Real-time transit information

Benefits, technologies, components, experiences and recommendations

White paper prepared by Trillium Solutions, Inc.
for Oregon Dept of Transportation (ODOT)

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About this white paper

Audience and purpose for this paper

This paper was prepared for Oregon Department of Transportation (ODOT). The intended audience is transit agencies and ODOT and similar regional entities. In particular, this was written in mind with small to medium (less than 200 vehicles) fixed-route transit providers that are designing and procuring real-time systems or providers that already have a real-time system they wish to expand, replace, or assess. The paper outlines technology considerations and choices for these organizations. Real-time for fixed-route transit is distinct from real-time dispatch for demand-responsive transportation [See "Flexible Transportation Services" on TransitWiki].

Authors

This white paper was written by a team of consultants with Trillium Solutions, Inc. ("Trillium"), a transit technology service provider and consulting firm based in Portland, Oregon. Trillium maintains GTFS data and provides consulting services related to transit technology and data for ODOT. Modular system design and open and interoperable data has been a core part of Trillium's approach and philosophy since its founding in 2008, which is reflected in the recommendations in this white paper. Many vendors, consultants, and transit agencies were interviewed in the course of writing this white paper.

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Disclosure of interests

As involved subject matter experts, Trillium discloses ongoing vested interest in the transit data and real-time space:

- Trillium provides GTFS Manager, software for maintaining GTFS data to ODOT and many transit agencies outside of Oregon.
- Trillium provides Transit Alerts for publishing service advisories in GTFS-realtime.
- Trillium has provided GTFS data for use in a variety of real-time information systems, including those offered by Swiftly, NextBus, Syncromatics, and others.
- Trillium has a commission-based resale agreement with Swiftly.
- Trillium regularly partners with *Transit* [app], IBI Group, University of South Florida, Cambridge Systematics, and other groups mentioned in this document or involved in real-time information.
- Trillium deployed and hosts the open-source OneBusAway software for Rogue Valley Transportation District.

Paper sections

The following questions are addressed by each section.

- *Summary:* A four-page outline of system definitions, principles, and recommendations.
- *Benefits:* How do riders benefit from real-time information? How do transit organizations use real-time information to gather insights?
- *Functions and components:* How can real-time information systems be separated into components, and what mechanisms and data standards exist for interoperability between systems?
- *Planning and design:* How should a transit agency consider and articulate needs and priorities for a real-time system to inform later procurement and implementation choices?
- *Procurement:* What are recommended steps for procuring real-time information system components?
- *Implementation:* What should transit agencies expect and prepare for during the implementation process?
- *Operation & Evaluation:* How can a real-time information system's performance be assessed? What should transit agencies expect during the phase of operation?
- *List of vendors:* Summary of cost ranges, with an extensive but non-comprehensive list of vendors that provide real-time information system components.
- *Agency experiences in Oregon:* Time requirements for real-time information system procurement, implementation, and ongoing operation for 4 transit agencies in Oregon.
- *Recommendations for ODOT & Regional Organizations:* How can regional organizations such as ODOT balance and support both regional goals and priorities and local autonomy?
- *Glossary of terms* used throughout this document.
- *Suggested real-time system requirements*, including hardware performance, support, base features, and open data formats and licenses, which can be incorporated wholly or in part in a procurement document to fulfill on the principles and recommendations outlined in this white paper.

Summary

Definition of real-time transit information

For the purposes of this white paper, “real-time transit information” includes three main functions:

- Computer-Aided Dispatch and Automatic Vehicle Location (CAD/AVL)
- Real-time passenger information (RTPI)
- Performance measurement

In the past decade, these systems have become more common for transit systems throughout the world.

Components

Functional area	Components
Computer-Aided Dispatch and Automatic Vehicle Location (CAD/AVL)	• On-board location sensing (GPS and other technologies) • Wireless connectivity • Assignment of vehicles to runs & routes • Computer aided dispatch for driver instruction and re-routes
Real-time passenger information (RTPI): System for providing arrival estimates, vehicle locations, and/or service advisories to customers.	• Mobile apps, including popular 3rd party apps such as Google Maps. • SMS text messaging • Interactive voice response (IVR) • Public signage/displays • Open data
Performance measurement: Systems that synthesize on-time performance and other key metrics for managers, decision-makers and planners.	• Dashboards • Report systems

Technologies, products, practices, data formats, and system architectures continue to evolve. Some real-time vendors provide all components. Others specialize in one or a few. An extensive but non-comprehensive review of real-time vendors and the components and services they provide is in this vendor list [Google Spreadsheet].

Benefits

Real-time systems can bring many benefits to riders, transit agencies and regional providers such as ODOT. The benefits listed in this paper are supported by research and information gathered from transportation providers. A summary of these benefits is listed below.

Benefits for riders:
- Reduced actual wait time at bus stop
- Reduced perceived wait time at the bus stop
- Greater peace of mind and feelings of safety
- Decreased learning curve for new riders

Benefits for transportation providers:
- Improved rider satisfaction
- Increased ridership
- Greater operator accountability
- Improved on-time performance
- Informed schedule improvements
- Informed capital improvements/investments

Benefits for ODOT/regional organizations:
- Improved rider satisfaction
- Visibility of operated transit networks
- Informed capital improvements/investments

Recommendations

Recommendations to transit providers

This white paper makes recommendations to transit providers for planning, procuring, and operating real-time transit information systems. These recommendations, outlined below, are based on interviews with transit agencies that have implemented real-time systems, interviews with vendors, and the authors' experience with real-time systems.

Planning

1. **Plan a modular (see definition link) system design** by understanding the system in terms of components and functions. Standardized data formats such as the General Transit Feed Specification (GTFS) and GTFS-realtime and interoperable interfaces enables modularity.

Below is a diagram of how real-time system components fit together.

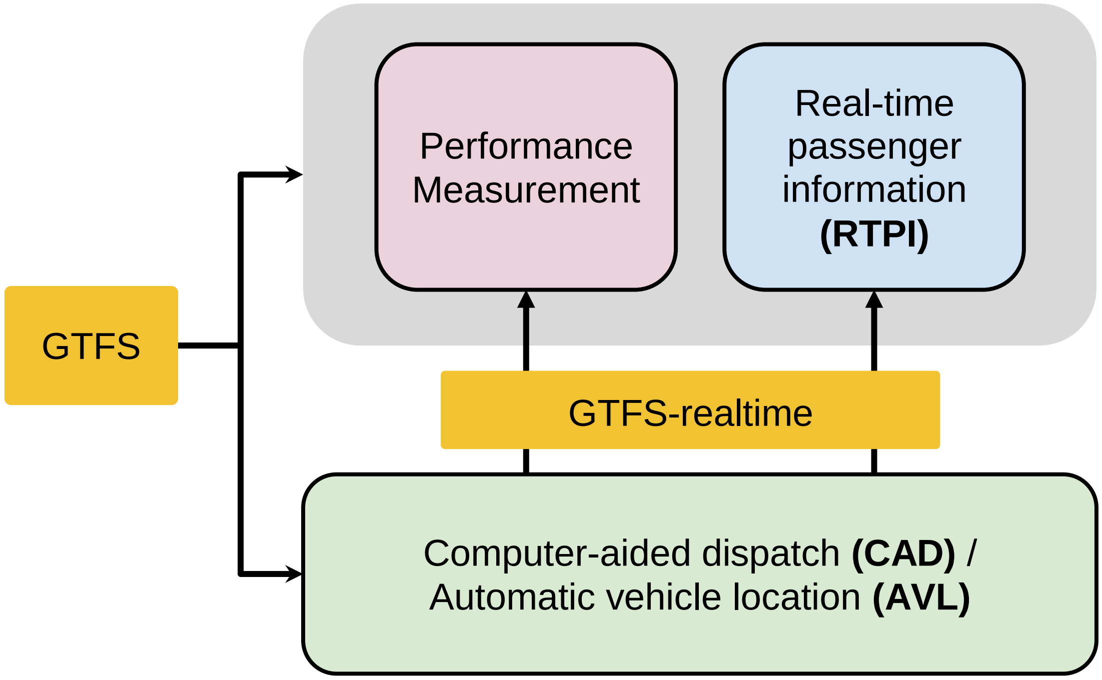

Figure 1: Modular system design

A modular and standards-based approach enables a transit provider to effectively:

- assemble the best fit technologies.
- add or replace components over time.
- negotiate with vendors.
- reduce the risk of vendor lock-in.
- publish data to 3rd party applications and regional systems.

2. **Establish core objectives** to guide requirements.
3. **Identify the transit provider's existing resources**, including:
   - hardware, software and interfaces.
   - staff time and expertise.
4. **Conduct an industry survey** to develop an understanding of possible solutions.

Procurement

1. **Consider a pilot** to evaluate a system through hands-on experience.
2. **Issue a procurement instrument (RFP/RFQ):** Lead with a statement of objectives (e.g. for open data, prediction accuracy, and analysis for planning) followed by core requirements. Avoid bloated requirements lists that unnecessarily limit respondents. Appendix A offers suggested requirements.

Operation

1. **Keep data inputs up to date:** GTFS (static) needs to be kept current for all schedule changes and maintained according to GTFS Best Practices.
2. **Monitor passenger usage and feedback:** Mobile apps, SMS & IVR queries, and customer feedback can provide useful analytics and help discover issues.
3. **Monitor prediction accuracy & real-time system performance:** The system needs continuous monitoring to ensure accurate information and predictions.
4. **Monitor transit operations:** To benefit from the performance dashboards, staff must actively monitor and respond to reports and metrics such as on-time performance.

Recommendations to ODOT

This white paper makes suggestions to ODOT to support successful and widespread implementation and operation of real-time transit information in Oregon:

- **Set standards:** Recommend or require interoperability, such as by using GTFS and GTFS-realtime, in order to support statewide use of data by travelers and planners.
- **Pilots:** ODOT might select standards-compliant vendors for selected pilots.
- **Statewide contracts with standards-compliant vendors:** By securing contracts with standards-compliant vendors and allowing transit agencies to purchase through those agreements, ODOT could save transit agencies significant staff hours involved in contracting and procurement.
- **Knowledge sharing:** Encourage transit agencies that implement real-time systems to share procurement documents and notes on their experience.
- **Support directories of real-time data:** Add real-time data to oregon-gtfs.com and support initiatives to add real-time to global directories such as Transit.land and TransitFeeds.com.
- **Validation and accuracy assessment:** The state could help provide transit agencies with trusted, neutral tools to deploy GTFS-realtime and check adherence and prediction accuracy by hosting or operating these systems.

Benefits

While some agencies see money spent on data and technology as *money not spent on providing service*, data and technology have actually become essential to the provision of transit service, particularly from the rider perspective. A growing body of academic and industry research shows that adding real-time information grows transit ridership and improves rider satisfaction. At the same time, incomplete or inaccurate trip-planning information can lead people to flee transit for other transportation options that travelers perceive to be more reliable.[1]

Vehicle location and real-time information systems for fixed-route public transportation can deliver benefits for riders and improve operational performance (which ultimately benefits riders). The

[1] Zak Accuardi, Chris Pangilinan, Aaron Antrim, and Greg Rucks. Upcoming (unpublished) report: "The Data Transit Riders Want" prepared by TransitCenter and Rocky Mountain Institute.

systems provide riders with the convenience of knowing when their bus, train, or other transit vehicle will arrive. Transit service operations can refine the schedule and improve on-time performance, which also benefits riders.

Benefits for riders

Real-time information can offer experienced transit riders many new benefits and lower the learning curve for new riders.[2] One of the biggest benefits riders see with the implementation of real-time data is decreased wait times. When riders have access to accurate bus arrival predictions, they can plan their own arrival at the bus stop more exactly and are less likely to show up early for a vehicle that is running late. Having access to real-time data can alleviate the uncertainty and frustration of not knowing when a bus is really going to arrive,[3] which can also lead to a shorter *perceived wait time*,[4] and decrease the learning curve for new riders.[5]

Studies have also shown that real-time info can increase feelings of safety for riders, especially at night.[6] One respondent explained, "I can plan when to leave the house better and spend less time waiting at dark or remote stops." Some riders even reported an increase in their walking based on real-time info, responding that they were more likely to walk to a different stop that offered them a faster trip.[7] More walking could offer health benefits to riders.

