On Bus Hardware, Software, Standards & Interoperability

Developed for ODOT by Trillium (with IBI Group)

Overview

There is a group of hardware and software systems that together provide information to drivers and riders of public transit. The individual components that make up this system represent, in aggregate, a CAD/AVL system or "Intelligent Transportation System." While software is critical to exchanging information between different parts of the system, various hardware components on board the bus are also required to collect and deliver information.

This hardware is often bundled with software under a single contract, but that is not always necessary. The central role of the onboard vehicle logic unit in onboard systems can present a barrier to modularity and interoperability. Emerging practice includes using GTFS data for configuration of onboard systems. Some initiatives aim to make onboard systems more interoperable and modular.

Note that all prices quoted below are for hardware only, without any software. Software costs vary widely and different vendor products contain different overlapping features, so software cost calculation can depend upon agency needs.

Purpose of this memo

The purpose of this memo is to provide information for transit agencies and ODOT to make decisions about purchasing such hardware.

Interoperable and modular hardware can reduce costs and improve efficiency for transit agencies by allowing them to purchase the best value components for a system. Being able to upgrade or replace these systems piecemeal enables flexibility and effective management of costs over time.

This memo aims to make purchasing interoperable components and implementing a modular system of onboard hardware more approachable for small transit agencies, and to support high quality and complete information for customers and for planners.

As part of the review, Trillium conducted an interview with IBI staff.

Common frameworks and CAD systems

The Dispatching system is at the center of on-vehicle hardware and the system most likely to connect to other systems on board the vehicle. Use of an on-board Computer Aided Dispatch (CAD) system is a major determinant of how other systems will function.

No "computer"

A lot of passenger information can be delivered without an onboard computer (sometimes called a vehicle logic unit or VLU), which automates the exchange of information between systems and provides the driver with dispatch information through a mobile data terminal (MDT). Computer Aided Dispatch information onboard the vehicle necessitates driver interaction and increases the cost of the overall system. For smaller systems, CAD with a driver interface might increase complexity and cost without offering commensurate benefits for dispatching efficiency or improved traveler information. Conversely, a transit provider can implement function-specific components without a central computer or VLU:

- Installing GPS units to provide vehicle location to off-board servers, which can power dispatching systems and GTFS-Realtime feeds.
- Providing headsigns, operated directly by drivers, who also can provide voice annunciation over the PA.
- Drivers can also manually track passenger counts and manage fare boxes directly.

Tablet-based

A tablet, most often a "ruggedized" Android device, can be connected to the vehicle console and serve as both the driver monitor and operating system for the bus. These devices range from commercial to highly specialized, but generally offer a similar driver experience and favorably compare with more complex systems that use a separate computer.

- The driver has a user interface to see route information and engage with onboard technology.
- It can connect to most other onboard systems, but often with limitations.
- Tablets cost from $500 - $3,000 per vehicle.

Vehicle Logic Unit and Mobile Data Terminal

In most modern, urban transit systems, a Linux or Windows computer runs behind the driver or elsewhere on the bus, in a cupboard along with other hardware systems. In this case, the driver has a touch-display monitor mounted on the vehicle console.

- In some cases, agencies may have a computer on board for automated annunciation (or another complex system like onboard cameras or automated passenger counters.
- VLU + MDT costs range from $3,000 - $8,000 per vehicle.

Other systems

Most onboard information hardware can integrate with the CAD system to automate various functionalities. These hardware items can often be transferred from one CAD software integration to another (although the integration charges may be similar to the hardware costs).

Most can be delivered without a CAD system on the bus. However, there are limited ways to automate these systems without going through the CAD system. Few of the vendors for these systems ingest schedule data (e.g. GTFS) separately from CAD software (although this is somewhat more common in the cases of APCs and fare boxes).

Headsigns

Vehicle headsigns can be set to rotate based on route information gathered from the dispatching software, or display custom messages and notices. If operated by the driver, it is typical for the driver to punch in a code in order to turn on a specific headsign.

The headsign field can be configured in GTFS[1] though traveler information tools like trip planners and on-board signage may have slightly different needs.

