2023 SolanoExpress Connection Protection Study

Final Draft

Prepared by:

AMG ADVANCED MOBILITY GROUP

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ABBREVIATIONS

AC Transit – Alameda-Contra Costa Transit District

AFC – Automated Fare Collection

AMG – Advanced Mobility Group

APC – Automatic Passenger Count

API – Application Programming Interface

AVL – Automatic Vehicle Locator

BART – Bay Area Rapid Transit

CAD – Computer Aided Dispatch

Caltrans – California Department of Transportation

CCTA – Contra Costa Transportation Authority

CON-OPS – Concept of Operations

CP – Connection Protection

D-RIDE – Dynamic Rideshare

DRISI – Division of Research Innovation and System Information

ETA – Estimated Time of Arrival

FAST – Fairfield Transit

FHWA – Federal Highway Administration

FOT – Field Operations Testing

GTFS – General Transit Feed Specification

IDTO – Integrated Dynamic Transit Operations

ITS – Intelligent Transportation System

LAVTA – Livermore-Amador Valley Transit Authority

MDT – Mobile Data Terminals

MOD – Mobility on Demand

MTC – Metropolitan Transportation Commission

PATH – Partners for Advanced Transportation Technology

PLT – Project Leadership Team

RSA – Route and Schedule Adherence

RSS – Really Simple Syndication

SE – SolanoExpress

SolTrans – Solano County Transit

STA – Solano Transportation Authority

T-CONNECT – Transfer Connection Protection

T-DISP – Dynamic Dispatch

TDT – Tri Delta Transit

TNC – Transportation Network Companies

USDOT – United States Department of Transportation

XML – Extensible Markup Language

WestCAT – Western Contra Costa Transit

WETA – Water Emergency Transportation Authority

Y-line – Yellow Line

Executive Summary

The Solano Transportation Authority (STA) seeks to integrate SolanoExpress (SE) service into larger regional transit services by offering Connection Protection (CP) on key routes to provide a seamless travel experience for as many riders as possible. The outcome of this study is a plan to implement CP throughout Solano County focusing on connections to and from SE routes. An assessment of the SE System, current technologies available at various transit agencies, a literature review, and a pilot study were conducted as part of this study to inform the Implementation Plan.

CONNECTION PROTECTION

Connection protection can provide a seamless travel experience for riders transferring between various transportation providers. With data sharing, open communication, and coordination among multimodal transportation providers, CP aims to improve transit reliability and save trip time, along with providing the rider a pleasant, safe, and stress-free trip.

EXPECTED BENEFITS

Based on the literature review conducted, the benefits realized varied among the CP deployments studied. In general, implementation of the CP system provides potential benefits at multiple levels to multiple users as listed below:

- **Regional Benefits:** As inter-agency connections improve, the viability of regional transportation and thus regional mobility will improve. Regional accessibility will in turn promote employment initiatives.
- **Transit Rider Benefits:** CP facilitates seamless transfers between multiple agencies and multiple modes with shorter wait times and fewer late arrivals because of a more consistent service. This will lead to greater passenger satisfaction with regional public transportation by providing real-time transit information availability to transit riders, thereby giving them greater control over their trips.

- **Transit Agency Benefits:** Increased connection opportunities for transit riders will help agencies gain operational efficiencies.

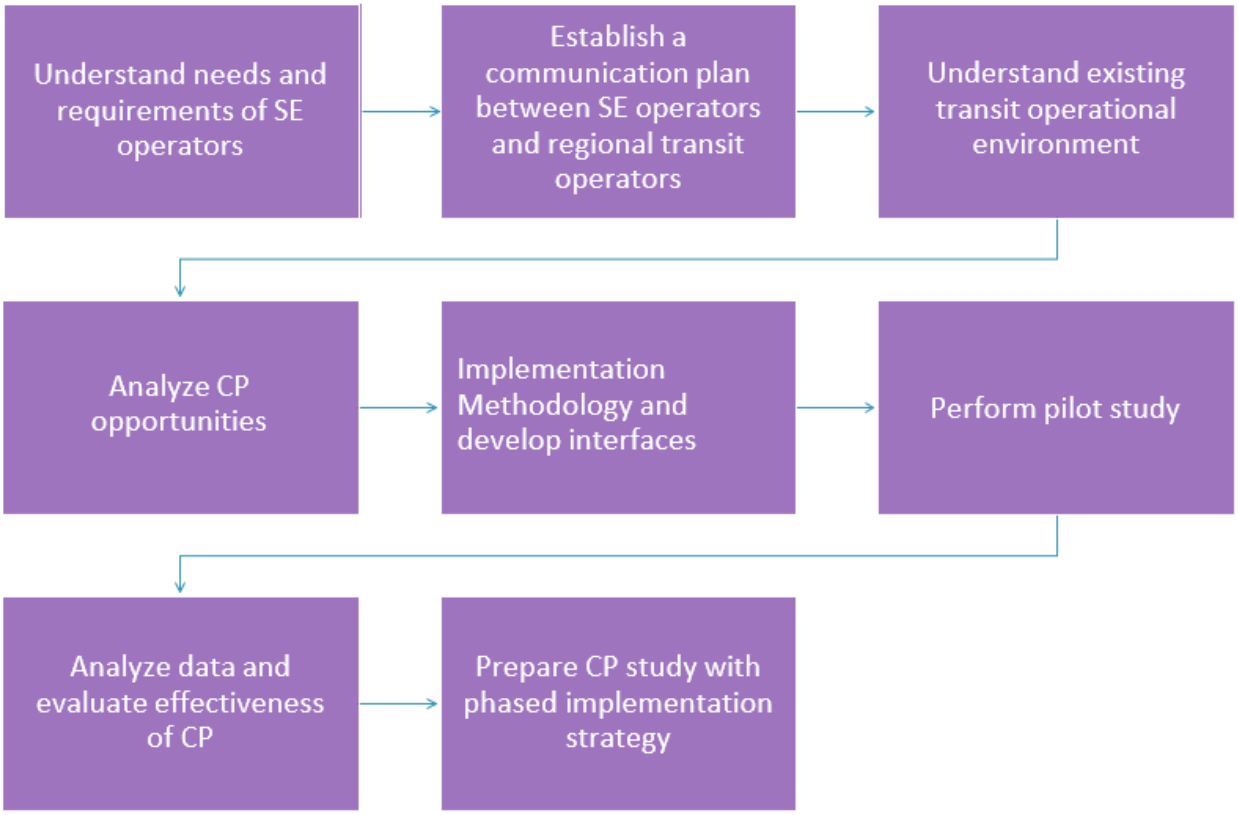
COMPONENTS OF CONNECTION PROTECTION SYSTEM

Various operational components needed to implement the CP concept are:

- **Real-time Scheduling/Request Brokerage System:** The central transfer request brokerage system is needed for processing transfer requests. Not all existing Computer Aided Dispatch/Automatic Vehicle Location (CAD/AVL) systems at individual agencies can share or process real-time data available from various external sources (e.g., multi-agency and multimodal operational subsystems) to determine the feasibility of a connection protection request. The system will first determine the feasibility of a transfer based on fixed-schedule and then monitor the real-time status using input from the control center(s).
- **Control Center:** Control centers will be critical to the CP application. These centers will continuously monitor the status of the vehicles involved in the transfer and their Expected Time of Arrival (ETA) at the transfer point. In an event where manual intervention is necessary, the system will notify the dispatchers. Sometimes, these control centers will also represent a centralized intermodal dispatch center for regional providers (when coordination is required) or a multimodal agency (when intermodal vehicles are dispatched and monitored by a multi-modal agency from the same location). Control centers will also be connected to regional traffic management centers to obtain real-time traffic information for determining the ETA accurately.
- **Voice and Data Communication Systems:** Vehicles will exchange data with the central system via wireless communication. Vehicle operators will also have access to a voice communication system/device installed in their vehicles, in an event where they need to talk to the dispatcher. Additionally, fixed-end CP system components will be connected with vehicle subsystems and other relevant systems for exchanging data when needed.
- **Traveler Information System:** The traveler information system will constantly monitor the status of the traveler requests and will notify them about the real-time status of the connections/transfers. Travelers will also be able to monitor the status of their requests using their web-enabled devices or via conventional phones.

CONNECTION PROTECTION STUDY DEVELOPMENT PROCESS

The following process was followed to complete the Connection Protection Study with oversight from a Project Leadership Team (PLT) from January 2022 to December 2023.



PILOT STUDY

The following methodology was used in conducting the pilot study from February 2023 to July 2023.

- **Route:** The Yellow Line was selected for testing the pilot. The Yellow Line is the shortest SE route connecting Vallejo Transit Center and Walnut Creek BART station. Any disruptions in the planned departure schedule due to CP pilot testing were perceived to be manageable. The variations in connection time from BART to the bus were studied and was determined that the connection protection opportunities were adequate to test the functionality of CP, and yet it is not overly disruptive to the regular operations.

- **Initiation of Connection Protection Request:** As discussed in the Technology Assessment section, there are two ways to trigger a connection protection request. A rider-initiated request or a system-initiated request. Considering SolTrans's requirement to fit in the CP solution within existing operations, a system-initiated connection protection was selected.

- **Dynamic Operations Server:** The UC Berkeley Partners for Advanced Transportation Technology's (PATH) fully functional Integrated Dynamic Transit Operations (IDTO) prototype used in Caltrans research and Connection Protection Field Operations Testing (FOT) on the Tri Delta Transit fleet was selected for assessing the need for CP and to push CP hold messages.

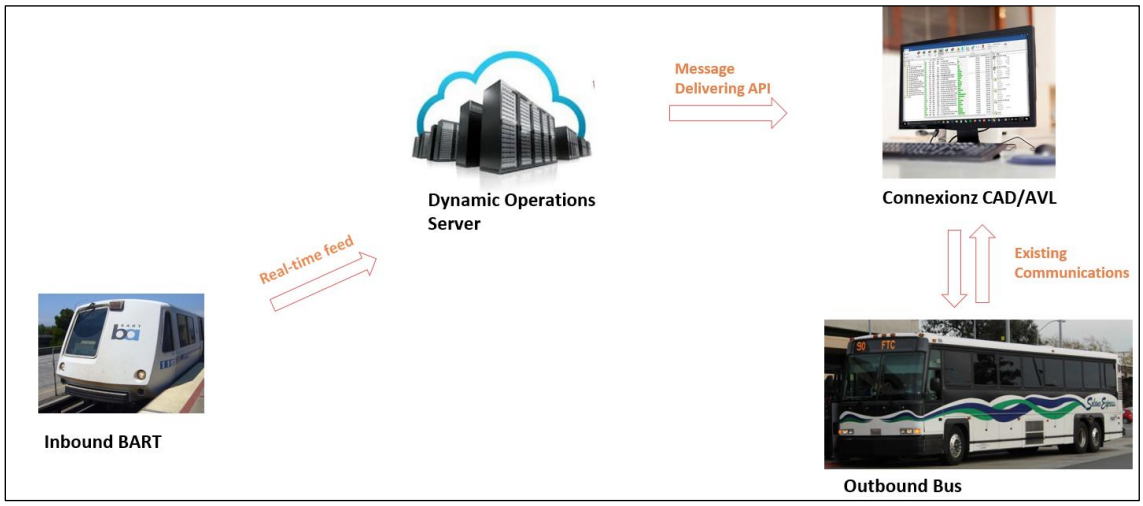
- **Driver Interface:** Various interfaces for drivers to get notifications about CP were considered including radio communications, off-board signs at bus stops, signs on buses, etc. Considering

SolTrans's requirement to fit in the CP solution within existing operations, existing on-board driver vehicle interface units (Cradlepoint devices) were selected.

- **Hold Time:** Calculations of walking time from BART to Y-line bus stop, and the tolerance levels for accommodating delays in planned departure times without affecting the on-time performance of the Y-line, a 3-minute maximum hold time for CP messages was selected.

DATA FLOW OF CONNECTION PROTECTION PILOT

The following figure illustrates the data flow for the CP solution implemented for the pilot study.



PILOT STUDY CONCLUSIONS AND LESSONS LEARNED

The following conclusions can be drawn from the pilot study conducted.

- A Connection Protection solution can be implemented to facilitate a protected transfer from an agency with a real-time general transit feed specification (GTFS) feed to a connecting SE line.
- No additional tools or technology are needed at SolTrans to implement CP for BART to SE bus transfers.
- Additional training and awareness for drivers and commuters is needed to understand the operations and benefits of CP.
- Wider implementation and longer monitoring periods are needed to evaluate driver and commuter perceptions of CP.

Based on the pilot study testing results and observations, the following could be listed as lessons learned for future pilot studies or CP implementation.

- **Driver's Compliance:** Training the drivers in the field on how to look for the CP hold messages, and how to respond to the hold messages was helpful. Most of the bus drivers who participated in the pilot study welcomed the additional tools to understand the arrival of BART. However, some drivers were worried about potential delays downstream if they held the bus longer than the planned departure. Additional training focusing on agency expectations regarding acceptance of the CP hold messages will help increase driver compliance in responding to the CP messages.

- **On-Board Driver Vehicle Interface Units:** The effectiveness of CP relies on the functioning of the on-board driver-vehicle interface units. During the testing period, there were situations where either the drivers turned off the units or the units were not functioning properly. Periodic checks of on-board driver-vehicle interface units before dispatch and preventive maintenance are recommended.

IMPLEMENTATON PLAN

All existing connections to and from SE lines were evaluated to understand the technology and integration needs to implement a route-based CP strategy, which has a similar approach to the pilot study. Probable cost estimates were also estimated. Several factors like technology availability, technology constraints, institutional constraints, costs, headways, and relative ridership were considered in ranking the potential implementation of CP to and from SE lines and various transit agencies. The results can be summarized as follows in order of recommended implementation.

No.	CP Opportunity	Deployment Costs	Operations and Maintenance Costs per year
1	BART to SolanoExpress	$74,000.00	$30,000.00
2	SolanoExpress to Yolobus	$23,000.00	$5,000.00
3	SolanoExpress to SolanoExpress	$92,000.00	$40,000.00
4	Solano Express to Fairfield Transit (FAST)	$99,000.00	$45,000.00
5	SolanoExpress to SolTrans Local Buses	$320,000.00	$200,000.00
6	SolanoExpress to LAVTA	$38,000.00	$10,000.00
7	SolanoExpress to Golden Gate Transit	$38,000.00	$10,000.00
8	SolanoExpress to VINE Transit	$104,400.00	$47,200.00
9	SF Bay Ferry to SolanoExpress	$42,000.00	$10,000.00
10	Amtrak to SolanoExpress	$42,000.00	$10,000.00
11	SolanoExpress to AC Transit	$110,000.00	$50,000.00
12	SolanoExpress to Rio Vista Delta Breeze	$356,500.00	$33,000.00
13	SolanoExpress to WestCAT	$56,000.00	$20,000.00
14	Solano Express to Vacaville City Coach	$387,600.00	$50,800.00
15	SolanoExpress to County Connection	$200,000.00	$100,000.00
16	Greyhound to SolanoExpress	$42,000.00	$10,000.00
17	SolanoExpress to Dixon Readi-ride	$294,000.00	$38,000.00

NEXT STEPS

The implementation plan and probable cost estimates provided in this report are at a planning level based on the understanding of the connection protection pilot study conducted for one connection from BART to Yellow Line at Walnut Creek BART station. For a full-scale rollout of the pilot study and further extending the same solution for other routes and/or other transit agencies in Solano County, the following steps are recommended.

- Gather consensus from transit agencies in Solano County to accomplish regional goals for CP.

- Develop agreements to adopt minimum guidelines for coordination to meet the needs of individual agencies, as well as to facilitate reaching the regional goals for CP.
- Establish data-sharing agreements as necessary.
- Establish operations and maintenance agreements to ensure accurate real-time data availability from participating agencies, and preventive maintenance to quickly recover from CP failures.
- Establish cost-sharing agreements between participating agencies.
- Secure funding for deployment and ongoing maintenance costs.
- Driver training and agency expectations need to be conducted to increase driver adherence to CP messages.
- Increase public awareness of the CP program through social media campaigns, brochures, and newsletters to achieve public acceptance.
- The design and CP solution in the pilot study was based on system-triggered CP need, integration of CP back-end server with Connexionz CAD/AVL, and Cradlepoint on-board driver vehicle interface units. In this situation, the design and technology are different, a brief pilot study is recommended for each agency-to-agency connection before the complete rollout.
- Detailed headway and ridership data transfer location details, and "To Agency" policies will need to be looked at to determine the holding time at the implementation phase.

Collaboration with regional efforts:

The Contra Costa Transportation Authority (CCTA) is currently developing a Mobility on Demand (MOD) application that will provide real-time, multimodal trip planning options based on origin and destination data. This app will serve up a variety of travel options based on a user's desire for the fastest, greenest, or most cost-effective trip. The app will also include a uniform payment system and incentives based on the time of day and mode to reward select travel behaviors.