Transit agencies have seen increases in ridership after real-time implementation.[8] [9] Riders with access to real-time data report making more transit trips, with more gains in non-commute trips.[10] A study on New York City Transit showed an increase in ridership associated with the availability of real-time information. "The model implied that real-time information increased ridership by about

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[2] C. Cluett, S. Bregman, and J. Richman (2003). "Customer Preferences for Transit ATIS," Federal Transit Administration. Available at http://ntl.bts.gov/lib/jpodocs/repts_te/13935/13935.pdf#sthash.jwn5Oltr.dpuf

[3] Brian Ferris, Kari Watkins, and Alan Borning (2010), "OneBusAway: results from providing real-time arrival information for public transit," in Proceedings of the 28th International CHI Conference on Human Factors in Computing Systems, Atlanta, Georgia, USA, pp. 1807-1816.

[4] Kari Edison Watkins, Brian Ferris, Alan Borning, G. Scott Rutherford, and David Layton (2011), "Where Is My Bus? Impact of mobile real-time information on the perceived and actual wait time of transit riders," Transportation Research Part A: Policy and Practice, Vol. 45 pp. 839-848.

[5] C. Cluett, S. Bregman, and J. Richman (2003).

[6] A. Gooze, K. Watkins, and A. Borning (2013), "Benefits of Real-Time Information and the Impacts of Data Accuracy on the Rider Experience," in Transportation Research Board 92nd Annual Meeting, Washington, D.C., January 13, 2013.

[7] Brian Ferris, Kari Watkins, and Alan Borning (2010).

[8] Lei Tang and Piyushimita Thakuriah (2012), "Ridership effects of real-time bus information system: A case study in the City of Chicago," Transportation Research Part C: Emerging Technologies, Vol. 22 pp. 146-161.

[9] Brakewood, Macfarlane and Watkins (2015). The Impact of Real-Time Information on Bus Ridership in New York City. Transportation Research Part C: Emerging Technologies, Volume 53, pp. 59-7

[10] Brian Ferris, Kari Watkins, and Alan Borning (2010).

340 rides per weekday on the largest quartile of routes, which is a median increase of 2.3% of route-level ridership."[11]

All these benefits lead to stronger rider satisfaction with transit. After an implementation of the real-time app OneBusAway, surveys found that 92% of respondents reported an increase in satisfaction with public transit as a result of using the app.[12]

Benefits for agencies

Improved rider satisfaction and increased ridership are tremendous benefits in themselves and are core goals of transit managers. Transit providers, including those that directly operate service and that purchase operated services, can also expect improvements in operational performance.

The vehicle location provided by real-time data creates more operator accountability. Oversight of vehicle behavior also makes it easier to review driver or rider-reported issues that would usually be difficult or time consuming to investigate.

Agencies have the ability to monitor the path of travel and arrivals of each bus, ensuring adherence to schedules. These insights can lead to many improvements. Real-time data can be used to refine schedules so that they more accurately represent travel times. Schedules can be made more efficient by removing unnecessary "dwell times" or operating time buffers. These enhancements can lead to improved on-time performance.

Identifying locations with slow and/or variable travel and dwell times can help identify where agencies should make capital improvements and/or service changes beyond just the schedule. This can include identifying locations for transit signal priority, changing route alignments, stop consolidation, and identifying stops to be moved from near-side to far-side of intersection.

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[11] Candace Elizabeth Brakewood (2014), "Quantifying the Impact of Real-time Information on Transit Ridership" (http://hdl.handle.net/1853/54029)

[12] Brian Ferris, Kari Watkins, and Alan Borning (2010).

Functions and components

Summary of functions

These are functional groupings of components in real-time information systems:

- **Computer-Aided Dispatch and Automatic Vehicle Location (CAD/AVL):** Automatic vehicle location (AVL) is essential to provide inputs to other functions. Computer-aided dispatch (CAD) is an optional (non-essential) function.
- **Real-time passenger information (RTPI)**: System for generating and providing arrival estimates, vehicle locations, and service advisories to customers.
- **Performance measurement:** Systems that synthesize on-time performance and other key metrics for managers, decision-makers and planners.

Each function uses multiple components. Separating a real-time system into components helps to:

- Plan and build a system component-by-component as needs arise, funds become available, and technologies mature.
- Negotiate with vendors through itemized (component-based) costs.
- Combine components from different vendors into one system, to implement cost-efficient and best-fit systems.

The notes on individual components, below, are intended to inform decision-making for system design and build out. Additional recommendations are in the procurement section.

Components & sub-components

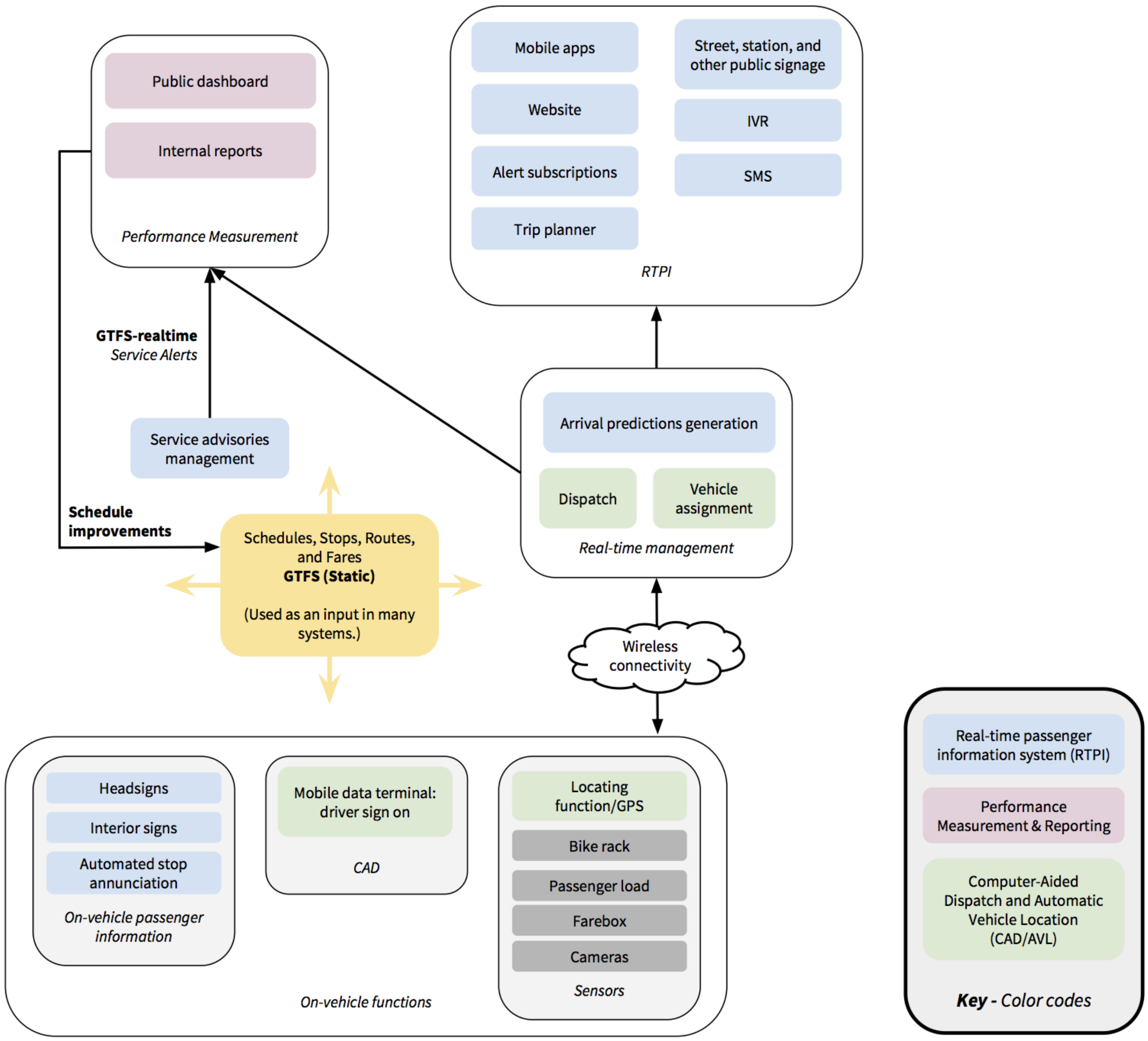

Figure 2: Multiple components of realtime systems

CAD/AVL Components

Onboard location sensor

GPS (global positioning system) is the most popular locating technology today. Prior to 2000, many AVL (automatic vehicle location) systems used ground-based beacons and odometer readings. Today, some AVL systems may use a combination of technologies — such as GPS with odometer integration.[13] Rail systems most often use specialized location technologies that integrate with track control systems.

Some parameters related to location sensing component include:

- **Location precision:** To what distance of accuracy are the geo coordinates returned by the locating systems? How reliable are those coordinates? In the case of GPS, this may be affected by where antennas are mounted on the vehicle. Location precision may vary among systems, but, given the reliability of consumer-grade GPS, we assume this is not a primary differentiator among real-time information technologies and approaches. In very dense urban environments with many skyscrapers, "urban canyons" between tall buildings diminish GPS performance[14] but this is not an issue in rural, small town, suburban, and medium-density urban environments. The accuracy and reliability of the locating system can be improved by cellular wireless connectivity, which supports Assisted GPS (A-GPS), and cellular network positioning where GPS is unavailable. Hardware or software support for "dead reckoning" may also be used to mitigate the "urban canyon" effect.
- **Polling rate:** The frequency with which location is transmitted to downstream components (e.g. every *x* seconds). Depending on hardware and software configuration, polling rate may be consistent, or it may be variable based on vehicle progress (more frequent when the vehicle is moving, less frequent when it's stationary).
- **Latency:** a measure of "real-timeness", which also depends on real-time passenger information (RTPI) components downstream from the location sensor. Latency is the time (e.g. *x* seconds) for information to flow from its source (e.g. vehicle positions from onboard location sensor) to the customer interface. High latency diminishes the quality of the customer experience. Low latency supports customer trust in the system; for example, a mobile app can notify the customer a transit vehicle is arriving at a stop or has left near the precise instant the event occurs. Latency can be affected by many components and steps in the system, including vehicle location transmission and GTFS-realtime data publishing.

Lower latency and higher polling rates translate to more timely information for riders and dispatchers. In practical terms, a polling rate of every 10 seconds with a downstream latency of 8 seconds means that after the location is polled, it will take 8 more seconds to get to the mobile app. Then the location would be polled again after 10 seconds, meaning the users may see data that is up to 18 seconds old. If a bus leaves a stop traveling about 12 miles per hour, it will be almost one Portland city block length away (317 feet) after 18 seconds.

<u>Cellular connectivity on vehicles</u>

The increasingly popular **standalone GPS Vehicle Trackers** provide connectivity through cellular networks. This is simple and inexpensive to implement but the connectivity cannot be shared with other onboard devices. GPS Vehicle Trackers, connected by an [on-board diagnostics port]() (see definition link), are low-cost and are supplied by some real-time vendors. Trackers plug into and are powered by this OBD port inside the vehicle. The GPS devices are easy to install. Some cellular

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[13] *Understanding and Applying Advanced On-board Bus Electronics* By John J. Schiavone, National Research Council (U.S.). Transportation Research Board, Transit Cooperative Research Program, Page 18. https://books.google.com/books?id=ve3fgfNa85wC

[14] MISRA, P., P. ENGE (2006). Global Positioning System: Signals, Measurements, and Performance, Second Edition. Lincoln (MA), U.S.A: Ganga-Jamuna Press.

modems also include GPS functions and may allow installing a GPS antenna outside the vehicle for increased reliability and location precision. See the below section on wireless connectivity for further notes on these technologies.

Cellular reception and RTPI performance

Some agencies may be concerned about whether lack of cell reception in rural areas negatively impacts real-time system performance. However, some RTPI systems can withstand this sort of outage and will continue tracking a bus once it comes back online. Particularly if there are no stops within or near the service corridor without cell coverage, then this will not be an issue with an RTPI that is designed for resilience to cellular coverage gaps. Reporting location coordinates also requires less signal strength than is required for a phone call, so service gaps are not as common as might be expected. Many agencies request a limited-scale pilot in order to test for possible issues such as this.