Procurement and Integration:

- Small number of hardware vendors, but integration with all CAD systems common.
- These can be purchased installed on the vehicle or separately.
- Costs range from $2,000 - 8,000 per vehicle.

Voice Annunciation

Vehicle annunciation of specific stops requires the integration of geographic information and agency business rules, and thus tends to require an onboard computer. The manual implementation of this technology is to have the driver speak stops through the bus PA.

Text-to-speech fields have been added to GTFS.[2] Originally, these were intended for text-to-speech features in mobile apps, but can also be useful for onboard voice annunciation. Using GTFS to configure multiple systems improves efficiency.

Procurement and Integration:

- Because a computer with geographic and route information is needed, voice annunciation is typically provided with the central CAD/AVL system.
- Cost is often included within the CAD hardware, but requires buses to have a PA system.

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[1] http://gtfs.org/reference/static#tripstxt
[2] https://github.com/google/transit/pull/49

Interior digital signage

Interior digital signage that displays next-stop information requires CAD software and cannot be managed directly by the driver. However, the simplicity of the information presented on signs means that sign hardware is moderately standardized and used across CAD software systems, similar to headsigns.

Procurement and Integration:

- Small number of hardware vendors, but integration with all CAD systems common.
- Many vendor add ons and specialty signage, such as for “infotainment.”
- Costs range from $500 - 2,000 per vehicle.

APCs

There are only a limited number of Automated Passenger Counter (APC) hardware companies that can interoperate with CAD/AVL systems. APC system outputs are, however, notoriously inaccurate. With manual review or extra software, data collection can be automated and certified for the NTD, but few APC integrations will be low-cost and easy-to-implement.

Procurement and Integration:

- Small number of hardware vendors, but integration with all CAD systems common.
- Costs range from $1,000 - 5,000 per vehicle, plus the cost for software licenses ($5,000 - $10,000).

Fare hardware

Occasionally, fare boxes are procured or purchased with the vehicle, but are more typically purchased after market. Genfare has a near monopoly on electronic fare boxes. The result is that all CAD/AVL vendors integrate with Genfare, but few integrate with other e-fare equipment. However, CAD/AVL vendors in a recent procurement by RVTD did not have a problem integrating with the non-standard Lecip fare boxes. Bluetooth beacons and QR readers that allow verification of tickets purchased via smartphone, or even standard point of sale hardware for some intercity services, are becoming more common. These are less common fare hardware and may not be able to be integrated with CAD/AVL systems.

Procurement and Integration:

- Near monopoly within the hardware market, although technology is changing quickly.
- The market for other payment systems is competitive, diverse, and immature.
- Standard fare boxes cost $12,000 - 18,000 per vehicle.

GPS units

There are various price points for GPS units and they are marketed for use with various systems for vehicle asset tracking. Most CAD/AVL vendors can easily integrate with a GPS unit designed for cabled communication with other onboard devices. However, a simple GPS unit broadcasting off vehicle is usually not sufficient to provide dispatching information to drivers (although can deliver real-time information to riders).

Procurement and Integration:

- There are many hardware vendors offering a range of models.
- Costs range from $250 - $1,500 per vehicle.

DVRs

Digital Video Recorders are not typically included in CAD/AVL procurements or integrated with other onboard systems. The DVR computer is often stored in the same cabinet as a vehicle logic unit, and some advanced CAD/AVL systems can integrate bus cameras within their dispatcher interface.

Procurement and Integration:

- Price and market information were not collected.

Opportunities for standardization and modular system design

While each of the above hardware systems is often manufactured by different parties and technically available a la carte, all such systems are generally purchased through contracts with a single vendor, providing the CAD/AVL software and hardware, which then subcontracts other vendors for other components or provides those components as well in an “integrated” solution. Two recent procurement processes managed by the consulting team drafting this memo, which specifically allowed for modular, multi-contractual system design and required standardized connections between components, each ended in the selection of a single vendor to provide all services (with subcontractors) integrated through on vehicle hardware and software. Such systems are the best and only systems widely available on the market. They do however require great care and cost to implement and manage, and involve considerable risk for the agency if the contract is not successful.