Transit CP service to improve successful transfer between multiple transit modes including BART to bus is one of the planned features of the MOD application. With the successful implementation of a BART-to-bus solution in place, the SolTrans/STA CP solution is ready to be integrated with the MOD application and set as an example for other transit agencies slated to be integrated into the MOD application. There is an opportunity to collaborate with CCTA to integrate real-time GTFS feeds of Solano County transit agencies into CCTA's MOD application to mutually share transit data to further enhance connection protection solutions and other traveler information solutions to support regional transit connections.

Introduction

Individual travel needs are based on origin and destination that often extend beyond the service area of a single transportation agency. To create a more seamless system for riders, integration among multiple transit agencies is successfully practiced in regions around North America and the world. The types of integration efforts among transit agencies are based on the needs of the region. The focus of this study is on technology integration needs to provide successful transfers between multiple agencies and/or multiple transit modes in Solano County with a focus on connection to and from Solano Express Routes.

PURPOSE OF THE STUDY

The STA seeks to integrate SE service into larger regional transit services by offering CP on key routes to provide a seamless travel experience for as many riders as possible. The outcome of this study is a plan to implement CP throughout Solano County focusing on connections to and from SE routes. An assessment of the SE System, current technologies available at various transit agencies, a literature review, and a pilot study were conducted as part of this study to inform the Implementation Plan.

GOALS + OBJECTIVES

The goals and objectives of CP as described in US Department of Transportation's IDTO Concept of Operations (USDOT, 2012) are listed below.

Goals:

- Implement a system that enhances system efficiency and increases resource utilization by improving inter and intra-modal transfer opportunities for travelers using public, private, and shared ride transportation modes.
- Build upon efficiently and effectively scheduled transfers and improve the probability of successful transfers/connections when needed.
- Optimize rider satisfaction regarding the length of their total travel time and overall transfer connection experience.
- Include traveler preference and priority to account for frequency and time of travel (e.g., hold the last trip of the day longer or prioritize daily commuters).

Objectives:

- Allow for agency-defined system configurations to balance traveler expectations regarding making connections and waiting times while on-board.
- Allow for transfer/connection times to be configurable by mode and route, depending on the specific operating environment (local, arterial, freeway).
- Allow for system configurations based on modal priority (e.g., buses wait longer than trains).
- Increase the probability of transfers being completed without a disruption in on-time performance (depending on the on-time performance standard).
- Reduce overall trip time for trips requiring a transfer.

- Improve accuracy and relevance of real-time information for a traveler's complete journey, which may include providing information about transfers on-board using an automated announcement system.

ORGANIZATION OF THE REPORT

This report is organized into the following sections:

- **SolanoExpress System Assessment:** This section includes an assessment of the current SolanoExpress System, connections to other transit providers, and connection protection opportunities on each SolanoExpress route.
- **Technology Assessment:** This section includes an assessment of the current technologies of various transit operators and about how these technologies can be integrated for potential connection protection opportunities.
- **Pilot Study:** This section includes the pilot study methodology, results and lessons learned.
- **Implementation Plan:** This section summarizes the ways CP strategies can be expanded to other SE lines and transit agencies with connections to SE lines. This section includes probable cost estimates to implement the CP strategies and recommended prioritization based on factors that impact the effectiveness of the implementation.
- **Next Steps:** This section lists next steps for full-scale roll out of the pilot study and to further extend the CP solution for other SE lines and/or other connected transit agencies with SE lines.

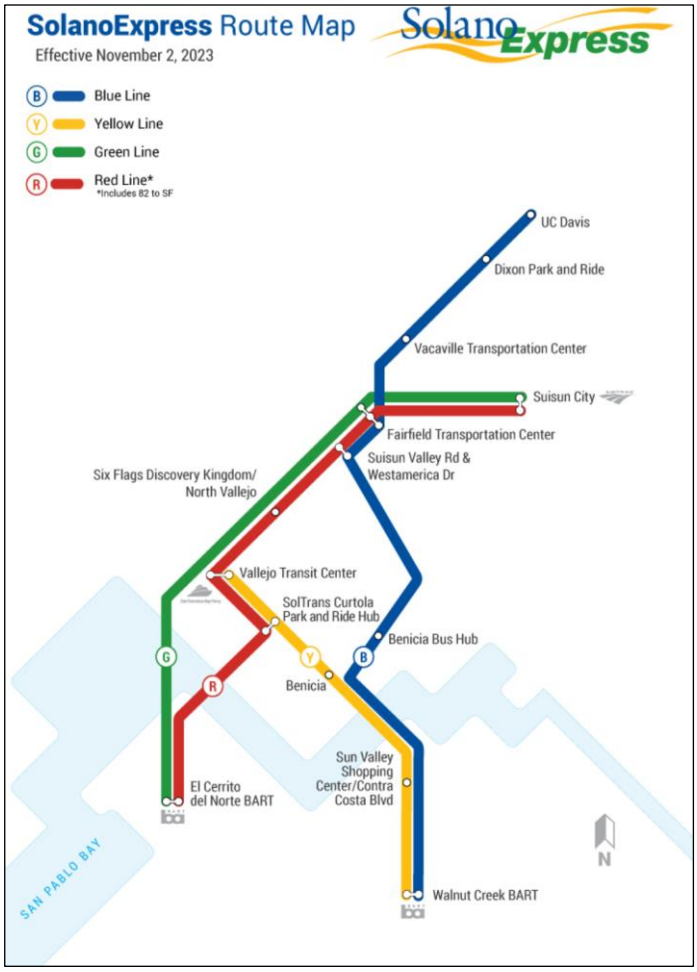
SolanoExpress System Assessment

This section includes an assessment of the current SE System, connections to other transit providers, and connection protection opportunities on each SolanoExpress route.

SOLANOEXPRESS SYSTEM

SolanoExpress is operated by SolTrans and provides express intercity bus service throughout Solano County. There are four SolanoExpress Routes operated by SolTrans: Blue Line, Yellow Line, Green Line, and Red Line. The SolanoExpress routes as of November 2, 2023, are shown in **Figure 1**.

Figure 1: SolanoExpress System Map



SOLANOEXPRESS RIDERSHIP

The weekly ridership numbers reported in STA's 2022 On-Board Transit Survey report for the four SolanoExpress routes are as follows:

- Blue Line: 1,576
- Yellow Line: 964

- Green Line: 1,280
- Red Line (including Route 82): 5,113

After the COVID-19 pandemic, there have been changes in the SE operations (two lines have been transitioned from Fairfield and Suisun Transit), routes, and service schedules. Those changes might affect the actual ridership, but these ridership numbers show relative ridership among the four SolanoExpress lines for this study.

CONNECTIONS BY ROUTE AND TRANSIT OPERATOR

The possible connections are listed by each SolanoExpress Route in this section. For each SolanoExpress Route, the possible connections by Transit Provider, Transit Type, and connection locations are listed.

In summary, the following are the potential CP opportunities for the transit providers connecting to SE lines.

- Amtrak to SolanoExpress
- BART to SolanoExpress
- Greyhound to SolanoExpress
- Water Emergency Transportation Authority (WETA) to SolanoExpress
- SolanoExpress to SolanoExpress
- Solano Express to Fairfield Transit
- Solano Express to Rio Vista Delta Breeze
- SolanoExpress to SolTrans Local Buses
- Solano Express to Vacaville City Coach
- Solano Express to AC Transit
- Solano Express to LAVTA
- Solano Express to VINE Transit
- Solano Express to WestCat
- Solano Express to Yolobus

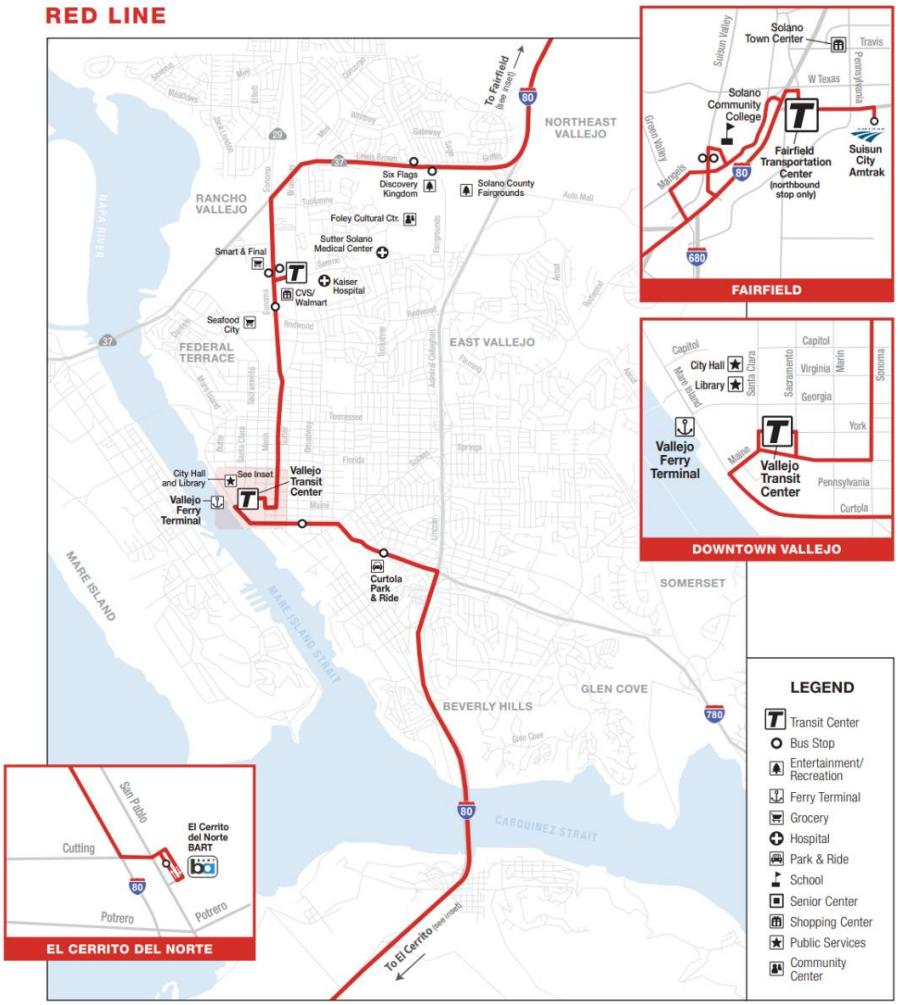
The locations for potential connections of SolanoExpress lines with other transit providers are as follows:

- Dixon Park and Ride (SolTrans, Dixon Readi-Ride)
- El Cerrito Del Norte BART station (AC Transit, BART, Golden Gate Transit, VINE Transit, WestCAT, SolTrans)
- Fairfield Transportation Center (Rio Vista Delta Breeze, VINE Transit, FAST, SolTrans)
- Serano Transit Center (SolTrans, VINE Transit)
- Soltrans Curtola Park and Ride (SolTrans)
- Suisun-Fairfield Amtrak Station (Amtrak, FAST, Rio Vista Delta Breeze, VINE Transit, SolTrans)
- Vacaville Transportation Center (SolTrans, Vacaville City Coach)
- Vallejo Transit Center (SolTrans, VINE Transit, SF Bay Ferry)
- Walnut Creek BART station (BART, County Connection, LAVTA, SolTrans)

Red Line

The Red Line connects Vallejo with the El Cerrito del Norte BART station seven days a week, with 15-to 30-minute weekday headways. The route also serves Fairfield in the north with 60-minute weekday headways, with limited service on Saturday. The locations served by this route include the Vallejo Transit Center, Sereno Transit Center, Curtola Park and Ride Hub, Solano Community College in Fairfield, Fairfield Transit Center, and the Fairfield-Suisun Amtrak Station.

SolTrans also operates Route 82 as an extension to the Red Line for two weekday morning and evening runs. This route connects the San Francisco ferry building to the El Cerrito del Norte BART station, Curtola Park and Ride, and Vallejo Transit Center



Connections

Red Line connections to other transit providers and transit routes are provided in the following table. All these connections provide potential connection protection opportunities.

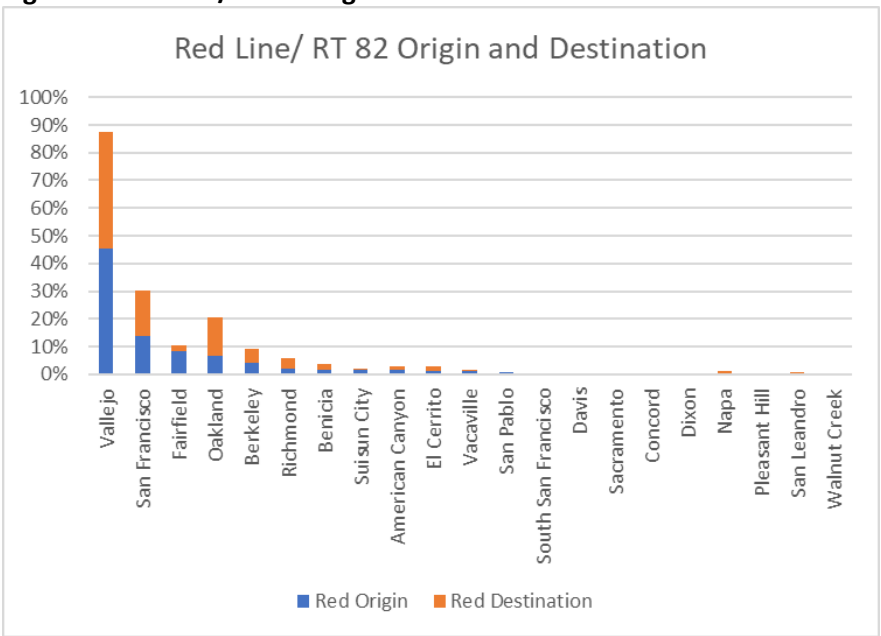
Provider	Type	Location	Routes
Amtrak	Intercity Passenger Rail	Suisun/Fairfield Amtrak Station	Capital Corridor
BART	Heavy-Rail Transit	El Cerrito del Norte BART	Richmond-Milbrae+SFO, Berryessa/North San Jose-Richmond
SolTrans	Intercity Express Bus, Bus	Fairfield Transportation Center,	B, G, R
		Vallejo Transit Center	R, Y, 82, 1,2,3,4,5,6,7A,7B, 8
		Serano Transit Center	R, 1,2,4,5,7A,7B
FAST	Bus	Fairfield Transportation Center	1,3,7

Provider	Type	Location	Routes
VINE Transit	Bus	Fairfield Transportation Center	21
		Vallejo Transit Center	11, 11X
		Serrano Transit Center	11
		Suisun-Fairfield Amtrak Station	21
Rio Vista Delta Breeze	Bus	Fairfield Transportation Center.	50
		Suisun-Fairfield Amtrak Station	50
AC Transit	Bus	El Cerrito del Norte BART	7,72,72R,72M,76,376,800
WestCat	Bus	El Cerrito del Norte BART	JL, JPX, JR
Greyhound	Intercity Bus	Suisun-Fairfield Amtrak Station	
Water Emergency Transportation Authority	Ferry	Vallejo Ferry Terminal	San Francisco/Mare Island
Private Providers	TNC & Micro-mobility	Fairfield Transportation Center, Vallejo Transit Center, Suisun-Fairfield Amtrak Station, Serano Transit Center, El Cerrito del Norte BART	

