

Research Article

A Framework for the TTE-less Railway: An End-to-end Operational Model for Automated Verification, Passenger Safety, and Service Management

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Abstract

This analysis presents a comprehensive, end-to-end operational model for a railway system without Travelling Ticket Examiners (TTEs), arguing that a simple technology replacement for ticket checking is fundamentally flawed. An operational deconstruction reveals the TTE's primary functions are not enforcement but the management of on-board safety, security, and passenger service, which cannot be automated. Consequently, a successful solution must be an integrated, four-part socio-technical system. The first phase, Automated Perimeter Control, establishes station-level access using a matrix of validation technologies from NFC smartcards to biometric gateways. Still, this model fails in open networks with unstaffed platforms. To address this, the second phase introduces the 'Intelligent Carriage', a layer of in-transit monitoring using service-specific technology: IoT-based seat sensor grids with passenger-facing "traffic light" indicators for reserved-seating trains, and privacy-compliant, anonymous AI-driven Automated Passenger Counting for unreserved commuter cars. The third phase is the 'Central Nervous System', a high-concurrency, real-time data architecture modelled on China's Passenger Service Record (PSR) system. This "brain" fuses live sensor feeds with the ticketing database to create an automated exception-handling system, flagging discrepancies like an "occupied but unbooked" seat. The final, critical phase addresses the non-automatable human element. It proposes that the TTE-less train is not unstaffed; instead, the enforcement-focused TTE is replaced by a service-and-safety-focused 'Passenger Welcome Host'. This new role does not proactively check tickets but responds only to system-generated alerts, while primarily focusing on high-value tasks such as passenger assistance, accessibility services, conflict de-escalation, and emergency response. This framework mandates robust solutions to bridge the digital divide for unbanked or non-smartphone users through cash-accepting kiosks. The business case shifts from labour savings to achieving near-total revenue protection, enhanced operational efficiency through rich data streams, and improved passenger throughput.

Keywords

TTE-less Railway Framework, Intelligent Carriage, Passenger Welcome Host, Central Nervous System (Data Fusion), TTE Role Analysis (Safety & Service)

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1. Executive Summary

This report delivers a comprehensive, end-to-end solution for a "TTE-less" railway system, one that automates passenger ticket verification. The central finding is that a simple technology replacement cannot achieve this objective. The query's focus on "checking tickets" fundamentally mistakes a single *task* for the entirety of the *role*. An operational analysis of the Travelling Ticket Examiner (TTE) reveals that their primary function is not enforcement, but the management of on-board safety, security, and passenger service. [31].

Consequently, a "complete solution" must be a holistic, four-part socio-technical system that successfully replaces all functions of the TTE, not just ticket validation.

- 1) Phase 1: Automated Perimeter Control. The first layer involves implementing "gated" or "verified" access at the station level. This requires a matrix of validation technologies, ranging from established, low-friction Near-Field Communication (NFC) smartcards [30] and low-cost QR codes [43] to high-efficiency biometric gateways that use facial recognition. [29] This approach is highly effective for "closed" networks (e.g., metros, high-speed rail terminals) but fails in "open" networks (e.g., unstaffed regional platforms).
- 2) Phase 2: The 'Intelligent Carriage'. The second layer provides in-transit monitoring to address the failure of a perimeter-only model. This "Intelligent Carriage" utilises a service-specific matrix of technologies: for reserved-seating trains, this includes IoT-based seat sensor grids (as pioneered by operators like LNER) [8] and Bluetooth beacons. [7] For unreserved commuter cars, this involves privacy-compliant, anonymous AI-driven Automated Passenger Counting (APC) systems. [36].
- 3) Phase 3: The Central Nervous System. This is the data architecture that functions as the system's "brain." It is a high-concurrency, real-time database, modelled on China's Passenger Service Record (PSR) system. [47] This "Central Nervous System" fuses the ticketing/reservation database with the live sensor feeds from the "Intelligent Carriage" to create an automated exception-handling system, flagging discrepancies (e.g., "occupied but unbooked seat") in real time.
- 4) Phase 4: The New Human Element. The TTE-less train is not an *unstaffed* train. The critical safety, security, and service functions of the TTE cannot be automated. This model proposes replacing the enforcement-focused TTE with a service-and-safety-focused 'Passenger Welcome Host'. [26] This new role is trained in advanced de-escalation and emergency response. [18] They do not proactively check tickets; they respond *only* to the exceptions flagged by the automated system, while focusing primarily on high-value passenger service.