Figure 3: A GPS tracker plugs directly into the vehicle's OBD port.[15]

Cellular modems (sometimes referred to as M2M or machine-to-machine cellular modems)[16] provide Wi-Fi and/or ethernet connectivity for onboard devices, and may also be used to provide Wi-Fi access to riders. Radio-based systems utilize dedicated channels to communicate vehicle information without the cellular telephone network.

Other on-board sensors

On-board sensors that track information other than location can be a source of further operational data and customer-facing information. Possible sensor capabilities include:

- A sensor that indicates bike rack position and utilization can determine operational costs (time) of bike loading in historical analysis, and to indicate if bike racks are in use in customer-facing real-time information. Many common bike racks come equipped with a sensor that indicates to the driver if the rack is up or down as a safety feature, since their vision is often obscured. It's possible to wire this sensor to feed into a real-time system to

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[15] Image source: https://www.fleetminder.com.au/gps-vehicle-tracking-devices/five-reasons-gps-vehicle-tracking-devices/

[16] Google Shopping search results for "m2m cellular modem": https://www.google.com/search?hl=en&output=search&tbm=shop&q=m2m+cellular+modem

track bike usage. Newer bike rack models from Sportsworks[17] can be equipped with a sensor on the arm that hooks around the bike wheel. In this case the number of bike spaces in use could be tracked and possibly used to provide availability info to riders.[18]

- Automatic passenger counting and passenger load sensors are useful for historical analysis and to indicate passenger crowding conditions in customer-facing real-time information.
- Wheelchair lift/ramp operation sensors can record uses of the ramp for historical analysis and optimization of schedules.

Vehicle assignments

A mobile data terminal (MDT)[19] can be used by a vehicle operator to sign in and designate the route/trips they are operating. Until recently, specialized hardware was almost always used for this component, but more generic hardware, including ruggedized and consumer-grade tablet computers, is now commonly used. Below are the merits of each:

- Generic hardware:[20]
  - Pro: Equipment is readily available and inexpensive. If equipment fails or is stolen, it can be inexpensively and quickly replaced.
  - Con: Consumer-grade tablets, for example, are designed to run a variety of applications. The variety of functions in their operating system software may cause less software reliability (application crashes/bugs).
- Specialized hardware:
  - Pro: Greater reliability as a single-purpose device.
  - Con: May be more expensive. Less readily available components make replacement more difficult.

Some software, such as Swiftly Transitime and TheTransitClock, automatically assign vehicles to trips and blocks. Blocks In GTFS, blocks describe vehicle assignments to runs (or trips) in the transit schedule. A "block" consists of two or more sequential trips made using the same vehicle.

Dispatch and driver schedule adherence feedback

A mobile data terminal (definition link) can be used to provide instructions and information to operators, including:

- Temporary re-routes (detours)
- Real-time schedule adherence and dwell time feedback

Dispatching for headway-based schedules

Headway-based schedules (for which there are not pre-scheduled times) require a real-time dispatch approach to avoid bus bunching. TheTransitClock provides one example of a method to use real-time location data to dispatch vehicles according to current operating conditions, instead of a schedule. This method provides holding instructions to operators at control points according to the natural headway.

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[17] https://www.sportworks.com/products/transit-bike-racks

[18] https://www.ourstreetsmpls.org/metro_transit_puts_sensors_on_bike_racks_to_track_usage_in_pilot_program

[19] TransitWiki: https://www.transitwiki.org/TransitWiki/index.php/Mobile_data_terminal

[20] Example ruggedized terminal runs Linux and Android: https://www.amazon.com/Rugged-Mobile-Terminal-Android-Linux/dp/B01F16AV9C

Figure 4: A Lextran bus' mobile data terminal, top, serves as a GPS device and receives information from the dispatch center and the control panel for the electronic farebox.[21]

RTPI Components

Arrival time prediction

Software predicts (or "estimates") when a vehicle will arrive at a stop, usually in order to provide this information to riders. This software generally requires transit schedules, vehicle locations, route/trip assignments, and historical data (collected from past operation) to produce predictions.

There are various arrival prediction algorithm types. Most use a statistical model approach, informed by past operational data. TheTransitClock offers a prediction method based on machine learning. Scheduled and frequency-based systems may necessitate different prediction algorithms, so the capabilities of the prediction system should be matched to the service type.

Assessing prediction accuracy is crucial. Without a trusted method to assess prediction accuracy, there is no mechanism for vendor accountability or to discover and fix recurring real-time system performance issues. Some arrival prediction software includes a built-in function for assessing prediction accuracy. Alternatively, this assessment can be performed by software independent from the RTPI vendor and their product, offering additional accountability and trust in the results. An independent downstream GTFS-realtime software is also a better proxy for the rider's experience

[21] Image source: http://www.kentucky.com/news/local/counties/fayette-county/article44369406.html

because it can identify all the same issues (i.e. high [latency](#) in the GTFS-realtime feed) that a customer-facing application does.

IBI Group's report "Customer-Focused Methodology for Determining Prediction Accuracy Using Automatically Collected Data", a TRB paper by Farah Machlab and co-authors,[22] and an associated presentation at the 2017 ITS World Congress[23] provide a methodology for assessing prediction accuracy. John Levin of Metro Transit (Minneapolis) has submitted a TCRP Synthesis project proposal on "Measuring Real-time Transit Information Accuracy" in February of 2018.

Service advisory publishing

Service advisories (or alerts) provide information that cannot be encapsulated in an arrival estimate.

Advisories can provide ***cause and context*** for exceptions and delays, such as:

- Demonstration
- Collision
- Mechanical issue
- Weather
- Construction
- Police activity
- Medical emergency

Advisories can provide specific information about ***service changes/exceptions***:

- Significant delays
- Detour
- Additional service
- Modified service
- Stop moved or closed

Using GTFS-realtime, service advisories can be targeted for display with particular stops, routes, and trips. This service alert feed can be ingested by apps, websites, and electronic signage to provide riders with the most up-to-date information for their trips. These are some tools to manage and publish service advisories:

- IBI's Transit Alerts
- Trillium's Transit Alerts
- OneBusAway Service Alerts[24]

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[22] Transportation Research Board paper 17-04789 http://amonline.trb.org/63532-trb-1.3393340/t005-1.3409009/249-1.3409732/17-04789-1.3402139/17-04789-1.3409740

[23] http://itsworldcongress2017.org/wp-content/uploads/2017/11/Machlab_IBI_PredictionAccuracy_Presentation_ITSWC.pdf

[24] Documentation for developers: http://developer.onebusaway.org/modules/onebusaway-service-alerts/current/
Application code: https://github.com/OneBusAway/onebusaway-service-alerts

Mobile apps

Smartphone apps can help customers plan trips and locate nearby stops and routes. The apps provide arrival estimates, vehicle locations, and service advisories. Some mobile apps are specific for a particular agency, while others provide information for many agencies (e.g. Google Maps, Moovit, or *Transit*[25]).

Most third-party mobile apps depend on open data formats such as GTFS and GTFS-realtime. If high quality and accurate data is supplied to these third-party applications, the applications in turn are able to provide high-quality and accurate information to customers. In some circumstances, mobile apps (e.g. *Transit or Google Maps*) may generate their own arrival predictions using vehicle position data (rather than merely display supplied data), and use this instead if agency-supplied arrival predictions are found to be of lower quality.

Many third-party mobile applications are rated highly, incorporate multiple modes and transit services, and are free for agencies and customers. Some third-party mobile apps offer partnership programs. Some of the most popular and well-known examples are in the table below.

Popular Real-time Mobile Apps

Google Maps	*Google Maps*[26] provides a free trip planning app that provides real-time trip updates and service alerts to riders. The app also offers trip planning with multiple mode choices, user location, favorite locations. In addition to GTFS static, agencies that want their real-time data represented in Google Maps need to provide a GTFS-realtime feed in protocol buffer format. GTFS-realtime can be represented in 3 separate feeds: Vehicle Locations, Trip Updates, and Service Alerts. Note that vehicle locations are not visualized in Google Maps, but that information can be used to generate predictions if a Trip Updates feed is not available.
OneBusAway	OneBusAway[27] provides a free, open-source mobile app that includes arrival estimates, service advisories and push notifications. The app shows real-time vehicle locations, departure information, and allows users to set favorites and alarms. The OneBusAway software is available free of charge under the open source Apache License, V2.0[28]. Transit agencies and independent developers are free to use, modify, and enhance the software in accordance with the terms of that license to meet their own needs.

[25] https://transitapp.com/
[26] https://www.google.com/maps
[27] https://onebusaway.org/
[28] http://www.apache.org/licenses/LICENSE-2.0.html

Transit	*Transit*'s[29] program provides partner transit agencies with usage data, including A-to-B trip plan requests, traveler mode choices, real-time information lookup requests, locations of users when they open the app, and favorite locations indicated by users. Location data is slightly modified to protect users' privacy. Transit also provides support and small local customizations to allow agencies to exercise more control over how their services are presented. To qualify for the Transit Partner program, GTFS-realtime is preferred but not necessary. Transit can also work with select other (GPS/AVL) API (see definition link) formats. If only vehicle positions (not arrival predictions) are available, Transit uses their own engine and algorithms to provide arrival predictions. Though there is no cost for transit agencies to participate in the partner program, *Transit* requires participating transit agencies to endorse the app and promote *Transit* to their riders as their official or recommended app for trip planning and real-time information. Some transit agencies, such as Boston's MBTA, conduct a competitive process before endorsing the app.[30] Many other transit agencies deliberate internally and make an endorsement without a public competition.
Moovit	*Moovit*[31] partners with municipalities, transit operators and big events around the world. Partners receive access to an online application called the Moovit editor, which gives the transit agency the ability to edit route lines, publish service alerts and send push notifications to the Moovit app users. Every activity in the editor is published and available in the app automatically. Moovit also allows the option for riders to contribute information to the Moovit editor. Moovit shares usage data and analytics, including an origin-destination visualizer, with its partners through a product called the Smart Transit Suite.[32] Moovit also advertises their own real-time prediction system. Moovit's default service terms state that they own all data, so agencies may be restricted in their use of static and real-time data in other systems.

Free and universal transit apps often earn revenue by linking to shared-used mobility options such as transportation network companies (TNCs) like Uber, Lyft or bikeshares. This may be of utility to customers. Though it hasn't been seen to be an issue, there is the theoretical possibility that an app that links to a TNC might follow business interests that are at odds with those of the transit agency.

Reasons that agencies choose to implement an app that is specifically for their agency (including

[29] https://transitapp.com/partners/transit
[30] "The MBTA Says This Is The Best Transit App For Greater Boston Riders" http://www.wbur.org/bostonomix/2016/09/06/mbta-best-transit-app
[31] https://www.solutions.moovit.com/
[32] https://www.solutions.moovit.com/

with branding) might include desires to:

- Suppress the display of other modes and options. Suppressing display of other modes is rarely in the customers' interest.
- Integrate information functions within a ticketing app.
- Gather customer usage data.
- Showcase the agency brand through the app name, icon, interface colors and elements.

The above desires and perceived benefits should be weighed carefully against the costs and potential limitations associated with an agency-specific app, as many highly-rated third-party applications are available to customers. Customers often appreciate and benefit from a universal app that works for many agencies and allows them to travel across agency boundaries.

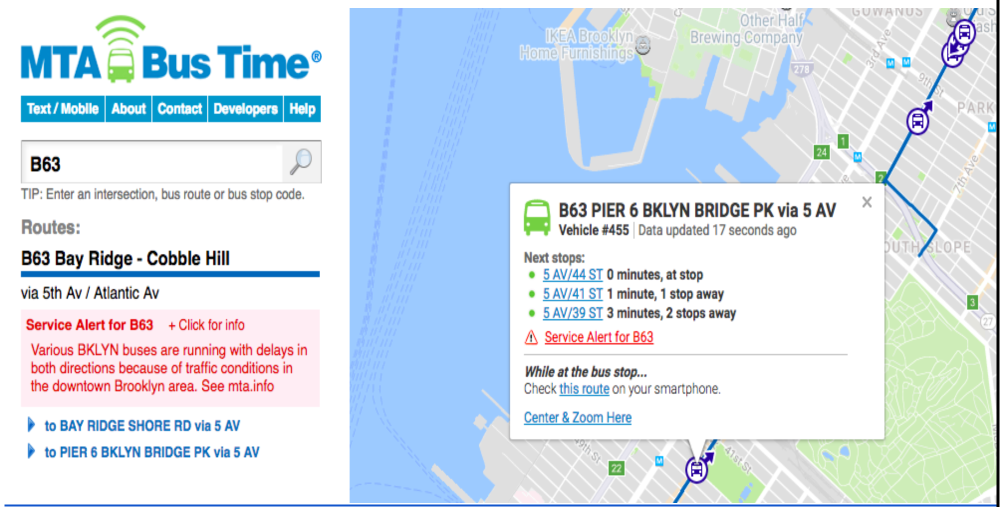
When a mobile app is being evaluated by a transit agency, customer experience should be a top consideration. Customer ratings are available in Apple and Android application marketplaces (App Store and Google Play Store).

