All Aboard the Train of the Future

How to Optimize the Passenger Experience and Enhance Operations With Improvements to Your Onboard Network

WHITE PAPER

Aditya Konathala | Solution Sales Director

Emerging digital technologies are shaping the future of mass transit. From automatic train control (ATC) and predictive maintenance to automated fueling, fleet management, and more, these advances are pushing the pace of innovation while connecting passengers, staff, and systems.

Mass transit owners and operators are increasingly investing in technology to balance day-to-day financial pressures with growing demand for a seamless rider experience. A drop in passenger volume during the COVID-19 pandemic gave many operators the opportunity to implement new technologies to improve their systems[1], and the industry is seeing something of a renaissance as a result. These technologies both hinge on and enable the transmission of data — a mission-critical component of the connected train.

But while there's widespread awareness of the transformative potential of technology to enable more efficient, safer, and more enjoyable transport, there's less clarity around how to harness it. While connected trains, tracks, and stations deliver operational efficiencies and a more personalized rider experience, they're almost impossible to deliver using legacy networks, manual processes, and incompatible systems that create a siloed approach to infrastructure management.

At Belden, we understand the critical importance of networks and connectivity to enabling the digital transformation required to make the connected train a reality. As more owners and operators adopt automation technologies for end-to-end communication and real-time data exchange, the demands on the network will only increase. In this white paper, we detail what you need to know to build a connected train network ready to flex as quickly as operational and passenger needs evolve.

[1] "How Digitalization and New Tech Drives the Rail Transport Beyond 2023." Draup, Dec. 9, 2022.

Are You Ready for Digital Trains?

Digitization delivers a variety of benefits related to the everyday management of a mass transit system, from asset productivity to passenger safety and security, predictive maintenance scheduling, and more. It enables operators to increase profitability by decreasing headway, improving safety performance, and enabling operators to perform maintenance proactively, plan asset use more intelligently, and offer — and charge for — a premium passenger experience.

Each of these leaps toward digitization relies on a robust data network to achieve its full potential. But, how do you know whether your mass transit system networks and connectivity are ready for fully digital trains?

- **Check your infrastructure.** Are tracks, signals, and power supplies suitable for digital trains? Do you have the data infrastructure to allow you to use real-time data effectively, efficiently, and securely?
- **Assess real-time connectivity.** Do you have the hardware in place to provide reliable and secure connectivity on board? Will trains have adequate network coverage throughout the journey, even in rural areas or locations with poor or nonexistent signal strength? Do you have the bandwidth required to support all the services you want to offer, including Wi-Fi and streaming?
- **Weigh the benefits of cable vs. wireless.** What factors are most important to your mass transit system? Cabled connections can enable faster and more reliable connectivity than Wi-Fi, which can be affected by interference from other devices or physical obstacles. Wi-Fi, however, offers greater flexibility for connectivity throughout the train, and it can be easier to scale up or down as needed. While many discussions of onboard connectivity focus on passenger Wi-Fi or mobile usage, a reliable, end-to-end inter- and intra-train wireless connection also opens a world of possibilities:
  - » Wireless connectivity helps ensure data is communicated consistently, from the first car to the last as well as between trains. This benefits staff as well as passengers.
  - » Knowing the number of people in each car enables operators to identify daily, weekly, and seasonal trends that help them schedule trains efficiently — maybe removing a car or two during off-peak hours.
  - » Unplugging cable coupling repeatedly can degrade the connectors, so moving to wireless might add car configuration flexibility and save money for the operator.
  - » Combining wired and Wi-Fi, a seamless redundancy is created and will ensure no data is lost even if one system fails.

The Connected Train Network

A deep, pervasive, and robust network is required for performance improvement powered by digital solutions. Therefore, owners and operators must invest enough attention and resources to get the network right. A poor network — as evidenced by high network latency, a lack of redundancy, low bandwidth capacity, and unsecured networks, among other indicators — can reduce or even eliminate the value realized from digital solutions.

The overall mass transit system network consists of dedicated component networks joined by a common backbone. The connected or onboard train network communicates with the wayside/trackside network of communication systems and devices installed alongside the tracks as well as the station network of systems and devices installed in train stations through the backbone network.

The onboard train network consists of communication systems and devices installed on a train to support its operation and communication with the outside world. Operators can establish connections onboard rolling-stock assets using:

- **Train control systems:** These systems govern functions like speed and braking, automated guidance, and door controls — critical devices that typically run on a private, closed network.
  - » Legacy systems for critical operations onboard rolling-stock assets use a wide range of Fieldbus technologies.

» Modern systems generally use Ethernet-based protocols for interoperability now and in the future. Ethernet-based protocols deliver enhanced network reliability and improved overall train performance by reducing the weight of the carriages due to harmonizing or eliminating the need for cabling and devices like protocol gateways.