Avoiding the pitfalls of the current market, and implementing a standardized and modular system of customer information technologies onboard a fleet of vehicles would require one of three conditions

1. **Scale**. The current marketplace works reasonably well for transit systems operating 1,000 or more vehicles. These agencies have the leverage to negotiate reasonable technology approaches with vendors, granted their technical capacity to do so.
2. **Widely available, well maintained (probably open source) software for the management of a Vehicle Logic Unit through commercially available computers, open data standards development for integrations with various hardware systems, and technical teams capable of implementing and managing systems based on the above.** All of this is as difficult as it sounds. There is no market incentive for the VLU vendor to remain exclusively the VLU vendor. There are too many opportunities to charge

rent for being the integration point, and government procurement policies facilitate the charging of rents through preferences for fewer, larger, longer-term contracts. If a proprietary or open source VLU alternative were successfully implemented, there would still be the need to push diverse hardware vendors towards more open standards and system implementation. These are highly technical processes and VLU vendors currently control the necessary limited human resources. There is no $50,000 - $500,000 open source system development project that breaks through this issue

3. **Adoption of Bluetooth connections and modern APIs by non-VLU hardware vendors.** Already beginning in the market is an evolving system approach that may partially solve the issue of system modularity, and may facilitate a standards-based approach in the long-term. Some hardware vendors and vendors have begun utilizing bluetooth connections to onboard components, which allow a commercial tablet to serve as the driver interface and vehicle logic unit. This change, along with the adoption of more complex APIs beyond typical ‘message’ protocols such as J1939, would reduce the upfront costs of system integration between CAD software and other hardware components, but does not require the standardization of connections between those components. This approach is being promoted by a group of firms (including currently Trillium) under an organization titled Open Transit Initiative, directed by Swiftly, Inc.
4. Adoption of new GTFS features for operations. Cal-ITP is working on some of data standards. (See Appendix).

APPENDIX

Potential technology vendors

https://docs.google.com/spreadsheets/d/1s-AiNONk5fOTgn4eeqXqMav4zTRB0CwDjrI8GcqODjw/edit#gid=0

Cal-ITP Data flows for operational data

The following data flow diagrams and discussion are direct excerpts from a Cal-ITP produced draft document that explores needs and opportunities for operational data.

Standards-based future-state data flows

These diagrams present a vision for the future of transit operations and service delivery, where standards exist to support the data flows between all relevant systems. A version with (Aggregated) and without (Parallel) a central onboard computer, known as the Vehicle Logic Unit (VLU), is shown.

Common key

Each version of the diagram shares the following numbered components:

1. GTFS static data configures CAD software system
    a. Encoding detours in GTFS is a standardization opportunity.
    b. Existing practice: MBTA encodes planned detours, bus shuttles, and snow routes in the GTFS.[3] Updates to calendars.txt and calendar_dates.txt can enable these detours.
2. GTFS-ops feed brings facility information, pull-in/pull-out schedules, relief points
    a. Existing practice: MBTA includes checkpoints.txt (describing timing points)
3. GTFS static feed connects schedule and route data to alerts management system to create the GTFS Service Alerts feed
4. GTFS-ops feed with driver and vehicle fleet information
    a. Drivers: name, badge/ID, seniority date, special credentials
    b. Vehicles: Operator requirements
5. GTFS static data is used for the run-cutting and later operations processes
    a. Vehicle blocks
6. The run-cutting process creates a series of possible runs ahead of driver bidding and assignment

[3] See MBTA's GTFS documentation for route_patterns.route_pattern_typicality (https://github.com/mbta/gtfs-documentation/blob/master/reference/gtfs.md).