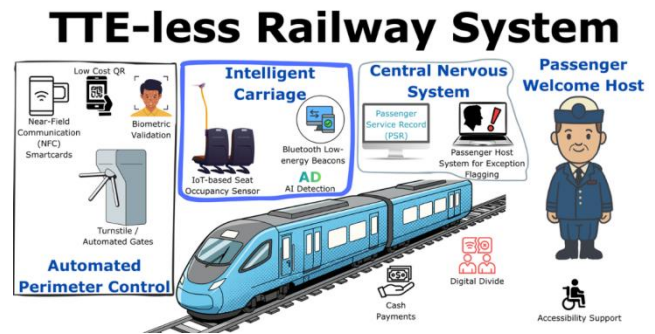


Figure 1. A holistic TTE-less railway model illustrating how automated access control, in-carriage intelligence, real-time data fusion, and a redefined human role combine to replace ticket enforcement without removing on-board staff.

This transition fundamentally shifts the business case. The solution does not offer significant labour cost savings, as the 'Host' role is essential for safety and service. Instead, the return on investment is found in near-total revenue protection, enhanced operational efficiency through rich new data streams [37], and improved passenger throughput. This framework also mandates robust solutions to address the "digital divide" for unbanked or non-smartphone users [20] and to ensure full accessibility for passengers with disabilities. [33].

2. Deconstructing the Conductor: The True Operational Scope of On-board Staff

The premise of eliminating Travelling Ticket Examiners (TTEs) is almost exclusively based on their most visible function: "checking tickets." However, this perception misrepresents their operational and legal value. An analysis of railway operational manuals and job descriptions reveals that ticket verification is a minor subset of a TTE's responsibilities. These duties are critical to safety, service, and revenue, and any automated solution must provide a viable replacement for every function.

3. Core Non-ticketing Duties of TTEs

The role of a TTE, or conductor, is fundamentally one of on-board governance. This role is comprised of four distinct, non-ticketing functions:

- 1) Safety and Emergency Management: The TTE is the primary on-board authority and "Person In-Charge" in the event of an incident. [41] This includes "Emergency Handling" and executing "safety procedures." [24] In a

crisis, such as a fire or derailment, the TTE is responsible for coordinating passenger evacuation, assisting emergency services, and communicating with the train operator and control centre. [18] This is a safety-critical, often legally mandated, human presence.

- 2) Passenger Assistance and Care: TTEs are mandated to "Assist passengers and address their concerns" [24] and "Attend to the comfort of all passengers, especially women and children." [31] This role serves as the human interface for all passenger needs. This is particularly crucial for passengers with disabilities or reduced mobility, who rely on the TTE for boarding assistance, securing accessible seating, and receiving information. This human element is the delivery mechanism for accessibility mandates like the 'Passenger Assist' program. [33].
- 3) Security and Conflict Resolution: The TTE is the sole authority responsible for "Maintain[ing] the decorum" of the carriage. [24] This involves managing passen-

ger-to-passenger conflicts (e.g., disputes over seats, noise, or luggage) and being the first line of defence against anti-social behaviour. [34] Their presence acts as a deterrent and a mediator, preventing minor issues from escalating.

- 4) Dynamic Revenue and Operations Management: TTEs perform real-time revenue and yield management. This includes the duty to "Allocate vacant berths to passengers on the waitlist" [24] and "ensure that vacant seats/berths should be allocated to waitlisted passengers on first come first serve basis." [44] This function is vital for managing perishable revenue; a TTE can identify an empty, reserved "no-show" seat, locate a waitlisted passenger in another car, and facilitate the upgrade, capturing revenue that would otherwise be permanently lost. They also handle on-board ticket sales and upgrades for passengers who change their plans mid-journey.