Real-time Passenger Information Components/Features

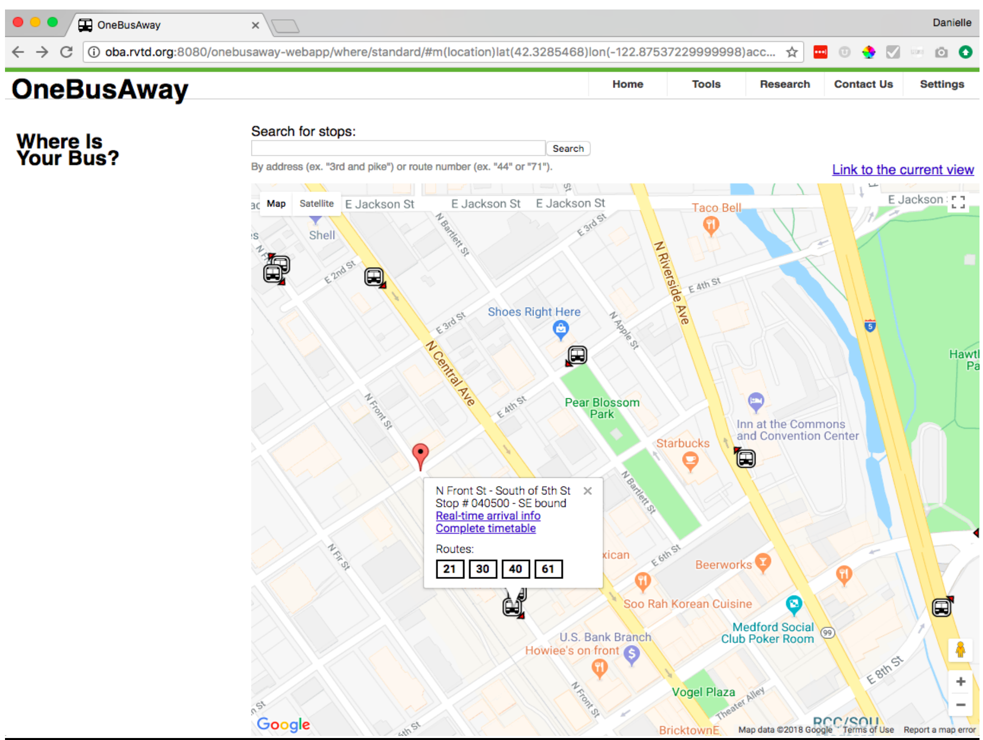
Text/SMS	An SMS response system allows customers to receive predicted arrival times by texting a stop code to a number. This enables customers who do not want to download an app or do not have a smartphone to look up times. Codes need to be defined for each stop. It is recommended that stop codes not have unnecessary digits so that they are easier for customers to remember.
IVR (Interactive voice response)	An IVR system allows customers to hear predicted arrival times by calling a number and entering or saying stop codes. Sometimes these features are incorporated into a 511 system.

Websites & web-apps

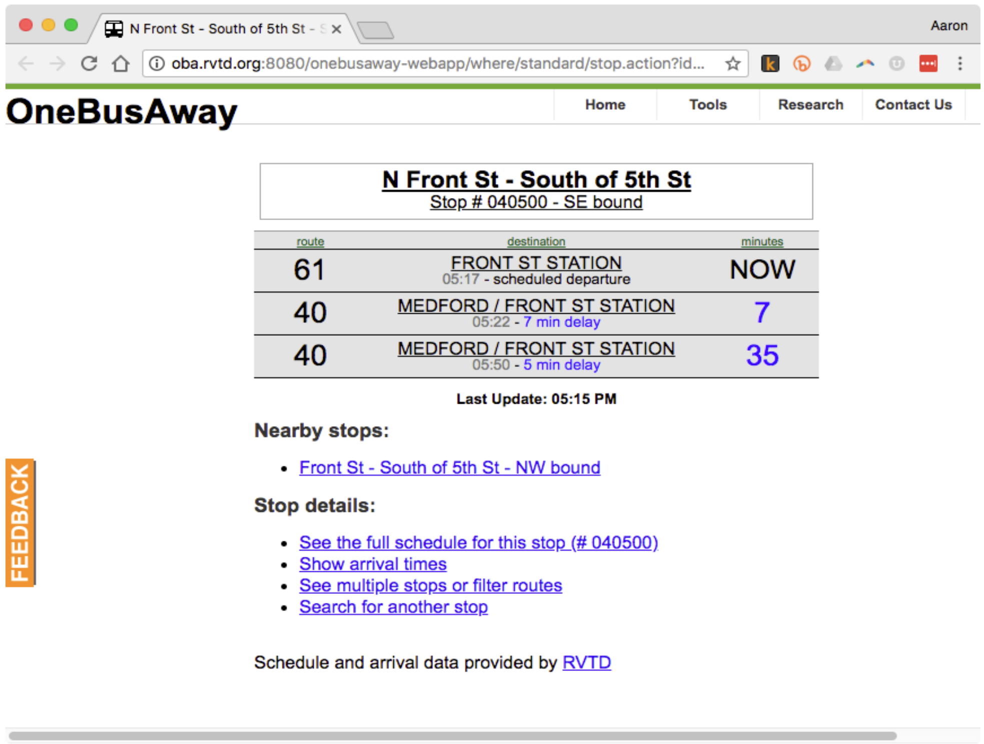
Websites can show arrival estimates, a vehicle location map, or service advisories. One example is MTA's Bus Time, based on OneBusAway, which allows riders to search by intersection, route, or stop code to find arrival predictions, service alerts, and real-time bus locations on the map.



A view of a specific vehicle on the B63 route in Bus Time.



Example of the OneBusAway web interface for Rogue Valley Transportation District



[Arrival predictions for N Front Street (Rogue Valley Transportation District) in OneBusAway]

Subscription-based alerts system	"Push notifications" by SMS, email, or app send alerts about transit service disruptions or changes. Examples include: ● Push message (subscriptions) feature in Transit app ● GovDelivery
Public (on-street) signage	On-street or in-building signage shows scheduled and predicted arrival times or other transit information. Common sign hardware types are LED, video monitor display, and E-Ink. Cascades East Transit has installed a monitor in one of their transit depots that shows real-time arrivals by using a transit widget[33] provided by the Transit App.
On-vehicle signage	Headsigns on the front of the bus indicate the route, direction, and/or a final destination of the vehicle. Interior signage can indicate the next upcoming stop. These signage systems depend on vehicle location (see location sensor) and on route/trip assignments (see vehicle assignments).  
Stop announcements (AVA/Automated Voice Annunciation)	An automated system triggered by bus location announces the next upcoming stop, which depends on the same inputs as on-vehicle signage.

Performance analysis and dashboards

Transit agencies use performance analysis and dashboard tools for several purposes, outlined below with example reports.

Purpose	Example reports & indicators
Dispatch and live monitoring	**Live Map:** Filter and locate vehicles in real time on a map, showing attributes such as on-time performance, headway adherence, or vehicle direction.
Public dashboards	Provide high-level decision-makers and/or members of the public with key high-level metrics such as system-wide or route-level schedule adherence.
Retrospective performance assessment and optimization	**GPS Playback:** Replay vehicle movements for a particular route or vehicle ID.
	On-Time Performance: Compare real vehicle arrival times to scheduled arrival times, analyzing on-time performance by route, stop, and time of day. Assess if vehicles go into service on-time.
	Vehicle Speed: Visualize vehicle speeds and dwell times to locate slowdowns. Where do vehicles travel slowly and incur delay, where queue jumps or transit signal priority could provide the most benefit? Incorporate boardings and passenger loads to determine how delay correlates to ridership demand.
	Runtime: Compare actual travel times with scheduled travel times and slack between trips, and view distributions of actual travel times for each scheduled trip.
	Missed trips: Which vehicle trips are scheduled but not operated (or not logged)?
	Customer-perspective metrics: ● Reliability: How frequently do delays occur? ● Travel time & access: What is the effect of delays on overall travel time and destination access? I.e. How much time is added to an average traveler's commute?
Mandated reporting tools	**Report production:** A reporting tool that uses historical vehicle location data to fulfill reporting requirements, for example for the Federal Transit Administration (FTA). In particular, such tools may provide "Actual Service Data" such as route miles and operating hours including deadheading and revenue service for the National Transit Database (applies only to "full reporters"). Full reporters are those with 30+ vehicles and/or fixed guideways; reduced reporters are those with less than 30 vehicles. Only full reporters also need to report passenger miles traveled (PMT).
Real-time system performance monitoring	**System status monitoring:** Monitor and log the status of the application and data streams. Send timely alert messages when application issues occur.
	Real-time prediction quality monitoring: A prediction monitoring tool records, analyzes, and benchmarks the quality of vehicle arrival predictions. This tool helps transit agencies ensure that vendors are meeting their contracted quality levels. This can pinpoint deficiencies in prediction accuracy and identify their potential causes.

Example performance dashboards

MBTA Performance System

The MBTA performance dashboard[34] (for Massachusetts Bay Transportation Authority in Boston) provides public on-time reliability, ridership, and financial information. The MBTA also has implemented internal dashboards, including to measure arrival prediction accuracy. MBTA's API for developers[35] makes performance metrics available to third-party applications. The performance management system consumes GTFS-realtime data, so it can sit upstream of any AVL and RTPI system that provides a GTFS-realtime Vehicle Positions feed. Some of the reports generated by the software factor in passenger arrival rates to better measure the effect of service disruptions and delays. MBTA plans to release the source code under an open-source license.[36]

TheTransitClock

TheTransitClock[37], maintained and led by Sean Óg Crudden from DynamicTime, is an open-source platform that uses historical and real-time vehicle location data to help transit agencies improve their services. It is utilized by several vendors, including goEuropa, Omnimodal, Cambridge Systematics and DynamicTime.