Key considerations include:

» Availability requirements.

» Whether priorities of connections require link-bypass functions during power loss.

» Whether offboard system deployment is required.

Isolate this critical network traffic from other networks to ensure low latency and deterministic behavior when using Ethernet-based networks for operations. You also need to extend connections within any train carriage and between carriages. Because trains are often reconfigured, ensure that the Ethernet train backbone (ETB) allows for easy reconfiguration to enable flexible carriage additions, removals, and order reversals.

- **Train operations systems:** Closed-circuit television (CCTV), public address (PA), and passenger information and infotainment systems, among other systems, perform necessary functions to extend oversight capabilities to onboard environments. While not as critical as the train control systems to safe train operations, these systems support on-train functions and passenger safety. These connections form a multi-service network that requires as much flexibility as the critical networks but marginally less redundancy.

Key considerations include:

» The number of Ethernet device connections within each car.

» Whether any devices need power over Ethernet (PoE or PoE+).

» Whether you need data traffic to leave the car or train.

The Ethernet consist network (ECN) within any given train car, and the larger train-wide Ethernet train backbone (ETB), have traditionally shared data in only one direction with offboard systems. Modern systems, however, require two-way communications for remote system management.

Keeping Riders Safe and Happy

The benefits of a connected train are not limited to owners and operators. Whether on subways or high-speed trains, passengers also reap the rewards of technology used to deliver better, more reliable passenger experiences.

- Entertainment: Secure, stable internet is the foundation of passenger access to information and entertainment options. Premium content offered for a fee can also increase the bottom line.
- Operations: The connected train enables smoother ticketing and transfer processes.
- Safety: Operators can use visible security measures to help deter theft, door alarms, and other technologies to help keep passengers safe.
- Personalization: Operators that tailor the passenger experience to the individual, for example by offering a predictive menu with vegan options for the non-meat-eating traveler, not only increase revenue but also bolster passenger loyalty.
- Comfort: By monitoring passenger counts and air quality or temperature, operators can prevent overcrowding and boost rider comfort. Other applications include coordinating headway for a train with passengers using a wheelchair or better accommodating parents traveling with a stroller.

- **Onboard passenger experience systems**: These systems enable travelers to remain connected to their world during their journey, including cellular signals and public Wi-Fi internet access. Public networks offer access to the internet and sometimes host multimedia content like music and movies. For adequate security, onboard network configurations must isolate public networks and prevent passenger access to operational networks.

Key considerations include:

- The number of client connections per car.
- Whether travelers move between cars during transit.
- Whether to provide internet access as a service.

For stable and effective public use, access points (APs) must provide high-speed access to large densities of clients close to one another while preventing crosstalk from outside the car. These APs typically rely on a high-bandwidth, wired network for onboard scalability and a load-sharing mechanism across multiple wireless links to access off-board stations and the internet.

Because these wireless local area networks (WLANs) allow public access, operators often use an authentication platform for access control — much like the redirect web pages in hotels that ask guests to accept terms and conditions. More advanced systems leverage dynamic access control lists that differentiate between standard passenger access and people who may have paid for higher-speed network access.

Passenger Safety and Security

The safety and security of passengers is a high priority for operators looking to ensure the well-being of passengers, reduce risk, and increase profitability.

How to enhance passenger safety

Components like closed-circuit television (CCTV), alarms, and automated doors can help reduce the risk of robberies and assaults, injuries during the closing of doors, vandalism, and other issues. Keeping security measures visible helps serve as a deterrent to reduce crime and help passengers feel safe.

How to increase network security

The interconnection of trains, tracks, and signals unlocks a vast amount of real-time data that enables operators to make faster decisions to reduce operating costs, increase passenger safety, and optimize the passenger experience. At the same time, however, this interconnection increases the risk of cybersecurity threats.

As in any environment where people bring their own devices, the connected train network poses potential security risks that can be mitigated by best practices that include:

- Allowing no physical connection to any operating system.
- Placing firewall technology so public users cannot reach peer-to-peer (P2P) networks or specific servers – wireless local area network (WLAN) controllers offer that filtering function.
- Including content filtering software.
- Leveraging centralized network access control solutions to fortify perimeters by limiting bandwidth per user type.

Designing the Connected Train Network

Operators are investing in a wide variety of digital solutions to increase operational efficiency and meet passenger expectations. Regardless of the technologies adopted, however, mass transit system owners and operators must invest in a network as a key enabler.

Characteristics of rolling stock present unique challenges when designing the connected train network. A train in motion vibrates constantly, complicating what is already a delicate balance of managing multiple systems competing for bandwidth across public and private networks. Temperature variations and high levels of electromagnetic interference (EMI) add to the complexity. All onboard telecommunication devices must comply with the EN50155 and EN45545-3 standards to ensure full environmental (radio emission, climatic and vibration conditions) and fire behavior compatibility.