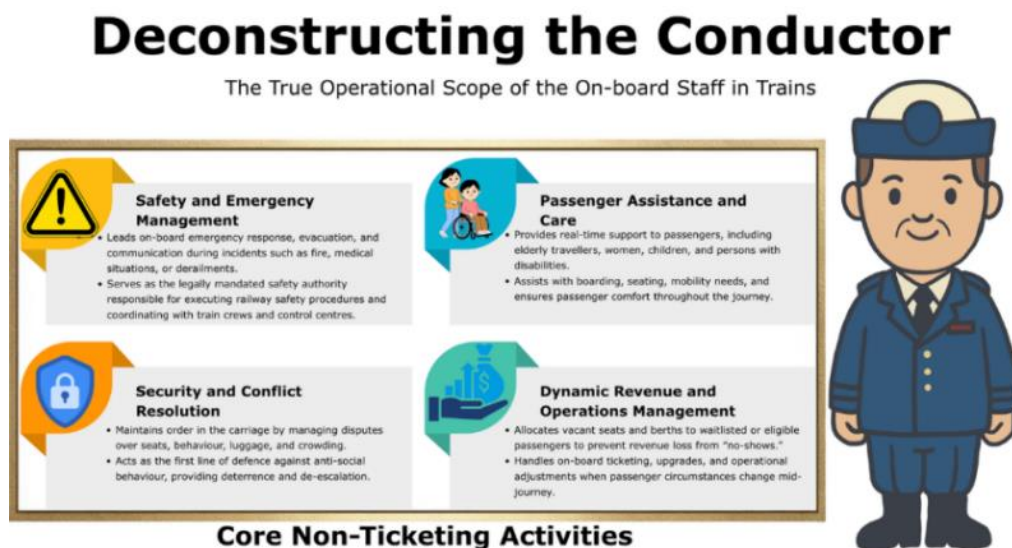


Figure 2. A functional decomposition of the traditional conductor role, demonstrating that safety, service, conflict resolution, and dynamic revenue management dominate over ticket checking and must be preserved in any automation strategy.

The attempt to automate "checking tickets" is therefore a red herring. The true challenge is not automating verification; it is replacing the TTE's role as the train's autonomous, mobile, human-in-the-loop decision-maker. Their functions—situational awareness in an emergency, human judgment in a conflict, and dynamic management of perishable revenue—cannot be replaced by a simple sensor.

Therefore, any proposed "TTE-less" solution must provide a robust, alternative system for *every one* of these non-ticketing functions. This reframes the entire problem from one of simple technology replacement to one of complex socio-technical systems design. The automation of verification is merely the *trigger* that necessitates the complete re-engineering of on-board safety, service, and revenue

management.

4. Phase 1: Automated Access Control at the Perimeter

The first component of a TTE-less framework is the creation of a "secure perimeter" at the station. This layer of technology aims to validate passengers *before* or *as* they board, shifting the point of verification from in-transit to the point of origin. This model is highly effective in "closed" systems (such as subways or dedicated high-speed rail terminals) where all passenger flow can be funnelled through access gates.

4.1. Gated Access and Smart Turnstile Integration

The physical backbone of perimeter control is the modern turnstile system. These are no longer simple mechanical barriers but integrated electronic access points. [15] Smart turnstiles connect to a central access control system [27] and are designed to be "media-agnostic," capable of supporting multiple validation methods simultaneously, including RFID, NFC, QR codes, and biometrics. [50] While this infrastructure is a highly effective enforcement mechanism, it represents a significant capital expenditure. It is operationally unsuitable for "open" rail networks (e.g., regional lines with unstaffed, platform-only stops).

4.2. The Validation Media Matrix

The effectiveness of a smart turnstile [50] is dependent on the validation medium it reads. There is a direct trade-off between speed, cost, and security.