Ridership Patterns

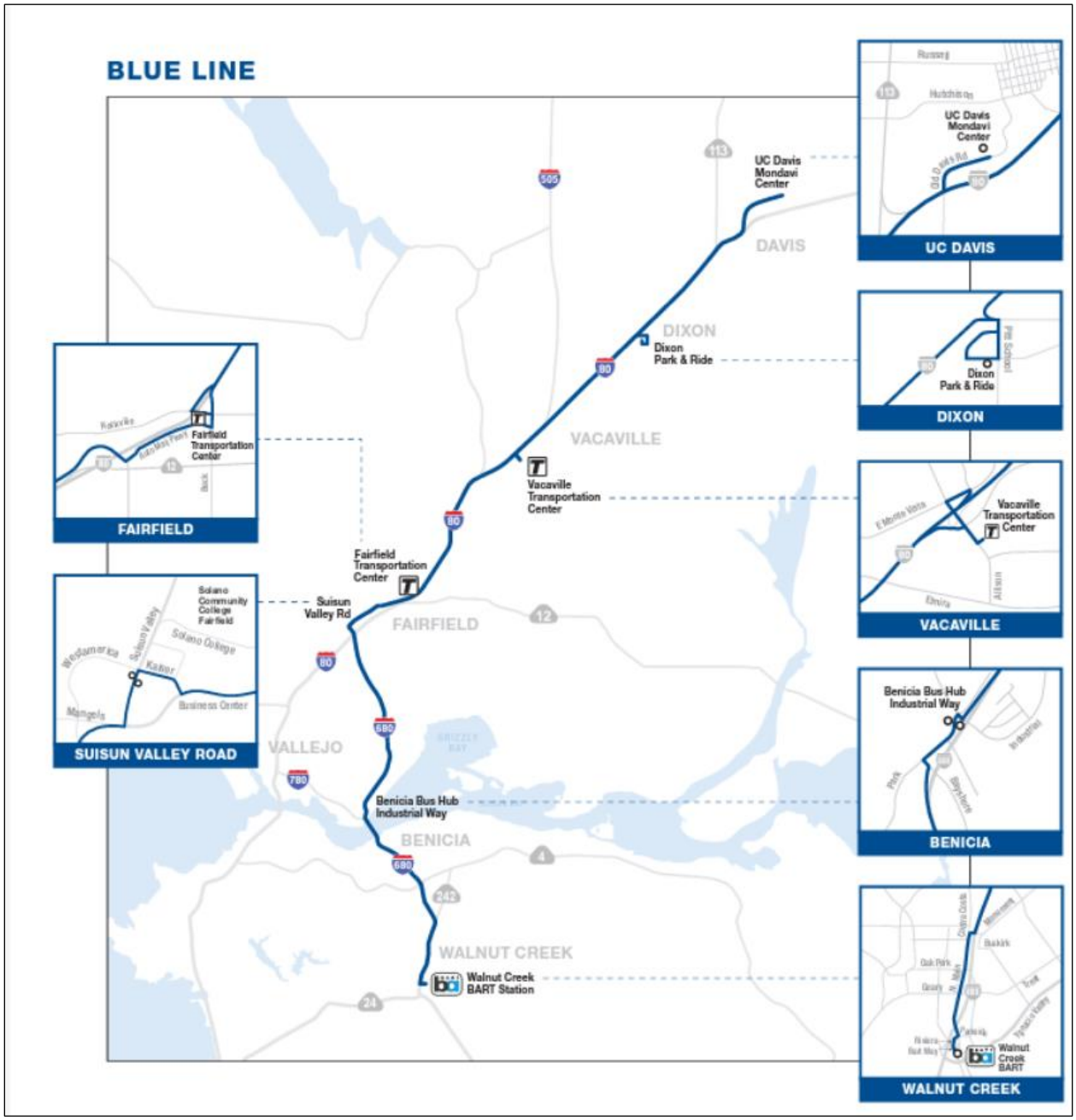
Figure 2 shows where the Red Line trips start and end as indicated in STA's 2022 On-Board Transit Survey. The Red Line has a significant percentage of riders to and from Vallejo.

Figure 2: Red Line/RT 82 Origin and Destination



Blue Line

The Blue Line connects Vacaville Transportation Center with the Walnut Creek BART station on weekdays and Saturdays with one-hour weekday headways. The route also serves Dixon Park and Ride and UC Davis on certain AM and PM routes and no service to UC Davis on Saturdays. The locations served by this route include Suisun Valley Road/ Kaiser Drive and Benicia Park and Ride.



Connections

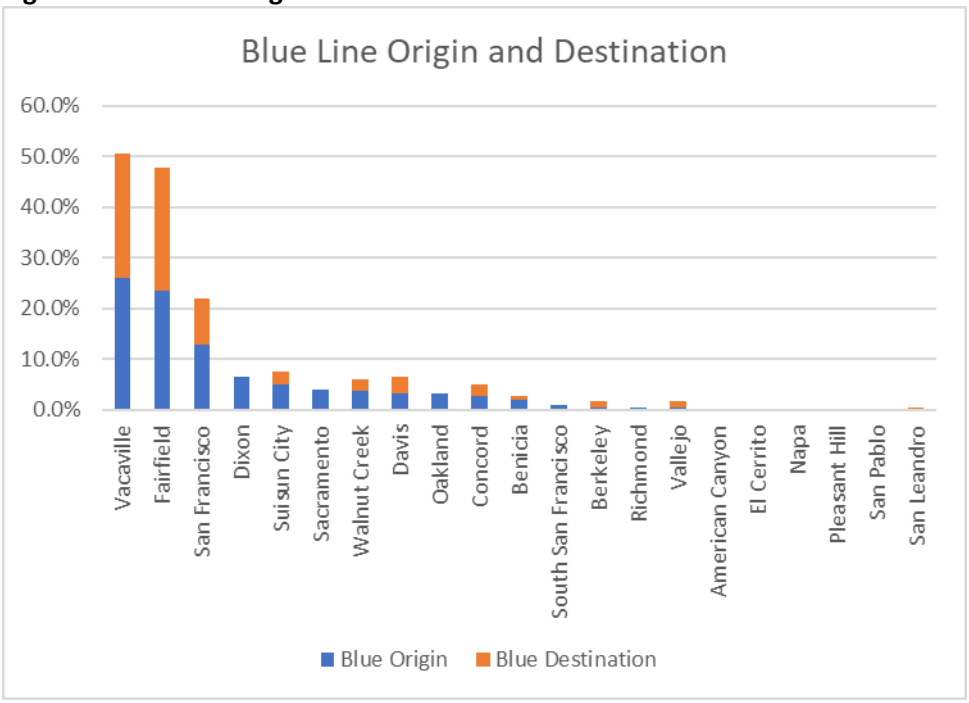
Blue Line connections to other transit providers and transit routes are provided in the following table. All these connections provide potential CP opportunities.

Provider	Type	Location	Routes
BART	Heavy-Rail Transit	Walnut Creek BART	Antioch-SFO
SolanoExpress	Intercity Express Bus	Fairfield Transportation Center,	B, G, R
		Vacaville Transportation Center	B
		Dixon Park and Ride	B
FAST	Bus	Fairfield Transportation Center	1,3,7
VINE Transit	Bus	Fairfield Transportation Center,	21
Rio Vista Delta Breeze	Bus	Fairfield Transportation Center	50
Dixon Readi-Ride	Shuttle Bus	Dixon Park and Ride	Dial-a-Ride
Yolobus	Bus	Mondavi Center	138
Vacaville City Coach	Bus	Vacaville Transportation Center	1,3,4,5,6
Private Providers	TNC & Micro-mobility	Fairfield Transportation Center, Vacaville Transportation Center, Dixon Park and Ride	

Ridership Patterns

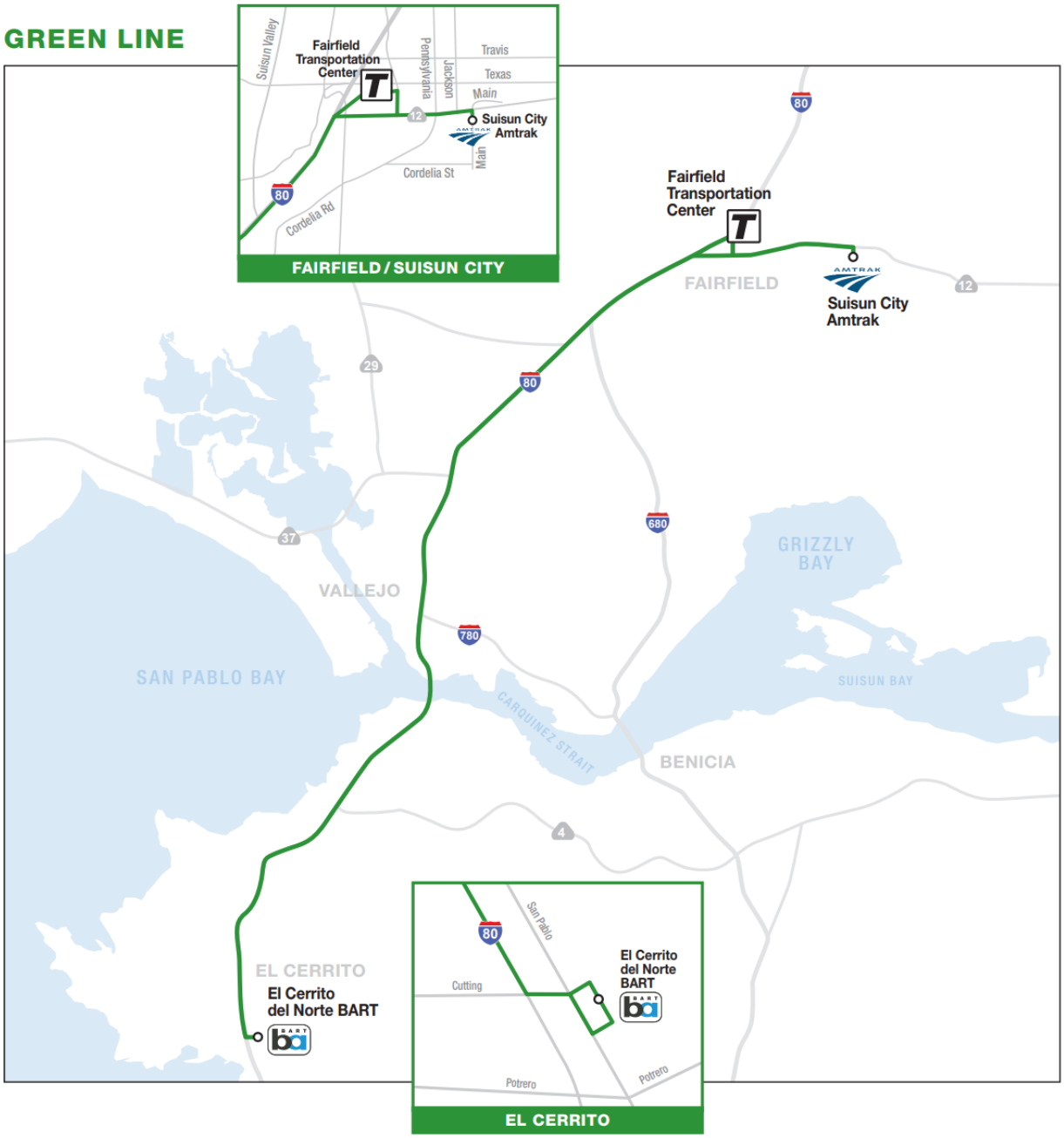
Figure 3 shows where the Blue Line trips start and end as indicated in STA's 2022 On-Board Transit Survey. The Blue Line has a significant percentage of riders to and from Vacaville and Fairfield followed by San Francisco.

Figure 3: Blue Line Origin and Destination



Green Line

The Green Line connects Fairfield Transportation Center and El Cerrito del Norte BART stations with half-hour headways in the morning and evening hours on weekdays.



Connections

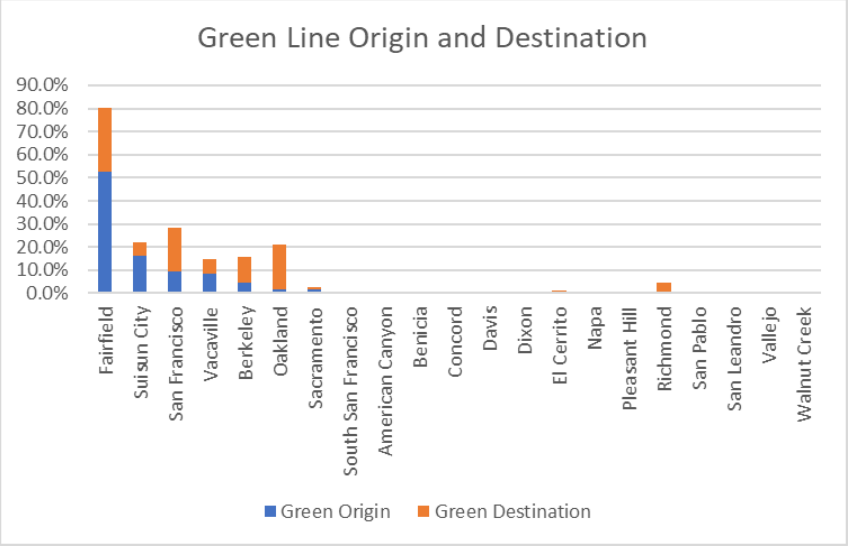
Green Line connections to other transit providers and transit routes are provided in the following table. All these connections provide potential CP opportunities.

Provider	Type	Location	Routes
Amtrak	Intercity Passenger Rail	Suisun-Fairfield Amtrak Station	Capital Corridor
BART	Heavy-Rail Transit	El Cerrito del Norte	Richmond-Milbrae+SFO, Berryessa/North San Jose-Richmond
SolanoExpress	Intercity Express Bus	Fairfield Transportation Center	B, G, R
		Suisun-Fairfield Amtrak Station	G, R
FAST	Bus	Fairfield Transportation Center	1, 3, 7
VINE Transit	Bus	Fairfield Transportation Center	21
		Suisun-Fairfield Amtrak Station	21
Rio Vista Delta Breeze	Bus	Fairfield Transportation Center	50
		Suisun-Fairfield Amtrak Station	50
Private Providers	TNC & Micro-mobility	Fairfield Transportation Center, Suisun-Fairfield Amtrak Station, El Cerrito Del Norte BART	
Greyhound	Intercity Bus	Suisun-Fairfield Amtrak Station	

Ridership Patterns

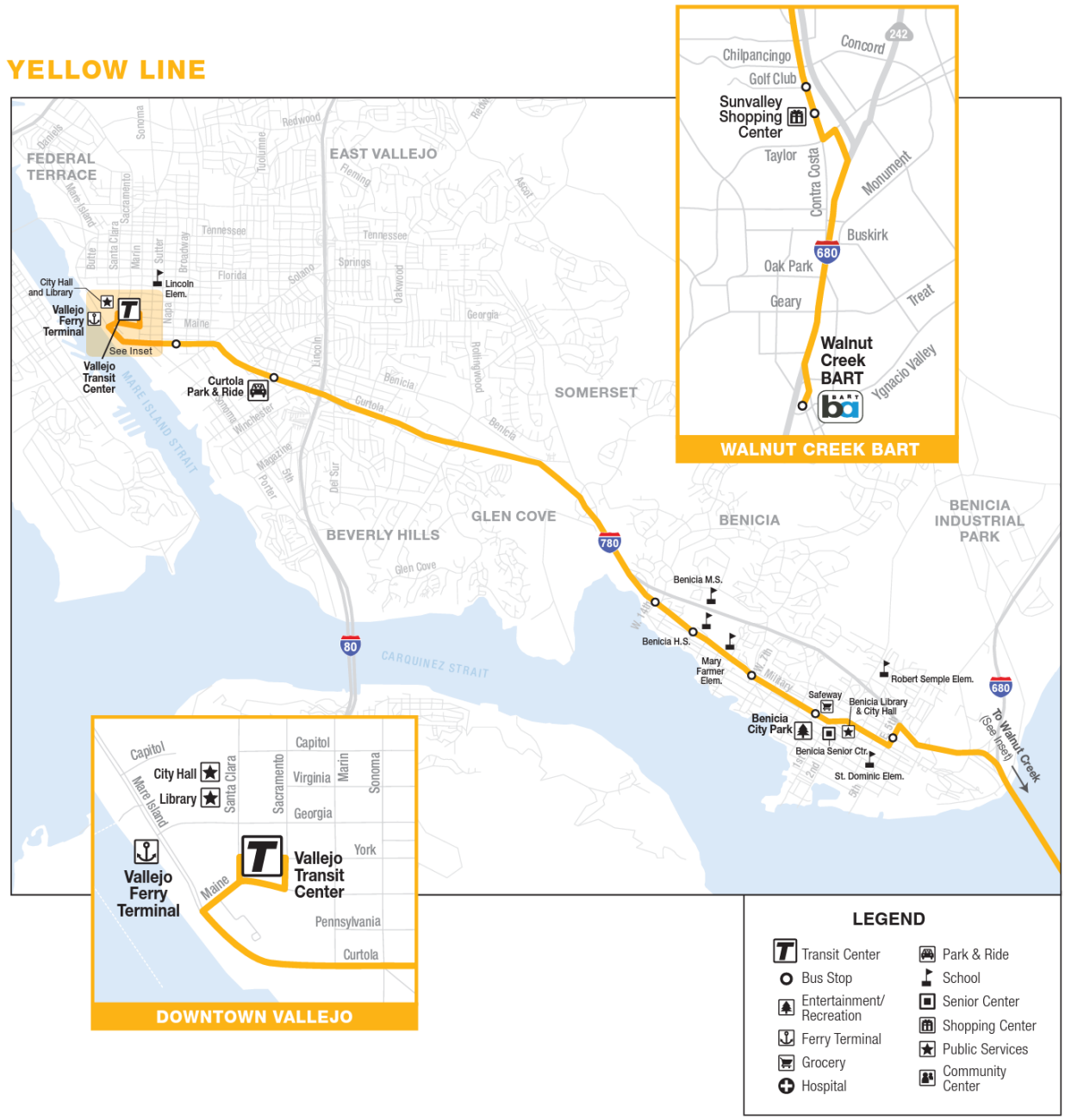
Figure 4 shows where the Green Line trips start and end as indicated in STA's 2022 On-Board Transit Survey. The Green Line has a significant percentage of riders to and from Fairfield followed by San Francisco and Suisun City.

