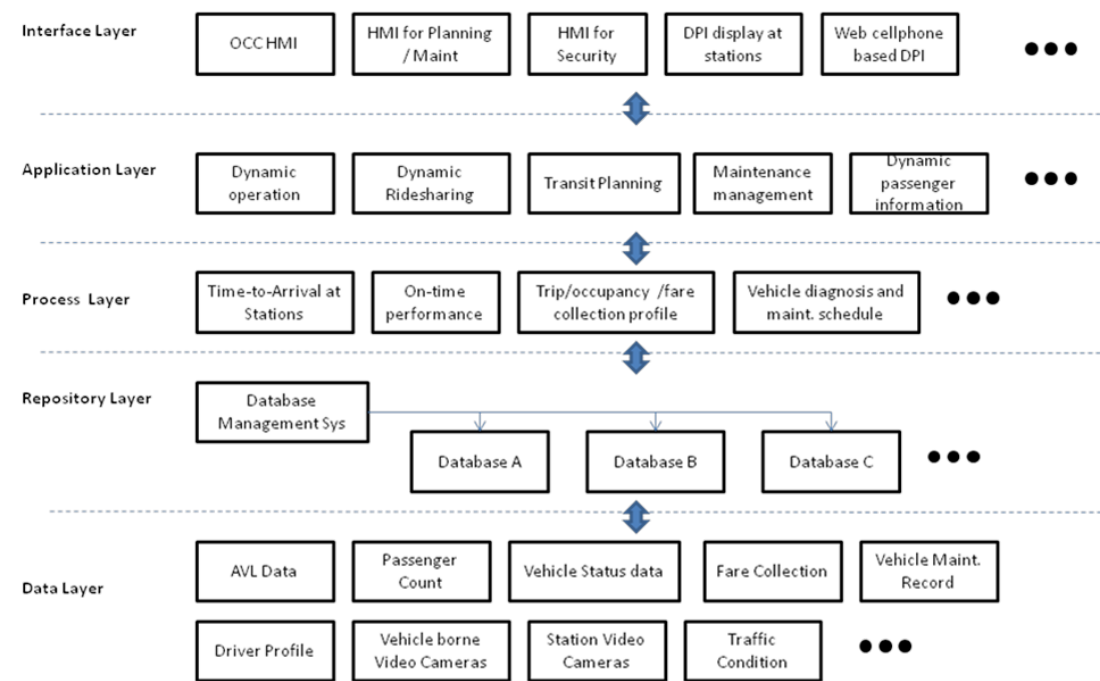

Figure 4-1 Integrated Transit Information/Management Architecture

Using this architecture as a base, an experimental architecture for the ITSIS was developed sufficiently to support the prototype testing. The architecture addresses two major aspects of ITSIS: (1) bus infrastructure integration and (2) the integration of interactive passenger information with transit operations.

There are several viable approaches for the integration of the bus and transit dispatch center with the passenger information center. With the existing transit CAD/AVL system built upon dedicated transit radio channels, transit vehicles send AVL and service data such as occupancy and bus conditions to the dispatch center and receive operational data back from the dispatch center at intervals of 60 to 120 seconds. Under the Connected Vehicle environment, the bus OBE broadcasts the Basic Safety Message (BSM) at high frequency to the RSU and receives messages from the RSU containing the interactive passenger inputs. It is envisioned that the DSRC link between the bus OBE and RSU can be utilized for communicating the transit vehicle's location

and speed data at a higher frequency to achieve higher resolution and more accurate transit information, and to enable interactive traveler input data for 'personalized' passenger information and dynamic transit operation (see Figure 4-2). ITSIS contains a Station Interactive Hub (SIH) to enable passengers to acquire transit information through a graphical user interface (GUI). Mobile devices, via cellular network, are also considered as an interactive device within this system architecture that serves as an outlet interface of real-time passenger information.
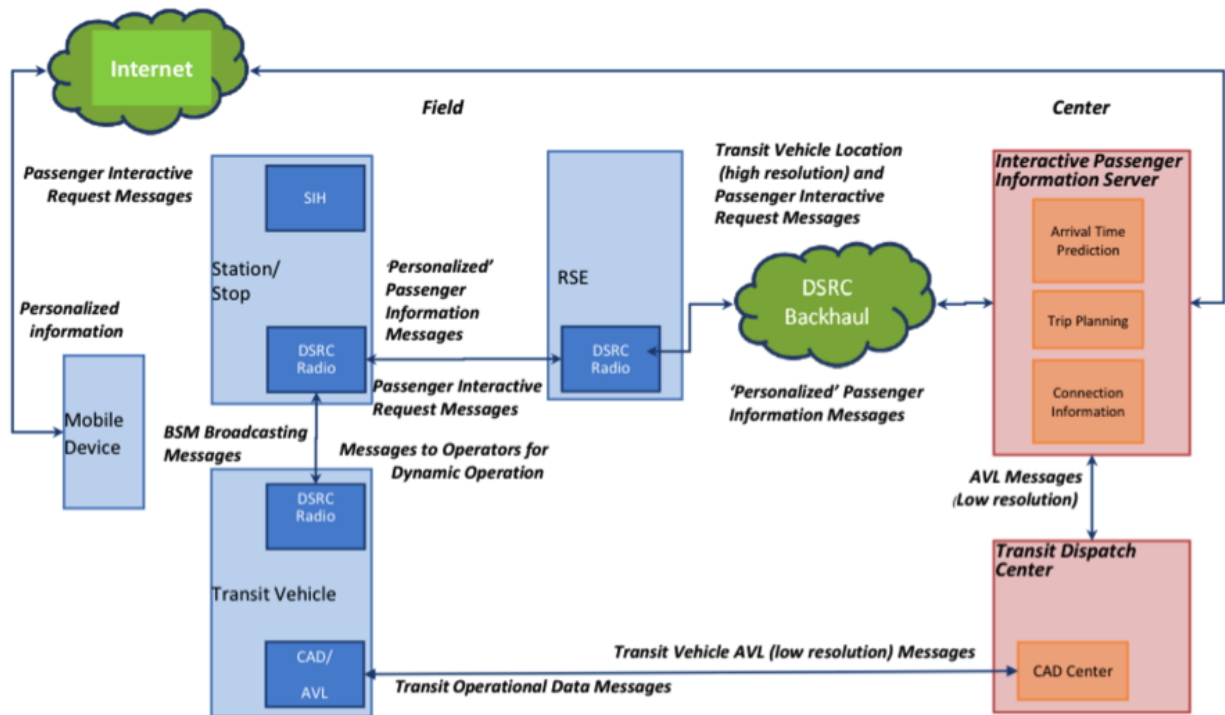

Figure 4-2 ITSIS Architecture and Data Flow

4.2 Communication Needs for ITSIS

Different approaches are considered to identify the most cost-effective method for the development and testing of the proposed ITSIS applications. The considerations include the communication needs of ITSIS, the specific conditions of the California Connected Vehicle Test Bed, the in-place transit communication technology and operation characteristics, and the testing facility and environment available at Richmond Field Station (RFS). The design of the ITSIS prototype is based on the existing technologies and test bed environment. The initial design was completed in the early stage of this research effort and presented to the Caltrans Division of Research and Innovation (DRI) and the Federal Transit Administration (FTA) for concurrence prior to proceeding to final prototype design.

The effectiveness of communications between on-board equipment (OBE) and roadside equipment (RSE), and between OBE and a centralized system through dedicated short range communications (DSRC) and its backhaul has been demonstrated by previous DSRC studies. However, the existing communication message sets are typically designed for personal cars with privacy concerns and constraints. On the other hand, transit fleets are publicly owned vehicles and real-time tracking of transit vehicle locations has been available to the public through transit traveler information systems. Under Task 2.3, the project team has investigated how the current protocol (including message sets) can be extended for transit-oriented applications and what additional message sets are required under the J2735 framework to accommodate the specific needs of ITSIS and to effectively bridge DSRC to the Interactive Passenger Information Center.

As shown in Figure 1 (ITSIS Architecture and Data Flows), there are multiple message sets for exchanging data between travelers (via the Station Information Hub [SIH] or mobile app) and transit bus operators (via OBE), including:

- ***Passenger Interactive Request Messages*** initiated at the SIH or mobile app to request trip planning, acquire transit information, and to request on-demand transit service;
- ***'Personalized' Passenger Information Messages*** initiated at the Interactive Passenger Information Server to respond to passenger interactive requests;
- ***Bus Basic Safety Message (BSM) Broadcasting messages*** initiated at the bus OBE to update bus locations at high frequency; and
- ***Messages to Operators for Dynamic Operation*** initiated at the Interactive Passenger Information Server and Transit Dispatch Center for advising bus operators regarding on-demand transit service requests.

Trip planning requests, static transit information inquiries and the responses from the Interactive Passenger Information Server are communicated throughout the DSRC backhaul. These messages are defined by the SAE J2735 standard – Message Set for Advanced Traveler Information Systems (ATIS) for messaging between the SIH/mobile app and the Interactive Passenger Information Server.

Other messages such as travelers' requests for on-demand transit service (i.e., I am waiting for Route X at Stop Y) and bus BSM Broadcasting, on-bus bike rack space availability information (and other bus on-board information) and dynamic operation messages to bus operators are intended to be communicated through DSRC and therefore should be governed by SAE J2735.

Under the current SAE J2735, BSM (Part I –Basic Safety Message) data, and Part II – Vehicle Safety Extension & Vehicle Status are designed for light vehicles and for safety applications. Existing BSMs include a data element of 'TemporaryID' to identify the vehicle (or OBE), which changes periodically due to privacy concerns. However, for ITSIS applications, carrying a static vehicleID within BSM (or HIA) is essential, as the arrival information, connection information, available bike rack space information, and requests for on-demand transit service are all associated with a particular bus and is linked with travelers' trip itineraries. We have evaluated

the possibility of using not-in-use BSM data elements to carry ITSIS critical messages such as vehicleID.

Messages for a bus to report its available bike space and for communicating with bus operators regarding requests of on-demand transit service are not currently included in the existing SAE J2735 standard. We plan to develop customized DSRC message sets under the SAE J2735 framework to accommodate the needs of information exchange for ITSIS-specific, but non-critical, information such as available bike space and on-demand service requests. In developing these messages, we intend to interact with and provide recommendations to the SAE standard committee on the needs for including necessary data elements in the J2735 standard to support transit-oriented applications, such as ITSIS, and required message sets to enable ITSIS service under DSRC environments.

4.3 Assumptions and Constraints

Our hypothesis is that some of the technical gaps for the implementation of ITSIS can be effectively overcome by using Connected Vehicle technologies and the innovative information gathering and dissemination methodologies envisioned by the Connected Vehicle environment.

Our assumptions are that (1) RSUs are installed at a sequence of signalized intersections and are connected to the communication backhaul, (2) on-board equipment (OBE) is instrumented on selected transit vehicles that travel through RSU-equipped intersections, (3) ITSIS is installed at selected transit stations/stops which are within the DSRC communication range of one of the RSUs, (4) communications between RSUs and bus OBE, and between bus OBE are based on the SAE J2735 standard, and (5) RSUs may have more than one communication channels, to include not only DSRC, but also Bluetooth or WiFi capabilities.

4.4 Development of a ITSIS prototype User Interface

The objective of ITSIS is to better inform transit travelers during their trips and to enable dynamic transit operations to better serve travelers. The ultimate goal is to make transit more friendly and attractive to the traveling population. Based on the review, study and implementation of the ITSIS concept, the information available on a stop hub interface includes:

1. Conventional transit information
   - Transit map
   - Schedules of all stops

2. Real-time information
   - Estimated arrival times (ETA) of next arrival buses
   - ETA at downstream stops

3. Transfer information
   - Transfer availability at downstream stops
   - Real-time trip information of the transfer-to route

In order to make the above static and real-time information available to users, user interfaces that can help acquire the following information elements have been developed.

① route names (in number for VTA agency);
② remaining time of next 3 arrivals (in minutes when available, "N/A" when not available);
③ route name with direction ("EB" denoted eastbound) and approaching trip id;
④ stop sequence for the current route, departure stop is highlighted in blue;
⑤ ETAs for corresponding stops;
⑥ real-time locations (between two successive stops) of vehicles on road;
⑦ current status of interface operation;
⑧ arrival stop is highlighted in yellow;
⑨ available transfer-to routes;
⑩ local map around transfer stop;
⑪ transfer-to route panel;
⑫ walking connection trip on map;
⑬ planned trip table.

The user interface designs and use cases for acquiring all this information using these interfaces are summarized in the next subsections.

4.4.1 Java Application Launching

This application applies to the following hardware and software environment.

- **Platform(s):** Mac OS X, Windows 10, Windows 7, Windows 8, Windows Vista, Linux 3.x
- **Browser(s)** Firefox, Internet Explorer, Safari, Chrome
- **Java version(s):** 8.0
- **Preferred display resolution:** 1920×1080 for Windows; regular setting for Mac

Note 1: Make your java version up-to-date. Reference site:
https://www.java.com/en/download/help/index_installing.xml
Note 2: Add the holding site (http://52.53.208.65/ITSIS) to the Exception Site List in your Java Control Panel
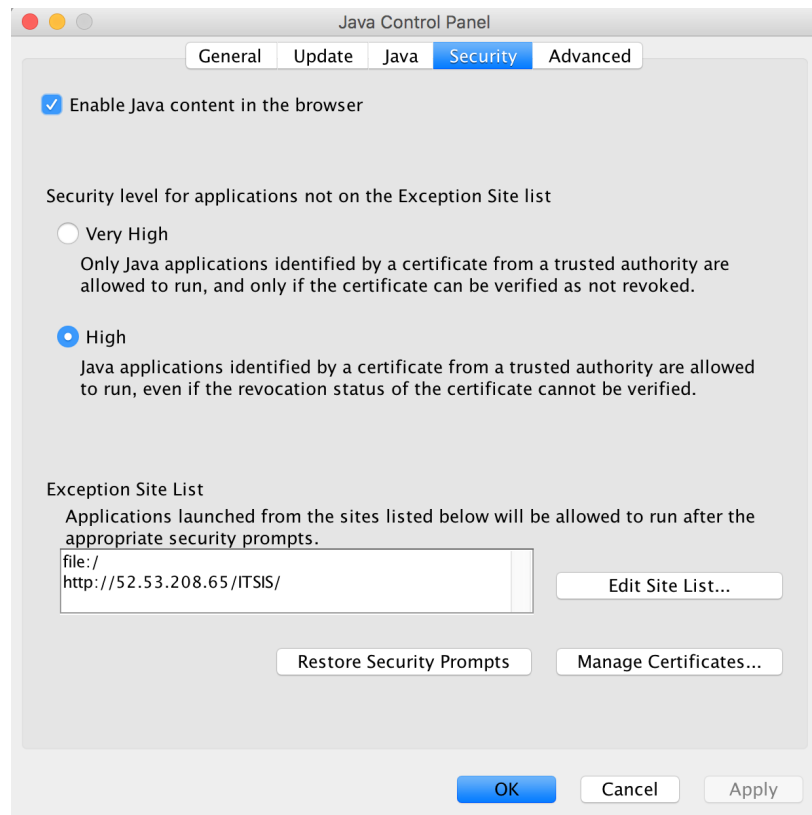
Figure 4-3 Java control panel

Launch the java application by following the steps below
Link to the URL of http://52.53.208.65/ITSIS/launchall.html
Click the "Guide to User Interface" to download this PDF manual
Click the "launch" button to launch the Java GUI application
Note 3: your browser may download the .jnlp file instead of directly opening it, if so, the application can be launched upon clicking the .jnlp file.

Note 4: At the beginning run of the application, some messages of "security warning" may pop up to request your permission to connect to other websites, press "OK" to proceed.