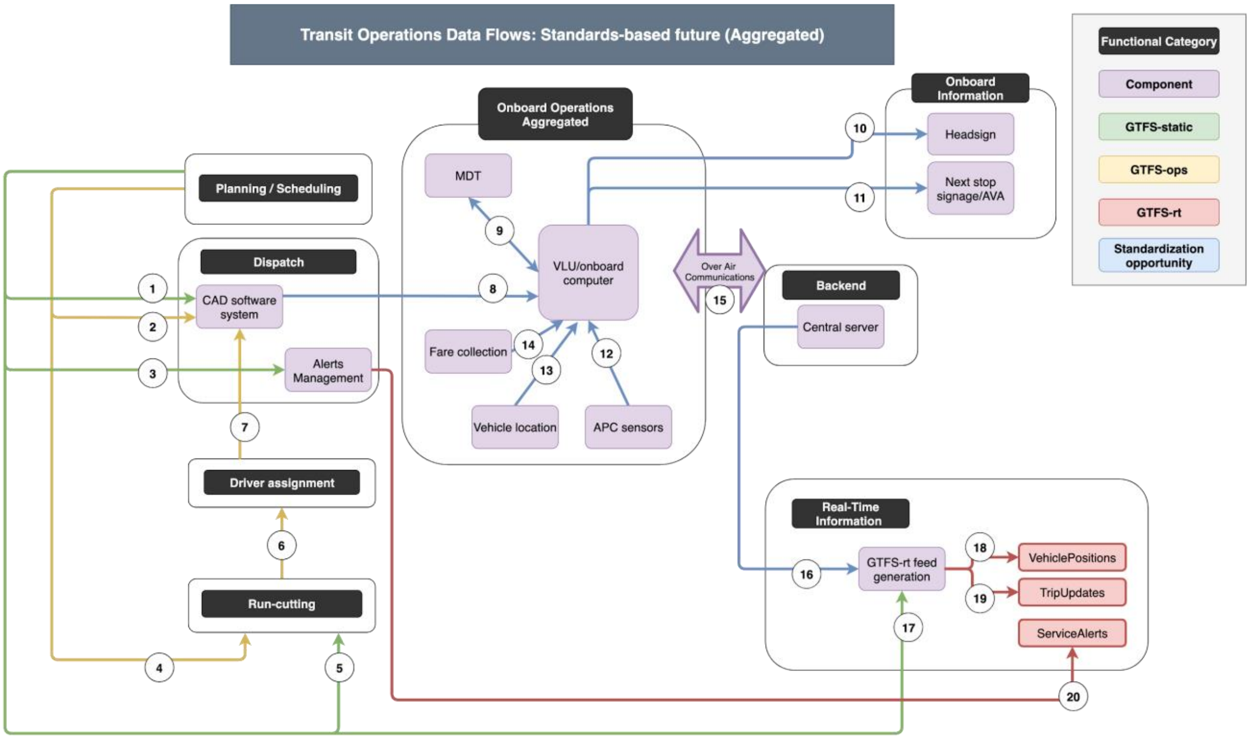
7. Driver assignments for each trip (runs) are fed into CAD

[see below for aggregated and parallel onboard operations data flows, components 8-14]

15. Onboard components communicate with a central server to relay data via radio/cellular communications.
    a. Architecture for backend data storage, aggregation, and reporting varies significantly. In some cases, farebox, passenger count, and historical location and on-time performance data are consolidated in a centralized database. In other cases, this data is stored in different databases. Specialized (transit-specific) or generalized software (e.g. R Shiny or Tableau) is used to generate reports. We recommend that standardization should support this variety of reporting needs and approaches.
16. The backend server communicates with a GTFS-rt feed generator
    a. Data transmitted:
        i. Vehicle ID
        ii. Assigned trip or run ID
        iii. Time reported
        iv. Location
        v. Optional:
            1. Direction (degrees)
            2. Speed
            3. Data quality
            4. Operator ID
    b. Existing specifications
        i. The above fields were implemented in MTA BusTime[4]
17. GTFS static data is used as the basis for a GTFS-rt feed
18. GTFS-rt feed generator creates a VehiclePositions feed
19. GTFS-rt feed generator creates a TripUpdates feed
20. Alerts management software generates a GTFS-rt Service Alerts feed