Figure 4: Green Line Origin and Destination



Yellow Line

The Yellow Line connects Vallejo and Benicia with the Pleasant Hill and Walnut Creek BART stations. Routes operate at 30-minute headways during peak periods, and 60-minute headways during off-peak periods, with limited service on Saturday and Sunday. This route also serves the Vallejo Transit Center, Curtola Park & Ride Hub, Benicia City Park, and Sunvalley Mall in Concord.



Connections

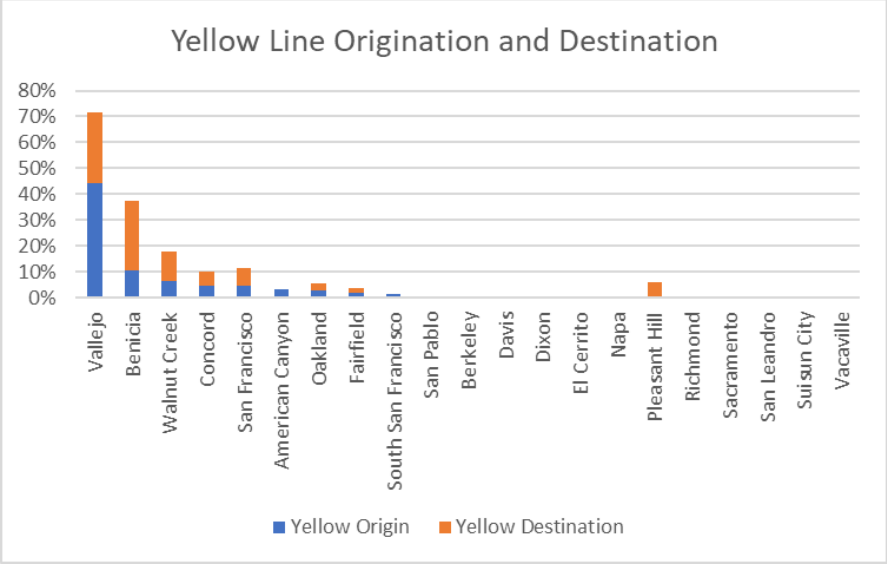
Yellow Line connections to other transit providers and transit routes are provided in the following table. All these connections provide potential CP opportunities.

Provider	Type	Location	Routes
BART	Heavy-Rail Transit	Walnut Creek BART	Antioch-SFO
SolanoExpress	Intercity Express Bus	Curtola Park and Ride	R, Y, 3
		Walnut Creek BART Station	B, Y
		Walnut Creek BART Station	B, Y
VINE Transit	Bus	Vallejo Transit Center	21
County Connection	Bus	Walnut Creek BART Station	1,4,5,9,14,21,93X,95X,96X,98X,4,301,311,321
LAVTA	Bus	Walnut Creek BART Station	70X
Water Emergency Transportation Authority	Ferry	Vallejo Ferry Terminal	San Franciso Bay Ferry
Private Providers	TNC & Micro-mobility	Walnut Creek BART, Curtola Park and Ride, Vallejo Transit Center	

Ridership Patterns

Figure 5 shows where the Yellow Line trips start and end as indicated in STA's 2022 On-Board Transit Survey. The Yellow Line has a significant percentage of riders to and from Vallejo followed by Benicia and Walnut Creek.

Figure 5: Yellow Line Origination and Destination



Technology Assessment

This section includes an assessment of the current technologies of various transit operators and about how these technologies can be integrated for potential connection protection opportunities.

TECHNOLOGY FOR TRANSIT CONNECTION PROTECTION

The literature review conducted for this study informed the state of practice, current regional efforts on CP, and the technology integration needs for CP.

State of Practice

A literature review was conducted to find past and ongoing studies relevant to the CP concept. The literature available on the CP concept is limited. The most relevant information available consists of USDOT research efforts and field operation tests conducted during 2003-2004 and 2011-2014. A prior literature review conducted by USDOT in 2011 determined that the state of implementation of this concept is very limited due to the level of coordination required between modes in terms of underlying technologies, policies, and inter-agency or inter-service coordination activities (SAIC, 2011).

Demand-responsive transfers were common in the 1960s and 1970s in smaller transit agencies where drivers and/or dispatchers communicated through voice radios to hold buses at points (Stern, 1996). However, with the implementation of CAD/AVL systems, transit agencies in the US have implemented fixed-route vehicle to fixed-route vehicle CP technology within their agency. Initial implementations of the CP technology for fixed-route vehicles to fixed-route vehicles required transit customers to verbally request a transfer when they board a transit vehicle and then the transfer requests are communicated to CAD/AVL systems through Mobile Data Terminals (MDTs) on the transit vehicles.

Dynamic transit operation is a desirable public transportation mode that has been implemented for a few paratransit services but has not been deployed for regular transit service routes in the United States (California PATH, 2018). The relevant information available from the literature review related to demonstration projects involving transfers between multiple agencies and multiple transit modes is summarized in **Table 1**. Ongoing research efforts in Eastern Contra Costa County in California are further discussed in the “Regional Research Efforts” section.

Table 1: Summary of Deployments/Field Operational Tests

	Salt Lake City, UT	Columbus, OH	Orlando, FL	Eastern Contra Costa County, CA
Agencies	• TRAX-light rail • Utah Transit Authority (UTA)	• Central Ohio Transit Authority (COTA) fixed bus routes • Ohio State University Campus Area Bus System (CABS) free on-campus shuttle	• Central Florida Regional Authority (LYNX) • UCF on-campus shuttle service • SunRail - commuter rail	• Contra Costa Transportation Authority • Tri Delta Transit (TDT) • Bay Area Rapid Transit (BART) rail
CP Scenarios	• LYNX to UTA bus transfers	• Bus to Bus transfers within COTA • CABS to COTA transfers	• Transfers within LYNX • UCF shuttle to LYNX transfer • SunRail to LYNX transfer	• Bus to Bus connections on TDT routes • BART to TDT Bus transfers.
Demo/Service Period	Demo in 2004	Service started in May 2014	Demo in April 2014	Demo from July 2017 to August 2017

	Salt Lake City, UT	Columbus, OH	Orlando, FL	Eastern Contra Costa County, CA
Evaluation Findings	• CP could improve the probability of successful train-to-bus connections. • Satisfaction among riders with connection experience was generally high. • Operators' perception on the value of CP are mixed. • Compliance with CP "hold until" messages by bus operators were relatively low.	• Difficult to investigate the effectiveness due to limited data. • CP enabled users to reach destinations faster compared to non-users. • CP increased the likelihood of making transfers. • CP is a cost-effective solution.		• Effectively detected trip delays and submitted CP requests to hold the connecting bus. • IDTO prototype ability to submit CP requests matched well with riders' phone requests. • The success rate of connections has increased with CP. • Average passenger wait time was decreased for bus-to-bus and BART-bus connections.

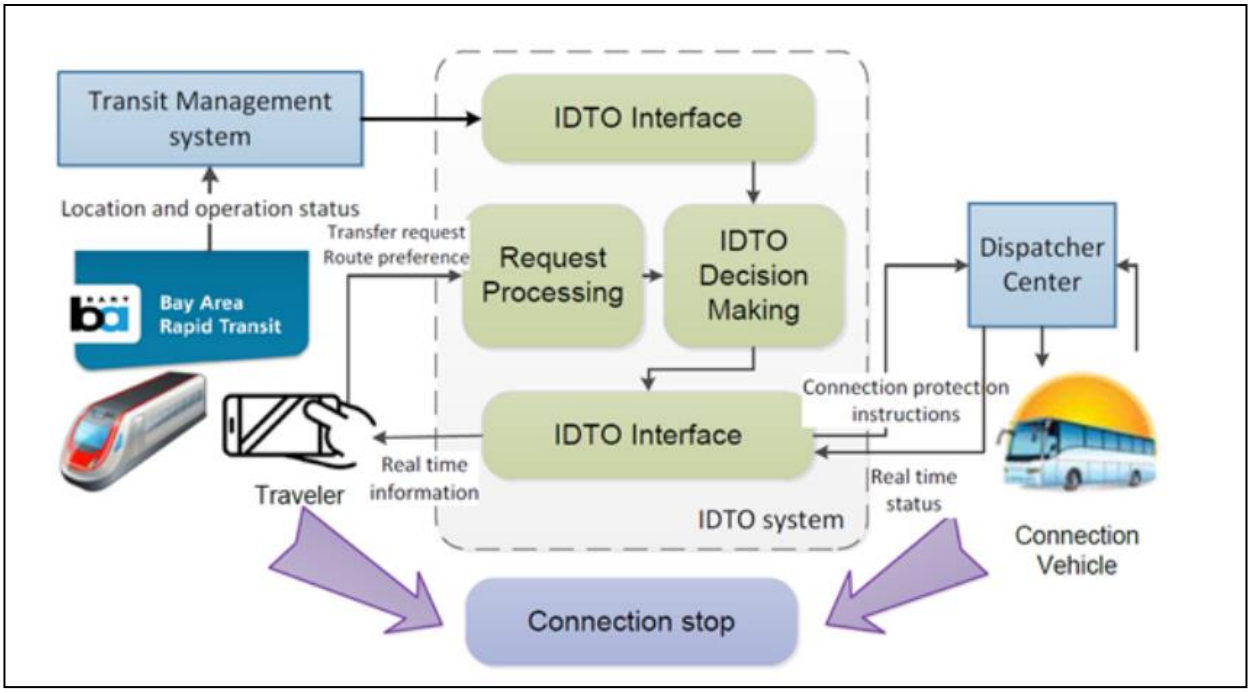
Regional Research Efforts

California Department of Transportation (Caltrans) Division of Research Innovation and System Information (DRISI) has developed and continues to demonstrate a fully functional IDTO prototype system that enables Dynamic Dispatch (T-DISP) and Transfer Connection Protection (T-CONNECT) services, as well as real-time information for transit operations and travelers.

California PATH has been conducting these IDTO efforts for multimodal suburban transit in collaboration with CCTA and Tri-Delta Transit. As of August 2020, the IDTO system has been developed and implemented with features of trip planning, CP requests, and real-time transit operation monitoring. Field operation testing demonstrated CP for a bus to bus and BART to bus transfers. The IDTO system developed for this effort supports integrated transit operation, provides multimodal information to travelers, interacts with transit operators, and makes smart trip planning to improve successful transfers. Efforts to deploy and test a fully functional IDTO system with integrated T-DISP and Dynamic Rideshare (D-RIDE) functionalities are ongoing.

The flowchart of system components included in the IDTO developed for this effort is shown in **Figure 4**. It should be noted that the system is designed to detect trip delays and submit CP requests automatically when CP conditions are met, without requiring any passenger intervention.

Figure 4: Caltrans IDTO – Flowchart of System Components



System components

There are variations in the systems components of each CP deployment that were studied. In general, the operational components needed to implement the CP concept are:

- **Real-time Scheduling/Request Brokerage System:** The central transfer request brokerage system is needed for processing transfer requests. Not all existing CAD/AVL systems at individual agencies can share or process real-time data available from various external sources (e.g., multi-agency and multimodal operational subsystems) to determine the feasibility of a connection protection request. The system will first determine the feasibility of a transfer based on fixed-schedule and then monitor the real-time status using input from the control center(s).
- **Control Center:** Control centers will be critical to the CP application. These centers will continuously monitor the status of the vehicles involved in the transfer and their Expected Time of Arrival (ETA) at the transfer point. In an event where manual intervention is necessary, the system will notify the dispatchers. Sometimes, these control centers will also represent a centralized intermodal dispatch center for regional providers (when coordination is required) or a multimodal agency (when intermodal vehicles are dispatched and monitored by a multi-modal agency from the same location). Control centers will also be connected to regional traffic management centers to obtain real-time traffic information for determining the ETA accurately.
- **Voice and Data Communication Systems:** Vehicles will exchange data with the central system via wireless communication. Vehicle operators will also have access to a voice communication system/device installed in their vehicles, in an event where they need to talk to the dispatcher. Additionally, fixed-end CP system components will be connected with vehicle subsystems and other relevant systems for exchanging data when needed.

- **Traveler Information System:** The traveler information system will constantly monitor the status of the traveler's requests and will notify them about the real-time status of connections/transfers. Travelers will also be able to monitor the status of their requests using their web-enabled devices or via conventional phones.

Development Approach

The CP system development approach was somewhat similar for all the deployments studied for this literature review. USDOT Federal Highway Administration (FHWA) systems engineering for Intelligent Transportation System (ITS) approach was used in the development of IDTO prototypes and applications with each step in the development tying back to the goals and objectives. The steps in the deployment of the CP system in general are as follows:

- Determine the requirement of the CP system based on the needs and requirements of participating transit agencies.
- Prepare the concept of operations (ConOps) and conceptual design based on the CP requirements.
- Design IDTO system architecture with details of functional components.
- Develop essential components of the system including the IDTO server, dispatch interface, and the IDTO mobile app based on the system design.
- Test systems components separately and then integrate into the IDTO prototype.
- Perform field operational testing, collect the data, and analyze to determine the effectiveness of CP.

Operational Scenarios

There are multiple ways to achieve a CP. The following two scenarios with slight variations were commonly considered in past efforts.

Scenario 1: Automatic transfer connection protection of a pre-determined connection between two agencies or two transit modes.

In this scenario, the CP system will automatically detect delayed inter-agency connections. The system includes hardware, software, and network needed for communications between individual agencies' CAD/AVL systems and a central server. The server will continually monitor and review the status of current operations and identify the transfers that are at risk of missing connections based on pre-defined inter-agency schedules. When the need for CP is identified, "hold until" messages are delivered to the concerned agency dispatch centers and/or drivers.

Scenario 2: Transfer connection protection of a rider-requested connection between two agencies or two transit modes.

In this scenario, the request for transfer connection protection is received by the CP system from transit riders through a smart phone app on their devices. Once the need and possibility of granting a CP are determined by the central server, "hold until" messages are delivered to the concerned agency dispatch centers and/or drivers.

System Architecture

Any surface transportation project that uses electronics, communications, or information processing for efficiency and/or safety is considered an ITS project. The National ITS Architecture provides a common framework for ITS interoperability. A regional ITS architecture is a regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects or groups of projects. The National ITS Architecture is used as a resource in the development of the regional ITS architecture. The network architecture of the Transfer Connection Protection service package, as it is currently included in the National ITS Architecture (Iteris, 2021) and regional Bay Area ITS architecture (MTC, 2020), is included in **Figure 5** and

Figure 6, respectively. Any CP application developed for Bay Area transit agencies must be within these frameworks.