Figure 4-4 Web Entrance of the User Interface

4.4.2 Basic Interface Frame

Two permanent panels are configured on the interface, including:

- Showing the remaining time of next three arrivals, for Line 22 and 522 respectively, consisting the elements of
  ① route names (in number for VTA);
  ② remaining time of next 3 arrivals (in minutes when available, "N/A" when not available); Info Index: TS-AB3-3

- Showing the real-time estimated arrival time (ETA) of the host stop and the additional travel times to all the downstream stops
  ③ route name with direction ("EB" denoted eastbound) and trip id (not for naïve user);
  ④ stop sequence for the current route, the host stop is in blue background;
  ⑤ ETAs for corresponding stops
  ⑥ real-time locations (between two successive stops) of vehicles on road

Note that all the real-time information automatically updates along with time.
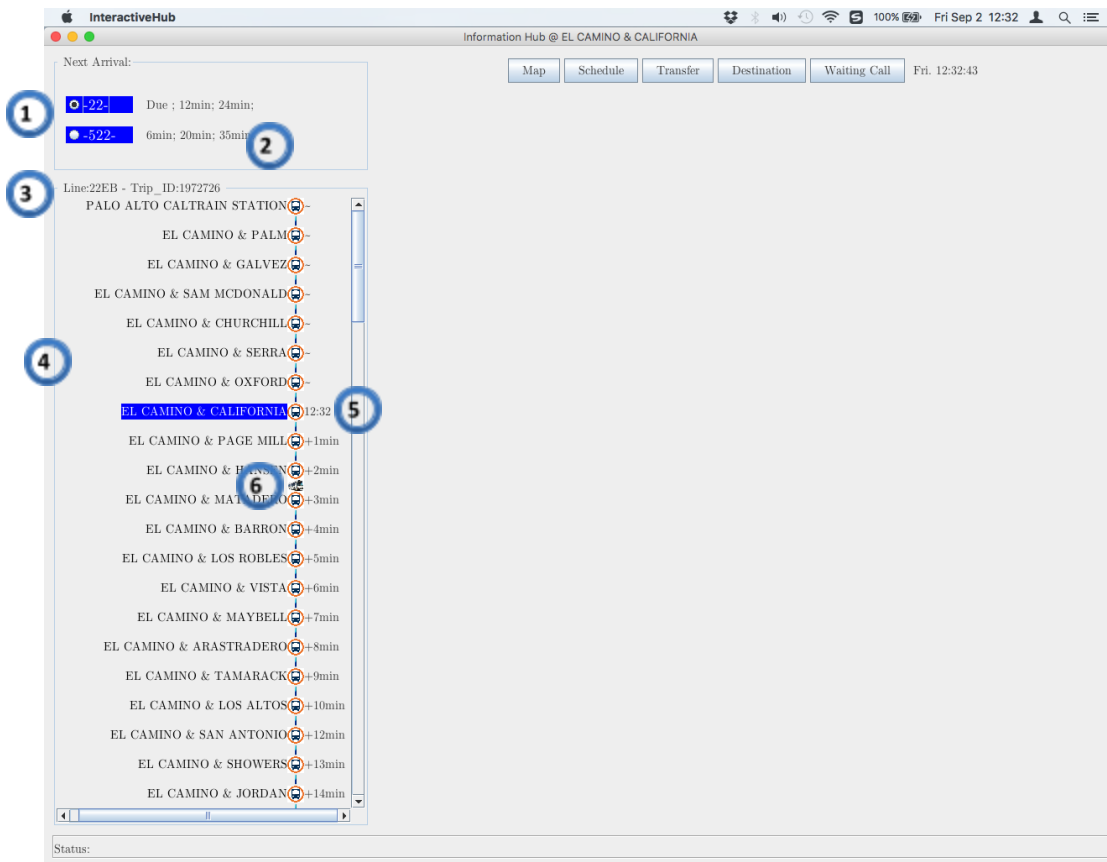
Figure 4-5 Basic Interface Frame (a)

User's actions:
    # Press the radio button to switch between Line 22 and 522

Press the top buttons to get further information

Figure 4-6 Basic Interface Frame (b)

4.4.3 Use Case 1：Searching through the map

The interface design supports information searching through the map. Upon pressing the "Map" button, the info window shows the transportation map by an unscalable image. The panel ⑦ presents the current status of the interface operation. Users may click and drag the scroll bars to check various parts of the map.
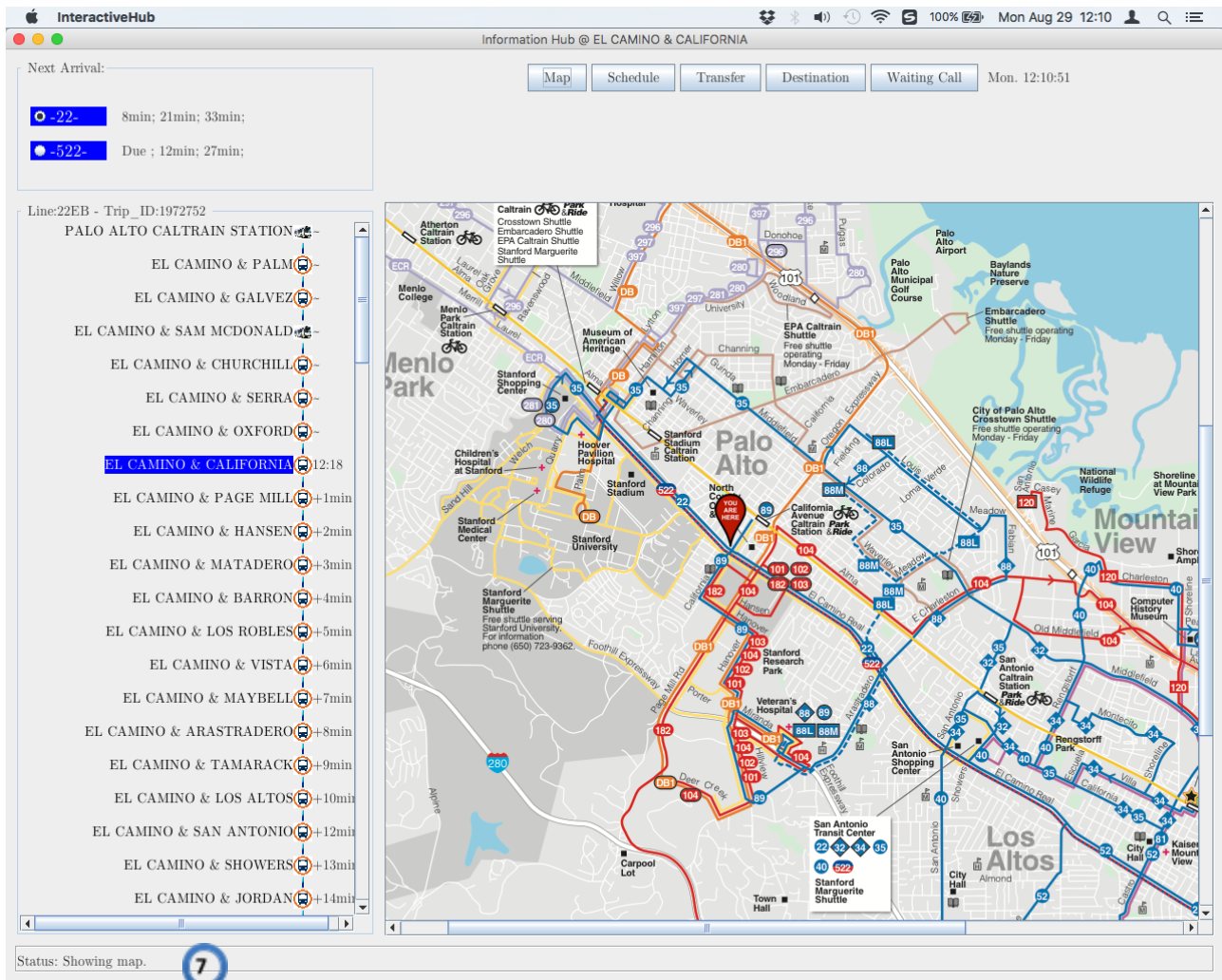

Figure 4-7 Searching through the map

User's actions:
Click and drag the scroll bars to check various part of the map.

4.4.4 Use Case 2: Checking Schedule

The interface design supports bus schedule inquiries. Upon pressing the 'Schedule' button followed by choosing a stop from the route (22 or 522) map, the info window shows the departure time schedules of weekdays, Saturdays and Sundays in different table columns. Note that the formats are all military time.

Figure 4-8 Checking schedule

User's actions:
   # Open the list box to find a stop and check its schedule
   # Click and drag the vertical scroll bar to check the bottom rows of the schedule table

4.4.5 Use Case 3: Acquiring Transit Transfer Information

The interface design supports inquiries for transfer information. Upon pressing the "Transfer" button, the user is able to choose the transfer stop from the downstream stop list. This function is for the passengers who are familiar with the route and have prior knowledge on the connection stops.
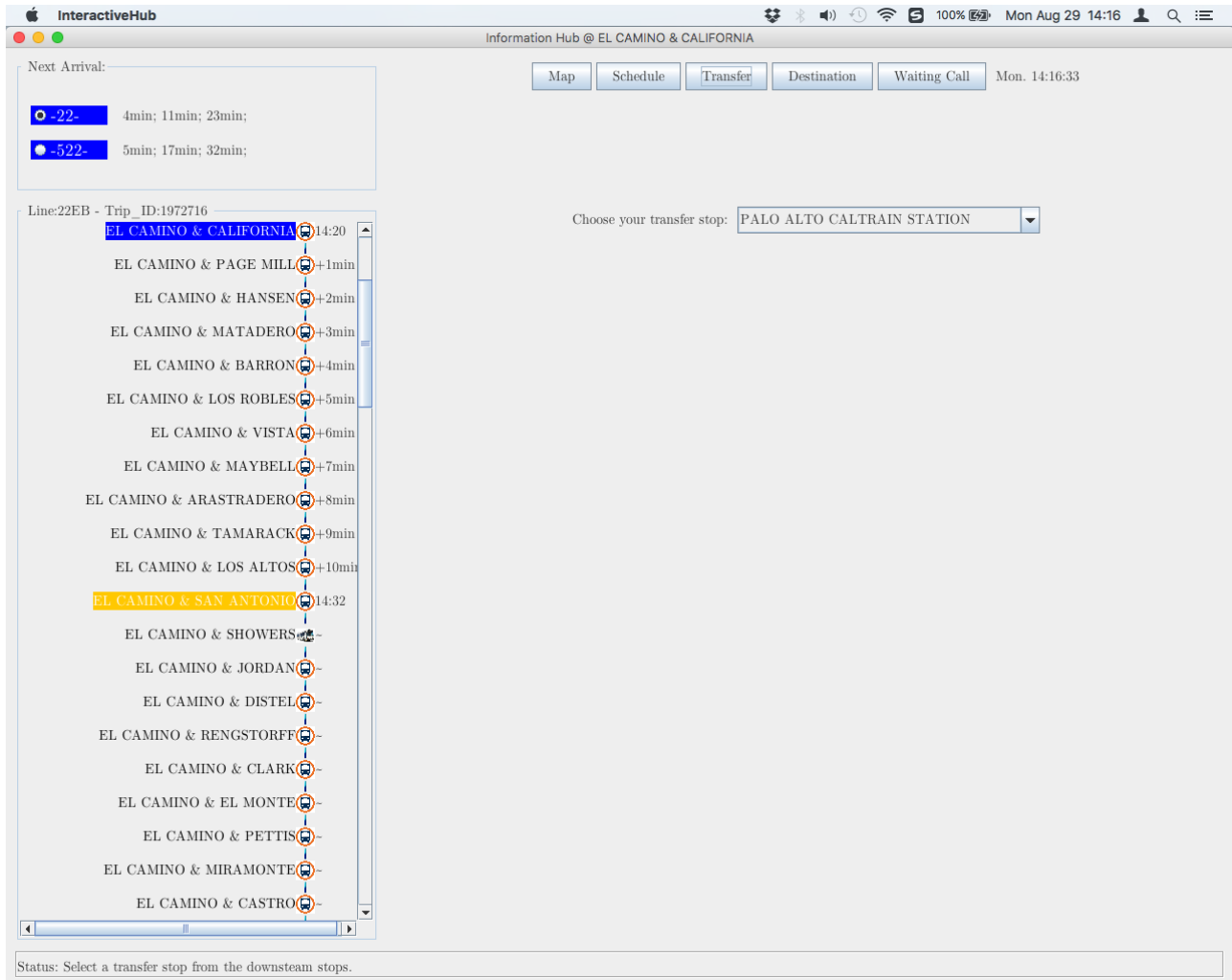
Figure 4-9 Acquire transfer information (a)

User's actions:
Open the list box to find a transfer stop to the next transit route.

After the transfer stop is chosen, the transfer stop in the host route ⑧ is marked by a yellow highlight. In the info window, all available transfer-to routes are shown in a table ⑨, and the local map around the transfer stop ⑩ is shown to help the passenger get familiar with the transfer surroundings.

Note: this step may take several seconds.
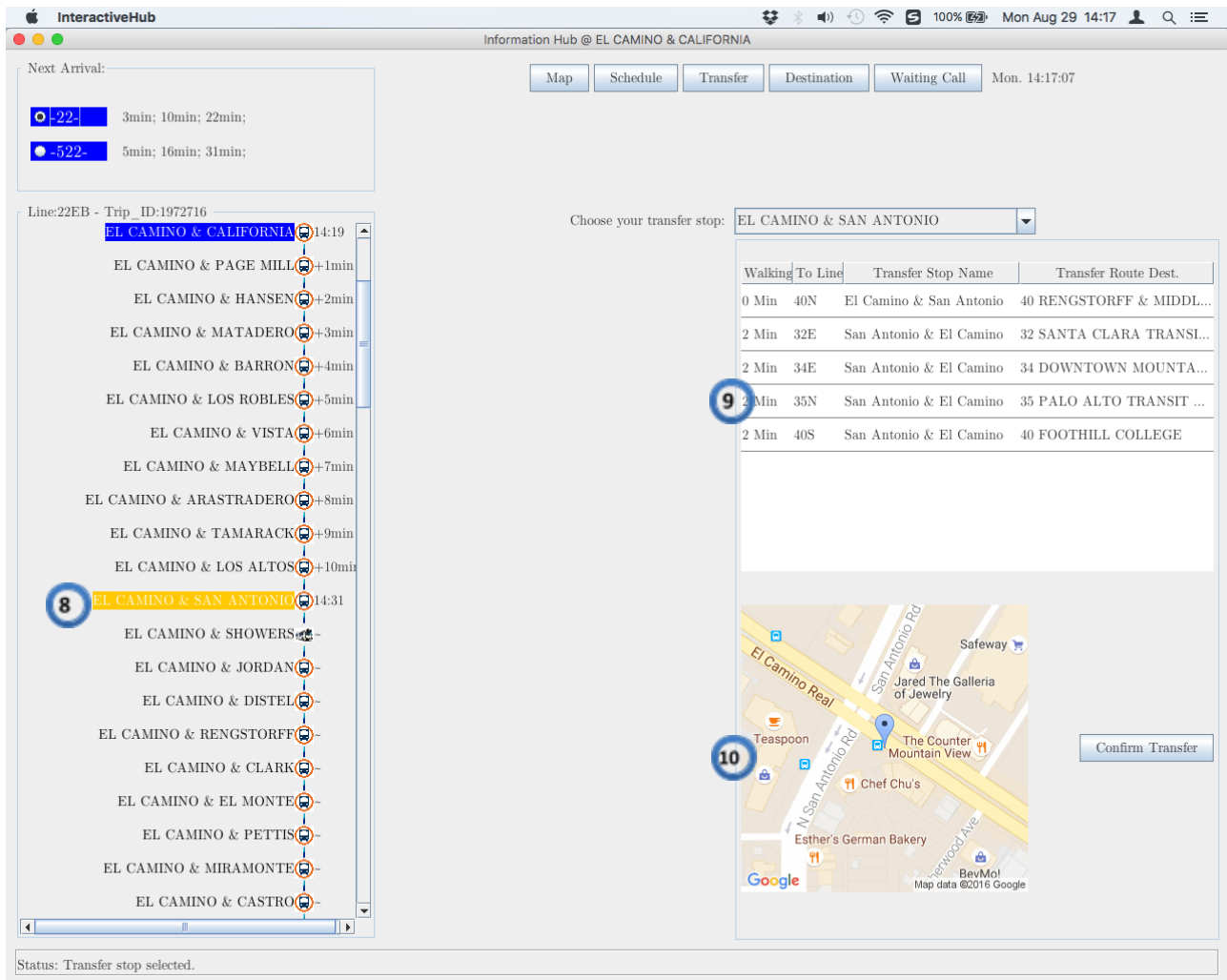
Figure 4-10 Acquire transfer information (b)

User's actions:
    # Choose a transfer-to route from the table rows;
    # Press the "Confirm Transfer" to obtain real-time information of the transfer-to route.

Upon the confirmation of transfer, the transfer-to route panel ⑪ appears in parallel with the host route panel, and with the same style. Meanwhile, the walking connection trip ⑫ from the transfer-from arrival station (blue point) to the transfer-to departure station (green point) is shown on the graphic map.

Figure 4-11 Acquire transfer information (c)

Because the stop has no available transfer connection, the transfer route table will be empty.