What Devices Do You Need?

Common Hardware Used to Enable Onboard Connectivity

- Industrial cables that connect end devices to communication electronics.
- M12 connectors, cylindrical electrical connectors designed to provide a secure and reliable connection in harsh industrial and transportation environments.
- M12 cordsets that facilitate connecting components such as sensors and control systems.
- Onboard access points that broadcast Wi-Fi signals, creating a local wireless network to which passengers can connect.
- Onboard access clients consist of devices connecting to the Wi-Fi network. When combined with onboard access points, they not only provide consistent internet access throughout the journey but also enable train operators to provide passengers with information about the train's location, arrival times, and other relevant information, improving passenger communication and overall safety.
- WLAN controllers that automatically configure and manage access points.
- No failure on the wireless communications, and establish smooth handoff with complete redundancy to support the critical systems and operations.
- Ruggedized Layer 2 switches designed to withstand the harsh environmental conditions and operational requirements of trains. They automatically reroute circuits or switch to backup equipment as needed.
- Ruggedized Layer 3 switches that have a more sophisticated routing capability than Layer 2 switches. This sophistication allows them to support more flexible and scalable network configurations, making possible more complex onboard systems and applications.
- Cellular routers that provide an uplink/downlink connection to the Internet.
- Cellular and Wi-Fi antennas that establish proper wireless links between wireless clients and access points.

Your Connected Train Roadmap

Follow these steps to deploy a connected onboard network that can flex as challenges and opportunities evolve.

Plan:

- Determine the type of network architecture that will offer the best return on investment. Consider redundancy, number of Ethernet devices to connect, device location, and bypass connections.
- Define the Wi-Fi network requirements by considering the list of applications, associated payloads, and number of users.
- Determine Wi-Fi access point locations, and select antennae to ensure optimal coverage.

Install:

- Ensure that the WLAN report has assigned the bands and channels for each service.
- Ensure appropriate grounding of any outdoor surge and lightning arresters.
- Adjust radio signal levels and overlap coverage of the onboard network to achieve required service levels.
- Pay special attention to underground tracks and review field-mounted M12 connectors to ensure proper connectivity.
- Use weatherproof tapes to secure the connectors.

Configure:

- Ensure that the WLAN controller has assigned a specific internet protocol (IP) range to WLAN clients.
- Use network address translation to deploy identical IP mapping within each part of the consist.
- Evaluate whether devices capable of power over Ethernet (PoE) require manual power assignment configuration per port to prevent excessive decreases in the power budget.
- Identify cabling defects via port diagnostics or statistics.

Proof of Concept (POC) before Go-Live:

- Create a backup of all device configurations once connected.
- Archive the backup in a safe, secure location.
- Leverage background maps at the network management system (NMS) graphical user interface (GUI) to help maintenance teams locate devices and links.