Figure 5: Transfer Connection Protection – National ITS Architecture

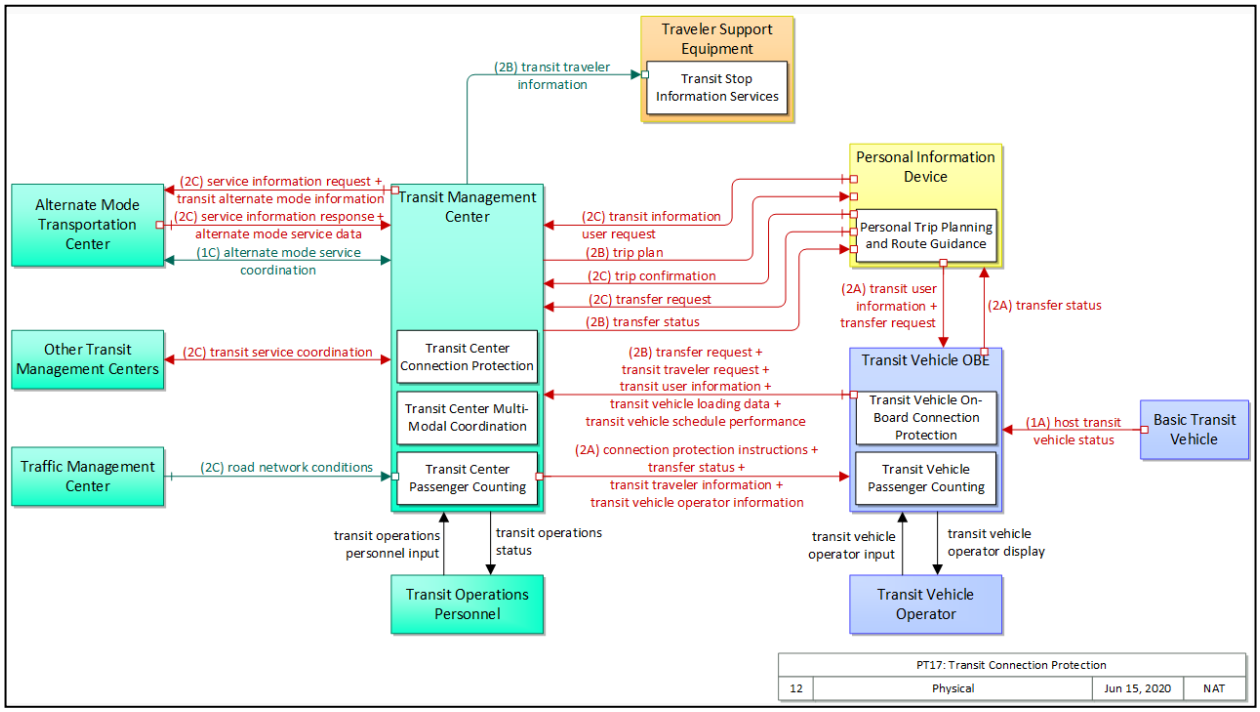
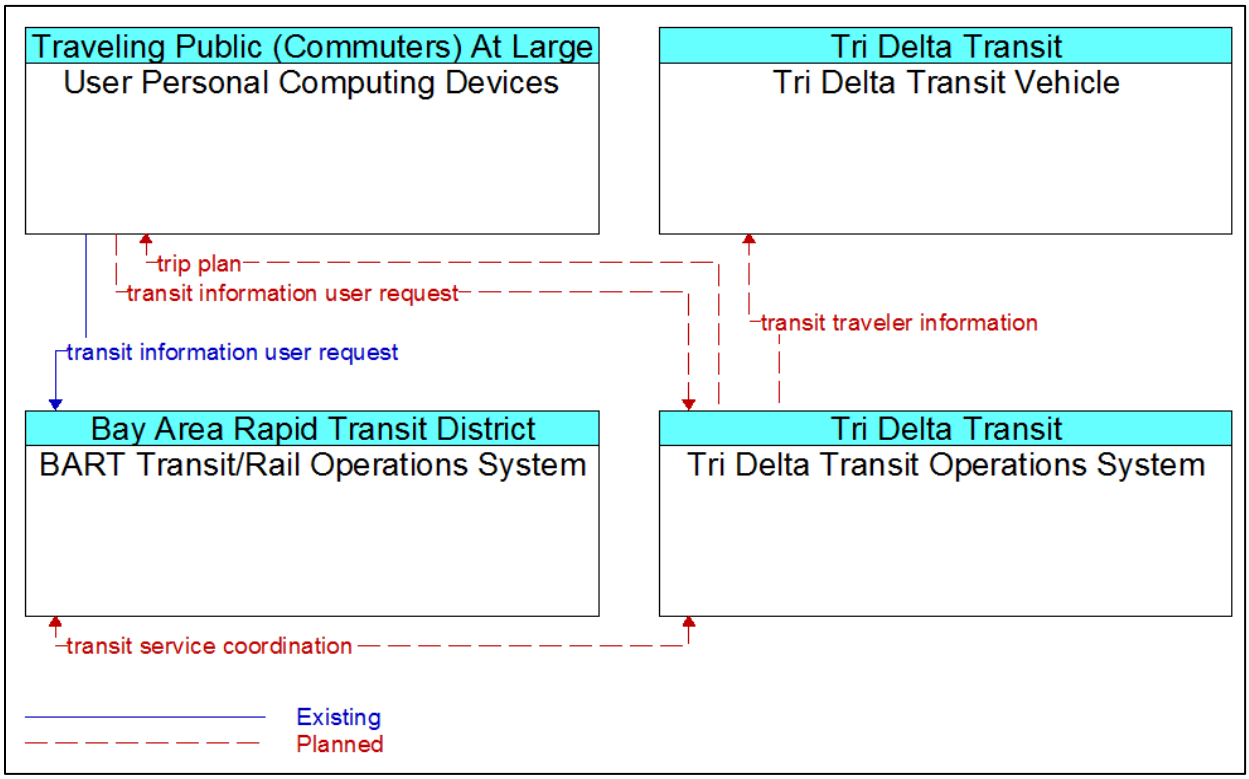


Figure 6: Transfer Connection Protection – Bay Area ITS Architecture



Network Integration Needs

The following interfaces are needed to integrate various components of a CP system as indicated by the past deployments. Integration needs to be varied with the available systems in each deployment.

- CAD/AVL system, used for managing incoming and outgoing vehicles for obtaining information on the current locations of vehicles and the most recent route and schedule adherence information.
- The fare payment system is used to determine the required amount of fare to be paid by the users who are requesting a transfer based on an agency's fare rules.
- Vehicle arrival prediction systems are used to obtain information on ETA of incoming and outgoing vehicles at transfer points.
- Automated Passenger Counting (APC) system, used to determine current vehicle capacity.
- Local traffic management center, used to obtain information on current and predicted traffic conditions to update the vehicle arrival prediction information.

Expected Benefits

Based on Advanced Mobility Group's (AMG) literature review, the benefits realized varied among the CP deployments studied. In general implementation of the CP system provides potential benefits at multiple levels to multiple users as listed below:

- **Regional Benefits:** As inter-agency connections improve, the viability of regional transportation and thus regional mobility will improve. Regional accessibility will in turn promote employment initiatives.
- **Transit Rider Benefits:** CP facilitates seamless transfers between multiple agencies and multiple modes with shorter wait times and fewer late arrivals because of more consistent service. This will lead to greater passenger satisfaction with regional public transportation. Real-time transit information availability to transit riders gives greater control over their trips.
- **Transit Agency Benefits:** Increased connection opportunities for transit riders will help agencies gain operational efficiencies.

Practices for Successful CP

The CP deployments studied for this literature review spanned over different periods of time with varying technological capabilities. Compared to earlier efforts, today's technological advancements in CAD/AVL systems, real-time arrival prediction systems, and traveler information systems with real-time traffic data are ideal for CP implementation. A wide range of traveler needs can be satisfied when the functionality of CP is combined with the other two applications (T-DISP and D-RIDE) in the IDTO bundle. AMG's literature review yields the following technology and policy considerations for the successful implementation of CP. Multiple sources were used as part of the literature review for this section; findings from IDTO field operating tests (USDOT, 2015) are the key documents.

Technology Considerations

- **Data Communication:** Frequent and uninterrupted data communication between vehicles and central dispatch/operations control is essential to determine the most appropriate "hold until" interval and inform the operators promptly. Data communication systems that rely on traditional data radio networks have limited bandwidth. Another factor is the rate at which data is communicated. If the vehicles are polled for location every 1-2 minutes, data required for CP algorithms are not delivered when needed.
- **Automatic Vehicle Location:** Real-time vehicle location is key to a successful CP system. CP algorithms determine if CP is required based on the last known location of the vehicle. If this information is outdated or inaccurate, the chances of the CP system delivering incorrect "hold-until" messages will increase.
- **Estimated Travel Arrivals (ETA) Predictions:** The effectiveness of IDTO is significantly affected by the accuracy of ETA predictions provided by the AVL system. Invalid "hold until" requests are caused by occasional inaccurate ETA predictions. Advanced approaches for predicting accurate ETA should be considered.
- **Route and Schedule Adherence (RSA):** Like AVL information, RSA is critical to determining CP accuracy. CP decisions are made based on the ETA of the "incoming" vehicle, which will rely on accurate RSA information.
- **On-Board Driver Information Terminal:** The lack of an on-board driver information terminal presents a constraint to connection protection. It is not always possible for the transit dispatch center to respond to dynamic operation recommendations by the CP system.

Policy Considerations

AMG's review of relevant documents indicated certain policy issues about mobility applications like connection protection.

- **Regional Agreements:** To accomplish the regional goals for CP, agencies will have to collectively develop agreements to adopt minimum guidelines for coordination and to be compliant with the regional ITS architecture. Formulation of the agreements may involve consensus building to meet the needs of the individual organizations as well as facilitate reaching the regional goals for CP. Roles and responsibilities relevant to regional partners should be developed, documented, and implemented.
- **Data Collection:** To ensure coordination among regional partners, agencies will be required to collect real-time data. The data collection needs will depend on the agency's characteristics and any relevant system configurations must be determined before system implementation. The purchase of new systems might be needed if real-time data is not readily available.
- **Data Sharing:** Two types of data are intended to be shared with CP applications. The first is static data such as routes and schedules and the second is AVL data. As these types of data are often broader (vehicle performance data) than the data that is typically published, there could be proprietary and confidentiality issues. Participating agencies will need to establish formal data-sharing agreements specifying which data elements are going to be shared.
- **Data Privacy:** CP applications associated with individual traveler's profiles. Some or all the information in the user profile is shared with a third-party CP provider. Users should be made aware of the use of their data and be provided with an option to opt-out.
- **Data Interoperability:** Achieving data interoperability is largely a technical challenge and will most likely involve policy challenges. Participating agencies will need to agree on common data formats and establish data-sharing protocols documented in a memorandum of understanding between the agencies.
- **Adjust Bus Schedules:** Provide slack in bus schedules to accommodate comfortable wait times at transfer stations and/or capacity to make up for lost time at intermediate points. This will reduce the burden on drivers to operate on tight schedules and will provide opportunities for more equitable treatment of transfer riders and on-board drivers.
- **Promote Rider Awareness of the CP Program:** More information and rationale of the CP program should be provided to riders to avoid concerns that the CP program is one-sided (e.g., the focus is on high-frequency regional services compared to less frequent bus services).
- **Data Accuracy:** CP decisions are based on the real-time data availability from participating agencies. Periodic checks to ensure that the real-time data is current and accurate will contribute to the success of CP. Also, agencies must ensure that real-time information shared with travelers is accurate. This will improve overall rider satisfaction goals.
- **Review of Current Performance Measures**: Existing performance measures should be revisited to measure the CP outcomes to ensure that on-time performance does not compete with the CP goals.

- **Organizational Restructuring**: Due to changes in operational procedures, an agency may have to re-evaluate its staffing and management structure to ensure smooth coordination across various departments within the agency, and across agencies in the region. There may be a need for additional staff, but in most cases, new roles and responsibilities may be created for existing personnel. Staffing and training needs are necessary as new roles and responsibilities are developed by deploying agencies at the time of system design.
- **Efficient Support and Maintenance:** The CP system is dependent on the availability of the underlying vehicles and systems/subsystems technologies. Preventive maintenance should be scheduled, and readily available support should be established to quickly recover from CP failures.
- **Agency Policy for "Holding" Vehicles:** Agencies should establish a policy that determines the amount of time a vehicle should be held. Various factors to consider in determining the "hold-until" interval include:
    - Considering the trade-off between "hold-until" times and the maximum allowable threshold for schedule deviations.
    - Considering travel time variability based on historic travel time and/or current traffic conditions.
    - Considering service anomalies and disruptions.
    - Accounting for "on-time" and other service standards for different agencies or modes to determine the impact on schedules when vehicles from different agencies and modes are involved in a transfer.
    - Determining an acceptable waiting time for passengers based on transfer waiting time, in-vehicle waiting time, and downstream waiting time.
    - Considering the impact of dwell time for the "outgoing vehicle" when determining the impact on downstream stops. Particularly, elements such as wheelchair boarding time should be considered.
    - The capacity of the "outgoing" vehicle should be considered by the CP vehicle algorithm.

CURRENT TECHNOLOGY OF TRANSIT PROVIDERS

Table 2 shows a summary of technology that is currently in use by the Solano County Transit operators and other connecting transit operators collected through requests for information and public information available.

Table 2: Summary of Existing Technology of Transit Providers

Agency/System	CAD/AVL	APC	AFC	Transit Data	API Capabilities	On-Board Devices that Can Receive Text Messages?	Communication between Drivers and Dispatching Unit
BART			Clipper	Real-time service alerts, trip updates	Legacy API		
SF Bay Area WETA			Clipper	Static GTFS. Service alerts are available through RSS feeds	RSS		
Amtrak				Statis GTFS of Capital Corridor. Real-time location is available through the app			
Greyhound				Static GTFS			
SolTrans	Connexionz Limited	Urban Transportation Authority (UTA)	Genfare Odyssey	Real-time service alerts, trip updates & vehicle positions	GeoFSON or Rest API	Yes. Cradlepoint Devices.	Radio communications

Agency/System	CAD/AVL	APC	AFC	Transit Data	API Capabilities	On-Board Devices that Can Receive Text Messages?	Communication between Drivers and Dispatching Unit
FAST	NextBus System with UMO IQ	NextBus System	GenFare/GFI System with Odyssey Fare Box	Real-time service alerts, trip updates & vehicle positions	XML Feed	Yes. Nextbus MDT units	Radio communications. Local buses have an all-broadcast digital radio system
Dixon Readi-Ride	None	None	None	None	None		
Vacaville City Coach	None	None	None	None	None		
Yolobus	TripSpark			GTFS Real Time		Ranger-in-vehicle MDT	
Rio Vista Delta Breeze	Operated and Maintained by Transportation Concepts						
VINE Transit	GMV Syncromatics			Real-time service alerts, trip updates & vehicle positions			
LAVTA	Trapeze	Trapeze	Genfare	Real-time service alerts, trip updates & vehicle positions			

Agency/System	CAD/AVL	APC	AFC	Transit Data	API Capabilities	On-Board Devices that Can Receive Text Messages?	Communication between Drivers and Dispatching Unit
Golden Gate Transit	INIT	IRMA Matrix	Clipper	Real-time service alerts, trip updates & vehicle positions			
County Connection	Clever Devices			GTFS, Real-time vehicle location			Radio communications
AC Transit	Clever Devices		Genfare SPX	Real-time service alerts, trip updates & vehicle positions			
WestCAT	HAWK	HAWK	Clipper	Static GTFS			

Pilot Study

A pilot study has been conducted to design and test a CP solution for a BART to SE bus connection. The methodology and testing have been conducted with oversight from STA, SolTrans, and the PLT consisting of staff from other agencies such as the MTC, Caltrans, CCTA, and FAST. Methodology, testing, and testing results are presented in this section along with conclusions and lessons learned.

METHODOLOGY

The following methodology was used in conducting the pilot study.

- **Route:** The Yellow Line was selected for testing the pilot. The Yellow Line is the shortest SE route connecting Vallejo Transit Center and Walnut Creek BART station. Any disruptions in the planned departure schedule due to CP pilot testing were perceived to be manageable. The variations in connection time from BART to the bus were studied and was determined that the connection protection opportunities were adequate to test the functionality of CP, and yet it is not overly disruptive to the regular operations.

- **Initiation of Connection Protection Request:** As discussed in the Technology Assessment section, there are two ways to trigger a connection protection request. A rider-initiated request or a system-initiated request. Considering SolTrans's requirement to fit in the CP solution within existing operations, a system-initiated connection protection was selected.

- **Dynamic Operations Server:** UC Berkeley PATH's fully functional IDTO prototype used in Caltrans research and CP FOT on the Tri Delta Transit fleet was selected for assessing the need for CP and to push CP hold messages.

- **Driver Interface:** Various interfaces for drivers to get notifications about CP were considered, including radio communications, off-board signs at bus stops, signs on buses, etc. Considering SolTrans's requirement to fit in the CP solution within existing operations, existing on-board driver vehicle interface units (Cradlepoint devices) were selected.

- **Hold Time:** Calculations of walking time from BART to Y-line bus stop, and the tolerance levels for accommodating delays in planned departure times without affecting the on-time performance of the Y-line, a 3-minute maximum hold time for CP messages was selected.

DATA FLOW

Figure 7 illustrates the data flow for the CP solution implemented for the pilot study. Real-time GTFS feed from BART was integrated with dynamic operations server. Algorithms were coded in the server to assess the need for CP and generate CP hold messages. An end-to-end API was developed to push the CP hold messages to the SolTrans CAD/AVL system, Connexionz. Through existing communications, the CP hold messages were delivered to the on-board driver vehicle interface unit (**Figure 8**). The ability for the drivers to respond to the CP messages was added as well (**Figure 9**). The dispatchers could see the messages delivered to the drivers and the responses back from the drivers. (**Figure 10**).