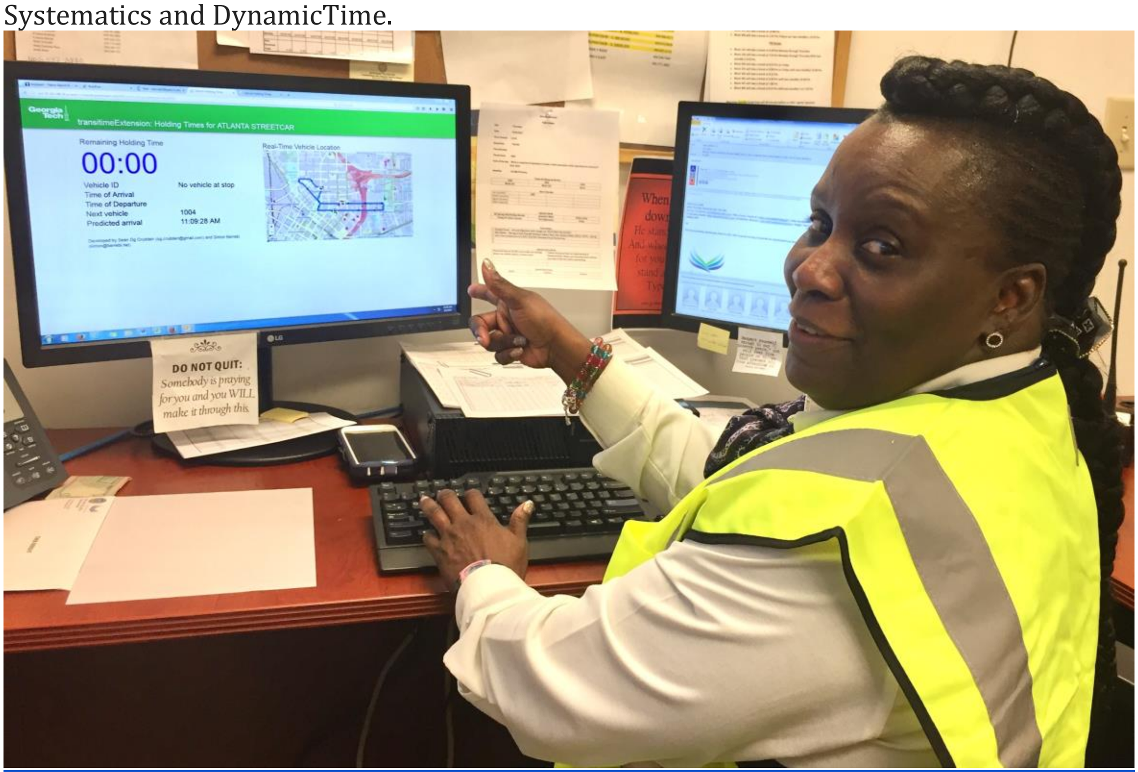


Figure 5: An Atlanta Streetcar dispatcher uses the DynamicTime dashboard.[38]

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[34] http://mbtabackontrack.com/
[35] https://www.mbta.com/developers/mbta-performance
[36] http://www.apta.com/mc/revenue/previous-conferences/2017revenue/presentations/Presentations/Performance%20Measurements%20Using%20Real-Time%20Open%20Data%20Feeds%20The%20MBTA-performance%20system%20-%20Ritesh%20Warade.pdf
[37] www.thetransitclock.org
[38] Image source: http://www.masstransitmag.com/article/12358944/from-research-to-practice-implementing-real-time-control-to-avoid-bus-bunching

OneBusAway

The open-source OneBusAway suite includes functions for assessing prediction quality. OneBusAway includes a Watchdog module,[39] which monitors and logs the status of the OneBusAway application and data input streams. Some OneBusAway instances connect Watchdog to Amazon Web Services Cloudwatch to send timely alert messages when application issues occur.[40]

Swiftly Insights

Swiftly Insights[41] is web-based software-as-a-service to store and analyze archived operational data, with reports and maps to analyze performance.

See List of vendors for those that offer performance reports.

Data & interface standards

The components of a single real-time system can be supplied by one to several vendors. A multi-vendor approach requires application interoperability & modularity — the capability for modules to be connected together and function as an integrated system.

Benefits of interoperability

Interoperability enables multi-vendor systems, which means that not all modules are supplied by the same vendor, or even installed by the same system integrator. Components from multiple vendors can be set up to work together to avoid gaps in functionality and enable greater system flexibility over the long-term.

Even for a single-vendor system, designing for interoperability maintains open doors for future opportunities. As practices change and needs and opportunities arise, information technology systems need to be remodeled and extended. Interoperability means new components, from any vendor, can communicate with each other using industry standard data formats. This helps to prevent vendor lock-in and can provide increased flexibility in the future. Seen as a building, an interoperable architecture will allow adding and remodeling rooms without replacing the entire structure. Interoperability enables the core components of a system to be procured by an agency in an initial phase, with confidence that additional components can be added later, procured from among a choice of vendors.

Interoperability also enables use of third-party applications and partnerships. Third-party applications, such as apps for trip planning and arrival estimates and public signage, are created by independent software developers and companies using official data feeds.[42] Third-party

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[39] Watchdog application code: https://github.com/OneBusAway/onebusaway-watchdog

[40] Watchdog announcement: https://groups.google.com/d/topic/onebusaway-developers/wH_kDZmPX3w/discussion
Watchdog & AWS Cloudwatch integration: https://github.com/OneBusAway/onebusaway-watchdog/issues/1

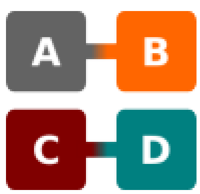
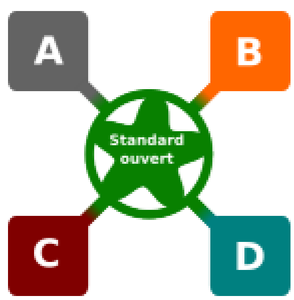
[41] https://www.goswift.ly/swiftly-insights/

[42] TriMet's definition: "Below, you'll find a list of apps created by independent developers that use our open data to provide similar information. These are not official TriMet products, and we do not endorse, warrant or support them." (https://trimet.org/apps/)

applications provide information channels that riders already use, like Google Maps. Such applications are available at no cost to the transit agency.

The Interoperability Working Group of the Association of Free Software Users[43] defines interoperability as “a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, in either implementation or access, without any restrictions.”[44]

The group distinguishes *interoperability* from *compatibility* in that interoperability requires many-to-many compatibility among systems.

Compatibility	Interoperability
	

<u>**Requirements for interoperability - Interface and data formats**</u>

Shared interfaces (application programing interface or API) and shared data specifications are necessary to achieve interoperability.

GTFS (static)

The General Transit Feed Specification (GTFS), also sometimes called “GTFS (static)” to differentiate it from GTFS-realtime, describes transit stops, routes, schedules, and fares. GTFS is generally updated not more than once every few days.
More on GTFS:
https://www.transitwiki.org/TransitWiki/index.php/General_Transit_Feed_Specification

Since real-time prediction systems need schedule, stop, and route information, GTFS is used as an input for many prediction and real-time systems, including Swiftly, OneBusAway, NextBus, and vendors that use TheTransitClock (DynamicTime, Omnimodal and Cambridge Systematics). This

[43] https://aful.org/gdt/interop
[44] http://interoperability-definition.info/en/

provides efficiency advantages, because GTFS is also used by other applications such as Google Maps and OpenTripPlanner.

GTFS data needs to contain particular data elements and meet a quality standard in order to be a suitable configuration input for real-time systems. For notes on GTFS (static) requirements for "Arrival Predictions", see http://gtfs.org/best-practices/. Below are some important notes.

- A **block** "refers to a vehicle schedule, the daily assignment for an individual bus."[45] GTFS has a block_id to express this vehicle schedule: "The block_id field identifies the block to which the trip belongs. A block consists of a single trip or many sequential trips made using the same vehicle, defined by shared service day and block_id."[46] For GTFS-consuming real-time systems, block_id in the trips.txt file is necessary for proper assignment of vehicles to routes.
- **Transit Hubs/Stations** present a unique problem because technically they are considered one "stop" (and thus share a common passenger-facing stop code), but there may be several bays within that stop where different routes pick up or drop off passengers. Sometimes the distances between those bus bays is far enough that a single GTFS stop location isn't sufficient. In this case, a common solution is to specify separate stop records for each bay (with distinct stop_id) that share the same stop code.

Swiftly and systems that use TheTransitClock (DynamicTime, Omnimodal and Cambridge Systematics) have no special requirements beyond GTFS Best Practices. This supports broaded compatibility with GTFS and makes such applications faster and easier to deploy. Other applications may have specific requirements for GTFS files. To make these requirements implementable, it is necessary that they are clearly documented. To emphasize this point further, a vendor that makes product-specific GTFS requirements but does so with clear documentation provides a reasonable path to system implementation and interoperability, whereas unclear requirements present a significant barrier. As examples, some of the requirements from vendors that provide documentation are described below.

- **NextBus** specifies requirements for how agency GTFS files should be set up and delivered.[47] Only one agency_id should be referenced in the agency.txt and calendar.txt files. If multiple agencies are represented in the GTFS file, they must share one agency_id, as well as conform to the same calendar configuration. In the calendar.txt file, it's preferred that all services have the same start_date and end_date and that only one service record is defined for each day of the week (whether it be wkday/sat/sun, or m/t/w/r/f/sat/sun, etc.). NextBus requires that all trips be assigned to a block_id. They also recommend that block_ids, stop_ids, route_ids, and agency_ids remain the same between updates.

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[45] http://www.actransit.org/customer/transit-glossary/#block
[46] http://gtfs.org/reference/#trips
[47] NextBus GTFS Manual: https://drive.google.com/open?id=1w-8xOUnCZ7Wk_ZUhOp6IH_ubKrVfqs0B
NextBus supported data elements in the GTFS-rt spec: https://drive.google.com/file/d/1N3WMbNOA-zapOeTwTFFV7qRZj5OYdecd/view?usp=sharing

- **Syncromatics** has some similar requirements as above and requires a Runcut.txt[48] file that identifies driver runs (distinct from blocks). IDs for stops and routes need to be changed to match Syncromatics values.

GTFS-realtime

GTFS-realtime is an extension or companion format to GTFS. The format is based on protocol buffers (protobuf) for compact data packets and fast transmission. Data elements are related to IDs in a GTFS (static) feed. GTFS-realtime can be used to provide real-time information in three separate feeds:

- Trip Updates - Predictions of when the vehicle will arrive.
- Vehicle Positions - Locations of vehicles.
- Service Alerts - Advisories of service exceptions, attached to particular agencies, routes, stops, and trips.

More on GTFS-realtime here: https://www.transitwiki.org/TransitWiki/index.php/GTFS-realtime.

GTFS-realtime can be used as an input for the following systems:

- Signage
- Mobile apps & trip planners
- SMS
- IVR
- Websites
- Historical analysis
- Push notification systems
- Prediction accuracy assessment

The only real-time transit data format that Google Maps ingests is GTFS-realtime, which confers a very significant advantage for using GTFS-realtime. However, GTFS-realtime is only accepted in a protocol buffer format, which is highly efficient but not human readable. Bing Maps[49] is currently developing an environment to provide GTFS-realtime data in their maps, which will be live by late summer, 2018. They will accept all three GTFS-realtime feeds, but at this stage only Trip Updates will be displayed in the maps.

Software-specific interfaces

Many pieces of software provide their own data interchange formats and interfaces. These APIs may be called "open" in the sense that they are available to third-party applications, but since they are idiosyncratic to the particular software they do not represent shared industry standards. This means that a software-specific interface may offer some of the benefits of interoperability, but not the same level of broad compatibility (i.e. approaching "plug-and-play") as provided by industry standard interfaces like GTFS-realtime. In some cases, however, a software-specific API may make some functions available that are not included in a shared industry standard such as GTFS-realtime.

[48] How Syncromatics runcut.txt file fits into GTFS
[49] https://www.bing.com/transit

NextBus API	The NextBus API makes arrival estimates and other information available to third-party applications. The IDs for stops and routes in many NextBus implementations do not align with those in the GTFS (static), posing barriers to integrating trip planning and real-time in third-party applications. NextBus provides a GTFS-realtime feed at an additional cost. The NextBus is mentioned here because of its historical popularity, with many data consumers utilizing the NextBus API.
Other vendor-specific/idiosyncratic APIs	Many other vendors offer idiosyncratic APIs, which pose the same limitations as the NextBus API.
Swiftly, TheTransitClock, and OneBusAway APIs	The Swiftly, OneBusAway, and TheTransitClock APIs make arrival estimates and other information available to third-party applications. The IDs for stops and routes in these APIs align with those in the GTFS (static) feed. All applications also provide GTFS-realtime for broad compatibility with many third-party applications.

SIRI (Service Interface for Real Time Information)

"SIRI is a CEN Technical Standard that specifies a European interface standard for exchanging information about the planned, current or projected performance of real-time public transport operations between different computer systems."[50] SIRI derived from Transmodel, the European data reference model for public transport. While not commonly used in the United States, global vendors do support SIRI, and it is used prominently by New York MTA[51] and in OneBusAway and TheTransitClock.

USDOT standards

The National ITS Architecture defines standards for "intelligent transportation systems" (ITS) including vehicles, roadways, and public transit. However, the suite of standards do not appear to be consistently practical, as evidenced by the absence of full implementations.

50 http://www.transmodel-cen.eu/standards/siri/
51 http://bustime.mta.info/wiki/Developers/SIRIIntro

Other interfaces

This [Transit Developers thread] offers a good comparison of various specifications for transit data, including SIRI, NeTEx, TransXChange, GTFS-realtime, and TCIP. The APTA-developed TCIP (Transit Communications Interface Profiles) has not been used for agency-to-external data streams, but has been used for some internal systems at New York MTA.[52] There are not universally interoperable data standards available for many other interfaces within a modular real-time system. Some vendors offer standard interfaces that are in regular use, and so it is up to implementers to research interoperability opportunities and implications.