- 1) *NFC / Contactless Smartcards*: This is the dominant, proven technology for high-throughput, high-frequency transit.
 - a) *Global Examples*: This model was perfected by systems like Japan's Suica card, Hong Kong's Octopus card, London's Oyster card, and Paris' Navigo card. [30]
 - b) *Technology and Speed*: These cards use Near-Field Communication (NFC) or a similar Radio-Frequency Identification (RFID) technology. [25] Their success lies in their transaction speed; a tap-to-validate transaction can occur in as little as 35 milliseconds. [49] This speed is essential for processing large crowds during rush hours. These systems also successfully integrate e-money, allowing the card to be used for both transit and at-station retail. [30]
- 2) *QR Codes*: This medium has become a popular "asset-light" alternative, as it leverages the passenger's own smartphone, eliminating the need for the railway to issue physical cards. [43].
 - a) *Benefits*: QR codes are exceptionally easy and inexpensive to produce and distribute digitally. [39]
 - b) *Drawbacks*: Operationally, QR codes introduce significant friction. Unlike a simple NFC tap, the passenger must unlock their phone, open the correct app, find the specific ticket, and then correctly align the screen with a scanner. This process is slow and failure-prone, leading to bottlenecks. This friction "creates an extra cost to transport operators/authorities as traveller assistance is regularly required to get through turnstiles." [39] The unreliability and slowness of QR codes have become so problematic that "some major train operators are already formulating plans to migrate from QR codes." [39]

4.3. The Biometric Gateway: Facial Recognition as the "Ultimate" Ticket

The most technologically advanced—and operationally "seamless"—perimeter solution is the biometric gateway. In this model, the passenger's face becomes their ticket. Passengers book tickets online, and their biometric data is linked to their reservation. This allows for a completely "hassle-free boarding" experience where passengers simply walk through a gate, identified by a camera. [29].

- 1) *Implementation*: These systems use advanced algorithms and AI-powered machine learning models to map facial landmarks (e.g., distance between eyes, shape of the nose). [29] This facial map is then compared to a secure database to confirm identity and validate the ticket
- 2) *Case Studies*:
 - a) *India (RRTS)*: A high-speed regional rail network is implementing an AI-based, ticketless travel system using facial recognition. Critically, this system was designed to "operate on-premises without internet or cloud support," providing maximum security and privacy to commuters and allowing it to function even in variable lighting conditions. [13]
 - b) *India (General)*: Facial recognition is also being deployed in busy railway stations for security, using AI to "identify people who try to travel without buying tickets" and "apprehend the blacklisted person." [48] This demonstrates the dual use of the technology for both ticketing and law enforcement. [16]
 - c) *China*: The national e-ticketing system is explicitly designed to link with "face recognition clusters" as part of its core architecture, enabling a fully integrated, high-speed validation process. [47]

4.4. The Governance Chasm: Addressing the Inherent Privacy and Ethical Crisis of Biometrics

Implementing facial recognition is not a simple technical upgrade; it is a profound political and ethical decision that carries immense, irreversible risks. Civil liberties organisations, in particular, have highlighted the dangers of deploying this technology in public transit.

- 1) *The Civil Liberties Argument*:
 - a) *Pervasive Surveillance*: Facial recognition "gives governments, companies, and individuals the power to spy on us wherever we go." [5] A railway network effectively becomes an involuntary, mass surveillance system
 - b) *Data Permanence*: The most significant danger is the permanence of biometric data. As the ACLU notes, "You can't reset your face." [52] If a database of faces is breached, a passenger's unique, unchangeable biometric identity is compromised forever