[4] https://github.com/camsys/onebusaway-nyc/wiki/Real-Time-Bus-Data

Aggregated onboard data flows

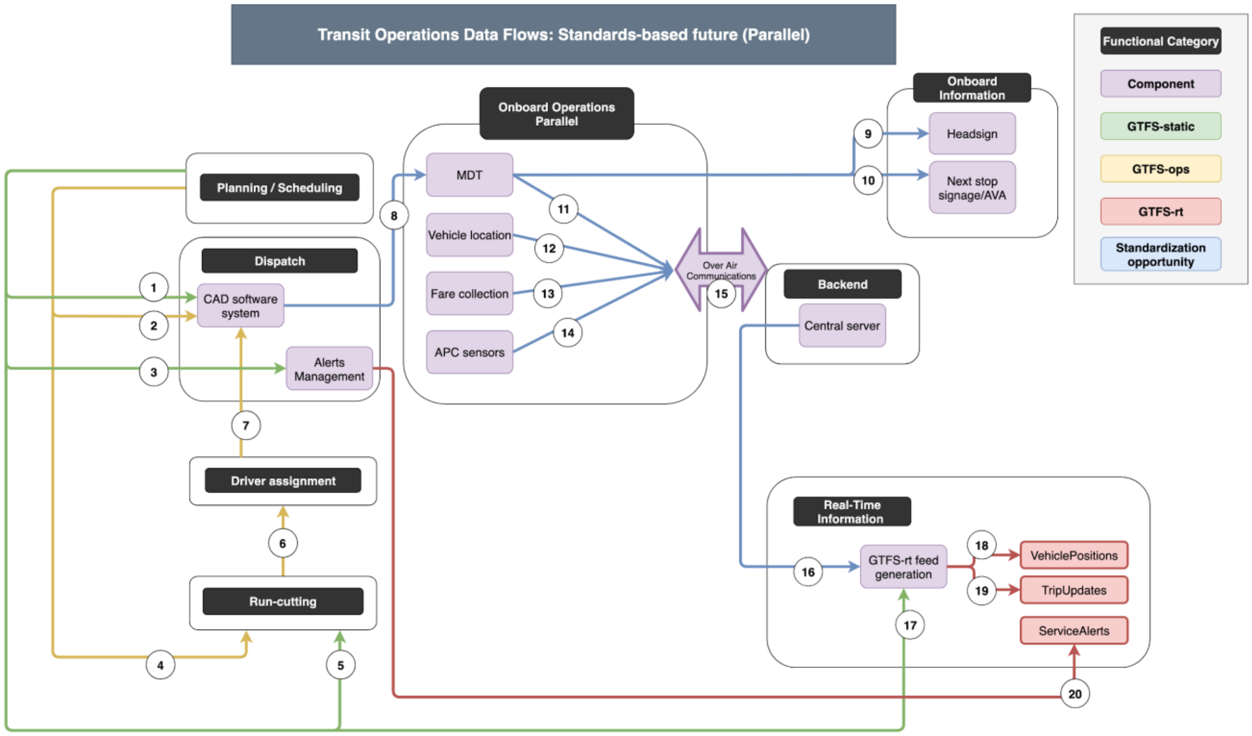


Key

Unsure if potential standards should consider onboard configuration or seek to be agnostic.

8. CAD communicates with the onboard VLU
9. The VLU and MDT communicate back and forth
10. The VLU controls the headsign display
    a. GTFS static trips.txt has trip_headsign, and stop_times.txt has stop_headsign values
11. The VLU controls the stop annunciator
    a. GTFS recently added text-to-speech fields that may be useful for this configuration (see https://github.com/google/transit/pull/49)
12. Onboard passenger and doorway sensors send data to the VLU
    a. Unclear if VLU sends data back to sensors
13. Onboard vehicle location sensors send data to the VLU
    a. Unclear if VLU sends data back to sensors
14. The fare collection systems send data to the VLU

Parallel onboard data flows



Key

Unsure if potential standards should consider onboard configuration or seek to be agnostic.

8. CAD communicates with the onboard MDT
9. The MDT controls the headsign display
    a. GTFS static trips.txt has trip_headsign, and stop_times.txt has stop_headsign values
10. The MDT controls the stop annunciator
    a. GTFS recently added text-to-speech fields that may be useful for this configuration (see https://github.com/google/transit/pull/49)
11. The MDT communicates via radio/cellular with the backend server
12. Onboard vehicle location sensors send data to the backend server via radio/cellular communications
13. Onboard passenger and doorway sensors send data to the backend server via radio/cellular communications
14. The fare collection systems send data to the backend server via radio/cellular communications