Figure 7: Connection Protection Data Flow

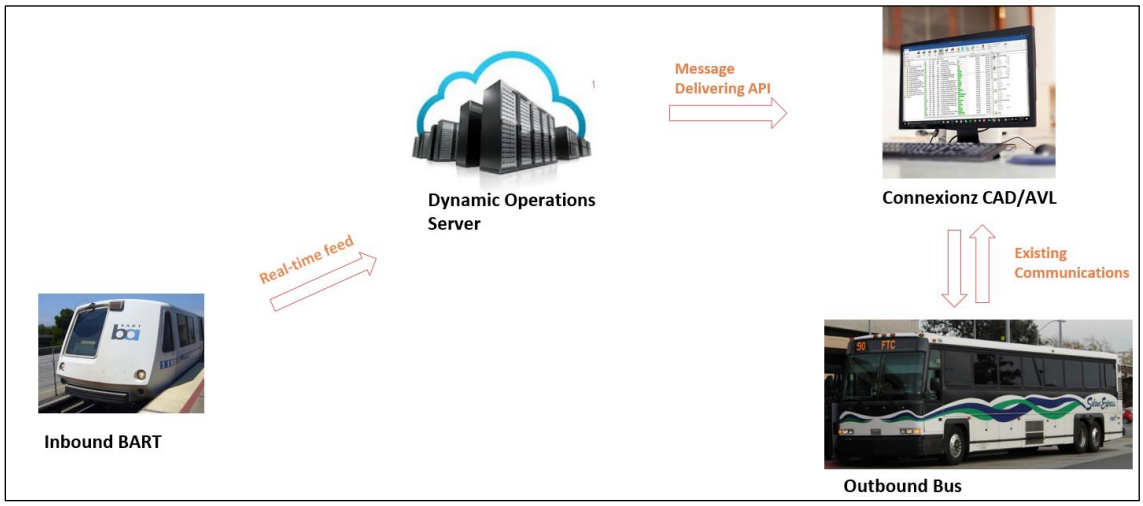


Figure 8: Connection Protection Hold Message on Driver Vehicle Interface Unit

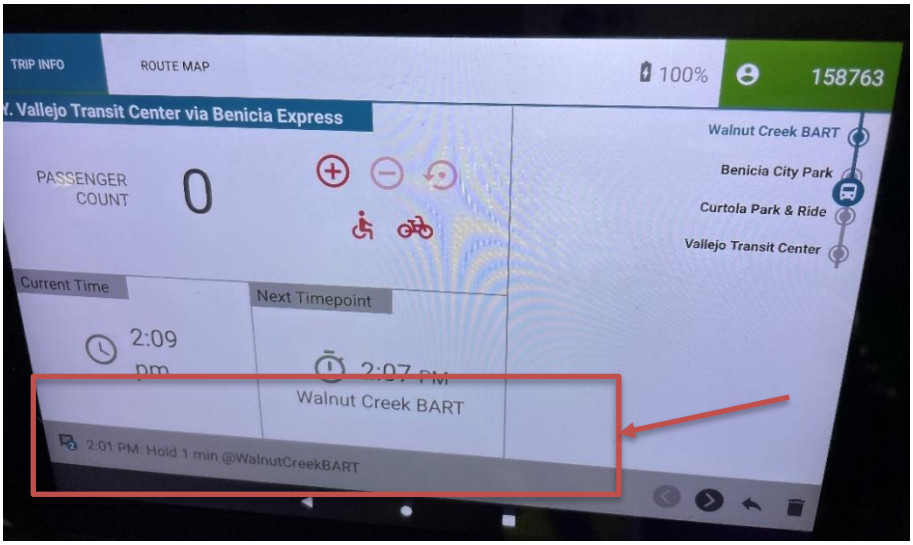


Figure 9: Options for Driver Response to Connection Protection Hold Messages

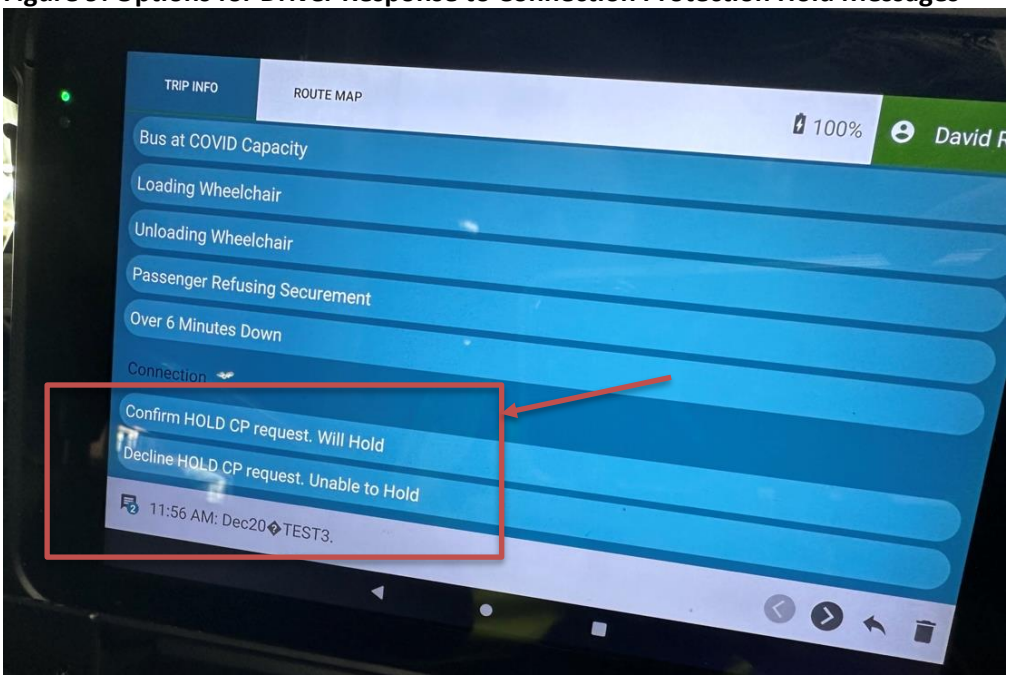
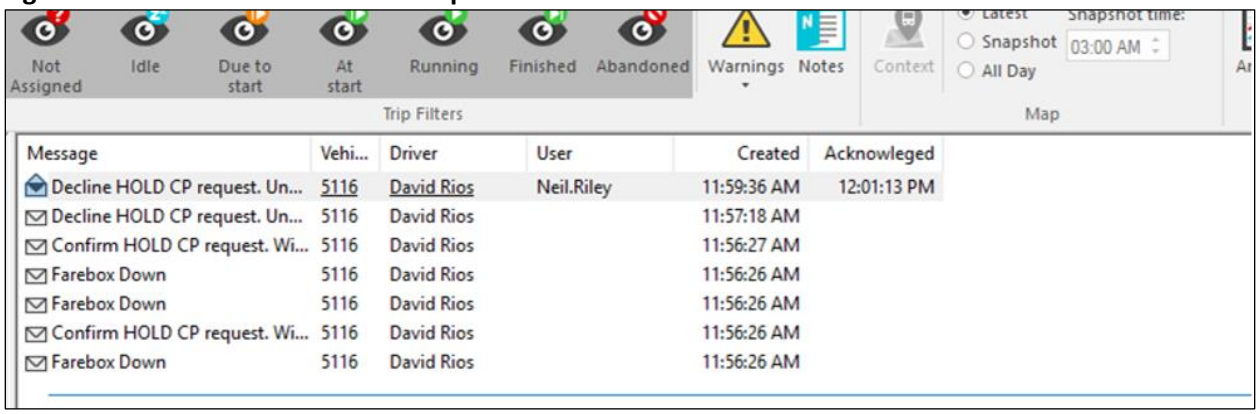


Figure 10: Screenshot of SolTrans Dispatcher Inbox



TESTING

There were three types of testing conducted to validate the pilot study.

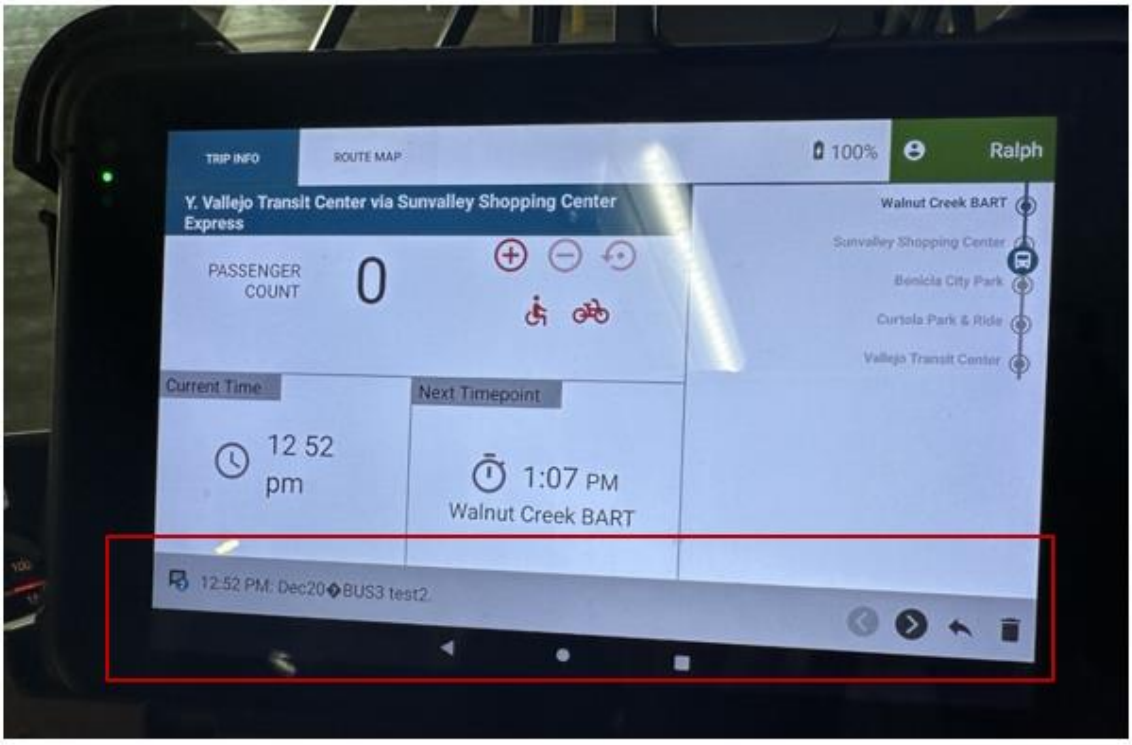
System Testing: Back-end server testing to test the CP messages were being delivered to the SolTrans Connexionz CAD/AVL. This test was passed after fixing some initial glitches between the connections. The results can be seen in **Figure 11**.

Figure 11: Results of System Testing

```
curl --location --request POST 'https://api-connectionprotection.connexionz.net/api/hold' \
--header 'accept: */*' \
--header 'Content-Type: application/json' \
--header 'ApiKey: 3919A164FFDACC919F949C8C97CC1' \
--data-raw '{
"ArrivalThreshold": null,
"GtfsStopId":"570",
"GtfsTrips": [{"gtfsTripId": "1289", "gtfsVehicleId": null}],
"Message":"TEST MSG.",
"Organization":"TzYxMjc4NzNFLUNFN0ItNEExOC1BMDJCLTREMzEyMTg2MURCQ1BDRTdCQkUxQi0yMjA0LTQ0MkMtOTk1Ny1FQ0JCQUFFREY5OUU="
}'
```

Alpha Testing: Alpha testing was conducted for two weeks in January 2023. During this phase test messages were sent to all the Y-line routes arriving at Walnut Creek BART station to test the capability of message delivery capability. The results are shown in Figure 12.

Figure 12: Connection Protection messages received by driver-Alpha Testing



Beta Testing: Beta testing was conducted starting on February 06, 2023, to test the delivery of CP hold messages when the need for CP is detected by the back-end dynamic operations server. Drivers of Y-line were trained on what to expect and how to respond to the CP messages at the same time. The testing was fine for a week and then it failed with the message “No Vehicles to Notify”. Permission

issues and feedback options to Connexionz back-end responses were fixed and the testing resumed in May 2023. The messages received by the driver are shown in Figure 13. A sample of dispatcher-received log is shown in Figure 14 and a sample of dispatcher-sent logs is shown in Figure 15.

Figure 13: Connection Protection messages received by driver-Beta Testing

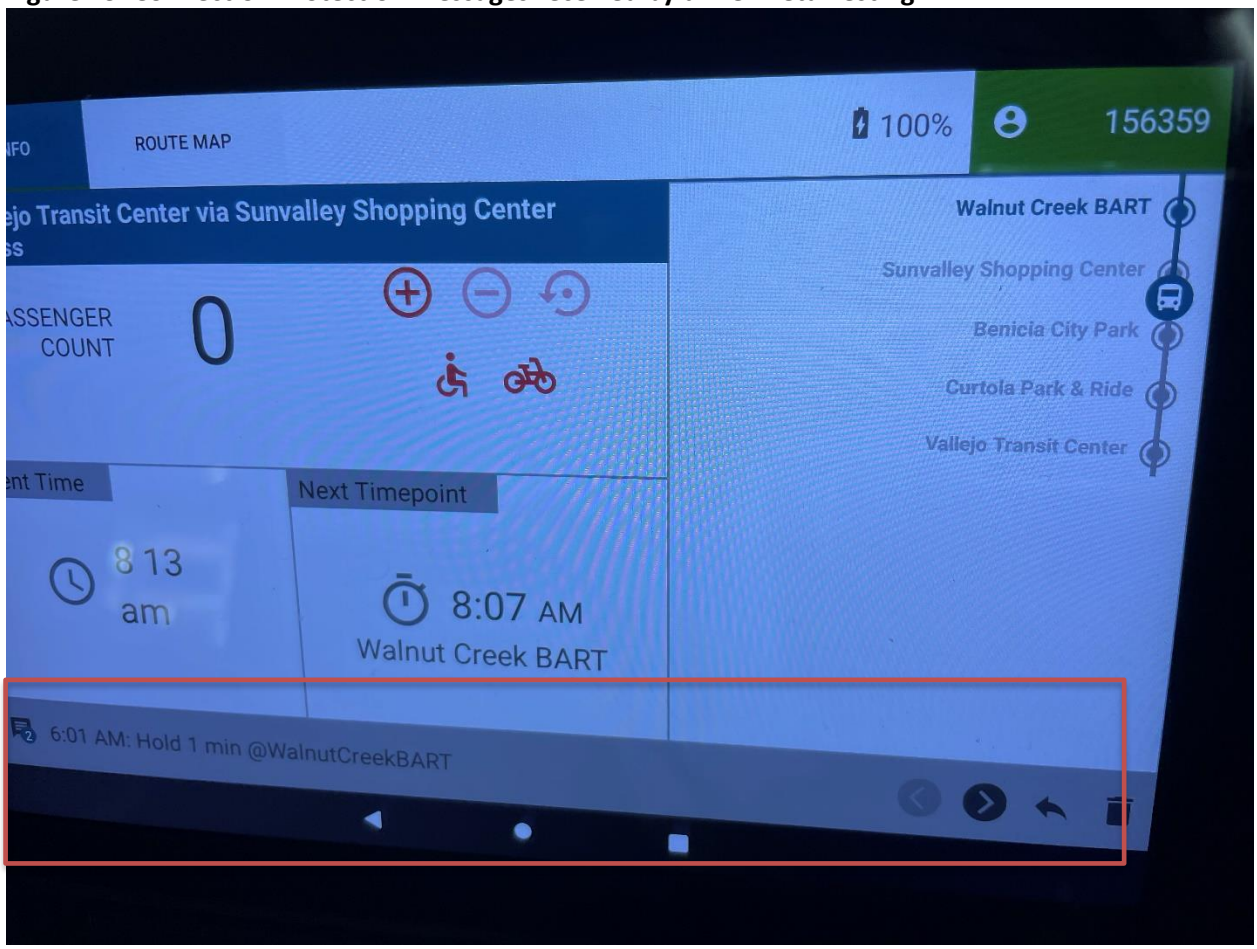


Figure 14: Sample of Dispatcher Log Received


```
{
  "created": "2023-05-12 12:06:15",
  "vehicleId": "5103",
  "driverId": "148208",
  "msg": "Confirm HOLD CP request. Will Hold"
```

Figure 15: Sample of Dispatcher Log Sent


```
"created": "2023-05-12 13:03:15",
"vehicleId": "5106",
"driverId": "153209",
"msg": "Hold 3 min @WalnutCreekBART",
"userName": "CPHOLD"
```


FINE-TUNING AND MONITORING

In May 2023, CP messages were delivered to “Hold 1 min @WalnutCreekBART”, “Hold 2 min @WalnutCreekBART”, or “Hold 3 min @WalnutCreekBART” when the system detected the need for CP. On average 4-7 messages were delivered on a weekday. After the discussion with SolTrans, the logic was changed to deliver only “Hold 3 min @WalnutCreekBART” when the system detects CP needs to hold the buses for more than 1 minute. This reduced the CP messages delivery to an average of 3-4 messages on a weekday. The system has been stable in detecting and delivering the CP hold messages in June and July 2023.

Additional observations can be listed as:

- Driver compliance to CP messages is mixed.
- Some passengers who were informed about the pilot were concerned about potential delays in reaching their destination.
- The on-board driver vehicle interface board was not working all the time.

CONCLUSIONS

The following conclusions can be drawn from the pilot study conducted.

- A Connection Protection solution can be implemented to facilitate a protected transfer from an agency with a real-time GTFS feed to a connecting SE line.
- No additional tools or technology are needed at SolTrans to implement CP for BART to SE bus transfers.
- Additional training and awareness for drivers and commuters to understand the operations and benefits of CP.
- Wider implementation and longer monitoring periods are needed to evaluate drivers’ and commuters' perceptions of CP.