Figure 4-12 Acquire transfer information (d)

4.4.6 Use Case 4: Acquiring Transit Trip Information

Similar to transfer information, the interface design also supports inquiries for trip information. Upon pressing the "Destination" button, the user is able to choose the "Destination of Interest" from the list box. The place set and corresponding addresses are obtained from the Place of Interest (PoI) page of VTA.org, which include the popular locations of colleges, libraries, museums, scene sites, shopping centers and transportation hubs. This function is for the passengers who know the approximate range of their trip destinations.
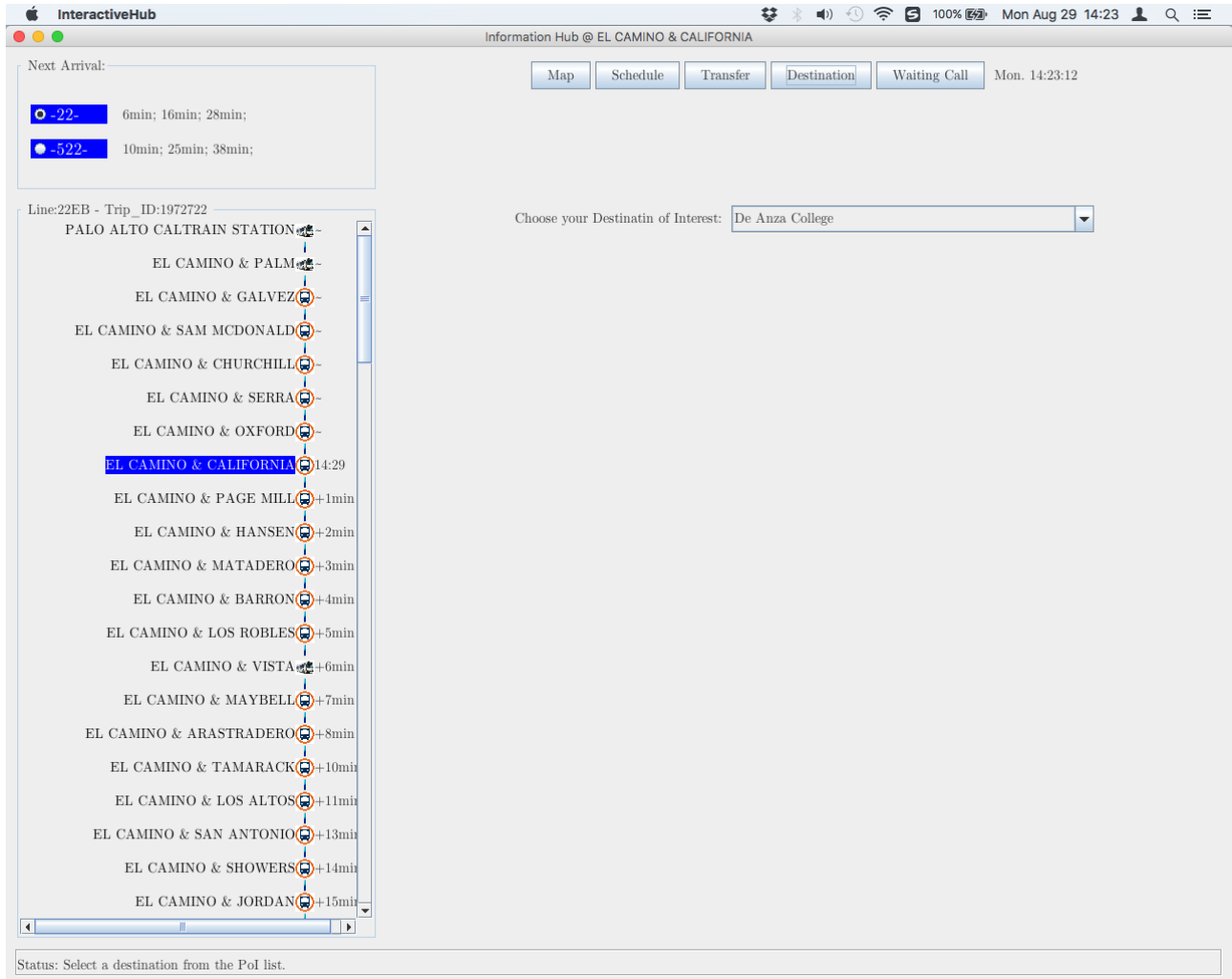
Figure 4-13 Acquire transfer trip information (a)

User's actions:
    # Open the list box to find a place of interest as the trip destination.

After the destination is chosen, a planned trip is shown in the info window in a table ⑬ by presenting the trip steps row by row. The planned trip is acquired using Google Direction API.
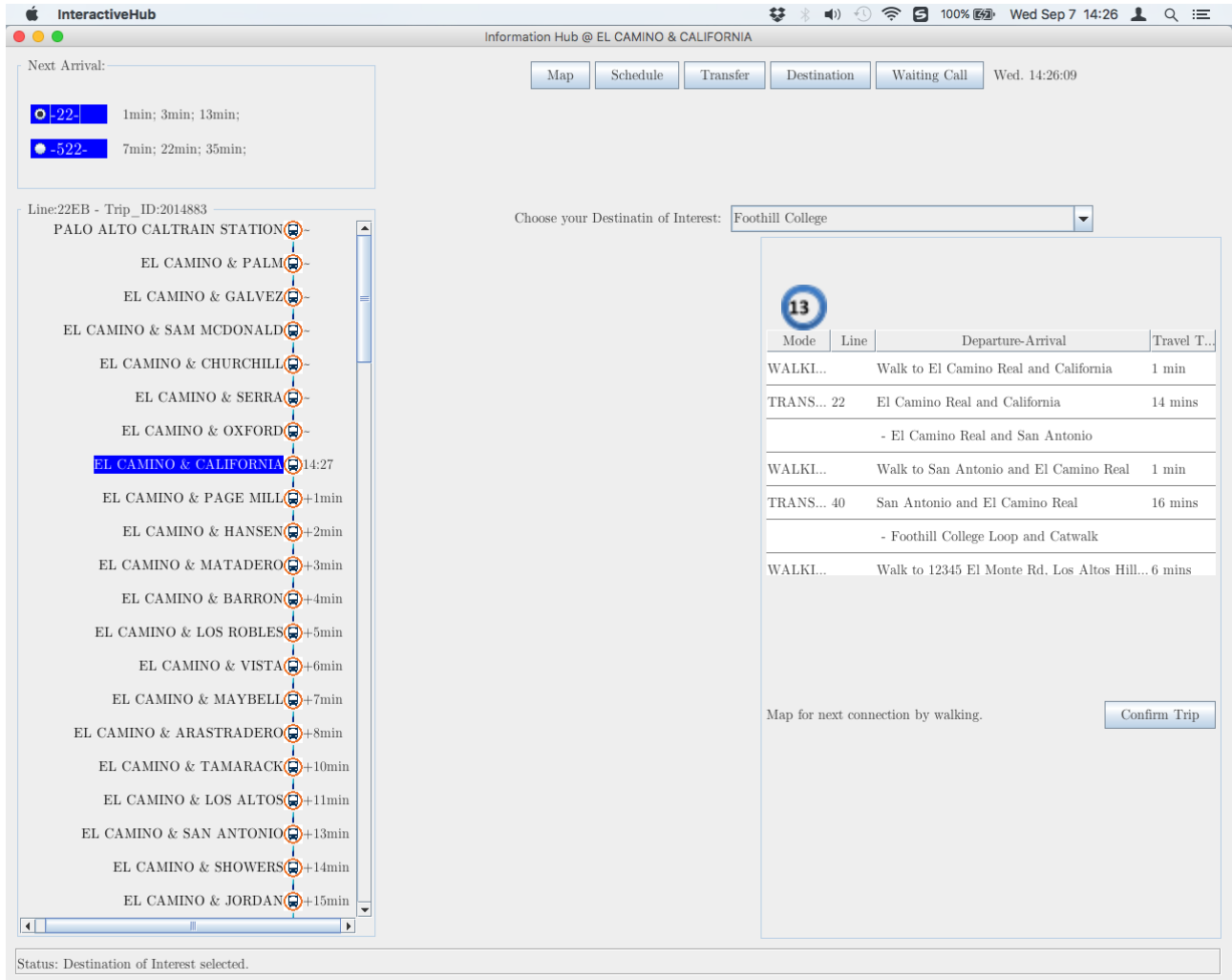
Figure 4-14 Acquire transfer trip information (b)

User's actions:

    # Press the "Confirm Trip" to obtain real-time information of the transfer-to route.

Upon the confirmation of trip, the transfer-to route panel ⑪ appears in parallel with the host route panel, and with the same style. Meanwhile, the walking connection trip ⑫ from the transfer-from arrival station (blue point) to the transfer-to departure station (green point) is shown on the graphic map.

Note: this step may take up to 12 seconds to complete.

Figure 4-14 Acquire transfer trip information (b)

4.4.7 Use Case 5: Passenger's Waiting Call

The interface design supports a passenger's waiting call. Note that this function has only been tested for feasibility using an automobile equipped with Connected Vehicle devices. Because VTA buses are not equipped with Connected Vehicle devices, this function was not enabled during the field testing.
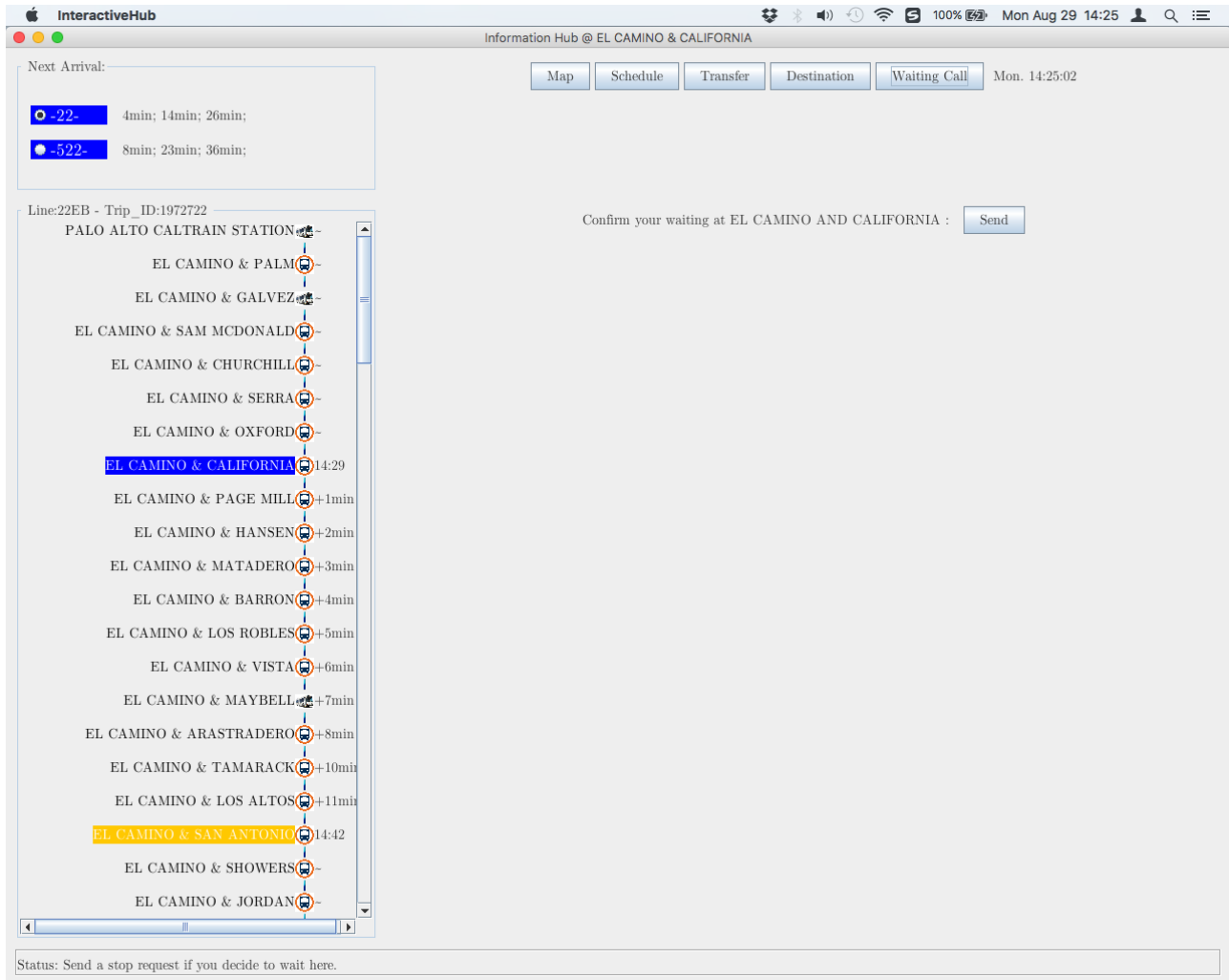
Figure 4-15 Passenger waiting call

4.5 Development of Improved Transit Vehicle Arrival Prediction

The development of the transit vehicle arrival prediction algorithms was an extension of the research under previous NT-T/SP and DPI projects and expanding it to use in the DSRC environment. For DSRC-based Automatic Vehicle Location (AVL) data collection, data comes in at a much higher frequency than the conventional AVL system; as such, there could be DSRC coverage gaps between adjacent RSEs. The bus arrival time prediction algorithm needs to be revised to accommodate the characteristic non-uniformly sampled location data and occasional

communication outages. Using Fused Automatic Vehicle Location (FAVL) information, derived from both transit CAD/AVL and DSRC-based AVL information, the accuracy of real-time bus/train arrival predictions can be improved upon. In addition, direct communication between a transit vehicle and a station when within the DSRC communication range provides a reliable way to update the status of the vehicle's approaching and then departing that station and also at bus stations further upstream and downstream.

During the period of conducting this research, more advanced AVL systems have been developed to achieve higher frequency vehicle real-time locations in order to provide a higher-quality transit information service including the PTA information. The approach is mainly upgrading the update frequency of the vehicle location data feed, either by upgrading the bandwidth of the AVL wireless communication subsystem or by replacing the conventional radio channel by some advanced commercial channels such as a cellular network. The high accuracy prediction of PTA then can be obtained based on the high-resolution vehicle location data. Recently, VTA has joined an association called transitime.org. By providing a complete open-source system the transit agencies in transitime.org have a cost effective system and have full ownership of it. The transitime.org association has offered a number of APIs for passengers and developers to access the route static data and the vehicle trip data, which contains all the available high-update-frequency real time GPS locations.

Considering that the main factor that determines the performance of predictions is the update frequency (or spatial resolution) of the raw data feed, regardless of what communication channel the data comes from, this study mainly uses the data polled from transitime.org instead of getting from DSRC links to verify the assumed improvement on the accuracies of PTA. Even though it can be verified through other substitutions of data feeds, the collection and analysis of DSRC data will still be conducted at the next stage of the ITSIS project.

Therefore, the goal of this study is to enable more timely and accurate passenger information. ITSIS bus-to-server communication will eliminate the possibility for inaccurate information that informs passengers the bus arrival when no bus is visible or a bus has already left the station. As a result, this study and the simultaneous development of the improved PTA have became one of the fundamental parts of the entire ITSIS project.

4.5.1 Vehicle Data Sources for PTA

The different types of data sources for comparison are listed, which are used to verify the hypothetical improvements brought about by the high-update frequency.

1) Scheduled arrival/departure time from route schedules.
Source: http://www.vta.org/getting-around/gtfs-info/data-file
2) Direct PTAs from API returns of 511.org.
Source: http://www.511.org/developer-resources_transit-api.asp
3) Vehicle real-time locations provided by the conventional AVL system, from API returns of transitime.org, with an update temporal interval of approximately 90 seconds.

Source:

http://api.transitime.org/api/v1/key/######/agency/vta/command/vehiclesDetails?r="routeID "format=xml

4) Vehicle real-time locations provided by new AVL systems, from API returns of transitime.org, with an update temporal interval of approximate 1 second.

Source:

http://api.transitime.org/api/v1/key/######/agency/vta/command/vehiclesDetails?r="routeID "format=xml

This XML file does not appear to have any style information associated with it. The document tree is shown below.