The following table lists some interfaces between other systems.

Components or functions to connect	Interface options
Providing vehicle locations to a real-time passenger information system (RTPI)	There is no industry standard; vehicle locations are transmitted from an AVL component to an RTPI in various data packets.
Providing vehicle assignments from computer-aided dispatch (CAD) to a real-time passenger information system (RTPI); linking a particular vehicle (and location sensor) with a scheduled block (see definition of blocks).	There is no industry standard. This is accomplished through vendor-specific means, making it necessary for an RTPI vendor to implement support for specific methods.
Onboard components including automatic vehicle location, farebox, automatic passenger counting (APC), signage, and automated voice annunciation	Local connectivity between these components is provided by an on-vehicle network: SAE J1708 / J1587 standards,[53] ethernet, Bluetooth, or Wi-Fi.

Open data: security and data ownership

Agencies need to specify data ownership and access rights in contracts with service providers to ensure their full access and ability to use data. Critical terms include:

- Free access to APIs and downloadable reports.
- Free access to documentation necessary to utilize APIs.
- Right to archive, analyze historical data.

All rights should be irrevocable, perpetual, unrestricted. Alternately, all data could be owned by the agency upon download. Suggested requirements for a procurement document appear in Appendix A.

Additionally, agencies need to make data available to third parties under "open" terms to get the maximum value out of real-time transit system investment and ensure that travelers have access to

[52] https://groups.google.com/d/msg/transit-developers/FjV406J-PPg/MSubzvFwvJwJ
[53] http://copperhilltech.com/a-brief-introduction-to-sae-j1708-and-j1587/

real-time information in their transit apps of choice. These terms may need to be required of a vendor or service provider, and/or implemented the vendor or service provider's participation.

There can be two layers of licensing for real-time open data to third-parties:

- **data license,** which may be the same as for GTFS (static) data. Currently there is no single standard for government open-data licenses. Transit.land provides a model open data license[54], which under which the paper authors recommend licensing transit data. Another suitable option is the CDLA-permissive license (Community Data License Agreement)[55].
- an application programming interface (API) or data format/specification **documentation license** to access the data, representing a contract between the transit authority and the app developer.[56] GTFS-realtime, which the paper authors recommend for agencies to publish, is licensed under the Apache 2.0 License[57] license, which permits broad use of the specification (but not necessarily published data), including commercial and private use, modification, and distribution.

"Since the underlying data cannot be accessed without the developer's agreement to the terms of use for the API, these terms add a layer of contractual obligation which may, in some cases, be significantly different from the terms of the open data license." However, in the United States, transit authorities have shifted towards a new approach that involves a single 'Developer's License Agreement' that merges the two agreements and covers both the rights to data and the terms of any API use.[58]

[54] https://drive.google.com/open?id=1mIMc0ccn9Rab4XCF-1Qs6ozMyi1qZvSg
[55] https://cdla.io/permissive-1-0/
[56] https://gcn.com/articles/2017/02/07/transit-data-open-licensing.aspx
[57] https://www.apache.org/licenses/LICENSE-2.0
[58] Scassa, Teresa and Diebel, Alexandra, Open or Closed? Open Licensing of Real-Time Public Sector Transit Data (December 19, 2016). (2016) Journal of e-Democracy 8:2, 1-19; Ottawa Faculty of Law Working Paper No. 2017-02. Available at SSRN: https://ssrn.com/abstract=2887339

Planning and design

There are many things to consider when an agency decides to implement a new real-time system. Instead of a completely new system, this may involve modifications and additions to an existing real-time system if it exists. In either case, planning and design are key.

In cases where the agency wants technical oversight outside of their vendor but does not have in-house staff with the time or skills to provide this, an outside consultant can be useful. Some transit agencies hire a consultant to assist with system design, integration, implementation, and/or monitoring. It seems these tend to be larger agencies (i.e. with 50 or more buses). This is likely because with a larger and costlier project, there is more opportunity to reduce overall project cost or achieve a better value through receiving outside technical guidance and perspective. However, technical perspective outside of that of a single vendor is almost certainly useful for every size of agency.

Below are suggested steps to take for procurement of a real-time system.

1. Consider objectives. Is the primary objective to provide a better passenger experience? Is it to improve on-time performance or operational efficiency? Or is the objective to comply with reporting requirements? How important is designing for modularity and preventing long-term single-vendor lock in? There will likely be multiple objectives; it is useful to rank them and distinguish between core objectives (most important) and nice-but-nonessential (least important).

Answering these questions fully will help to guide system design. Providing this information to potential vendors in a procurement instrument will allow them clear guidance on core objectives while also allowing them freedom to propose diverse approaches.

2. Identify and document existing resources, including:

- Technology. This inventory should include manufacturer and model for hardware, and, if applicable, available interfaces, APIs, or data formats for connections to other systems. This information is useful and necessary to decide which systems to replace and which to retain and integrate. This is a determination that could be made by the agency in advance of procuring the system, or by a proposing vendor or system integrator on the basis of a cost efficiency or value recommendation. Existing agency technology and data may include:
    - AVL or on-board GPS
    - On-board connectivity
    - Schedule and stop data, e.g. GTFS
    - On-vehicle signage
    - Off-vehicle signage
- Available staff and time and relevant expertise for transit technologies.

3. Consider an industry survey in order to develop understanding of possible solutions the marketplace can offer, including state-of-the-practice and state-of-the-art solutions. This can take the form of a Request for Information (RFI) or a more informal survey. In addition, informal interviews with vendors and consultants, prior to the release of an RFP/RFQ, can yield insights and provide a chance to test ideas and hone thinking. This is an opportunity to signal needs, priorities, and intentions to potential vendors before the release of an RFP/RFQ, which may improve the quality and/or breadth of responses.

Conducting a broad survey makes it possible to benefit from current industry perspectives, but also to have conversations with vendors in a way that is fair, because an electronic survey with broad distribution and many respondents can be conducted without excessive effort. Free electronic forms such as Google Forms, SurveyMonkey, or SoGoSurvey are some useful tools (among others).

The survey might ask for:

- Descriptions of the products offered by the vendor
- Recommended requirements to specify in an RFP, and why
- Recommendations of what NOT to put in an RFP, and why
- Whether the vendor is able to do a limited-scale pilot, and at what cost
- Open-ended comments

The survey introduction also might supply information and statements such as:

- Background on the anticipated procurement process
- The agency's priorities and objectives for the project
- A note that explicitly positions the survey outside of the official procurement, e.g. "A response to this survey is not necessary to be eligible to respond to any RFP that may be released. Responses to this survey will not factor into any later proposal scoring process. No statements made by [agency] during this survey process shall constitute a later commitment for this project or any procurement process."

For an example of an industry survey that followed the above process, see this survey instrument for ride-matching software conducted by the Vermont Agency of Transportation: https://goo.gl/forms/CvXEzuiGSzTS9BZw1 or this survey conducted by PVTA for paratransit scheduling software: http://www.sogosurvey.com/preview.aspx?k=YsYYVSXsR.

The survey can be distributed to a list of vendors (see vendor survey for some possibilities) and to mailing lists such as transit-developers and TRANSP-TDM@LISTSERV.USF.EDU.

Summarize responses from the electronic survey, and schedule follow up calls with respondents with compelling perspectives or whose responses generate additional questions.

Finally, synthesize lessons from the industry survey: are there new opportunities or notes of caution to consider? Some respondents may offer recommendations that are at odds with each other. The procuring agency will need to either make a determination of which respondent is more trustworthy, or decide to side-step the question and avoid specifying a requirement in the procurement instrument.

4. Assess and prepare for capacity to maintain the system. Consider the tasks which would not be performed by the vendor(s)/consultant(s), or which will need significant input and participation from the agency staff. What does ongoing support for a real-time system typically mean for agency staff (drivers, operators, and planners)? Potential for staff turnover and training time should be evaluated. If there is limited staff time, specify requirements to make the best use of available staff time. Potential new tasks for transit agency staff might include:

- Ongoing monitoring to make sure all GPS/buses are reporting.
- Reviewing system reports for schedule adherence and finding opportunities for schedule changes/improvements, as part of the service planning process.
- Training new drivers/dispatchers to use the system.

- Hardware maintenance - road calls, RMAs to return equipment, equipment replacement.
- Monitoring prediction quality.

For agency experiences with these tasks and associated time, see the Agency experiences section.

5. Prepare for the procurement or pilot(s) by synthesizing requirements out of the above steps.

Procurement

Depending on the components desired, a transit agency may choose to procure a contract with a single vendor or multiple vendors to implement the best value, best-of-breed system. The agency may release several distinctly-scoped requests (procurement instruments) for specific functions and modules or may release a consolidated request that allows vendors to bid on single or multiple component parts. Procurement instruments for distinctly-scoped components require should require vendor-neutral interoperability through the support of standardized data and APIs. This prevents pre-ordaining an outcome through vendor-specific interfaces.

Procurement can be conducted by a Request for Proposals (RFP) or Request for Quotes (RFQ). A two-step procurement is allowed through the FTA 4220.1F, but Oregon 279b is more restrictive. FTA procurement guidelines that specify “Recipients are not allowed to divide or split the procurement to avoid additional procurement requirements that apply to the larger acquisitions.”[59]

Issuing a procurement instrument (RFP/RFQ) is the traditional way of selecting a vendor and purchasing services. It is recommended that agencies be cautious of requirements bloat because it may unhelpfully limit vendor responses and the approaches. Requirements bloat can be avoided by (1) carefully selecting requirements, and (2) avoiding uncritical recycling (copying/pasting) of scopes of work and requirements from previous procurements: these requirements may become out of date or not be applicable to all agencies.

Many agencies also find that it is useful to conduct a **limited-scale pilot** to “test drive” software and hardware. A limited-scale pilot makes it possible to evaluate a system and a vendor through hands-on experience rather than relying purely on a proposal response for this evaluation. A pilot that is implemented for a limited duration (for example, for three months) and on a subset of the vehicle fleet (for example, for one or two vehicles) can allow the transit agency to:

- Discover configuration issues or challenges.
- Test the accuracy of arrival predictions.

- Identify connectivity issues.
- Begin to make assessments of schedule adherence.
- Test automatic vehicle assignment features (if offered by the vendor).
- Test any driver and dispatcher interfaces for effectiveness and ease of use.
- Evaluate reporting function usefulness and ease of use.

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[59] Federal Transit Administration, “Best Practices Procurement & Lessons Learned Manual” October 2016. FTA Report No. 0105. Page 54
https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/funding/procurement/8286/fta-best-practices-procurement-and-lessons-learned-manual-2016.pdf

- (In select cases) Solicit feedback from riders, though there are barriers to providing rider-facing information when the real-time system is not implemented throughout the fleet (customers will not consistently be able to access real-time information).

A test pilot can be initiated by selecting vendors to provide pilot services within an agency's discretionary purchasing threshold. After the pilot, a successful pilot vendor can be directed to perform full implementation of the real-time system.

At a minimum, the scope of work and requirements in an RFP or RFQ for the core of a real-time passenger information (RTPI) system should include:
- Key objectives and priorities (See planning and design)
- Information about relevant legacy systems in use (See planning and design)
- Requirements for modularity and interoperability (see data & interface standards), as well as requirements dictated by funding source. Core recommended requirements are:
  - Stops, routes, schedules, and blocks should be configurable using standard GTFS (static) datasets, defined by the GTFS Best Practices at gtfs.org/best-practices. This supports interoperability with GTFS-publishing applications and easy configuration and updates of the real-time system.
  - The application should produce GTFS-realtime feeds (Trip Updates and Vehicle Positions, at a minimum) that comply with the latest GTFS-realtime documentation[60], which at the time of writing is version 2.0[61]. The vendor should be able to assert that a third-party application is successfully consuming a GTFS-realtime feed from the system.