LESSONS LEARNED

Based on the pilot study testing results and observations made during the pilot study, the following could be listed as lessons learned for future pilot studies or CP implementation.

- **Driver's Compliance:** Training the drivers in the field on how to look for the CP hold messages, and how to respond to the hold messages was helpful. Most of the bus drivers who participated in the pilot study welcomed the additional tools to understand the arrival of BART. However, some drivers were worried about potential delays downstream if they held the bus longer than the planned departure. Additional training focusing on agency expectations regarding acceptance of the CP hold messages will help increase drivers' compliance with responding to the CP messages.
- **On-Board Driver Vehicle Interface Units:** The effectiveness of CP relies on the functioning of the on-board driver-vehicle interface units. During our testing period, there were situations where either the drivers turned off the units or the units were not functioning properly. Periodic checks of on-board driver-vehicle interface units before dispatch and preventive maintenance are recommended.

Implementation Plan

This section summarizes the ways CP strategies can be expanded to other SE lines. This section includes probable cost estimates to implement the CP strategies and recommended prioritization based on factors that impact the effectiveness of the implementation.

Two types of CP strategies are recommended for SE connections.

1. **Stop-Based CP:** This type of CP strategy is implemented at the transit centers or at bus stops where the passengers transfer to or from SE lines.
2. **Route-Based CP:** This type of CP strategy is implemented on individual routes transferring to or from SE lines.

STOP-BASED CONNECTION PROTECTION

At the pilot study design phase, this strategy was considered and discarded for a targeted pilot study on one BART to bus connection. This strategy has its merits for wider implementation of CP strategies and hence included for consideration and further evaluation in the future.

Stop-based CP strategy informs drivers and passengers of real-time arrivals of SE buses so that drivers and passengers can make informed decisions about their transfers. When the signs are placed at strategic locations, drivers from multiple transit agencies can be informed about the SE arrivals without any integration of transit agency networks. Transportation Network Companies (TNC) and micro-mobility services can benefit from this strategy as well. However, one drawback of this strategy is that there will be no record of the protected transfers and no accountability for the driver's compliance to provide protected transfers.

Applicability to Solano County

The four SE lines Blue, Yellow, Green, and Red connect to and from other regional and local transits at the following major transit centers.

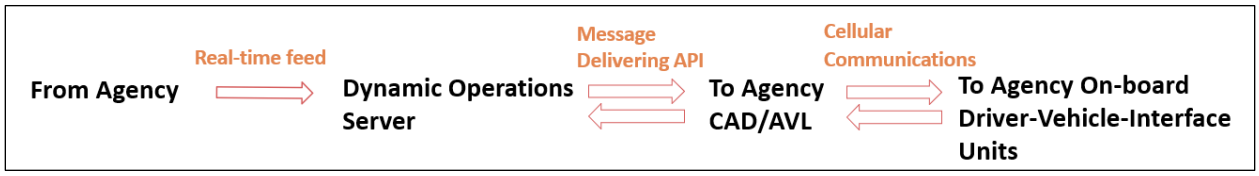
- El Cerrito del Norte BART
- Fairfield Transportation Center
- SolTrans Curtola Park and Ride Hub
- Suisun-Fairfield Amtrak Station
- UC Davis Mondavi Center
- Vallejo Transit Center
- Walnut Creek BART

Implementation of Stop-based connection protection will require collaboration and coordination with the facility owners. The most feasible implementation is at Vallejo Transit Center and Curtola Park and Ride Hub maintained by SolTrans. The next feasible implementation is at Fairfield Transportation Center maintained by FAST. The implementation of a Stop-based CP strategy at these transit centers can facilitate connections from SE lines to SolTrans local routes, FAST, VINE Transit, Rio Vista del Breeze, TNC, and micro-mobility services.

ROUTE-BASED CONNECTION PROTECTION

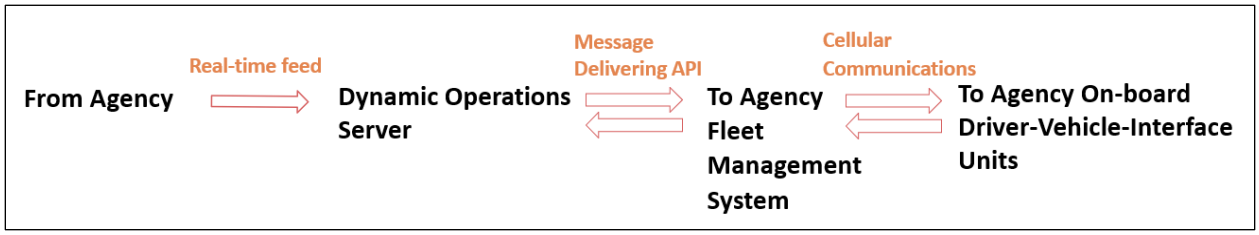
All existing connections to and from SE lines are evaluated to understand the technology and integration needs to implement a Route-based CP strategy and probable cost estimates are estimated. This strategy is similar in design and approach to the pilot study conducted. The data flow in this type of strategy that is preferred is shown in **Figure 16**. "From Agency" is a transit agency from where the passengers will be transferred and a "To Agency" is a transit agency to which the passengers will transfer. All the probable cost estimates are based on this design and approach.

Figure 16: Route-Based CP Strategy – Preferred Data Flow



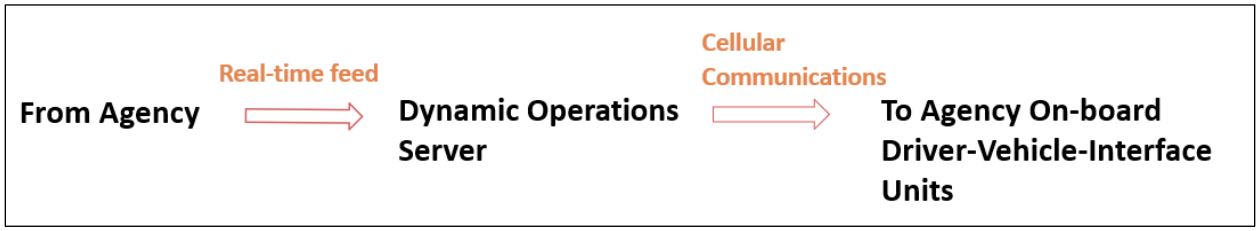
There are two other variations to this data flow through which CP can be implemented when there are any constraints for a "To Agency" to establish a CAD/AVL component for their agency. **Figure 17** shows the data flow for variation where only the fleet management system component of the "To Agency" is used to establish a connection between the CP dynamic operations server and the on-board driver vehicle interface units. The advantage of this variation is that when a "To Agency" is small, a full-blown CAD/AVL system might not be necessary for their day-to-day operations, and it will be an added burden for that agency to operate and maintain a CAD/AVL system solely to implement CP strategies.

Figure 17: Route-Based CP Strategy – with Fleet Management System



Another variation is shown in **Figure 18**, where a connection can be established between the CP dynamic operations server and the on-board driver vehicle interface units directly through cellular connections without a connection to "To Agency's" back-end system. The advantage of this design is that the integration of on-board devices with the CP server will be easy and is economical to establish CP strategies for smaller transit agencies connecting to SE lines that do not have any CAD/AVL or Fleet Management System in place.

Figure 18: Route Based CP Strategy – Direct Communication



Expand BART to SE

Through the pilot study, tools and mechanisms are in place to provide CP for transfers from BART to the SE Yellow Line. There is potential to expand CP to other SE lines connecting to BART at El Cerrito del Norte and Walnut Creek BART stations.

From Agency	To Agency	Type of Connected Transit	Connection Locations	Routes with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
BART	SolTrans SE	Fixed Route	El Cerrito del Norte	R, G	NA
			Walnut Creek	B, Y	All the buses have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from BART, CAD/AVL at SolTrans, Y-line configured in CP back-end server, established message delivering API between CP back-end server and SolTrans CAD/AVL, on-board driver vehicle interface units, existing communication between CAD/AVL and driver.
Additional tools & Technology needs for CP	Establish a connection between BART and the back-end server, code the From Route in the back-end server, End to End API development for To Routes.
Technical Constraints	All the technology needed for CP is in place. It is assumed that the SolTrans SE fleet is connected to BART are equipped with an on-board driver vehicle interface unit.
Headways	BART has 15-20 min headways and SE lines have 20-60 min headways.
Ridership	The 2022 ridership survey indicates that 3.6% and 6.6% of Y Line and B line riders have Walnut Creek as their origin respectively.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	6	$30,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	2	$20,000
3	End-to-End API Development (To Route)	$8,000	3	$24,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	6	$30,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SF Bay Ferry to SE

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
WETA SF Bay Ferry	SolTrans SE	Fixed Route	Vallejo Ferry Terminal	San Francisco/Mare Island	R, Y	NA All the buses have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, existing on-board driver vehicle interface unit, and existing communication between CAD/AVL and on-board driver vehicle interface units.
Additional tools & Technology needs for CP	Establish a connection between Ferry and the back-end server, code the From Route in the back-end server, and end API development for To Routes.
Technical Constraints	The availability of real-time GTFS for Ferry is not known.
Institutional Constraints	The willingness of WETA to work with SolTrans/STA to provide real-time GTFS is not known.
Headways	SF Bay Ferry has 30 min 45 headways during peaks. R, Y lines have 30 min to 60 min headways.
Ridership	The 2022 ridership survey indicates that 4.6% and 13.7% of Y Line and R line riders have San Francisco as their origin respectively.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$8,000	2	$16,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	1	$10,000
3	End-to-End API Development (To Route)	$8,000	2	$16,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	2	$10,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

AMTRAK to SE

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
Amtrak	SolTrans SE	Fixed Route	Suisun-Fairfield Amtrak Station	Capital Corridor	R, G	NA All the buses have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, existing on-board driver vehicle interface unit, and existing communication between CAD/AVL and on-board driver vehicle interface units.
Additional tools & Technology needs for CP	Establish a connection between Amtrak and the back-end server, code the From Route in the back-end server, and end API development for To Routes.
Technical Constraints	The availability of real-time GTFS for Amtrak is not known.
Institutional Constraints	The willingness of Amtrak to work with SolTrans/STA to provide real-time GTFS is not known.
Headways	R and G lines have 45-minute to 60-minute headways at Suisun-Fairfield Amtrak Station.
Ridership	The 2022 ridership survey indicates that 16.0 % and 1.6% of G Line and R line riders have Suisun City as their origin respectively.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$8,000	2	$16,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	1	$10,000
3	End-to-End API Development (To Route)	$8,000	2	$16,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	2	$10,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

Greyhound to SE

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
Greyhound	SolTrans SE	Fixed Route	Suisun-Fairfield Amtrak Station	-	G, R	NA All the buses have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Static GTFS for Greyhound is publicly available. Real-time GTFS feed from SE, CAD/AVL for SolTrans.
Additional tools & Technology needs for CP	Establish a connection between Greyhound and the back-end server, code the From Route in the back-end server, and end-to-end API development for To Routes.
Technical Constraints	The availability of real-time GTFS for Greyhound is not known.
Institutional Constraints	The willingness of Greyhound to work with SolTrans/STA to provide real-time GTFS is not known.
Headways	R and G lines have 45-minute to 60-minute headways at Suisun-Fairfield Amtrak Station.
Ridership	The 2022 ridership survey indicates that 16.0 % and 1.6% of G Line and R line riders have Suisun City as their origin respectively.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$8,000	2	$16,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	1	$10,000
3	End-to-End API Development (To Route)	$8,000	2	$16,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	2	$10,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to SE

From Agency	To Agency	Type of Connected Transit	Connection Location	Possible Connection	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	SolTrans SE	Fixed Route	Suisun-Fairfield Amtrak Station	G-R, R-G	NA All the buses have on-board driver vehicle interface units in place.
			Vallejo Transit Center	R-Y, Y-R	
			El Cerrito del Norte BART	G-R, R-G	
			Walnut Creek BART	Y-B, B-R	

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, and end API development for To Routes.
Technical Constraints	No new tools and technology are needed.
Institutional Constraints	None
Headways	30 min to 60 min headways.
Ridership	Varies

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	8	$40,000
2	Coding of the route in the back-end, monitoring and fine-tuning to start the CP process (From Route)	$10,000	2	$20,000
3	End-to-End API Development (To Route)	$8,000	4	$32,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	8	$40,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to SolTrans Local Routes

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	SolTrans Local	Fixed Route	Vallejo Transit Center	R, Y	1,2,3,4,5,6,7A,7B, 8	NA All the buses have on-board driver vehicle interface units in place
			Serano Transit Center	R	1,2,4,5,7A,7B	

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, and end API development for To Routes.
Technical Constraints	No new tools and technology are needed.
Institutional Constraints	None
Headways	30-minute to 45-minute headways for SE lines. 30-minute to 60 min headways on local routes
Ridership	The 2022 ridership survey indicates that 27.4 %, and 42.3% of Y Line and R line riders have Vallejo as their destination respectively.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	40	$200,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	4	$40,000
3	End-to-End API Development (To Route)	$8,000	10	$80,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	40	$200,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to FAST

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	FAST	Fixed Route	Fairfield Transportation Center	R, B, G	1,3,7	NA All the buses have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, CAD/AVL for FAST, existing on-board driver vehicle interface unit, and existing communication between CAD/AVL and on-board driver vehicle interface units.
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, and end API development for To Routes.
Technical Constraints	No new tools and technology are needed.
Institutional Constraints	There is a need to have an operations and maintenance agreement between SolTrans/STA and FAST to establish CP.
Headways	30 min to 60 min headways.
Ridership	The 2022 ridership survey indicates that 2.0 %, 1.7% ND 27.7% of R line, Y line, and G line riders have Fairfield as their destination respectively.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	9	$45,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	3	$30,000
3	End-to-End API Development (To Route)	$8,000	3	$24,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	9	$45,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to Dixon Readi-Ride

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	Dixon Readi-Ride	On-Demand Curb to Curb	Dixon Park and Ride	B	Shuttle Bus	30 Assumed no. of buses to have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, End-to-end API development for To Routes, new CAD/AVL for Dixon Readi-Ride, new on-board driver vehicle interface units, and cellular communications.
Technical Constraints	Additional technology needs are listed.
Institutional Constraints	There is a need to have an operations and maintenance agreement between SolTrans/STA and Dixon Readi-Ride to establish CP.
Headways	B Line-60 min headways during peak.
Ridership	Unknown

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	1	$5,000
2	Coding of the route in the back-end, monitoring and fine-tuning to start the CP process (From Route)	$10,000	1	$10,000
3	End-to-End API Development (To Route)	$8,000	1	$8,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	$700	30	$21,000
6	CAD/AVL for To Agency*	$250,000	1	$250,000
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	$15,000	1	$15,000
9	Annual Subscription for Cellular Connection	$600	30	$18.000
10	Yearly System Maintenance and Updates (Connection)	$5,000	1	$5,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to Vacaville City Coach

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	Vacaville City Coach	Fixed Route	Vacaville Transportation Center	B	1,3,4,5,6	18 Assumed no. of buses to have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, End-to-end API development for To Routes, new CAD/AVL for Vacaville City Coach, new on-board driver vehicle interface units, and cellular communications.
Technical Constraints	Additional technology needs are listed.
Institutional Constraints	There is a need to have an operations and maintenance agreement between SolTrans/STA and Vacaville City Coach to establish CP.
Headways	B Line-60 min headways during peak.
Ridership	The 2022 ridership survey indicates that 24.7% of B-line riders have Vacaville as their destination.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	5	$25,000
2	Coding of the route in the back-end, monitoring and fine-tuning to start the CP process (From Route)	$10,000	1	$10,000
3	End-to-End API Development (To Route)	$8,000	5	$40,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	$700	18	12,600
6	CAD/AVL for To Agency*	$300,000	1	$300,000
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	$15,000	1	$15,000
9	Annual Subscription for Cellular Connection	$600	18	$10,800
10	Yearly System Maintenance and Updates (Connection)	$5,000	5	$25,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to Rio Vista Delta Breeze

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	Rio Vista Delta Breeze	Fixed Route	Fairfield Transportation Center	B, G, R	50	5 Assumed no. of buses to have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans.
Additional tools & Technology needs for CP	Establish connection between transit and back-end server, code the From Route in the back-end server, End to End API development for To Routes, new CAD/AVL for Rio Vista Delta Breeze, new on-board driver vehicle interface units, and cellular communications.
Technical Constraints	Additional technology needs are listed.
Institutional Constraints	There is a need to have an operations and maintenance agreement between SolTrans/STA and Rio Vista Delta Breeze to establish CP.
Headways	R Line- 60 min headways B Line-60 min headways during peak, G Line-40 min headways during peak at Fairfield Transportation Center. Route 50 -65 min to 270 min headways.
Ridership	The 2022 ridership survey indicates that 2.4%, 6.1%, and 0.2% of B-line, G-line, and R-line riders have Suisun City as their destination respectively.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	3	$15,000
2	Coding of the route in the back-end, monitoring and fine-tuning to start the CP process (From Route)	$10,000	3	$30,000
3	End-to-End API Development (To Route)	$8,000	1	$8,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	$700	5	3,500
6	CAD/AVL for To Agency*	$300,000	1	$300,000
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	$15,000	1	$15,000
9	Annual Subscription for Cellular Connection	$600	5	$3,000
10	Yearly System Maintenance and Updates (Connection)	$5,000	3	$15,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to VINE Transit