- c) Data Aggregation: The technology "makes it easy for them [companies and governments] to get together and compare notes on your behaviour." [52] This allows for the creation of a permanent, detailed log of a citizen's movements, associations, and presence at sensitive locations (e.g., protests, clinics, places of worship). [19]
- d) Algorithmic Bias: The systems are notoriously "dangerous if inaccurate." [19] Biased training data can lead to high error rates for specific demographics, resulting in "discrimination" [29] and false accusations.
- 2) *The Data Security Argument*: Storing millions of biometric identifiers creates a "honeypot" for malicious actors, with a data breach having catastrophic consequences for passenger privacy. [52]
- 3) *The Legal Framework*: The legal and regulatory environment is a minefield. Many U.S. cities have *banned* government use of facial recognition [19], and the rules governing how such data can be shared with law enforcement are ill-defined and contentious. [35]

This analysis reveals a "Perimeter Control Paradox." The most operationally seamless and efficient solution (facial recognition) [29] is the most ethically toxic and legally volatile. [52] Conversely, the cheapest and easiest-to-deploy solution (QR codes) [39] is the most operationally inefficient and friction-filled.

Furthermore, the entire concept of perimeter control contains a critical "Open Network Failure." Gated access [50] is a non-solution for the majority of the world's regional and commuter rail networks. These "open" systems (e.g., Italian Regionale trains, many UK and German lines) feature unstaffed platforms with no gates. Passengers are expected to validate a ticket at a simple trackside machine. In this model, there is nothing to stop a passenger from boarding without a ticket.

This operational reality proves that *Perimeter Control (Phase 1)* is *insufficient on its own*. It must be paired with a robust *In-Transit Verification (Phase 2)* system to manage passengers who board at open, ungated platforms.

5. Phase 2: The 'Intelligent Carriage' and Real-time In-transit Verification

Given the limitations of a perimeter-only model, a robust TTE-less solution requires a second layer of verification: an "Intelligent Carriage" capable of real-time, in-transit monitoring. This system creates a live, digital twin of the carriage's occupancy, which can then be compared against the central ticketing database.

5.1. The Technology Matrix: Reserved Seating vs. Unreserved Commuter

The train's service model dictates the choice of in-transit

verification technology. A single solution cannot serve all purposes. A reserved-seating, long-distance train requires granular data on *which passenger is in which specific seat*. A high-capacity, unreserved commuter train simply requires an accurate *headcount* to check against the number of "tapped-in" passengers.

- 1) Reserved Seating Model (e.g., High-Speed, Intercity): Requires a system that can verify *one person, one seat*. An IoT sensor grid [8] is ideal, but an Automated Passenger Counter (APC) [36] is insufficient as it cannot determine *who* is in *which* seat.
- 2) Unreserved Seating Model (e.g., Commuter, Metro): Requires a system that can count total passenger volume. An APC [36] is perfect for this, while a seat-specific sensor grid [8] is cost-prohibitive, complex, and useless for standing passengers.

Therefore, the "Intelligent Carriage" is a modular concept, deploying different technologies based on the service type.

5.2. Solution for Reserved Seating (High-speed / Intercity)

For trains where passengers book a specific seat, the system must validate that the *correct* seat is occupied by a *valid* ticket-holder for the *correct segment* of the journey.

5.2.1. The Seat Occupancy Grid (IoT Sensors)

This is the most precise solution, embedding sensors within the carriage to monitor every seat.

- 1) Technology: The system uses a grid of IoT-driven sensors. These sensors are described as "compact, ultra-low-power, and rail-certified." They can be wired or wireless, with some offering a 10-year battery life, and can be placed "anywhere within the seating area."
- 2) Sensor Type: While basic systems could use simple pressure sensors [22], this creates a "bag on seat" false-positive problem. More advanced systems, such as those from Attensys, use "advanced algorithms" to "sense the difference" between a "Body, backpack or wheelchair." This sophistication is crucial for accurate verification.
- 3) Passenger-Facing Interface (Critical): The data from these sensors is not just for enforcement; it is a powerful passenger service tool.
 - a) LNER Case Study: The London North Eastern Railway (LNER) pioneered a "traffic light" system using LED indicators above every seat. [8] This system communicates seat status to passengers in real time:
 - i) Green: Unreserved for the whole journey
 - ii) Amber: Reserved for a *future part* of the journey (i.e., the seat is currently empty but the reserving passenger will board at a later stop). This brilliantly signals to a non-reserving passenger that they *can* sit there, but must move later

- iii) Red: Occupied and/or reserved for the current journey segment. This system directly addresses a primary source of passenger friction and "awkwardness": the uncertainty of asking a passenger if a seat is free or having to ask someone to move from a reserved seat. [4]
- b) EAO System: A similar solution from EAO uses a high-contrast digital display integrated directly with the seat and the passenger information system to show reservation status.