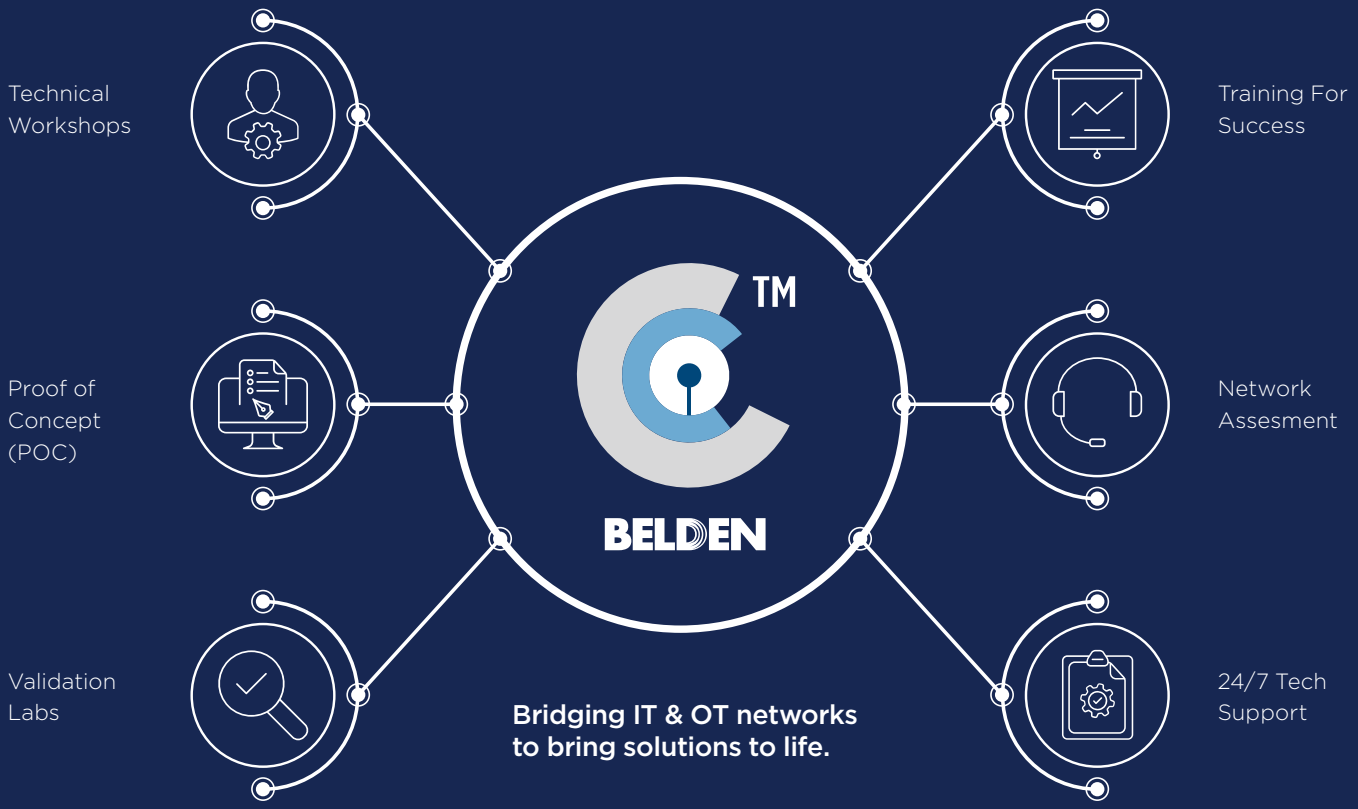
Belden: Your Connected Train Specialist

In an industry where data transmission is mission-critical, a modern, automated, and connected mass transit system is the clear path forward. Belden can help you navigate a path to a future-ready network, regardless of where your starting point is.

Mass transit operators today are faced with rising operational costs and increased passenger expectations for a connected experience, so it is the ideal time to reach out to Belden to ensure that you have a robust, reliable onboard network infrastructure that can deliver on the promises of the connected train. As an end-to-end network solution provider, we offer the most comprehensive networking profile for your mass transit system. From design to installation and maintenance, our experts and partners meet you where you are in your digital transformation journey and help you prepare for the future of mass transit.

Enabling Customer Success

Customer Innovation Center



How Belden Supports Your Digitization Journey

With all the other priorities you manage, you shouldn't be expected to serve as a digitization and network expert, too. Finding a trusted partner makes your journey faster and more cost effective—and ensures that you achieve the outcomes you expect.

Our in-house team of domain experts and solutions consultants has decades of experience in industrial automation and railway environments. Together, they crafted a step-by-step process to get your digitization project off the ground.

1. Identify your goals
A digitization project should start by talking about your needs, challenges, goals and inefficiencies. What are you struggling with? What do you hope to accomplish? What needs to change about current processes? What's working really well? What do you wish you could achieve—but can't due to technology or system limitations?

2. Take a gemba walk
A gemba walk is a walkthrough of your site that lets us see work in action. We spend time observing employees and processes, asking questions about what's working and what isn't, understanding tasks and identifying areas of potential improvement.

3. Conduct assessments
Our network and workflow assessments explore six technical elements to uncover opportunities for optimization in:

1. Operations workflows
2. Industrial cybersecurity
3. Network infrastructure
4. Edge computing
5. Wireless
6. Data management

4. Present the results
After we complete the network and workflow assessments, our experts document the results and present them to you in a digital maturity report. These documents analyze your operations, provide workflow visibility and pinpoint the benefits of digital transformation to your organization.

We report on things we notice, such as a lack of network segmentation, utilization and optimization, so you better understand your network infrastructure's availability, security and redundancy.

We also look for things like slow switching, outdated hardware, lack of authentication, lack of visibility and lack of consistent and reliable protocols.

Recommendations about tools and software to help you visualize your network and monitor equipment 24/7 are also included.

The goal of providing you with this information is to empower you to succeed and make the most of your data, people and processes. Together, we can build a blueprint that acts as your guide to meeting your KPIs and requirements.

Let's build the future.

When you're ready to move your digitization initiatives forward, our team is ready to help.
Visit **www.belden.com/mass-transit** to learn more.

About Belden

Belden Inc. delivers the infrastructure that makes the digital journey simpler, smarter and secure. We're moving beyond connectivity, from what we make to what we make possible through a performance-driven portfolio, forward-thinking expertise and purpose-built solutions. With a legacy of quality and reliability spanning 120-plus years, we have a strong foundation to continue building the future. We are headquartered in St. Louis and have manufacturing capabilities in North America, Europe, Asia, and Africa. For more information, visit us at www.belden.com; follow us on Facebook, LinkedIn and Twitter.

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