If the agency requires or strongly prefers particular specifications or features, these may also be incorporated in the procurement. These may include, for example:
- Vehicle assignment approach: Either automatically assigned (by software) or manually assigned through a dispatch or operator interface
- Modularity — required interfaces with other systems, beyond the GTFS and GTFS-realtime requirements, for example:
  - Capability to receive location data from installed AVL and GPS
  - Capability to interface with signage system
- Required reports, e.g. for:
  - On-time performance
  - Vehicle miles traveled
  - Unassigned vehicles
  - Prediction accuracy metrics
- Acceptance requirements, e.g. minimum prediction accuracy (however, it will present an additional task to define realistic and measurable accuracy thresholds; such thresholds may be developed as a follow up to this white paper)

[60] https://github.com/google/transit/blob/master/gtfs-realtime/spec/en/reference.md
[61] https://medium.com/@sjbarbeau/whats-new-in-gtfs-realtime-v2-0-cd45e6a861e9

The procurement instrument (RFP, RFQ, etc.) should allow various license models, or, if a single and/or specify the preferred license models is preferred, specify that clearly., such as: Different license models have different strengths and advantages:

> ***Open source software*** is a software application under a license which states that any party may use and adapt the software source code for their own purposes. There are a variety of open source licenses, some of which prevent or explicitly allow the adaptation of the software for commercial purposes. ***Source code*** for software can be thought of as the equivalent of a recipe for food. The Linux Information Project defines source code: "(also referred to as source or code) is the version of software as it is originally written (i.e., typed into a computer) by a human in plain text (i.e., human readable alphanumeric characters)."[62]
>
> ***Installed and licensed software:*** Traditionally, software applications have been purchased as an ***asset***—a license fee or development fees are paid for a copy of an application that is then hosted either by the vendor or purchasing agency. That application in the delivered version is an asset that the agency owns (though perhaps only under restricted terms). Support and maintenance costs can then be managed through a variety of forms, but generally are low relative to the up-front cost of the initial expenditure and meant only to keep the software application running in the delivered state. In this model, the software application fits into the agency's system in a manner that is defined at the time of installation. Changes to the integration may be possible, but also might not be practical.
>
> ***Software-as-a-Service (SaaS)*** is a license model where a vendor commits to delivering particular results, not a particular piece of software. Subscription fees are paid on a recurring basis. The SaaS model has the benefit of ensuring that software upgrades or enhancements will be made available within the SaaS license terms, shared amongst all users.

Non-essential specifications are recommended to be omitted from core requirements and/or listed as an optional/desired feature. It is recommended to specify fewer requirements to allow proposers
more creativity in their responses. A less prescriptive request for proposals and qualifications (focused on objectives, rather than specifications) can yield more respondents and a range of approaches.

To choose vendors, evaluate proposals based on their responsiveness to core objectives and to the experiences of references. It is highly recommended to interview references thoroughly on their experience using the system and interacting with the vendor, and to seek out some clients of the proposing vendors who are not listed as references in their proposal. In particular, it is useful to verify claims of interoperability and open data: ask references about the success, ease, and cost of

[62] http://www.linfo.org/source_code.html

integrations with other vendors and systems, for example, whether GTFS-realtime data from an RTPI is implemented in Google Maps and other third-party mobile apps. Suggested template scope and requirements appears in the Appendix.

Implementation

The details of implementation steps and process will depend on the vendor(s) and system(s) that are selected. In general, implementation steps will include the following:

1. Schedule data preparation: If GTFS data is used as an input (as is generally recommended), the GTFS data may need to be modified for use as a configuration input:
    a. block_id values need to be present.
    b. stop locations, schedules, and patterns need to be accurate.
2. Hardware installation: Devices need to be installed on-board the buses, either by the vendor, a local installation contractor, or maintenance staff.
3. Testing: When the system is implemented, test the accuracy of the predictions and review if vehicles are consistently assigned to a route/trip so that predictions can be generated.
4. Public beta: Perform a limited public rollout, announcing the real-time app, phone number (SMS and IVR), or other customer interfaces, along with a request for customers to share feedback. By calling this a public beta, customer expectations will be adjusted to expect and tolerate occasional inaccuracies.
5. Full public rollout: Once the agency is confident in the reliability of the system, conclude the beta period and announce the system is fully implemented.

Operation

Once a real-time system is implemented, it needs to be maintained and monitored. These are the ongoing tasks that need to be undertaken:

1. **Keep data inputs up to date:** GTFS (static) with schedules, blocks, and stop locations needs to be kept current for all schedule changes, and maintained according to GTFS Best Practices. A vehicle "block" is the schedule of travel of a vehicle for a given day, including: (1) a pull-out from the depot, (2) a sequence of trips from the timetable, (3) any deadhead trips, and (4) a pull-in back to the depot. Blocks or blocking, at the very least for passenger revenue trips, is necessary for a real-time system to anticipate the scheduled trips for a particular vehicle and generate predictions accordingly. This information will need to be maintained with each schedule update.
2. **Monitor passenger usage and feedback:**
   - Apps: Many mobile apps can provide analytics on usage and requested queries. *Transit*, for example, through their partner program, provides information about number of users, origin and destination for trip planning requests, real-time information lookup requests, and traveler mode choices. This information can be used to assess the impact and usefulness of real-time information to customers, and to get insights about travel demand and behavior. More information about the partner program is available under Mobile Apps - Transit.
   - SMS & IVR: Similarly, as for mobile apps, SMS and IVR systems can track number of queries system-wide and for particular stops.
   - Customer feedback on the real-time system can be solicited through a website, mobile app, and/or other mechanisms. It is important to continuously gather customer feedback in order to discover and address issues quickly.
3. **Monitor operational performance:** A real-time information system and operational performance monitoring system does not itself identify and resolve operational issues. Particular staff must be assigned to monitor operational performance and study reports on a regular interval. Potential issues that may be identified include:
   - A schedule may be unrealistic, with too little or much travel time scheduled, owing to travel distances, passenger demand, or traffic
   - A driver may not be following the schedule or route.
   - A consistently late or early departure from a stop may actually indicate that the stop is misplaced in the source GTFS (static) data.
   - Similarly, a vehicle consistently not following the route may indicate the route alignment is not correct in the source GTFS (static) data.
4. **Monitoring prediction accuracy & real-time system performance:** The system needs continuous monitoring to determine that:
   - It is providing reliable arrival predictions to users

- On-board AVL/GPS equipment is operating and reporting locations (that is, scheduled trips are being reported/logged)
- Operating vehicles are being assigned to routes (matched to schedules)

List of vendors

This spreadsheet lists results of an extensive but non-comprehensive survey of vendors[63] conducted from late 2017 through early 2018. The components provided by each vendor are listed.

Establishing benchmark costs for real-time systems is a significant research effort as prices are changing, and different systems and contracts include different components in the total price. The range of cost is significant. One example project from 2013 is a $3.3 million contract for the supply of automated vehicle location, demand response, integrated ticketing system, voice and data radio system, Intelligent Transportation (ITS) and Real Time Public Information (RTPI) system for the Golden Empire Transit District (GET) in Bakersfield California.[64] At the time, GET had 83 fixed-route buses plus 19 demand response vehicles.

In 2017, Tillamook County Transportation District (8 vehicles) implemented a real-time passenger information system (RTPI) with performance reporting dashboard at a cost of $20,450 for implementation and hardware and one year of software-as-a-service subscription and wireless fees.

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[63] https://docs.google.com/spreadsheets/d/1KISVEeoFNRBuM3T80gbm8AG5m_FZw9_9a2ChaiSeJ5E/edit?usp=sharing

[64] http://www.connexionz.us/news/bakersfield-selects-connexionz/

Agency experiences in Oregon

See also: Appendix B. Real-time transit information in Oregon

The authors of this paper interviewed four transit agencies in Oregon — Rogue Valley Transportation District (RVTD), Cascades East Transit (CET), Tillamook County Transportation District (TCTD), and Corvallis Transit System (CTS) — about their experiences procuring, implementing, and operating real-time information systems from TripSpark (formerly Mentor Engineering), Connexionz, and Swiftly. Below is a digest of their responses.

Procurement

In every case, the agency staff time for research, procurement and selection, and contracting exceeded (in some cases, very significantly) the staff time for system configuration, installation, and acceptance testing. The reported time for procurement-related activities ranged from 2.5 months of staff time to just over one week. Less recently procured and more expensive systems appear to have necessitated more involved procurement process, while more contemporary and less expensive systems took significantly less time to procure.

- RVTD
    - The system was installed around 2011.
    - RVTD reported approximately 400 hours of time initially for research, procurement, selection.
    - They invest 40 hours per year in contract oversight.
- TCTD
    - Reported that procurement and contracting did not take much time. Because of the smaller dollar value of the procurement, it was called “intermediate procurement” under Oregon DOJ rules.
    - Most of the time was spent writing a memo to the board to explain the purchase and then setting up the pilot.
    - Over the previous year, TCTD had been conducting an informal survey of technology providers to get a sense of the market and cost ranges.
    - By using a modular approach, TCTD continued to use existing systems such as the Hanover electronic signs installed on their vehicles.
- CET
    - Reported 30 hours of time to undertake the procurement process. Most of that time was spent doing research.
    - The staff spent 20 hours collectively to assess proposals and select a vendor.
    - CET reported that using a modular approach — separating the system into components — was advantageous for vendor negotiation: by requesting line item

(per component) costs and a la carte purchasing, it was possible to identify and negotiate for the best value system components from various vendors.

- **CTS**
  - Reported 1 month of time for contracting and procurement.
- **Columbia Gorge Express**
  - The system was procured by their contractor MTRWestern. Unknown procurement time.

<u>**Installation & Implementation**</u>

Device installation time varied based on the components installed:

- **RVTD**
  - The system included mobile data terminals, automated stop annunciator, and automatic passenger counting with wiring.
  - Installation was completed by an installation team that was subcontracted to the system vendor, which took about 5-6 hours per vehicle.
- **CET**
  - CET utilized off-the-shelf wireless routers (the Peplink BR-1 mini,[65] which cost about $300 per vehicle).
  - Installation was performed by CET's maintenance staff. For the first few installations, it took about 2 hours per vehicle, and subsequently about a half hour per vehicle.
- **TCTD**
  - TCTD utilized GPS tracker devices that were hardwired into on-board vehicle diagnostics (OBD port) connector interfaces. The OBD port connects to a vehicle's self-diagnostic and reporting system. OBD systems give the vehicle operator or repair technician access to the status of the various vehicle subsystems.
  - Installation was performed by TCTD service technicians, taking about 1-2 hours per vehicle.
- **Columbia Gorge Express**
  - Their system uses tablet-based tracking, which took 1-2 hour per bus to install.

<u>**Data preparation**</u>

No interviewed transit agency said that data preparation was a time-intensive task.

<u>**Third party app integration**</u>

- **Google Maps**
  - Once a GTFS-realtime feed has been provided, it can typically take 1-3 months for the Google Transit team to implement, review, and launch the feed.
- **Transit App**
  - With Swiftly, Transit app integration can be implemented in two weeks.
- **OneBusAway**

[65] https://www.peplink.com/products/max-cellular-router/single-cellular/#br1mini

- OneBusAway requires an instance (OneBusAway server) to be available for 99.5% of the time of a 30-day period, in order to be added as a "production region" in the shared OneBusAway app.[66]

Training

Training time mostly consisted of an initial training of drivers and dispatchers on the new system.

- **RVTD** reported spending roughly a total of 40 hours a year on training incoming drivers and refresher training for existing drivers.
- **TCTD** dispatchers received one-hour long training sessions on how to use the new Swiftly dashboard.
- **CTS** employees required one day each to be trained.
- **Columbia Gorge Express**
    - Three employees received 1.5-hour training sessions for the route/schedule editing software that is part of their system.
    - The system has been running for 2 weeks and drivers/dispatch are still in a learning process.