5.2.2. Passenger-device Pairing (BLE Beacons)

A complementary or alternative system pairs the passenger's mobile device directly to their seat.

- 1) Technology: Bluetooth Low-Energy (BLE) iBeacons are small, low-power transmitters placed in each seat or carriage area. [7]
- 2) How it Works: The passenger's mobile rail app [11] detects the unique code broadcast by the nearest iBeacon. The app securely transmits this code to the central server, which then "translates the code into a carriage and seat number." [7] This automatically confirms that the passenger (or at least, their device) is in the correct, assigned seat, effectively an automated "check-in"

5.2.3. Automated Manifest Check-in (Wi-Fi)

This model leverages the on-board passenger Wi-Fi as a "digital turnstile."

- 1) Technology: Uses the on-board passenger Wi-Fi network as an access control system.
- 2) How it Works: To gain access to the "Free Wi-Fi," a passenger must authenticate using their reservation code or through the mobile app. This action registers them with the system, creating a live, digital "manifest" of passengers who have successfully boarded, similar to the "EarlyBird Check-In" logic used by airlines.

5.3. Solution for Unreserved Seating (Commuter / Metro)

For high-capacity commuter systems, the verification goal is different. The system must match the *total number* of passengers in a carriage against the *total number* of "tap-ins" (from Phase 1) assigned to that carriage, identifying mass fare evasion or overcrowding.

5.3.1. AI-driven Automated Passenger Counting (APC)

This is a highly scalable and privacy-conscious solution.

- 1) Technology: This method uses AI-powered computer vision to turn existing on-board security cameras into smart, anonymous counting sensors. [36]
- 2) How it Works: Fisheye cameras are typically placed overhead at the carriage doors. [36] The AI algorithm,

running on the camera, "anonymously" counts passengers as they "get on and off at each stop." [36] This provides a precise, real-time "headcount" or "occupancy level" for each car [36], with accuracy rates reported at over 98-99%. [36] Advanced systems can also be trained to distinguish passengers from objects like bicycles, luggage, and wheelchairs, preventing them from being counted as passengers

5.3.2. Privacy by Design (The Critical Enabler)

This technology is only viable because it is *explicitly anonymous*. [2] This fundamentally differentiates it from the "Facial Recognition" in Phase 1.

- 1) Parquary Case Study: The architecture of these APC systems is the key to their compliance. The Parquary system, for example, is GDPR-compliant because its AI software runs on an "on-site edge computer" (i.e., a small processor on the train itself). [36] The video data *never leaves the vehicle* and is not stored. Only the *anonymised statistical counts* (e.g., "Car 3, +10 passengers, -5 passengers") are encrypted and sent to the central server. No faces, biometrics, or personal data are ever recorded. [36]

This "Intelligent Carriage" technology, deployed to solve the ticket verification problem, creates a powerful secondary effect. The rich, real-time data it generates revolutionises railway operations. This "Data to Decision" pipeline [37] provides a new, high-value dataset with a clear business case:

- 2) Fleet Optimisation: APC data allows operators to "optimise their fleet and vehicle capacities", for example, by adding carriages to a specific train that is consistently overcrowded at 17:30, or reducing carriages on a route that is always empty.
- 3) Predictive Maintenance: The same data becomes a management tool. Maintenance can be planned "based on actual usage." [37] Doors, seats, and HVAC systems in heavily-used carriages can receive predictive maintenance *before* they fail, while lightly-used carriages can have their maintenance schedules extended.
- 4) Energy Savings: Occupancy data allows for dynamic energy optimisation. The system can ask, "Why heat or light empty carriages?" [37], and automatically adjust climate control and lighting, leading to significant energy and cost savings. The true return on investment for the TTE-less solution is not found in eliminating TTE salaries (which will show are reinvested), but in the massive operational efficiencies unlocked by this new real-time data.