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▼<apiVehicles>
  ▼<vehicles id="4321" routeId="522" routeShortName="522" headsign="Rapid Palo Alto" direction="1" vehicleType="3">
    <loc lat="37.35773" lon="-121.84524" time="1516218306" speed="9.1" heading="238.4" source="AmigoProxy"/>
  </vehicles>
  ▼<vehicles id="4322" routeId="522" routeShortName="522" headsign="Rapid Palo Alto" direction="1" vehicleType="3">
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  </vehicles>
  ▼<vehicles id="4311" routeId="522" routeShortName="522" headsign="Rapid Palo Alto" direction="1" vehicleType="3">
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  </vehicles>
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  ▶<vehicles id="4307" routeId="522" routeShortName="522" headsign="Rapid Eastridge" direction="0" vehicleType="3">...</vehicles>
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  </vehicles>
</apiVehicles>
```

Figure 4-16 vehicle location information of a certain route in XML format

5) Vehicle real-time locations obtained through the DSRC channel, with an update temporal interval of approximate 0.1 seconds.

Source: DSRC OBU, RSE and relevant facilities

Note that all the data sources were sampled at the same sampling interval of 10 seconds, which is small enough to satisfy passengers' requirement on the PTA that is always at a minute level. This means that the data sources 4 and 5 above that were obtained and used in this study have only an update frequency of 10 seconds.

4.5.2 Methods of Time of Arrival Prediction

A number of methods for bus arrival prediction are investigated.

Method 1: using the route schedule, bus arrival times can be simply calculated by subtracting the current time from the scheduled arrival time.

Figure 4-17 Departure schedule for a certain stop

Day	Departure(AM)	Departure(PM)	Day	Departure(AM)	Departure(PM)	Day	Departure(AM)	Departure(PM)
Weekdays	02:49	12:11	Saturday	02:47	12:01	Sunday	02:46	12:01
Weekdays	03:41	12:23	Saturday	03:38	12:16	Sunday	03:40	12:16
Weekdays	04:26	12:35	Saturday	04:25	12:31	Sunday	04:22	12:31
Weekdays	05:15	12:47	Saturday	05:22	12:46	Sunday	05:22	12:46
Weekdays	05:46	12:59	Saturday	06:21	13:01	Sunday	06:22	13:01
Weekdays	06:16	13:11	Saturday	06:45	13:16	Sunday	06:46	13:16
Weekdays	06:33	13:23	Saturday	07:09	13:31	Sunday	07:10	13:31
Weekdays	06:49	13:35	Saturday	07:33	13:46	Sunday	07:33	13:46
Weekdays	07:02	13:47	Saturday	07:55	14:02	Sunday	07:53	14:01
Weekdays	07:13	13:59	Saturday	08:13	14:17	Sunday	08:13	14:16
Weekdays	07:25	14:11	Saturday	08:30	14:32	Sunday	08:33	14:31
Weekdays	07:36	14:23	Saturday	08:47	14:48	Sunday	08:48	14:46
Weekdays	07:48	14:35	Saturday	09:02	15:03	Sunday	09:03	15:01
Weekdays	08:00	14:47	Saturday	09:17	15:18	Sunday	09:17	15:16
Weekdays	08:12	14:59	Saturday	09:32	15:33	Sunday	09:32	15:31
Weekdays	08:24	15:11	Saturday	09:47	15:48	Sunday	09:47	15:46
Weekdays	08:36	15:23	Saturday	10:02	16:03	Sunday	10:02	16:01
Weekdays	08:48	15:35	Saturday	10:17	16:18	Sunday	10:17	16:16
Weekdays	09:00	15:47	Saturday	10:32	16:31	Sunday	10:32	16:31
Weekdays	09:12	15:59	Saturday	10:46	16:45	Sunday	10:46	16:46
Weekdays	09:24	16:11	Saturday	11:01	17:00	Sunday	11:01	17:01
Weekdays	09:24	16:23	Saturday	11:16	17:15	Sunday	11:16	17:16
Weekdays	09:36	16:35	Saturday	11:31	17:30	Sunday	11:31	17:31
Weekdays	09:48	16:46	Saturday	11:46	17:45	Sunday	11:46	17:46
Weekdays	10:00	16:57	Saturday		18:00	Sunday		18:01
Weekdays	10:00	17:08	Saturday		18:15	Sunday		18:16
Weekdays	10:12	17:20	Saturday		18:30	Sunday		18:31
Weekdays	10:24	17:33	Saturday		18:45	Sunday		18:46
Weekdays	10:37	17:45	Saturday		19:00	Sunday		19:01
Weekdays	10:49	17:57	Saturday		19:15	Sunday		19:16
Weekdays	11:00	18:10	Saturday		19:30	Sunday		19:32
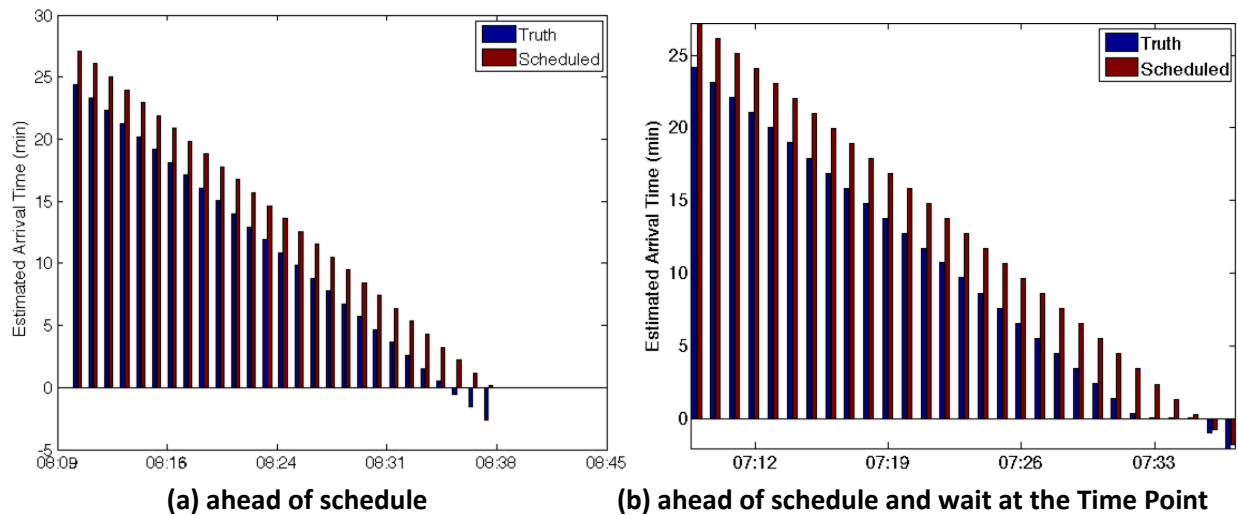
(a) ahead of schedule   (b) ahead of schedule and wait at the Time Point
Figure 4-18 Differences between the schedule and the actual arrival along the time

For the PTA comparison figures above and in the following paragraphs, the positive values of y-axis stand for approaching and the negative ones stand for departing, while the zero means stopping right at the stop. Here, we can find the delay of the bus (red bars are shorter than blue bars) and the bus being ahead of schedule (blue bars shorter than red bars) from the comparison data. The scenario of Figure 4-18 (b) is from the bus route (such as VTA22) that has special stops called Time Point, where the drivers are required to get matched with the schedule at their best. In the scenario of Figure 4-18 (b), the bus was ahead of schedule when arriving at the stop and waited for 3 minutes before departing.

The existence of Time Point stops has raised a problem with regards to the definition of PTA. As illustrated above, the Time of Arrival may not be the same as the Time of Departure if there is a significant waiting at a stop. Actually 511.org is using Real-Time Departure as the name of this information service. For more precise interprets, the passenger waiting right at a stop needs Time of Arrival, while Time of Departure is more useful for the passenger who is inquiring whether he/she can catch a bus at any place off stop. Thus for the data analysis in this memo, the PTA refers to the value of predicted arrival before actual arrival, zero for after arrival and before departure, and estimated past time after actual departure. Note that the past time after departure also needs to be estimated because we don't have the exact departure time for the low-resolution data.

Method 2: using the real-time departures API of 511.org, bus arrival times can be obtained directly after inputting a certain stop.
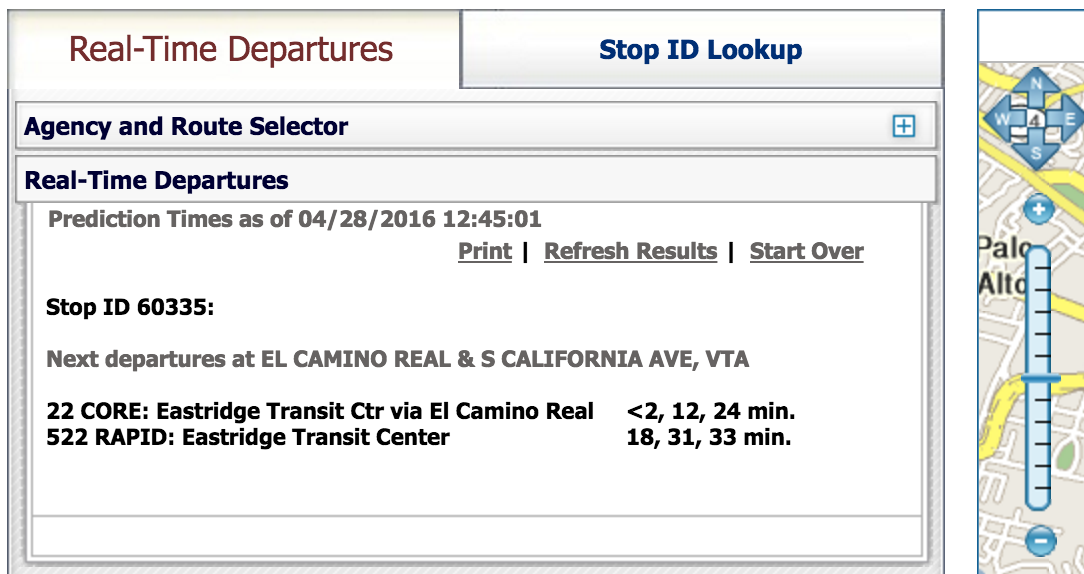
Fig. 4-19 Website interface of "Real-Time Departures" service of 511.org
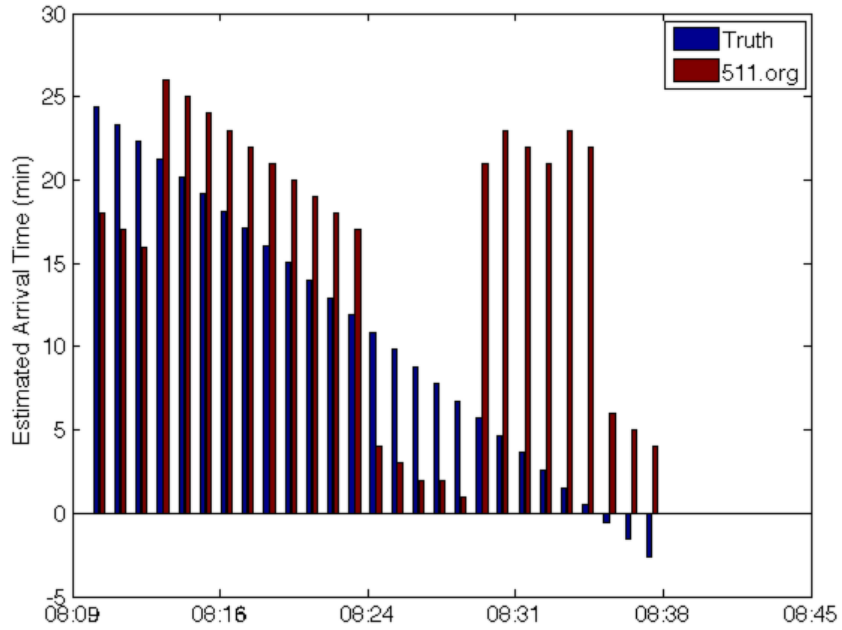
Figure 4-20 Differences between the direct PTD output of 511.org and the actual arrival along the time

From the results above, we can find there is something wrong with the direct outputs of 511.org. We have no theory to support the irregular jumps between the successive time period, which are possibly for different approaching vehicles but even so the prediction errors are still far from reasonable.

Method 3: Using the vehicle real-time locations to predict the ETA. The real-time data source is generated from the AVL system and the update rate is around 90 seconds.
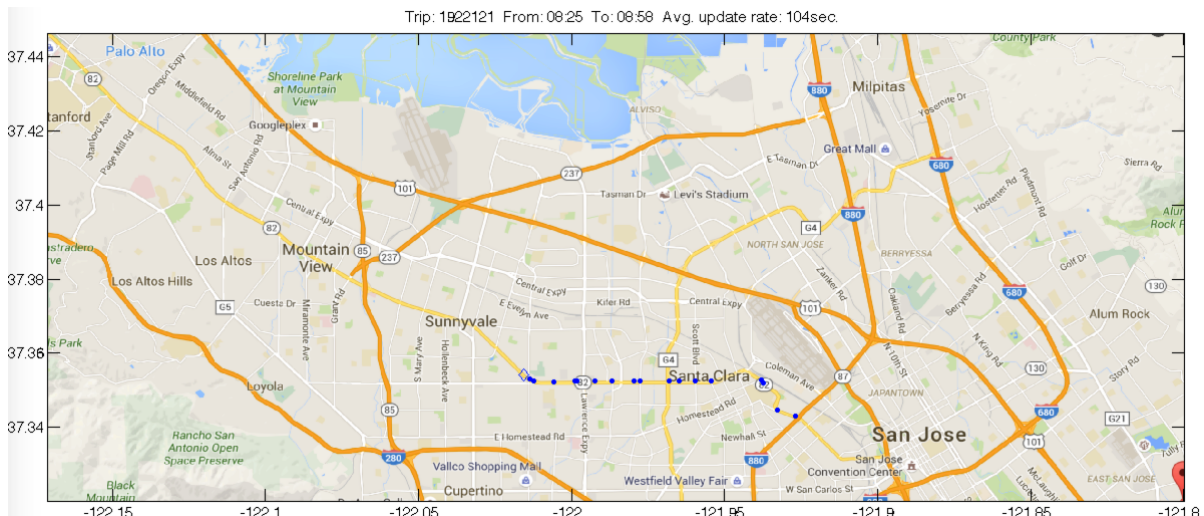
Figure 4-21 Vehicle trajectory plotted on map, with an update interval around 90 seconds

The blue dots on the map are the successively received locations of a running bus. The diamond symbol stands for the end of this segment indicating the direction of this trip. From the figure,

the sparse trajectory can be illustrated. Based on this set of data, two methods can be adopted for predicting.

Method 3.1: Adopting the time prediction algorithm without interpolations between the received sampling locations, the countdown value of ETA will be stuck when no location update is coming.
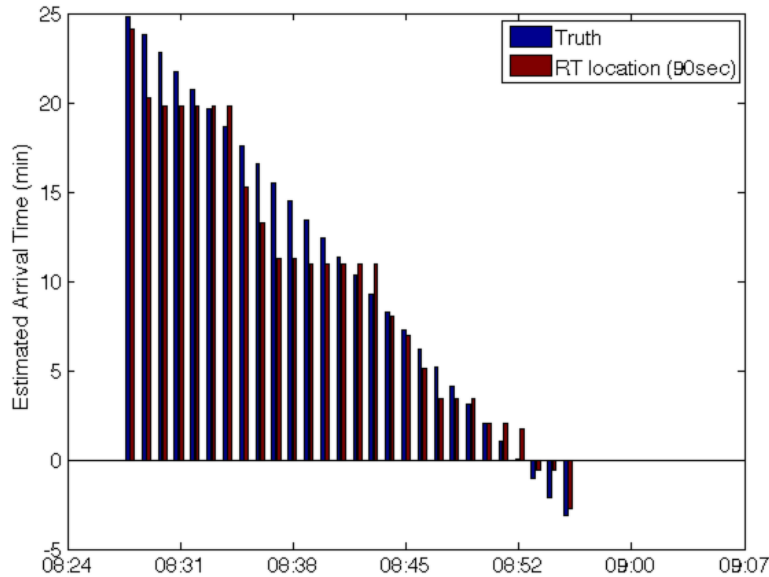
Figure 4-22 Differences between the real-time location based PTA and the truth (without interpolation)

Method 3.2: Adopting the time prediction algorithm with interpolations between the received sampling locations, the countdown will continue to decrease linearly while no location update comes.
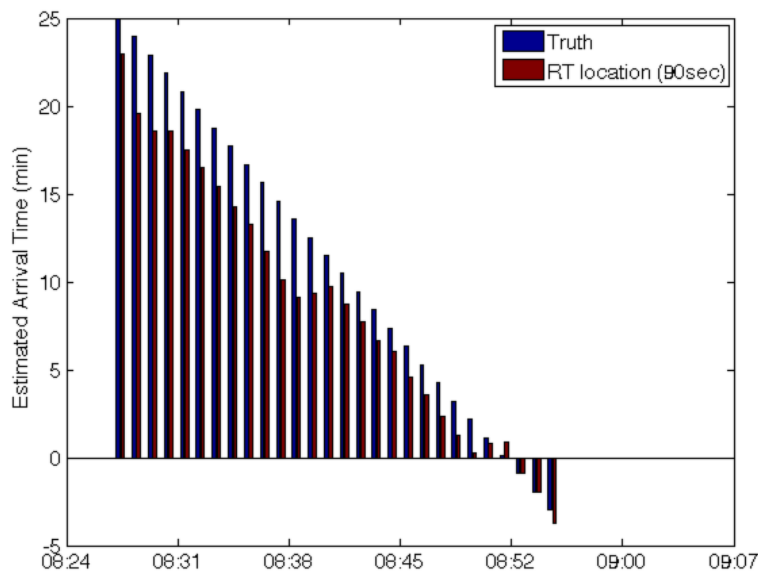
Figure 4-23 Differences between the real-time location based PTA and the truth (with interpolation)

45

Method 4: Using the vehicle high-resolution real-time locations to predict ETA. The real-time data is generated from new GIS system and the AmigoCloud system, the update rate is around 1 second.
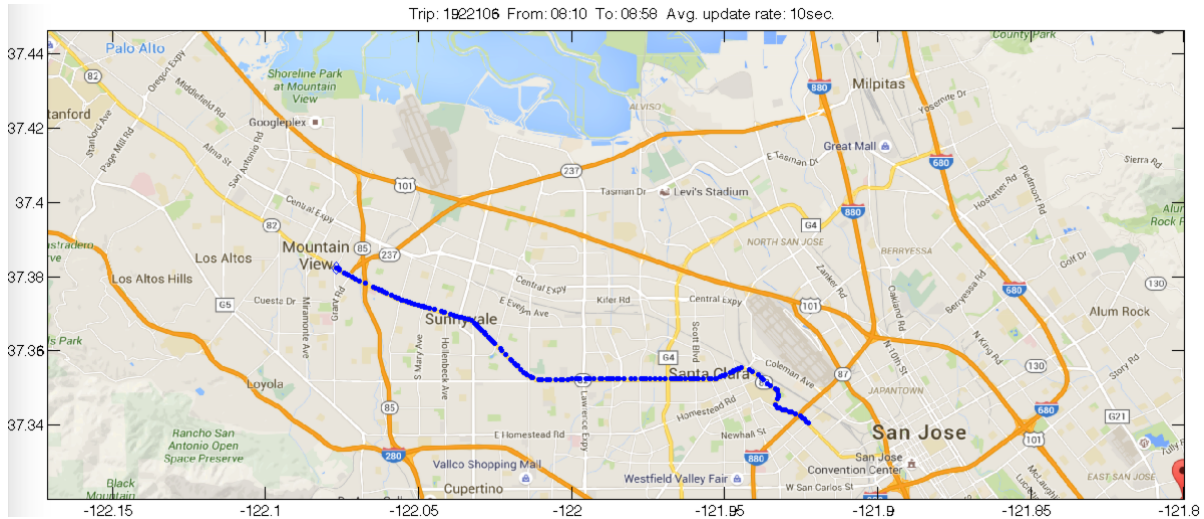
Figure 4-24 Vehicle trajectory plotted on map, with an update interval around 1 seconds
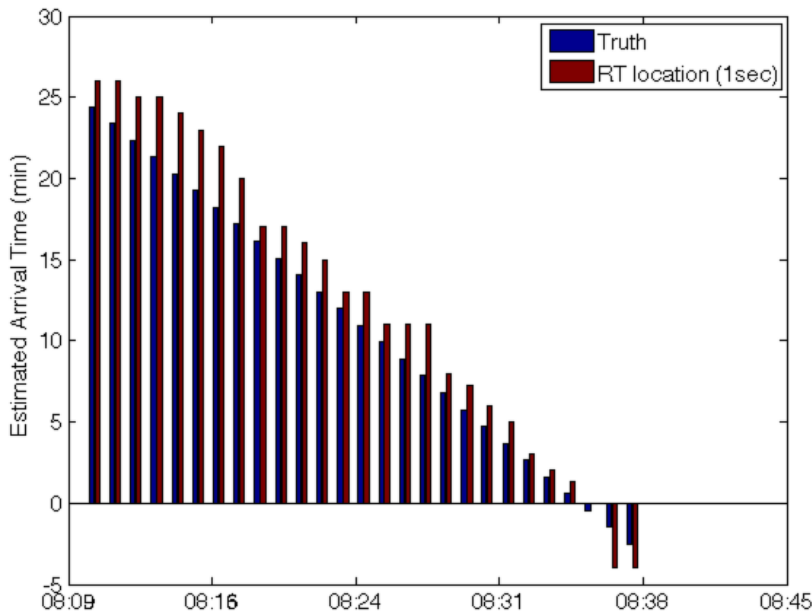
Figure 4-25 Differences of PTA between the real-time location based prediction and the truth

4.5.3 Comparisons of Statistical Performances

Examples of PTA along time: We show the results of PTA by using different methods or different data sources. There are two example trips shown as below. The bus arrived at the first stop (a) ahead of schedule and at the second stop (b) later than scheduled. Also, the stop 440 is a Time Point. The curves of location-based predictions show the changes of PTA along the time axis.
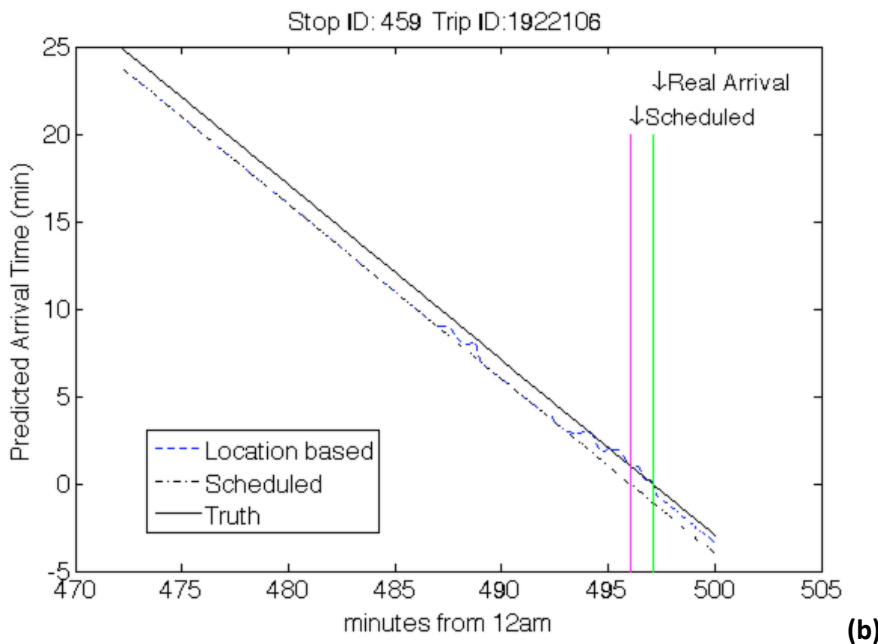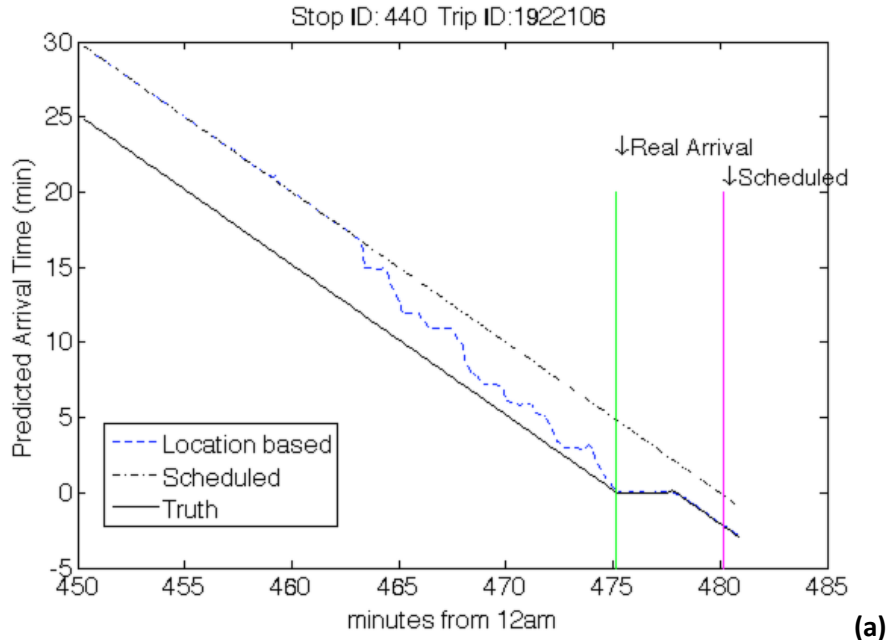
Figure 4-26 Prediction errors of RT location data-based PTA for 90 sec. versus 1 sec. update rate

Methodology: The predictions of ETA always have higher accuracies for the periods close to arrival and have lower accuracies when far from arrival, which is a natural characteristic of time-axis prediction and also related to various uncertainties of traffic conditions. Thus we divide the time axis into 3 segments:

- 25 min. to 15 min. before arrival;
- 15 min. to 5 min. before arrival;
- 5 min. before arrival to 3 min. after departure;

The statistical results are shown in the figures below.
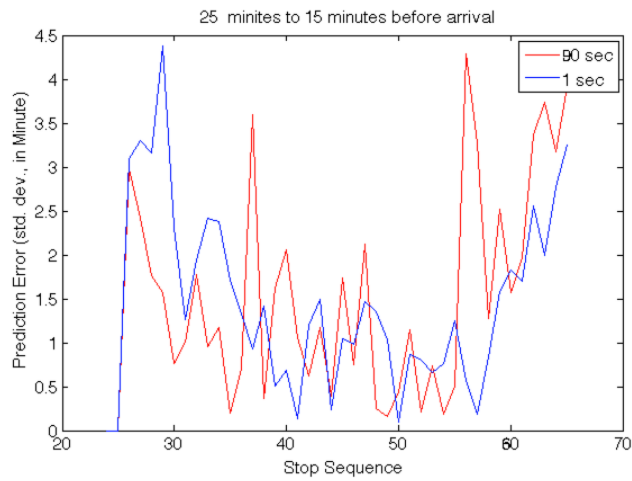
(a) 25 min. to 15 min. before arrival
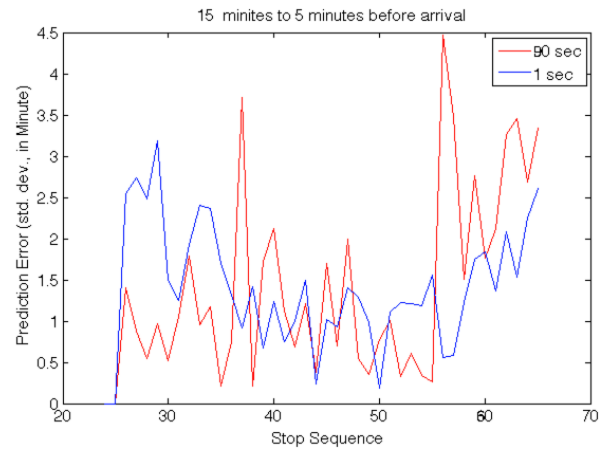
(b) 15 min. to 5 min. before arrival
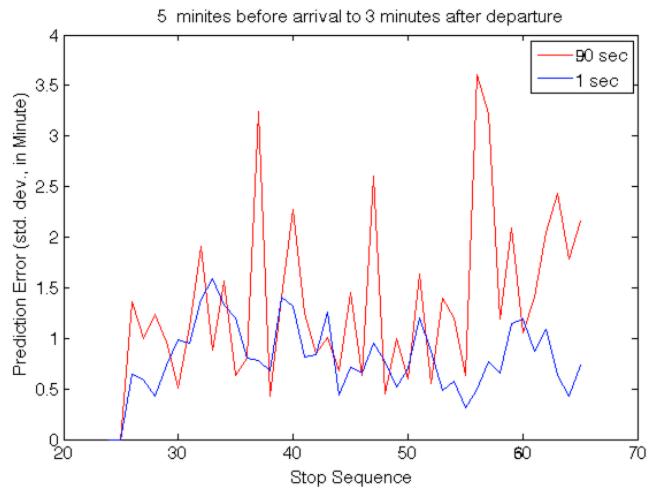
(c) 5 min. before to 3 min. after arrival

Figure 4-27 Prediction errors of RT location data based PTA for 90 sec. versus 1 sec. update rate

The statistical results obtained from the sample trips lead to the following conclusions: For the time period that is more than 5 minutes before arrival, the accuracy performances of PTA based on the real time location with the update rate of 90 seconds and 1 second have no significant differences. For the time period from 5 minutes before arrival to 3 minutes after departure, the second by second data can achieve a better prediction accuracy due to their high resolution characteristic. Passengers served by the advanced AVL system and the corresponding algorithms will definitely establish trust on the information service proposed and developed in the ITSIS project.

4.5.4 Implementation of PTA algorithm

By utilizing the real-time location data, the time of arrival can be predicted with the help of the schedule information and the road geometric (denoted as shape) information.

The basic algorithm is based on the estimated travel time from the current location to the reference stop. The planned schedule contains the empirical travel time between stops, while the shape information provides the high-resolution physical travel distances from point to point along the route. Additionally, the driver's behavior of approaching and stopping at Time Points is considered as a factor affecting the final results.
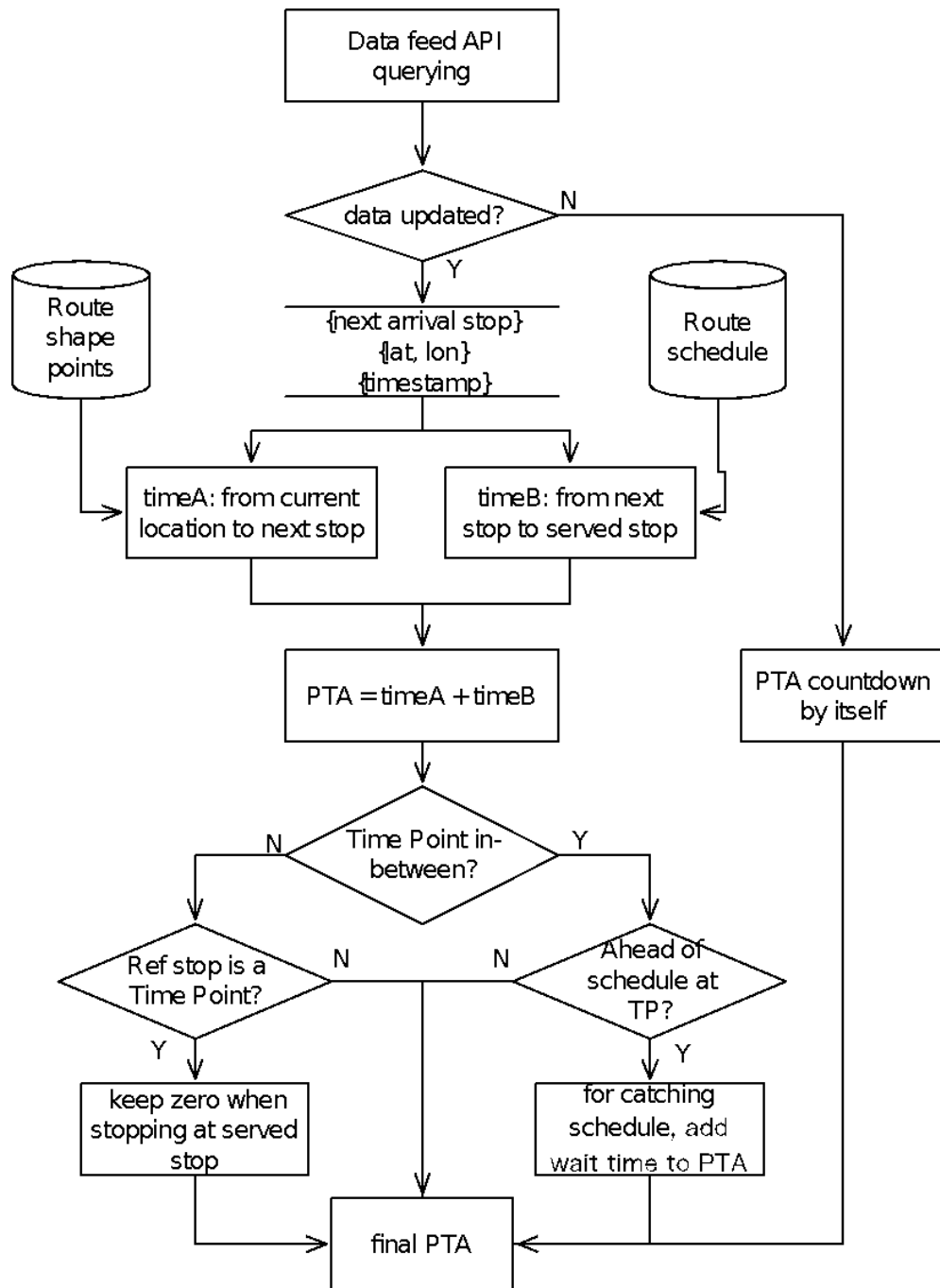
Figure 4-28 Diagram of the Arrival/Departure Time Prediction algorithm

4.6 Implementation

4.6.1 Locations of survey being conducted

Two bus stops are utilized, including the Southbound station at El Camino Real & California and the southbound station at Santa Clara Street at 6th Street (near SJSU).

Figure 4-29 A typical stop with shelter

4.6.2 System installation

The hardware components developed for field instrumentation, illustrated in Figure 4-30, are listed in Table 4-1.

Table 4-1 List of Hardware components

		Specs	Accessories
1	Touch Screen	32"; outdoor use	Power wire; Mini-USB to HDMI wire
2	Mounting bracket		Hooks for hanging
3	Tablet computer	9" Surface (available)	Power wire
4	Portable hotspot		A Wi-Fi data plan
5	Vehicle battery	Capacity >30 kW-hours	
6	Power inverter	12V to 110V	Power wire 2 or 3 power plugs
7	Container box	Put 3,4,5,6 in Height<12 in.	

Figure 4-30 Hardware components

And Figure 4-31 shows the ITSIS demo system mounted on a shelter for the field data collection.

Figure 4-31 The ITSIS demo system mounted on a shelter

5.0 Field Operational Test

In this section, the field operational test is summarized, the way the survey was conducted is described, and the data collection, related response distributions, analysis approach and analysis results are discussed and displayed.

5.1 ITSIS Demonstration and Survey Plan

5.1.1 Focus of the Survey