Operation

- **RVTD**
    - RVTD spends approximately 40 hours per year looking for opportunities to improve schedules and routes and reviewing stop activity data.
    - They check GPS/bus reporting reliability using OneBusAway about 8 hours a year.
    - They spend 200 hours a year (5 FTE weeks) on road calls, and RMAs to return or swap equipment.
    - About 40 hours a year are spend on exporting GTFS from Trapeze, updating the Gateway real-time adapter and GTFS website hosting.
- **TCTD**
    - Overtime costs have dropped by $18,000 per year by crafting more forgiving vehicle schedules at specific timepoints.[67]
    - Call volume has decreased 90%, representing $15,000 per year in regained productivity, by implementing accurate real-time passenger information.
    - TCTD performs an analysis of route performance 2 to 3 times per year that takes approximately 3-5 hours.
    - When they receive calls from riders about missing or habitually late buses, they use the Swiftly GPS historical playback to identify possible driver issues. Previous investigations involved pulling video from the bus and could take days to complete. The Swiftly dashboard feature allows them to investigate in real time when these issues arise.
- **CET**

[66] https://github.com/OneBusAway/onebusaway/wiki/Multi-Region

[67] https://medium.com/@SwiftlyInc/back-to-tranquility-swiftly-restores-transit-calm-on-the-oregon-coast-fc98b1f5cca7

- CET has been able to pull insights from spending very little time reviewing schedule adherence reports.
- **CTS**
  - CTS devotes 30 minutes per week to reviewing schedule adherence reports.
  - Dispatchers assign buses to routes and make sure that all GPS devices and buses are reporting on a daily basis.
- **Columbia Gorge Express**
  - Pulling reports is fast, but the review and data manipulation may take 1-2 hours.
  - CGE plans to review reports at least once a week.
  - They regularly check if vehicles are reporting throughout the day. A total of 1 hour per day.
  - They plan to review runtimes/dwell times once a month in order to improve schedules. This takes 1-2 hours

Recommendations for ODOT & Regional Organizations

The engagement of a regional organization like ODOT in transit technology can be designed to support local priorities, enact state-level priorities, or blend local and state-level priorities. ODOT can be prescriptive or permissive in its approach to technology requirements. A prescriptive approach can help to fulfill region-level priorities. A permissive approach allows transit providers to experiment and to pursue local priorities. Overall, the prescriptive and permissive approaches are not actually mutually exclusive. Instead, ODOT can define requirements and create programs related to the most important state-level priorities, while carefully preserving opportunities for local technology choice. For example, one approach might be setting data requirements or guidelines on a regional level, while also allowing a choice of vendor.

Blending and balancing priorities also requires deciding which functions the ODOT should take responsibility for, and which functions local organizations should be responsible for, perhaps with some level of support from the regional organization.

Below are functions and actions which the consultant team suggests ODOT might best pursue.

Standards-setting: Recommend or require real-time systems that comply with industry standards for interoperability, such as GTFS and GTFS-realtime, in order to support system modularity and compatibility with statewide and third-party applications. Education for transit agencies can help them to understand and appreciate the benefits of interoperability. A soon-to-be-published document from TransitCenter called *"The Data Transit Riders Want: A shared agenda for public agencies and transit data application developers"* will be a useful education resource for transit agencies.

Regional organizations should be permissive of piecemeal (local) procurement of modular systems. Achieving regional integration and seamlessness can be achieved through modularity and interoperability rather than a top-down or monolithic decision-making model, by pursuing the guidelines and processes outlined in this white paper. This will make it possible for organizations to choose and purchase software and hardware that will work together as an integrated system.

Statewide contracts with standards-compliant vendors: Interviewed transit agencies stated that contracting and procurement was time-intensive. By securing contracts with standards-compliant vendors and allowing transit agencies to purchase through those agreements, ODOT could save transit agencies significant staff hours.

Piloting and experimentation: Various real-time systems have already been implemented in the state. We interviewed 3 transit agencies with these systems. Swiftly (software-as-a-service) and TheTransitClock (open-source) both appear to be the most standards-compliant and would be good candidates for pilots. Interoperability with other components like displays, computer-aided dispatch (CAD), and stop annunciation needs to be further developed. ODOT may be in a position to signal this need so the industry will respond.

Knowledge sharing: Encourage transit agencies that implement real-time systems to share procurement documents and notes on their experience.

Support directories of real-time data: Add real-time data to oregon-gtfs.com and support initiatives to add real-time to global directories such as Transit.land and TransitFeeds.com.

Validation and accuracy assessment: Various systems in development and in production are available to check for adherence with the GTFS-realtime format and to assess prediction accuracy. Transit agencies most often do not have trusted, neutral tools to for these functions. The state could play a role by hosting and operating these systems (or participating in a larger centrally-hosted instance if that became available). This would allow transit agencies to assess the quality and performance of the systems that they procure.

Glossary

API - Application Programming Interface. An API is a set of commands, functions, protocols, and objects that programmers can use to create software or interact with an external system. Real-time transit APIs generally make arrival estimates, vehicle locations and other information available to third-party applications.

Block "refers to a vehicle schedule, the daily assignment for an individual bus."[68] GTFS has a block_id to express this vehicle schedule: "The block_id field identifies the block to which the trip belongs. A block consists of a single trip or many sequential trips made using the same vehicle, defined by shared service day and block_id."[69] For GTFS-consuming real-time systems, block_id in the trips.txt file is necessary for proper assignment of vehicles to routes.

Latency - a measure of "real-timeness", which also depends on real-time passenger information (RTPI) components downstream from the location sensor. Latency is the time (e.g. *x* seconds) for information to flow from its source (e.g. vehicle positions from onboard location sensor) to the customer interface. Low latency supports customer trust in the system; for example, a mobile app can notify the customer a transit vehicle is arriving at a stop or has left near the precise instant the event occurs. High latency diminishes the quality of the customer experience. Latency can be affected by many components and steps in the system, including vehicle location transmission and GTFS-realtime data publishing.

Limited-Scale Pilot - A limited-scale pilot makes it possible to evaluate a system and a vendor through hands-on experience rather than relying purely on a proposal response for this evaluation. A pilot that is implemented for a limited duration (for example, for three months) and on a 1 or 2 vehicle subset of the fleet. This can allow the transit agency to test software and hardware operation and prediction accuracy and identify connectivity issues.

Mobile Data Terminal - In public transportation, a mobile data terminal (MDT) is usually a portable computer added to a vehicle to assist with information and data management at service delivery. The computer may be a laptop, tablet computer, or customized hardware. There are many applications for MDTs such as managing paratransit trip manifests, collecting passenger and fare data, communicating with dispatch, and trip routing.

Modular - A system that is constructed using standards-based interfaces, allowing flexibility and variety in use. In this context, a real-time system can be broken down into components and functions that may be provided by the technologies of multiple vendors, but work together to make a more flexible system.

On-board Diagnostics (OBD) Port - The OBD port connects to a vehicle's self-diagnostic and reporting system. OBD systems give the vehicle operator or repair technician access to the status of the various vehicle subsystems.

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[68] http://www.actransit.org/customer/transit-glossary/#block
[69] http://gtfs.org/reference/#trips

Polling rate - The frequency with which location is transmitted to downstream components (e.g. every *x* seconds). Depending on hardware and software configuration, polling rate may be consistent, or it may be variable based on vehicle progress (more frequent when the vehicle is moving, less frequent when it's stationary).

Appendix

Appendix A. Suggested base real-time system requirements

These goal, understanding, and scope/requirements elements can be incorporated wholly or in part in a procurement document to fulfill on the principles and recommendations outlined in this white paper.

Project goals

The goal of real-time fixed-route transit data is three-fold, in this order of importance:

1. Provide customers with accurate information about when vehicles will arrive.
2. Provide agencies with actionable information about where their vehicles are right now, and historically, and how those vehicles conform to expected service.
3. Provide developers with a single, authoritative source of real-time information that is open and free to use.

Project understanding

While the most important goal is ultimately to deliver quality customer information, this scope does not include customer interfaces. This is because there is a large, diverse market of free apps that transit riders already use, and standard data formats defined to provide information to those apps easily. Therefore, by focusing on procuring goal #3, goal #1 is achieved.

Project scope

- Provide the hardware and software infrastructure to track vehicle positions for all fixed-route vehicles in agency fleet.
    - Required:
        - GPS hardware devices to provide vehicle location based on cell signals for all fixed-route vehicles
            - Alternatively, a technical plan to integrate with existing GPS devices

              [Note to procuring agency, not intended to be pasted into requirements document: Procuring agency would need to itemize all exact specifications of current devices to support this]
        - All services necessary to provide ongoing information about the vehicle location, bearing, speed, etc., including, but not limited to
            - Device software
            - Device support
            - Device repair and replacement plan

        - Device cell service
    - Specify installation time, location poll rate, and system latency in proposal response.
  - Desired:
    - Easy installation (20 minutes or less per vehicle) by local staff
    - Vehicle location poll (sample) rate of 10 seconds or better
    - Latency of less than 8 seconds from vehicle location poll to GTFS-realtime data feed
- Provide functions for configuration and schedule loading.
  - Required:
    - System should provide the capability for loading schedule data through GTFS (static) datasets, provided by a 3rd party.
    - Provide documentation for system configuration, including any system-specific requirements for GTFS (static) data that are not listed at gtfs.org.
- Provide API endpoints and historical archive of vehicle information, synced with current and historical local agency GTFS feeds and with outputs owned by local agencies.
  - Required:
    - API endpoints open for free use by any developer, providing the following data formats:
      - GTFS-realtime Trip Updates, synced with the agency's current GTFS feed (provided by a 3rd party).
      - GTFS-realtime Vehicle Positions, synced with the agency's current GTFS feed (provided by a 3rd party).
      - All GTFS-realtime feeds must be of proven quality to allow integration into Google Maps.
    - GTFS-realtime endpoints must be available for use by any developer under open license terms. Two acceptable licenses include the Transit.land model open data license[70] and the CDLA-permissive license (Community Data License Agreement)[71].
    - Interface through which to download past data from a certain time period, in a .csv or another spreadsheet format.
    - All hosting, support, server expenses, etc. necessary for the continued operation of these items with 99% or greater uptime, for the duration of the contract period.

[70] https://drive.google.com/open?id=1mIMc0ccn9Rab4XCF-1Qs6ozMyi1qZvSg
[71] https://cdla.io/permissive-1-0/

        - All data in any format retrieved from these endpoints and interfaces must be fully owned by the agency, or licensed in such a way that the agency has free, unrestricted, transferrable, and irrevocable rights to store and use said data, including its combination with other datasets.
    - Desired:
        - A well-documented JSON or XML [API](API) giving various useful endpoints, for example,
            - Current location by vehicle
            - Upcoming arrivals by stop
            - Etc.
        - The highest possible arrival estimate accuracy, demonstrated through quantitative research, and the capability to produce retrospective indicators of arrival prediction accuracy.
- (Optional) Provide a dashboard that gives dispatchers and system managers tools to analyze fixed-route performance.
    - Vendor to define approach and features in their submission. On-time performance tracking is the most important concern and feature request.
    - List available reports in proposal submission.
    - Support for dashboard application.
- (Optional) Support for integration into and communication with third-party app developers for public integration.
    - [Agency] seeks to integrate real-time information into Google, Transit, and other free-to-use apps available on the App Store and other public app marketplaces. [Agency] is interested in a vendor able to perform the communication with these developers necessary to complete those real-time integrations.

Appendix B. Real-time transit information in Oregon

As of June 2018.
Linked from https://docs.google.com/spreadsheets/d/19cWjFrkvD6pLUrG66zenmUnBZ_RNr-DMniJakyCm3DM/edit#gid=0

Agency	Status		Vendor & Technology			Google Maps	
	In process	Live	CAD/AVL	Service Alerts	RTPI	GTFS-realtime Trip Updates	GTFS-realtime Service Alerts
Cascades East Transit (CET)		●	Swiftly	Trillium Transit Alerts	Swiftly + Transit [app]	*	●
Cherriots (Salem-Keizer Transit)	●						
Clackamas Community College (CCC Xpress)		●	Swiftly	Trillium Transit Alerts	Swiftly + Transit [app]	●	●
Columbia Gorge Express		●	Doublemap	Trillium Transit Alerts	Doublemap		●
Corvallis Transit System (CTS)		●	Connexionz		Connexionz	**	**
Josephine Community Transit	●		RouteMatch				
Lane Transit District (LTD)		●				●	●
Lincoln County Transit	●						
Portland Streetcar		●	NextBus	TriMet internal application	NextBus + Transit [app]		●
Rogue Valley Transportation District (RVTD)		●	TripSpark		OneBusAway	●	
Sandy Area Metro/Mt. Hood Express		●		Trillium Transit Alerts			●
Tillamook County Transportation District (TCTD)		●	Swiftly	Trillium Transit Alerts	Swiftly + Transit [app]	●	●
TriMet		●	INIT	TriMet internal application	TransitTracker [TriMet	●	●
U-Trans	●						

*In process

**Not available: static and real-time feeds out of sync

Figure 6: Real-time transit information in Oregon