6. The Central Nervous System: An Architecture for Real-time Data Fusion

The "Intelligent Carriage" (Phase 2) provides the "eyes" of

the system, but it is operationally useless without a "brain." This "Central Nervous System" is a backend data architecture capable of ingesting billions of data points in real time from the entire fleet, comparing them against the ticketing database, and identifying discrepancies for action.

6.1. The Passenger Service Record (PSR) as the Core Data Object

The entire automated framework must be built upon a "master record" for each passenger's journey. The blueprint for this is China's national e-ticketing system, which is built on a "Passenger Service Record (PSR) data storage model." [47].

The PSR is the "single source of truth." It is the data object that links the passenger's *identity* (or an anonymised identifier), their *ticket* (fare paid, class), and their *reservation* (specific train, carriage, seat number, and journey segment). When a passenger buys a ticket, a PSR is created. Every action—from passing a turnstile (Phase 1) to sitting in a seat (Phase 2)—is a validation event checked against this master record.

6.2. A Conceptual Model for a Real-time, Integrated Database

The core engineering challenge of the TTE-less system is *not* the sensor; it is data synchronisation. The system must solve the problem of "synchronisation technique in a distributed heterogeneous database system." [47].

This central database must be built for "high-speed access... under high concurrency conditions" [47], as it will be pro-

cessing validation requests from millions of passengers and sensors simultaneously. This "IoT in railway" model [51] must fuse, in real time, data from at least four distinct sources:

- 1) Ticketing & Reservation Systems: The master database of all PSRs. [45]
- 2) Live Sensor Data (IoT): The real-time feeds from every seat sensor, BLE beacon [7], and Automated Passenger Counter [36] across the fleet
- 3) Train Control & Management System (TCMS): This system provides the train's precise, real-time GPS location, speed, and next-station data. [11] This is critical for validating journey segments
- 4) Passenger Manifest: Data from passengers who have "checked in" via the on-board Wi-Fi or activated their ticket in the mobile app. [1]

The sensors of not determine the success of this entire framework, but by the *speed and accuracy* of this backend synchronisation. A train is a high-speed, dynamic environment. A passenger's PSR is valid for "Segment A-B." The *instant* the train's TCMS reports that it has departed Station B, that PSR is marked "invalid" for that seat.

Suppose the sensor data (reporting "Seat 4A Occupied") is checked against a database that is even one minute out of date. In that case, the system will be overwhelmed with false positives (flagging valid passengers for Segment B-C as invalid) and false negatives (failing to flag the Segment A-B passenger who has overstayed). This "real-time or nothing" imperative means the *true* engineering challenge is the high-concurrency, high-transaction database architecture [47] that can definitively answer the "IS THIS VALID RIGHT NOW?" query millions of times per minute.