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	Vine Transit	On-Demand Fixed OD	Fairfield Transportation Center	R, B, G	21	12 Assumed no. of buses to have on-board driver vehicle interface units in place
			Vallejo Transit Center	R, Y	11, 11X	

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, CAD/AVL for VINE Transit.
Additional tools & Technology needs for CP	Establish connection between transit and back-end server, code the From Route in the back-end server, End to End API development for To Routes, new on-board driver vehicle interface units, and cellular communications. CP integration needs with existing CAD/AVL and new on-board units.
Technical Constraints	Additional technology needs are listed.
Institutional Constraints	There is a need to have an operations and maintenance agreement between SolTrans/STA and VINE Transit to establish CP.
Headways	21-60 min headways, R Line- 60 min headways B Line-60 min headways during peak, G Line-40 min headways during peak at Fairfield Transportation Center. R Line 30 to 60 min headways and Y Line 60 min headways at Vallejo Transit Center.
Ridership	The 2022 ridership survey indicates that 0.3%,0.7%, and 1.2% of B Line, Y Line, and R Line riders have Napa as their destination respectively.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	8	$40,000
2	Coding of the route in the back-end, monitoring and fine-tuning to start the CP process (From Route)	$10,000	4	$40,000
3	End-to-End API Development (To Route)	$8,000	2	$16,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	$700	12	$8,400
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	$600	12	$7,200
10	Yearly System Maintenance and Updates (Connection)	$5,000	8	$40,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to County Connection

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	County Connection	Fixed Route	Walnut Creek BART	B, Y	1,4,5,9, 14,21,93X, 95X,96X,98X, 4,301,311,321	NA All the AC Transit buses have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, CAD/AVL for County Connection, existing on-board driver vehicle interface unit, and existing communication between CAD/AVL and on-board driver vehicle interface units.
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, and end API development for To Routes.
Technical Constraints	All the technology needed to have CP is in place. It is assumed that the County Connection fleet is connected to SE are equipped with an on-board driver vehicle interface unit.
Institutional Constraints	County Connection is outside of STA Transit Consortium. Their CP priorities may not align with SolTrans/STA goals. There is a need to have an operations and maintenance agreement between SolTrans/STA and County Connection to establish CP.
Headways	B, Y lines-60 min headways at Walnut Creek BART station. County Connection varies.
Ridership	Varies.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	20	$100,000
2	Coding of the route in the back-end, monitoring and fine-tuning to start the CP process (From Route)	$10,000	2	$20,000
3	End-to-End API Development (To Route)	$8,000	10	$80,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	20	$100,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to AC Transit

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	AC Transit	Fixed Route	El Cerrito del Norte BART	R,G	7,72,72R,72M, 76,376,800	NA All the AC Transit buses have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, CAD/AVL for AC Transit, existing on-board driver vehicle interface unit, and existing communication between CAD/AVL and on-board driver vehicle interface units.
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, End to End API development for To Routes.
Technical Constraints	All the technology needed to have CP is in place. It is assumed that the AC Transit fleet is connected to SE are equipped with an on-board driver vehicle interface unit.
Institutional Constraints	AC Transit is outside of STA Transit Consortium. Their CP priorities may not align with SolTrans/STA goals. There is a need to have an operations and maintenance agreement between SolTrans/STA and AC Transit to establish CP.
Headways	R Line and G-Line 20 min to 60 min headways at El Cerrito BART station. AC Transit varies.
Ridership	The 2022 ridership survey of Red Line indicated 1.0% and 2.0% of riders have origin and destination respectively in El Cerrito while 1.4% of El Cerrito riders have destination as El Cerrito

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	10	$50,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	2	$20,000
3	End-to-End API Development (To Route)	$8,000	5	$40,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	10	$50,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to LAVTA Wheels

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	LAVTA Wheels	Fixed Route	Walnut Creek BART Station	Y, B	70X	NA All the LAVTA buses have on-board driver vehicle interface units in place.

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, CAD/AVL for LAVTA Wheels, existing on-board driver vehicle interface unit, and existing communication between CAD/AVL and on-board driver vehicle interface units.
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, End to End API development for To Routes.
Technical Constraints	All the technology needed to have CP is in place. It is assumed that the LAVTA fleet is connected to SE are equipped with an on-board driver vehicle interface unit.
Institutional Constraints	LAVTA is outside of the STA Transit Consortium. Their CP priorities may not align with SolTrans/STA goals. There is a need to have an operations and maintenance agreement between SolTrans/STA and LAVTA to establish CP.
Headways	Blue and Yellow Lines – 60 min headways at Walnut Creek BART station. 70X morning and evening one route.
Ridership	The 2022 ridership survey of Blue and Yellow Lines does not indicate specific numbers to and from Dublin.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	2	$10,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	2	$20,000
3	End-to-End API Development (To Route)	$8,000	1	$8,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	2	$10,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to Golden Gate Transit

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	Golden Gate Transit	Fixed Route	El Cerrito del Norte BART	R, G	580	NA All the Golden Gate buses have on-board driver vehicle interface units in place.

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, CAD/AVL for Golden Gate Transit, existing on-board driver vehicle interface unit, and existing communication between CAD/AVL and on-board driver vehicle interface units.
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, End to End API development for To Routes.
Technical Constraints	All the technology needed to have CP is in place. It is assumed that the Golden Gate Transit fleet is connected to SE are equipped with an on-board driver vehicle interface unit.
Institutional Constraints	Golden Gate Transit is outside of STA Transit Consortium. Their CP priorities may not align with SolTrans/STA goals. There is a need to have an operations and maintenance agreement between SolTrans/STA and Golden Gate Transit to establish CP.
Headways	580-30 to 60 min headways, Red Line-20 min to 60 min headways at El Cerrito BART station
Ridership	The 2022 ridership survey of Red and Green Lines indicated that 2.1% and 4.2% of riders have an origin and destination in Richmond respectively. Ridership numbers for San Rafael were not specifically indicated.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	2	$10,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	2	$20,000
3	End-to-End API Development (To Route)	$8,000	1	$8,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	2	$10,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to WestCAT

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	WestCAT	Fixed Route	El Cerrito del Norte BART	R, G	JL/JR, JPX	NA All the WestCAT buses have on-board driver vehicle interface units in place

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, CAD/AVL for WestCAT, existing on-board driver vehicle interface unit, and existing communication between CAD/AVL and on-board driver vehicle interface units.
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, End to End API development for To Routes.
Technical Constraints	All the technology needed to have CP is in place. It is assumed that the WestCAT fleet is connected to SE are equipped with an on-board driver vehicle interface unit.
Institutional Constraints	WestCAT is outside of STA Transit Consortium. Their CP priorities may not align with SolTrans/STA goals. There is a need to have an operations and maintenance agreement between SolTrans/STA and WestCAT to establish CP.
Headways	JPX-30 to 40 min headways, JR/JL-30 min headways, Red Line-20 min to 60 min headways at El Cerrito BART station
Ridership	The 2022 ridership survey of Red Line and Green Lines indicated that 2.1% and 4.2% of riders have an origin and destination in Richmond respectively. Ridership numbers for Hercules and Pinole were not specifically indicated.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	4	$20,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	2	$20,000
3	End-to-End API Development (To Route)	$8,000	2	$16,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	4	$20,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SE to Yolobus

From Agency	To Agency	Type of Connected Transit	Connection Location	From Route with a Possible Connection	To Route with Possible Connections	Total of Vehicles in the Fleet that Need New On-Board Driver-Vehicle Interface Units
SolTrans SE	Yolobus	Fixed Route	UC Davis Modavi Center	B	138	NA All the Yolobus buses have on-board driver vehicle interface units in place.

Factors Considered in Cost Estimates and Prioritization of CP	
Available tools & Technology	Real-time GTFS feed from SE, CAD/AVL for SolTrans, CAD/AVL for Yolobus, Real-time GTFS feed for Yolobus, existing on-board driver vehicle interface unit, and existing communication between CAD/AVL and on-board driver vehicle interface units.
Additional tools & Technology needs for CP	Establish a connection between transit and back-end server, code the From Route in the back-end server, End to End API development for To Routes.
Technical Constraints	All the technology needed to have CP is in place. It is assumed that the Yolobus fleet is connected to SE are equipped with an on-board driver vehicle interface unit.
Institutional Constraints	Yolobus is outside of STA Transit Consortium. Their CP priorities may not align with SolTrans/STA goals. There is a need to have an operations and maintenance agreement between SolTrans/STA and Yolobus to establish CP.
Headways	Yolobus - One-hour headways from 6 am to 9 pm @ UC Davis Mondavi Center. Blue Line – Two routes in the morning and two routes in the evening with two-hour headways.
Ridership	The 2022 ridership survey of Blue Line indicated that 4.1% and 11.5% of riders have an origin and destination in Sacramento respectively.

From Agency	Work Description	Unit Cost	No.of Units/Routes	Cost
1	Establish a connection between transit and back-end server (From Route to To Route at one location)	$5,000	1	$5,000
2	Coding of the route in the back-end, monitoring, and fine-tuning to start the CP process (From Route)	$10,000	1	$10,000
3	End-to-End API Development (To Route)	$8,000	1	$8,000
4	CAD/AVL for From Agency	NA		
5	On-board Driver-Vehicle-Interface Unit	NA		
6	CAD/AVL for To Agency*	NA		
7	Yearly maintenance for From Agency CAD/AVL	NA		
8	Yearly maintenance for To Agency CAD/AVL*	NA		
9	Annual Subscription for Cellular Connection	NA		
10	Yearly System Maintenance and Updates (Connection)	$5,000	1	$5,000

Notes: *CP Strategies can be accomplished without this component. Hence these costs are not considered in the cost ranking used for prioritization.

SUMMARY OF PROBABLE COST ESTIMATES

The probable cost estimates are summarized in **Table 3**, which are based on a CP design and approach similar to the CP established from BART to Y-line transfers at Walnut Creek BART Station through pilot study implementation. The costs are divided into deployment costs and annual operation and maintenance costs. Since the CAD/AVL for "To Agency" is not needed, the deployment costs and annual operation and maintenance costs without that component are also shown.

Table 3: Summary of Probable Cost Estimates

No.	CP Opportunity	Deployment Costs	Operations and Maintenace (per year)	Deployment Costs without CAD/AVL for "To Agency"	Operations and Maintenace (per year) without CAD/AVL for "To Agency"
1	Expand BART to SE	$74,000	$30,000	$74,000	$30,000
2	SF Bay Ferry to SE	$42,000	$10,000	$42,000	$10,000
3	Amtrak to SE	$42,000	$10,000	$42,000	$10,000
4	Greyhound to SE	$42,000	$10,000	$42,000	$10,000
5	SE to SE	$92,000	$40,000	$92,000	$40,000
6	SE to SolTrans Local	$320,000	$200,000	$320,000	$200,000
7	SE to FAST	$99,000	$45,000	$99,000	$45,000
8	SE to Dixon Readi-Ride	$294,000	$38,000	$44,000	$23,000
9	SE to Vacaville City Coach	$387,600	$50,800	$87,600	$35,800
10	SE to Rio Vista Delta Breeze	$356,500	$33,000	$56,500	$18,000
11	SE to VINE Transit	$104,400	$47,200	$104,400	$47,200
12	SE to County Connection	$200,000	$100,000	$200,000	$100,000
13	SE to AC Transit	$110,000	$50,000	$110,000	$50,000
14	SE to LAVTA Wheels	$38,000	$10,000	$38,000	$10,000
15	SE to Golden Gate Transit	$38,000	$10,000	$38,000	$10,000
16	SE to WestCAT	$56,000	$20,000	$56,000	$20,000
17	SE to Yolobus	$23,000	$5,000	$23,000	$5,000

PRIORITATION OF IMPLEMENTATION

Various factors like technology availability, technology constraints, institutional constraints, costs, headways, and relative ridership were considered in ranking the implementation of the possible CP to and from various transit agencies and summarized in **Table 4**. Different weights are applied for each factor considered.

Table 4: Ranking Summary for Prioritization

No.	CP Opportunity	Cost Rank (0.30)	Technical Constraints Rank (0.20)	Institutional Constraints/ Readiness Rank (0.15)	Headways Rank (0.10)	Ridership rank (0.25)	Weighted Ranking	Overall Rank
1	Expand BART to SE	10	1	1	14	1	5	1
2	SF Bay Ferry to SE	3	15	11	4	11	8.7	9
3	Amtrak to SE	3	16	11	3	12	9.05	10
4	Greyhound to SE	3	17	13	1	16	10.35	16
5	SE to SE	12	2	1	9	8	7.05	3
6	SE to SolTrans Local	17	2	3	12	2	7.65	5
7	SE to FAST	13	3	4	11	3	6.95	4
8	SE to Dixon Readi-Ride	8	14	5	17	17	11.9	17
9	SE to Vacaville City Coach	11	13	5	13	5	9.2	14
10	SE to Rio Vista Delta Breeze	8	12	5	9	6	7.95	12
11	SE to VINE Transit	14	10	5	8	7	9.5	8
12	SE to County Connection	16	5	14	16	9	11.75	15
13	SE to AC Transit	15	5	15	7	10	10.95	11
14	SE to LAVTA Wheels	2	5	16	2	14	7.7	6
15	SE to Golden Gate Transit	2	5	17	10	15	8.9	7
16	SE to WestCAT	8	5	14	15	13	10.25	13
17	SE to Yolobus	1	11	9	5	4	5.35	2

Based on the overall ranking the recommendation order of CP implementation based on funding availability is:

1. Expand BART to SE
2. SE to Yolobus
3. SE to SE
4. SE to FAST
5. SE to Soltrabs Local
6. SE to LAVTA Wheels
7. SE to Golden Gate Transit
8. SE to VINE Transit
9. SF Bay Ferry to SE
10. Amtrak to SE
11. SE to AC Transit
12. SE to Rio Vista Delta Breeze
13. SE to West CAT
14. SE to Vacaville City Coach
15. SE to County Connection
16. Greyhound to SE
17. SE to Dixon Readi-Ride

Next Steps

The implementation plan and probable cost estimates provided in this report are at a planning level based on the understanding of the connection protection pilot study conducted for one connection from BART to Yellow Line at Walnut Creek BART station. For a full-scale rollout of the pilot study and further extending the same solution for other routes and/or other transit agencies in Solano County, the following steps are recommended.

- Gather consensus from transit agencies in Solano County to accomplish regional goals for CP.
- Develop agreements to adopt minimum guidelines for coordination to meet the needs of individual agencies, as well as to facilitate reaching the regional goals for CP.
- Establish data-sharing agreements as necessary.
- Establish operations and maintenance agreements to ensure accurate real-time data availability from participating agencies, and preventive maintenance to quickly recover from CP failures.
- Establish cost-sharing agreements between participating agencies.
- Secure funding for deployment and ongoing maintenance costs.
- Driver training and agency expectations need to be conducted to increase driver adherence to CP messages.
- Increase public awareness of the CP program through social media campaigns, brochures, and newsletters to achieve public acceptance.
- The design and CP solution in the pilot study was based on system-triggered CP need, integration of CP back-end server with Connexionz CAD/AVL, and Cradlepoint on-board driver vehicle interface units. In this situation, the design and technology are different, a brief pilot study is recommended for each agency-to-agency connection before the complete rollout.
- Detailed headway and ridership data transfer location details, and “To Agency” policies will need to be looked at to determine the holding time at the implementation phase.

Collaboration with regional efforts:

The CCTA is currently developing a MOD application that will provide real-time, multimodal trip planning options based on origin and destination data. This app will serve up a variety of travel options based on a user’s desire for the fastest, greenest, or most cost-effective trip. The app will also include a uniform payment system and incentives based on the time of day and mode to reward select travel behaviors.

Transit CP service to improve successful transfer between multiple transit modes including BART to bus is one of the planned features of the MOD application. With the successful implementation of a BART-to-bus solution in place, the SolTrans/STA CP solution is ready to be integrated with the MOD application and set as an example for other transit agencies slated to be integrated into the MOD application. There is an opportunity to collaborate with CCTA to integrate real-time GTFS feeds of SolTrans into CCTA’s MOD application to mutually share transit data to further enhance connection protection solutions and other traveler information solutions to support regional transit connections.

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