The survey focuses on information contents of the Interactive Transit Station Information System, rather than the user interface itself. The plan assumes a focus on information contents or its accuracy, not on the user interface. This phase of the research has been focused on the information contents, not on the user interface. A possible next phase of study may include a focus on user interface; experts in user interface or "user experience" may be explored for possible collaboration.

5.1.2 The Plan - Two Major Components or There

On-site passenger surveys at two bus stops are planned, including the southbound station at El Camino Real and California Ave, and the southbound station at Santa Clara Street and 6th Street (near SJSU).

A focus group meeting of San Jose State University students or a Master's Project of MS Human Factors Engineering (MS-HFE) student, or both, are planned. The participants are identified as:

- Focus Group: A focus group meeting of San Jose State University (SJSU) student passengers in a classroom or human-factors-lab environment, after having visited the Line 22 and Line 522 bus stop along Santa Clara Street at 5th Street (toward the Palo Alto Transit Center and across the Santa Clara Street from the City Hall) and having seen a demo at the Line 22 bus stop along Santa Clara Street at 7th Street (toward the Palo Alto Transit Center and across the Santa Clara Street from the City Hall). The reason why the demo is conducted at the Line 22 bus stop at 7th Street is that the Line 22 and Line 522 bus stop at 5th Street is not a standard bus stop and does not have a back wall or any wall on which the touch-screen monitor can be hung for convenient interaction with the user.
- A Master's Project of MS Human Factors Engineering (MS-HFE) student – Ms. Kavitha Srishva Kulasekaran.

5.1.3 On-Site Passenger Survey

ITSIS was designed to focus on and accentuate the value-added by a bus-stop information system for use by the passengers already having arrived at a Line 22 or Line 522 bus stop or, through an extension

smartphone "App" that may be developed in the future, for use by passengers planning to arrive at the bus stop at a later time to catch a Line 22 or Line 522 bus. Although this ITSIS can be coordinated or even integrated with other traveler information systems, the focus of this survey is exclusively on the ITSIS prototype as a bus-stop information system.

The surveys are planned for the following days:

Three days @ El Camino Real; 9 AM – 7 PM: 2/22 (Wednesday) – 2/24 (Friday), 2017;
Three days @ Santa Clara; 9 AM – 6 PM: 3/8 (Wednesday) – 3/10 (Friday), 2017.

The objectives of the surveys are identified:

Objective 1: Verification of the accuracy of the estimated arrival times: At this moment, focus will only be on the actual arrival of the next bus at the current bus stop as displayed on ITSIS. This will be done by the engineer conducting the survey, instead of the surveyors.

Objective 2: Regarding Scenario 1:
- The static information and real-time information about the current bus trip, before possible transfers, as provided by the current ITSIS prototype.
- Other information suggested by the passengers as useful.

Objective 3: Regarding Scenario 2:
- Real-time information about the entire trip, including bus arrival times at the transfer bus stop and at the final destination.
- Other information suggested by the passengers as useful.

5.1.4 Surveyors

The surveyors are graduate students of San Jose State University. They are trained by the system developers and have taken rehearsals to get proficient with the questionnaire. They are provided with the survey instructions to face different types of passengers and their ability to deal with possible on-site situations may have effects on the survey statistics.

5.2 Development of the Questionnaire

The questionnaire developed for and actually used in the survey is attached as Appendix A. A set of passenger-profile questions were also developed but were not used explicitly in the survey due to the likeliness of an insufficient amount of survey time. However, some of the questions were incorporated into the questionnaire. All these questions resulted from an iterative process involving a non-PATH subcontractor, the PATH designers/developers of the ITSIS prototype, a representative of Caltrans Division of Research, Innovation and Information Systems, and a representative of the Federal Transit Administration of the US Department of Transportation.

The questionnaire was designed for surveying transit passengers of Line 22 and Line 522 of the Valley Transportation Authority (VTA), which operates multiple modes of public transportation, including light-rail, regular bus and Bus Rapid Transit (BRT). Line 22 is a regular bus service while Line 522 is a BRT service, but without dedicated lanes. The two Lines coincide along the main, long commute corridor of El Camino Real (connecting townships of Palo Alto and Stanford with Downtown San Jose) through Santa Clara Street (connecting Downtown San Jose to East San Jose). The survey was to be conducted at two different bus stops, each of which serves both Line 22 and Line 522. The weekday headway of Line 22 is 12 minutes, and Line 522 is 15 minutes. Two questionnaires were designed so that all the high-priority questions can be completed in six minutes, which is half of the shorter headway of the two Lines. 20 questions were developed but are grouped into three different categories according to their relative importance: 11 high-priority questions, five medium-priority questions and four low-priority questions. The questions in each category are also ordered with respect to their relative importance.

To facilitate the discussion of this memo, we briefly describe the high-priority questions of the questionnaire in Table 5-1. Rather than stating the questions as they would be read to the surveyed passengers (as part of a script), we, for each question, state the question number (in column 1), the essence of the question (in column 2) and a couple of keywords of the question (in column 3, for ease of reference). Questions 1, 5, 9 and 11 have two parts and are labeled accordingly. Question 10 asks about types of information desired by the passenger but not provided by the ITSIS prototype. Due to the non-ranking nature of the question, no response distribution can be derived from the passengers' responses. As a result, it is omitted from the data analysis, which is the main focus of this memo. In fact, few surveyed passengers suggested any information types as candidates for possible improvements to the ITSIS prototype, due to satisfaction of the current information types or due to lack of time to provide thoughtful suggestions.

The initial display that appears immediately after launching the ITSIS prototype can be found in Figure 5-1. The high-priority questions of the questionnaire can be partitioned in three groups, corresponding to three areas/blocks of the initial display. The first area is the upper-left corner of the display, where one can find the estimated wait times for the next buses (of the chosen bus line); we will refer to this area as the Wait-Time Block. The second area is the panel below the aforementioned area, on the left-hand side of the screen. It displays the buses' locations and their estimated arrival times; we will refer to it as the Bus-Line Block. The third area is the Function Bar appearing to the left of the Wait-Time Block and near the top of the screen; we will refer to it as the Function Block. The ordering of the functions displayed in the Function Bar reflects the relative importance to the passenger, as conjectured by the survey designers, of the functions provided by the ITSIS prototype. This relative importance and the relative importance of the information provided in the Wait-Time and Bus-Line Blocks over the information provided by the functions of the Function Block, as additionally conjectured by the survey engineers, motivated the ordering of the high-priority questions of the questionnaire by beginning with the most important one. The ordering also smoothed the flow of questioning: going from the top-left corner (i.e., the Wait-Time Block), down through the left panel (i.e., the Bus-Line Block), back to the top (i.e., the Function Block) and then one function at a time from the left to the right.

Questions 1-1 and 1-2 seek passenger feedback about the information provided in the Wait-Time Block. Questions 2 and 3 seek passenger feedback about the information provided in the Bus-Line Block. Questions 4 through 8 are about the Function Block. Question 9 asks about whether the passenger will ride the bus more often, because of the ITSIS. The purpose of Question 11 is to find out if the information that can be provided by the ITSIS adds a significant amount of value to the experience, and if it goes beyond what a simple device like a horizontal message display or a horizontal scroll bar can provide.
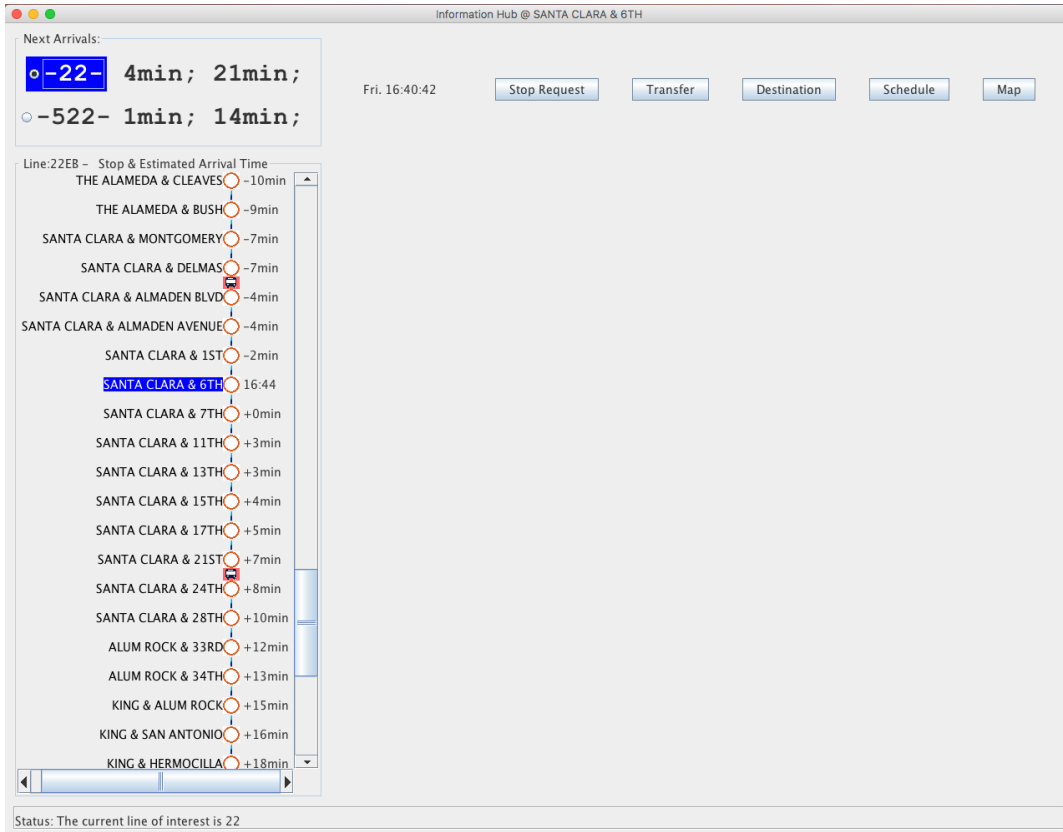
Figure 5-1 Initial ITSIS Screen, Displayed After Launch

Figure 5-2 shows a screen displaying transfer information provided by the Transfer Function of the ITSIS prototype.

5.3 The Survey

In this section, we briefly describe how the survey engineers (i.e., the subcontractor and his research assistant) conducted the survey and how the data were collected.

Given the random arrivals of passengers and the resulting random amount of time available for answering the questions, not all questions of the questionnaire could be answered by all surveyed passengers. In fact, to maximize the number of passengers who have a chance to answer some or all of the high-priority questions, once the passenger has answered all the high-priority questions, we turned to another passenger, if available, to ask high-priority questions. As a result, we never even had a chance to ask any of the medium- or low-priority questions in a systematic way. Many respondent passengers could not answer all the high-priority questions. Given that all the high-priority questions were ordered according to their relative importance, as perceived by the survey engineers and as mentioned earlier, the more important questions were answered by more passengers. The survey engineers adjusted the pace of the questioning and skipped questions depending on surveyed passengers' questions about ITSIS functions and/or the survey engineers' perception of the surveyed passengers' understanding of the question.
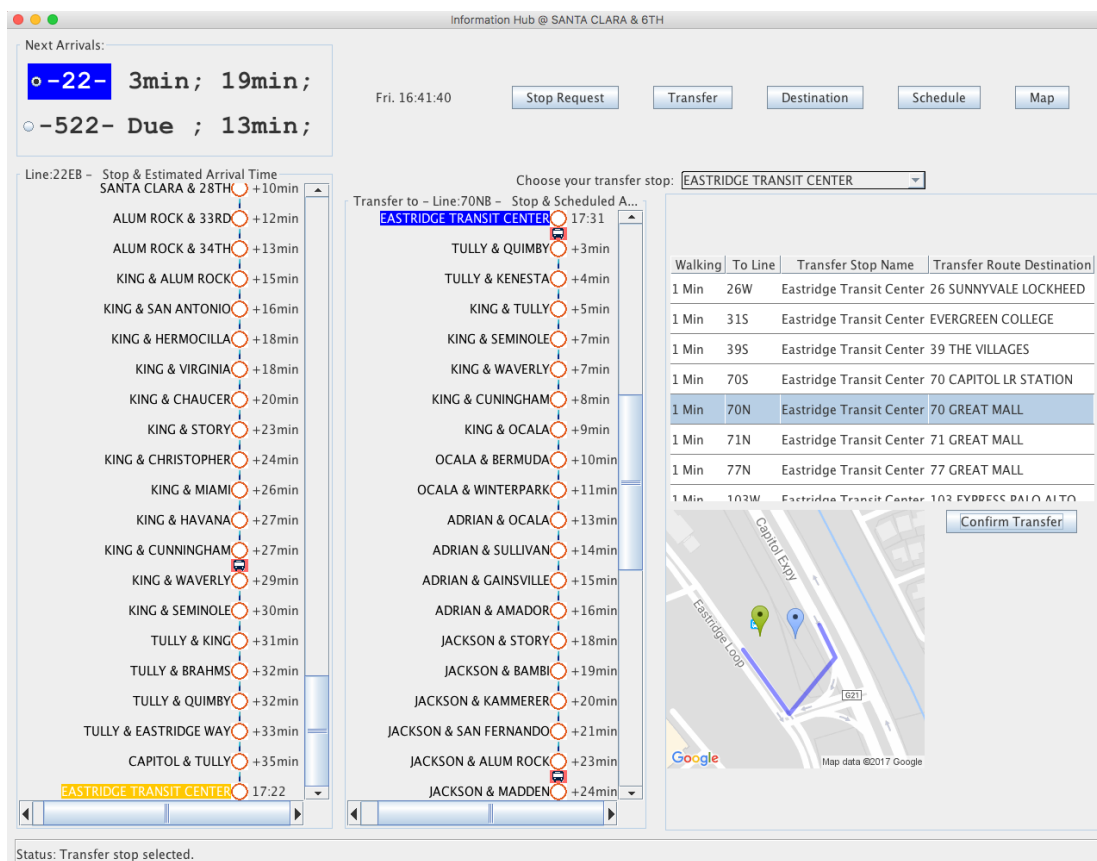
Figure 5-2 A Screen Displaying Transfer Information Provided by the Transfer Function

Table 5-1 The Questionnaire

Question No.	Question Statement	Question Key Words
Q1-1	The wait-time estimates for the next two buses are important to you.	Wait-Time: Importance
Q1-2	Given your other possible sources of information, the wait-time estimates for the next two buses provided by this system STILL adds value to you.	Wait-Time: Value Added
Q2	The estimated arrival times of the next bus at subsequent stops (including mine) add value to you.	Arrival Times: All
Q3	The locations of the buses currently traveling the Line add value to you.	Bus Locations
Q4	The function of "Stop Request" adds value to you.	Stop Request
Q5-1	Do you transfer to another bus often? Yes _____; No _____	Frequent Transfer
Q5-2	The Transfer Information (produced by the Transfer command button), including scheduled arrival time of the next transfer bus along the transfer line and the map of the streets near the transfer station, adds value to you.	Transfer Info
Q6	The Trip Information, produced by the Destination command button and including scheduled arrival time of the next transfer bus along the transfer line, adds value to you.	Trip Info
Q7	Provision of this scheduled departure times adds value to you, above and beyond other possible sources of information to which you have convenient access.	Schedule
Q8	Provision of this system map adds value to you, above and beyond other possible sources of information to which you have convenient access.	Map
Q9-0	Are you a frequent rider? (Do you ride a bus often?) (This was not an explicit question, but many were asked and most of those who were asked provided answers.)	Frequent Rider
Q9	You would ride buses more frequently because of this system.	Riding More
Q11-1	Question 11 refers to all the functions of this system except F1 (Estimated arrival times for the next two buses). The information provided by these functions is important to you.	All But F1: Importance
Q11-2	Question 11 refers to all the functions of this system except F1 (Estimated arrival times for the next two buses). Given your other sources of information, these functions provided by this system STILL add value to you.	All But F1: Value

The survey took place at two bus stops, namely El Camino Real at California Street (in Palo Alto) and Santa Clara Street at 6th Street (in San Jose downtown and in front of the San Jose City Hall), in the (south-east) direction from the Palo Alto Transit Center in Palo Alto to the Eastridge Transit Center in East San Jose. For ease of reference, the former bus stop will be referred to as the Palo Alto Station, and the latter, the City Hall Station. The survey engineers conducted the survey at the Palo Alto Station on February 22, 23 and 24 (Wednesday, Thursday and Friday) and at the City Hall Station on March 7 and 8 (Tuesday and Wednesday), all between the hours of 10 AM and 7 PM.

91 surveys were conducted at the Palo Alto Station, and 62 at the City Hall Station. (One of the passengers surveyed at the Palo Alto Station returned on the next day to provide feedback on questions not asked on the previous day due to lack of time.) Overall, approximately 150 passengers were surveyed at the two stations on the five workdays. Not all surveyed passengers

had a sufficient amount of survey time to answer all the questions. Because the questions were ordered in decreasing importance, the sample size is larger for the more important questions.

All the questions are formally posed as an assertion, and the passenger is asked to respond with their degree of agreement or disagreement to the assertion on a seven-level Likert Scale (i.e., Strongly Disagree, Disagree, Somewhat Disagree, Neutral, Somewhat Agree, Agree and Strongly Agree). To maximize the efficiency of the survey in cases where the estimated wait-time is much shorter than the six minutes allocated for the totality of the high-priority questions, the survey engineers rephrased the questions and used the adjective "valuable" to gauge the passengers' degree of agreement or disagreement to the importance or value assertion made in the questions. (We did make it clear to the surveyed passenger about the difference between the importance of a piece of information and the value added by the ITSIS prototype, whether it went above and beyond all the possible sources of the same information to which they might already have convenient access.) In case of such rephrasing, the passenger was asked whether a type of information provided by the ITSIS would be "very valuable", "valuable", "somewhat valuable" or "not valuable". When the answer was "not valuable", we further probed for a more discerning answer of "neutral", "somewhat not valuable", "not valuable" or "not valuable at all" (in correspondence to "neutral", "somewhat disagree", "disagree" or "strongly disagree" with the importance of value assertion of the question). This was done to save time by not repeating the seven Likert-type levels many times, and asking the passengers to remember the seven levels after being told only one did not seem to be realistic, all due to the short amount of available survey time.

Occasionally, a small group of passengers agreed to be surveyed together, from the start. The group may consist of friends or strangers who were present when the survey engineers were ready to start a new survey. After a survey session has started, if another passenger arrived at the bus stop shortly after the start, the survey engineers might invite the passenger to join the survey session. If the invitation was accepted, the survey engineer would repeat the questions already asked. Once a survey session has reached Q2, the survey engineers typically would not invite other passengers to participate in the same survey session.

The vast majority of the passengers approached were willing to participate in the survey while some declined because of language barriers, a few gave indication that they did not want to be bothered, and some just politely declined. Some really wanted to help with the survey, and made improvement suggestions about the system or about VTA. The survey engineers would not survey any passenger if their estimated wait-time was two minutes or less. Typically, the survey engineers would approach a passenger if their estimated wait-time was three minutes or longer. Several non-passengers were curious about the system and, after invitation, agreed to participate in the survey.

5.4 Data and Response Distributions

The concept of Interactive Transit Station Information System (ITSIS) was partially motivated by a large survey conducted by Dr. Joy Dahlgren about types of information most desired by transit users, as part of a 2002 research project titled "Advanced Bus Stops for Bus Rapid Transit". The survey result was summarized in a table; the table is restated as Table 5-2. It

gauged the degrees of usefulness of various types of bus-station information perceived by bus users, as of 2002, and served as a baseline for comparison with the degrees of usefulness of the ITSIS prototype perceived by the current bus users. For example, the recent ITSIS survey has shown that real-time information, e.g., estimated arrival time of the next and the subsequent buses, has gained more interest than its static counterpart, such as the bus schedule and route map.

As will be pointed out in Section 5.5 – Analysis Approach, we use the Chi-squared Test to test for possible dependence of the response distribution on a possible factor. The validity of such Chi-squared Tests hinges on the existence of a sufficiently large count. The individual counts of Strongly Disagree, Disagree, Somewhat Disagree and Neutral are all very low and too low for the Chi-squared Tests to be valid. Therefore, we first aggregated the four individual counts into one aggregated count, for all the questions, before conducting the Chi-squared Tests. Such aggregation results in four different aggregated responses for all the questions; they occupy the first four columns of percentages, namely "Negative or Neutral", "Somewhat Agree", "Agree" and "Strongly Agree". (The four corresponding percentages in each row sum to 100.) We regard "Agree" and "Strongly Agree" as sufficient support for the importance/value assertion of each question (but not "Somewhat Agree"). For ease of gauging the level of such sufficient support, we include a fifth column of percentages aggregated and named as "Agree or Strongly Agree", showing the sums of the percentages associated with the columns "Agree" and "Strongly Agree".

The rest of this section is partitioned into eight subsections (5.4.1 through 5.4.8), each of which summarizes the data collected with one response-distribution table (from Table 5-3 through Table 5-10). We first provide the overall response distributions for all the high-priority questions (except Question 10, whose answers are additional information types desired by the surveyed passengers), in Table 3. We then provide response distributions associated with the data collected at the Palo Alto Station, in Table 4, and the data collected at the City Hall Station, in Table 5-5. As will be pointed in a later section (Section 6 – Analysis Results), there is no statistically sufficient evidence that the passengers surveyed at the Palo Alto Station and their City Hall Station counterparts are any different in perceived usefulness of any of the information types.

Table 5-2 How Useful is Bus-Station Information (Dahlgren 2002)

Information type	Very useful to me		Very or somewhat useful to me	
	Number	Percent of all surveyed	Number	Percent of all surveyed
Schedule	598	62%	753	79%
Time when the next bus will arrive	474	49%	646	67%
Route maps	402	42%	605	63%
Connecting routes and transfer points	392	41%	574	60%
Current time of day	379	40%	558	58%
Updates on bus services	326	34%	545	57%
Fares	325	34%	496	52%
Customer service phone number	310	32%	500	52%
Map of activities close to the bus stop	277	29%	468	49%
• Medical and health services	360	38%	551	58%
• Shops and businesses	330	34%	492	51%
• Parks and recreation	309	32%	488	51%
• Movies and entertainment	256	27%	445	46%
• Activities for children and families	248	26%	443	46%
• Government services	243	25%	422	44%
Information about other transit agencies	265	28%	477	50%
Bus web address	211	22%	406	42%

We next provide and compare the response distributions, in Table 5-6, about the perceived value of the transfer information provided by ITSIS as perceived by those passengers who transfer often vs. those who do not. As will be pointed out in Section 5.6, there is no statistically sufficient evidence that the perceived value of the transfer information depends on the frequency of transfer. We next provide and compare the response distributions collected from male passengers (in Table 5-7) vs. their female counterparts (in Table 5-8). As will be pointed out in Section 5.6, there is no statistically sufficient evidence that response distributions depend on the gender. Finally, we provide and compare response distributions, in Table 5-9, on the question of whether the passenger would ride the bus more often because of the ITSIS between those who already ride the bus often vs those who do not. Not all surveyed passengers answered or had a chance to be asked the question whether they already ride the bus often. To increase the respondent count for those who already ride bus often for better accuracy, we include those respondents who transfer (to another bus) often but did not answer or did not have a chance to be asked the question whether they already ride bus often. We provide and compare the resulting response distributions in Table 5-10.

5.4.1 Overall Response Distributions

The distributions of the responses from all surveyed passengers are summarized in Table 5-3.

Table 5-3 The Distributions of the Responses from All Surveyed Passengers

Question No.	Question Key Words	Negative or Neutral	Somewhat Agree	Agree	Strongly Agree	Agree or Strongly Agree (Sum of Last Two Columns)
Q1-1	Wait-Time: Importance	2.7	6.7	21.3	69.3	90.7
Q1-2	Wait-Time: Value Added	7.8	10.6	34.8	46.8	81.6
Q2	Arrival Times: All	5.6	9.0	34.7	50.7	85.4
Q3	Bus Locations	11.8	16.7	31.9	39.6	71.5
Q4	Stop Request	8.8	15.4	22.1	53.7	75.7
Q5-1	Frequent Transfer	69.5	30.5	0.0	0.0	N/A
Q5-2	Transfer Info	5.6	11.9	31.0	51.6	82.5
Q6	Trip Info	2.5	16.7	38.3	42.5	80.8
Q7	Schedule	6.4	19.3	38.5	35.8	74.3
Q8	Map	16.2	35.4	30.3	18.2	48.5
Q9-0	Frequent Rider	16	84	0	0	N/A
Q9	Riding More	34.1	30.8	22.0	13.2	35.2
Q11-1	All But F1: Importance	3.4	18.6	40.7	37.3	78.0
Q11-2	All But F1: Value	10.5	10.5	57.9	21.1	78.9

Note that all functions of ITSIS are important (or valuable) or very important (or very valuable) to more than 70% of the surveyed passengers, except for the map function. Also note that 35.2% of the passengers agree or strongly agree that a system like ITSIS would make them ride buses more frequently.

5.4.2 Response Distributions of the Palo Alto Station Passengers

The distributions of the responses collected at the Palo Alto Station are summarized in Table 5-4.

Table 5-4: The Distributions of the Responses Collected at the Palo Alto Station

Question	Question Key Words	Negative or Neutral	Somewhat Agree	Agree	Strongly Agree	Agree or Strongly Agree (Sum of Last Two Columns)

Question	Question Key Words	Negative or Neutral	Somewhat Agree	Agree	Strongly Agree	Agree or Strongly Agree (Sum of Last 2)
Q1-1	Wait-Time: Importance	2.3	2.3	20.5	75.0	95.5
Q1-2	Wait-Time: Value Added	5.0	8.8	40.0	46.3	86.3
Q2	Arrival Times: All	3.6	9.5	33.3	53.6	86.9
Q3	Bus Locations	13.1	14.3	31.0	41.7	72.6
Q4	Stop Request	9.0	12.8	25.6	52.6	78.2
Q5-1	Frequent Transfer	69.5	30.5	0.0	0.0	0.0
Q5-2	Transfer Info	6.1	12.1	36.4	45.5	81.8
Q6	Trip Info	3.3	21.3	34.4	41.0	75.4
Q7	Schedule	9.6	26.9	30.8	32.7	63.5
Q8	Map	16.3	34.9	34.9	14.0	48.8
Q9	Riding More	46.3	26.8	17.1	9.8	26.8
Q11-1	All But F1: Importance	0.0	16.7	41.7	41.7	83.3
Q11-2	All But F1: Value	25.0	25.0	50.0	0.0	50.0

5.4.3 Response Distributions of the City Hall Station Passengers

The distributions of the responses collected at the City Hall Station are summarized in Table 5-5.

Table 5-5 The Distributions of the Responses Collected at the City Hall Station

Question	Question Key Words	Negative or Neutral	Somewhat Agree	Agree	Strongly Agree	Agree or Strongly Agree (Sum of Last 2)
Q1-1	Wait-Time: Importance	3.2	12.9	22.6	61.3	83.9
Q1-2	Wait-Time: Value Added	11.5	13.1	27.9	47.5	75.4
Q2	Arrival Times: All	8.3	8.3	36.7	46.7	83.3
Q3	Bus Locations	10.0	20.0	33.3	36.7	70.0
Q4	Stop Request	8.6	19.0	17.2	55.2	72.4
Q5-1	Frequent Transfer	69.5	30.5	0.0	0.0	0.0
Q5-2	Transfer Info	5.0	11.7	25.0	58.3	83.3
Q6	Trip Info	1.7	11.9	42.4	44.1	86.4
Q7	Schedule	3.5	12.3	45.6	38.6	84.2
Q8	Map	16.1	35.7	26.8	21.4	48.2
Q9	Riding More	24.0	34.0	26.0	16.0	42.0
Q11-1	All But F1: Importance	4.3	19.1	40.4	36.2	76.6
Q11-2	All But F1: Value	6.7	6.7	60.0	26.7	86.7

5.4.4 Response Distributions for the Transfer Information Question with Respect to Frequent Transfer or Not

We next contrast, in Table 5-6, the value of the transfer information perceived by those who transfer (to another bus) often with that perceived by those who do not transfer often.

Table 5-6 The Distributions of the Responses about Value of Transfer Information (Q5-2) with Respect to whether the Passenger Transfers Often or Not (Q5-1)

Frequent Transfer or Not	Negative or Neutral	Somewhat Agree	Agree	Strongly Agree	Agree or Strongly Agree (Sum of Last 2 Columns)
Frequent Transfer	5.2	11.7	31.2	51.9	83.1
No Frequent Transfer	5.6	13.9	25.0	55.6	80.6

5.4.5 Response Distributions of Male Passengers

We studied whether the surveyed passengers' responses depended on their gender. The distributions of the responses among male surveyed passengers are summarized in Table 5-7.

Table 5-7 The Distribution of the Responses Collected from Male Passengers

Question	Question Key Words	Negative or Neutral	Somewhat Agree	Agree	Strongly Agree	Agree or Strongly Agree (Sum of Last 2)
Q1-1	Wait-Time: Importance	1.1	7.5	22.6	68.8	91.4
Q1-2	Wait-Time: Value Added	5.6	10.0	37.8	46.7	84.4
Q2	Arrival Times: All	4.5	10.2	33.0	52.3	85.2
Q3	Bus Locations	15.7	14.6	30.3	39.3	69.7
Q4	Stop Request	11.0	15.9	23.2	50.0	73.2
Q5-1	Frequent Transfer	75.0	25.0	0.0	0.0	0.0
Q5-2	Transfer Info	5.2	14.3	36.4	44.2	80.5
Q6	Trip Info	1.4	20.3	36.5	41.9	78.4
Q7	Schedule	7.7	18.5	43.1	30.8	73.8
Q8	Map	10.5	35.1	38.6	15.8	54.4
Q9	Riding More	38.6	28.1	22.8	10.5	33.3
Q11-1	All But F1: Importance	3.0	12.1	51.5	33.3	84.8
Q11-2	All But F1: Value	18.2	18.2	54.5	9.1	63.6

5.4.6 Response Distributions of Female Passengers

The distributions of the responses among female surveyed passengers are summarized in Table 5-8.

Table 5-8: The Distribution of the Responses Collected from Female Passengers

Question	Question Key Words	Negative or Neutral	Somewhat Agree	Agree	Strongly Agree	Agree or Strongly Agree (Sum of Last 2)
Q1-1	Wait-Time: Importance	5.3	5.3	19.3	70.2	89.5
Q1-2	Wait-Time: Value Added	11.8	11.8	29.4	47.1	76.5
Q2	Arrival Times: All	7.1	7.1	37.5	48.2	85.7
Q3	Bus Locations	5.5	20.0	34.5	40.0	74.5
Q4	Stop Request	5.6	14.8	20.4	59.3	79.6
Q5-1	Frequent Transfer	60.9	39.1	0.0	0.0	0.0
Q5-2	Transfer Info	6.1	8.2	22.4	63.3	85.7
Q6	Trip Info	4.3	10.9	41.3	43.5	84.8
Q7	Schedule	4.5	20.5	31.8	43.2	75.0
Q8	Map	23.8	35.7	19.0	21.4	40.5
Q9	Riding More	26.5	35.3	20.6	17.6	38.2
Q11-1	All But F1: Importance	3.8	26.9	26.9	42.3	69.2
Q11-2	All But F1: Value	0.0	0.0	62.5	37.5	100.0*

*Only eight female surveyed passengers answered this question, five of whom agreed and the other three strongly agreed.

5.4.7 Response Distributions for the Riding More Question with Respect to Frequent Rider or Not

We studied whether a passenger's response to the question of Riding More depends on whether the passenger is already a frequent rider. We studied this possible dependence in two different methods. The first is focusing on those who have explicitly answered the question whether the passenger is a frequent bus rider (Yes vs. No of question Q9-0) and have selected one of the seven choices as their explicit answers to the Riding More question (Q9). In other words, those who either did not explicitly answer this Yes vs. No question (of Q9-0) or did not select any of the seven choices as their answers to the Riding ore question (Q9) are excluded from the analysis. The percentage results are summarized in Table 9. Note that we collected only 50 responses from the surveyed passengers. 42 of them answered explicitly that they are frequent riders while 8 of them answered explicitly that they are not frequent riders. We did not collect responses from all the other surveyed passengers. Reasons include unavailability of time to reach the questions, their hesitation to answer the questions, etc.

Table 5-9 The Distributions of the Responses about Riding Bus More Often Because of Systems Like ITSIS (Q9) with Respect to Whether the Passenger is Already a Frequent Rider (Q9-0)

Frequent Rider or Not	Negative or Neutral	Somewhat Agree	Agree	Strongly Agree	Agree or Strongly Agree (Sum of Last 2 Columns)
Not a Frequent Rider	25.0	37.5	25.0	12.5	37.5
A Frequent Rider	42.9	31.0	19.0	7.1	26.2

5.4.8 Response Distributions for the Riding More Question with Respect to "Frequent Rider or Frequent Transfer"

The second method is to consider those who answered 'Yes' to the Frequent Transfer question (Q5-1) as frequent riders, and whether or not they had provided an answer to or had a chance to be asked of the question of Frequent Rider (Q9-0). The motivation is to enlarge the data set, and the rationale is that those who transfer often must be a frequent rider to begin with. Then, we compared their responses to the Riding More question (Q9) to the responses of all those other surveyed passengers who provided their answers to the same Riding More question, some of whom explicitly answered No to the Frequent Rider question while the rest of whom did not. This method enlarges the data set to 91 surveyed passengers. 56 of them are either a frequent rider or a frequent transfer while the other 35 are neither a frequent rider nor a frequent transfer. The percentage results are summarized in Table 5-10.

Table 5-10: Distributions of the Responses about Riding Bus More Often Because of Systems Like ITSIS (Q9) with Respect to Whether the Passenger Rides Bus Often or Makes Transfer Often (Q9-0 or Q5-1)

A Frequent Rider/Frequent Transfer or Not	Negative or Neutral	Somewhat Agree	Agree	Strongly Agree	Agree or Strongly Agree (Sum of Last 2 Columns)
Neither a Frequent Rider Nor a Frequent Transfer	22.9	34.3	22.9	20.0	42.9
A Frequent Rider or Frequent Transfer	41.1	28.6	21.4	8.9	30.4

5.5 Analysis Results

The analyses performed for the survey have already been mentioned at the beginning of Section 5.4. This section provides their details. We analyzed the possible effects of four factors on the response distributions and summarize the four analyses in the following four subsections. In each of these subsections, we first state the factor whose effect is analyzed and summarize the results

of the analysis, in bold font and as a summary of that subsection. We then provide the details of the analysis.

5.5.1 Analysis Approach

Due to the random amounts of time available to interview willing passengers, the number of questions a surveyed passenger was able to answer was random as well. The later questions received fewer answers. Although the total number of 150 surveyed passengers is significantly larger than the target of 100, the numbers of answers to some of the later questions are smaller than the target. The numbers of the answers to Map (Q8) and More Riding (Q9) are slightly smaller than the target while their counterparts of All But F1: Importance (Q11-1) and All But F1: Value (Q11-2) are significantly smaller than the target.

The survey was conducted at two different locations, and, before combining the two sets of data, it would be good to conduct hypothesis testing to make sure that such combination is justified or is at least not unjustified. Such combination is important for those questions receiving fewer answers and is particularly important for those for which the total count of any of the seven answers (from "strongly agree" to "strongly disagree") is less than 5; this importance is derived from the validity of Poisson approximation of the distribution of a random "count variable." Testing this hypothesis will also help us ascertain that the current sample size would suffice.

We conducted a "Chi-squared Test" to test the hypothesis that the response distribution associated with the survey conducted at the Palo Alto Station (i.e., the station of El Camino Real at California) is the same as that associated with the survey conducted at the City Hall Station (i.e., the station of Santa Clara Street at 6th Street).

Because the counts for the negative and neutral choices (i.e., "strongly disagree", "disagree", "somewhat disagree" and "neutral") are small and typically much smaller than 5, we aggregated the counts associated with these four choices. After the aggregation, there are only four possible outcomes for each of the questions, and they are "negative or neutral", "somewhat agree", "agree" and "strongly agree". The response distributions for which we tested the validity to combine the two sets of data have these four outcomes. The tests are about whether the response distribution can be regarded as being independent of the location.

This hypothesis testing approach, particularly the Chi-squared Test, is used to compare possible effects of several other factors on passenger evaluations, e.g., the effect of gender on all questions, the effect of frequent transfer (Q5-1) from one line to another on the Transfer Information question (Q5-2), and the effect of frequent riding (Q9-0) on the Riding More question (Q9).

5.5.2 Location Factor on Response Distributions

The Effect of Location on the Response Distributions: The Hypothesis of No Location Effect Cannot Be Rejected with 0.05 Alpha ("False Alarm") Risk for Any of the Questions; Rejection for Two Questions at a Higher Risk May Be Considered, for (Q1-1) and (Q7).

Our analysis showed that, for each of the survey questions, the hypothesis that the response distribution is independent of the location cannot be rejected with a significance level of 0.05. In other words, under the independence assumption, the occurrence probability of the observed difference is not less than 0.05. Put in another way, the observed difference is not sufficiently rare to justify rejection of the hypothesis.

However, rejecting this hypothesis for (Q1) Part (1),which is about the importance of the wait-time estimates, and (Q7), which is about bus schedule, may be considered, because the p-value is close to 0.05 (and smaller than 0.1). (Please note that 0.05 or 0.01 is a commonly accepted threshold. 0.1 as a threshold for possible consideration of rejection is not; all the other p-values are greater than or equal to the p-value of 0.16 for Q9, which is about riding a bus more frequently.) The observed difference is rare, although not so rare that a rejection is justified at the commonly accepted Alpha ("false alarm") risk of 0.05. (If they are indeed independent, the likelihood of observing the empirical difference or worse is the p-value.) The p-values associated with the two questions are 0.061 (slightly above 0.05) and 0.093.

These possible differences about the answers to the two questions, (Q1-1) and (Q7), may actually exist and may not be surprising, given the characteristics of the passengers. We observe, through talking with the surveyed passengers beyond the survey questions, that disproportionately many of the bus users at the Palo Alto Station are technology workers while disproportionately many of the bus users at the City Hall Station are students. Regarding the possible difference in answers to (Q1-1), the technology workers may value the wait-time estimates more because of their stronger needs for on-time arrivals at their destinations or their generally higher value of time. As for the possible difference in answers to (Q7), although they may have cared more about the schedule had the schedule been adhered to, they may have found the schedule to be unreliable.

The absence of difference in responses to (Q11) Part (1) cannot be concluded with statistical validity. Neither can the absence of difference in responses to Part (2). This is because the counts of some of the response choices are too low. But, the empirical differences as reflected by the Chi-squared statistics are small or at least not large.

5.5.3 Factor of Frequent Transfer on Value of Transfer Information

The Effect of Frequent Transfer on Value of Transfer Information: The Hypothesis of No Effect Cannot Be Rejected with 0.05 Alpha ("False Alarm") Risk.

Based on Table 6, the response to (Q5-2) about value of the transfer information seems quite independent of the response to (Q5-1) about whether the passenger transfers often or not. A similar Chi-squared test produced a p-value of 0.923.

5.5.4 Gender Factor on Response Distributions

The Effect of Gender on Response Distributions: The Hypothesis of No Effect Cannot Be Rejected with 0.05 Alpha ("False Alarm") Risk.

None of the null hypotheses that the response distributions associated with the individual questions are independent of the gender can be rejected. However, rejecting this hypothesis about the Map function can be considered, at a higher Alpha ("false alarm") risk and with the p-value of 0.106. At this higher risk, it can be concluded that male passengers appreciate the Map function more than their female counterparts. (A couple of female surveyed passengers said that they do not read or do not like to read maps anyway.)

5.5.5 Factor of Frequent Rider on Riding More

The Effect of Frequent Rider on Riding More: The Hypothesis of No Effect Cannot Be Rejected with 0.05 Alpha ("False Alarm") Risk.

We make some observations about Table 9 and Table 10 first. In Table 9, the response distribution for the frequent riders peaks at the Negative or Neutral choice (42.9%) and steadily decreases on Somewhat Agree (31%), Agree (19%) and Strongly Agree (7.1%), while its non-frequent-rider counterpart peaks at Somewhat Agree (37.5%) and decreases on both sides. Note that the former is a strictly decreasing while the latter shows some degree of central tendency. The same pattern occurs in Table 10. In Table 10, the response distribution for the frequent riders peaks at the Negative or Neutral choice (41.1%) and steadily decreases on Somewhat Agree (28.6%), Agree (21.4%) and Strongly Agree (8.9%), while its non-frequent-rider counterpart peaks at Somewhat Agree (34.3%) and decreases on both sides. Despite these observations and a similar pattern, the hypothesis of no effect cannot be rejected with 0.05 Alpha ("false alarm") risk with a Chi-squared test. Other tests may be explored later to sharpen the comparison.

6.0 Conclusion and Recommendations

Under this project a number of objectives have been achieved. Researchers, through literature review and working with representatives of transit agencies, identified issues and gaps of the existing real-time traveler information communication systems. A concept of operation of ITSIS for addressing identified issues using Connected Vehicles technologies and an ITSIS system architecture were developed and documented. An ITSIS prototype, including a transit trip planner, the arrival time prediction algorithm and a functional user interface, was developed. Field testing was conducted at two transit stops. Passenger surveys were conducted.

The response distributions associated with the survey conducted at Palo Alto can be considered as consistent with that associated with the City Hall counterpart, although the response distributions for (Q1-1), about importance of wait-time estimates, and (Q7), about importance of schedule, may be considered different. However, the two possible differences can possibly be explained by the observation that the Palo Alto passengers have a higher proportion of technology workers.

With the two sets of survey answers combined, we can conclude the following:

- All functions of ITSIS are important (or valuable) or very important (or very valuable) to more than 70% of the surveyed passengers, except for the map function. The current Map function of the ITSIS prototype provides a static map, which is also provided as all bus stops as a poster; the current Map function is considered as valuable or very valuable by 48.5% of the surveyed passengers. (We asked the passengers to express their opinions about the static map currently provided by the ITSIS prototype, although we did tell them the potential of the current map function for many added features.)
- 35.2% of the passengers agree or strongly agree that a system like ITSIS would make them ride buses more frequently.
- The result of this survey suggests that, compared with the result of a 2002 survey of revealed interest in bus-station information, real-time information, e.g., estimated arrival time of the next and the subsequent buses, now receives more interest than its static counterpart, such as the bus schedule and route map.

Overall, the results showed that the passengers are pleased with ITSIS and the general appreciation of the ITSIS information does not depend on the location of the bus station and the gender of the passenger.

The project team recommends that a larger scale and longer duration of field testing ITSIS be conducted using real-time transit information panel products. Valley Transportation Authority is deploying these products at a few busy bus stop locations. The deployed real-time transit information panels provide most of the basic functions that ITSIS provides. It is recommended that ITSIS transit connection information be incorporated into these products and a thorough field operation test and evaluation be conducted. Future improvements based on this field operation test will support a path forward, ending with a workable and deployable ITSIS product.

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APPENDIX A: PASSENGER QUESTIONNAIRE ABOUT INTERACTIVE TRANSIT STATION INFORMATION SYSTEM (ITSIS)

The following pieces of information about the survey or the surveyed passenger are entered by the survey engineers, before or after the survey:

Line 22: ___or Line 522_____; Date: _____; Time: _____; Location: _____

Gender: Male __ or Female ___ ; Est. Age: up to 18 __; up to 40 __ ; up to 60 __; older _____ .

Ethnicity: White _____; Black _____ ; Hispanic _____; Asian _____; Others _____

The Questionnaire:

High-Priority Questions - Questions about ITSIS

 (Q1) Part (1) The wait-time estimates for the next two buses are important to you.

For most questions, please choose one from these SEVEN choices as your answer:

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q1) Part (2) Given your other possible sources of information, the wait-time estimates for the next two buses provided by this system STILL adds value to you.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q2) The estimated arrival times of the next bus at subsequent stops (including mine) add value to you.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q3) The locations of the buses currently traveling the Line add value to you.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q4) The function of "Stop Request" adds value to you.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q5) (Part 1) Do you transfer to another bus often? Yes _____; No _____
(Q5) (Part 2) The Transfer Information (produced by the Transfer command button), including the scheduled arrival time of the next transfer bus along the transfer line and the map of the streets near the

transfer station, adds value to you.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q6) The Trip Information, produced by the Destination command button and including scheduled arrival time of the next transfer bus along the transfer line, adds value to you.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q7) Provision of the scheduled departure times adds value to you, above and beyond other possible sources of information to which you have convenient access.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q8) Provision of the system map adds value to you, above and beyond other possible sources of information to which you have convenient access.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q9) You would ride buses more frequently because of this system.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q10) Would you want more information beyond what is currently provided by this system? If so, please specify: _____, _____, _____, _____.

Survey Engineer: Question 11 refers to all the functions of this system except F1 (Estimated arrival times for the next three buses)

(Q11) Part (1) The information provided by these functions is important to you.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q11) Part (2) Given your other sources of information, these functions provided by this system STILL adds value to you.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral (Undecided)	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

(Q12)   Should this system provide information about forthcoming permanent changes to routes or bus stopping locations?

(Q13)   Should this system provide information about forthcoming temporary changes to routes or bus stopping locations?

(Q14)   Should this system's Route Map contain the most up-to-date information, including the aforementioned permanent or temporary changes?

(Q15)   Should this system's Schedule information about a bus line distinguish between headway (time between two buses consecutively dispatched at a route end) and the scheduled arrival time at each or some station?

(Q16)   For those who ride the bus with a bike:
- How often do you ride the bus with a bike?
- How often are all the bike racks fully occupied when you need one?
- What do you do when this happens?
- Would you like to be able to know whether the bike rack of the next bus has capacity to accommodate your bike?
- Would you like to be able to know how full the next bus is and whether the next bus has enough capacity to accommodate your bike within the bus?
- Would you like to be able to know the same information about the following bus?

Low-priority Questions

(Q17)   What are the major problems you encounter at this or other bus stations?

(Q18)   If you have access to the estimated arrival time for the next bus, how satisfied are you about the accuracy?

(Q19)   What is your destination?

(Q20)   Do you have a scheduled event to catch?

APPENDIX B: The Passenger-Profile Questions That Were Developed But Were Not Used in the Survey Due to Time Constraints

In this Appendix, we describe a set of passenger profile questions that were developed but not used due to the likeliness that there was an insufficient amount of time to accommodate all of these questions in the passenger survey. However, some of them have been incorporated in the survey questionnaire described in Appendix A.

<u>Passenger-Profile Questions</u>

(PP1) Are you a regular user of this or other VTA bus lines? YES: _____ or NO: _____.

(PP2) Do you use a smartphone or other mobile devices to get real-time wait-time estimates for this bus line? YES: _____ or NO: _____.
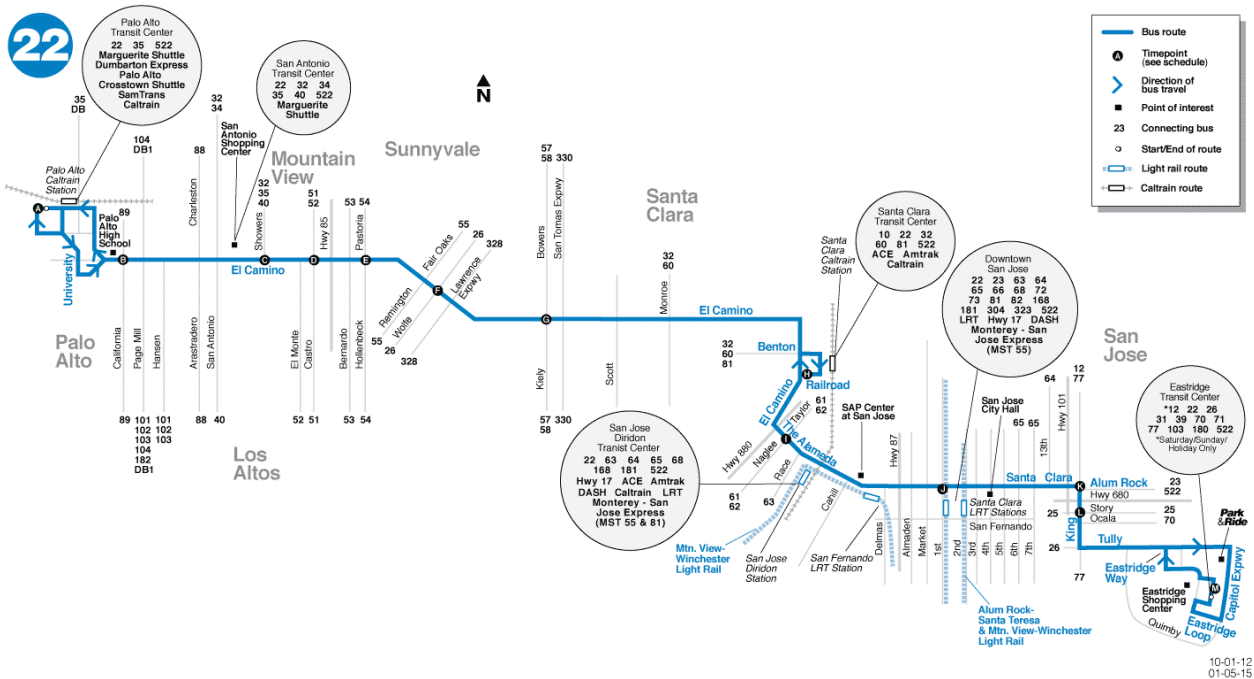
- If YES,
  - From which Apps: _____; _____; _____

 (PP3) Do you use computer tools other than a smartphone or mobile devices to get information about this bus line? YES: _____ or NO: _____.

- If YES, the information sources are: m.511.org: _____; vta.org _____; please specify others: _____, _____, _____, _____

(PP4) Do you follow the bus schedule? YES: _____ or NO: _____

Appendix C Route Maps for VTA 22 and 522

Route Map for VTA Route 22 (http://www.vta.org/routes/rt22)

Route Map for VTA Route 522 (http://www.vta.org/routes/rt522)