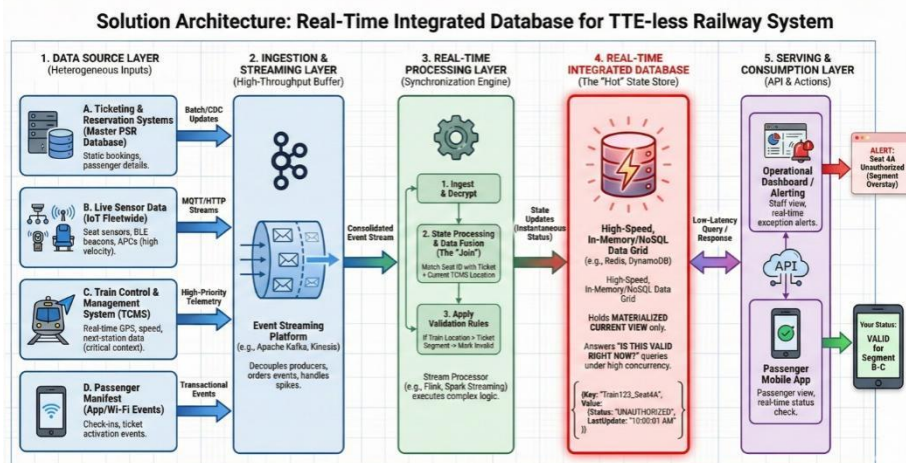


Figure 3. A real-time data architecture that synchronises ticketing records, live sensor inputs, and train location to continuously validate passenger status and trigger targeted human or automated interventions.

6.3. The Data Fusion & Exception-trigger Model

The "Central Nervous System" uses this data fusion to execute a continuous logical query, identifying discrepancies that are

then flagged for action. The following table provides a conceptual model of this automated logic.

Table 1. Data Fusion Model for Occupancy Discrepancy.

Event Trigger	Data Source 1 (Sensor)	Data Source 2 (PSR/Ticket DB)	System Query (executed by server)	Result / Discrepancy Flag	Automated Action (Ref: Sec V)
Scenario 1: Valid Passenger	Seat 4A occupancy sensor (Sensor_ID: 8F3B) triggered at 14:05. Status: Occupied.	PSR_ID: 9942 (linked to Ticket_ID 7A). Seat: 4A. Passenger: J. Doe. Journey Segment: London-York. Train_Location: Between London-York.	IS Sensor_ID: 8F3B_Status (Occupied) == PSR_ID: 9942_Status (Booked)? AND IS Train_Location within PSR_ID: 9942_Segment?	MATCH (Occupied == Booked) AND (Location == Valid)	No Action. Logged.
Scenario 2: Un-verified Passenger	Seat 4B occupancy sensor (Sensor_ID: 8F3C) triggered at 14:06. Status: Occupied.	PSR_ID: ---. Seat: 4B. Status: Unbooked. Train_Location: London-York.	IS Sensor_ID: 8F3C_Status (Occupied) == PSR_Seat: 4B_Status (Unbooked)?	MISMATCH: OCCUPIED_UNBOOKED	Trigger Workflow 5.1 (Alert Passenger Host / Remote Ops).
Scenario 3: "Seat Squatter" (Wrong Seat)	Passenger J. Smith app (Device_ID: 45A) pings iBeacon 4A at 14:07.	PSR_ID: 9981. Passenger: J. Smith. Assigned Seat: 8C. Device_ID: 45A.	IS BLE_Beacon_Seat (4A) == PSR_ID: 9981_Seat (8C)?	MISMATCH: VALID_PASSENGER_WRONG_SEAT	Trigger Workflow 5.2 (Push Notification to Passenger's Device).
Scenario 4: Post-Journey Overstay	Seat 4A occupancy sensor (Sensor_ID: 8F3B) status: Occupied at 15:30.	PSR_ID: 9942. Seat: 4A. Journey Segment: London-York. Train_Location: Between York-Newcastle.	IS Sensor_ID: 8F3B_Status (Occupied) == PSR_ID: 9942_Status (Booked)? AND IS Train_Location within PSR_ID: 9942_Segment?	MISMATCH: PASSENGER_OVERSTAY (Occupied == Booked) BUT (Location != Valid)	Trigger Workflow 5.1 (Alert Passenger Host).
Scenario 5: Commuter Car Over-Capacity	APC Sensor (APC_ID: C03) reports +20 passengers at 17:05. Total_Car_Occupancy: 130.	TCMS Data. Car_ID: C03. Max_Capacity: 100.	IS APC_Occupancy (130) > TCMS_Max_Capacity (100)?	MISMATCH: DANGEROUS_OVERCROWDING	Trigger Workflow 5.3 (Alert Driver / Ops Center; Update PIS).

7. Automated Exception Handling and On-board Revenue Management

The "discrepancy flags" generated by the Central Nervous System are the triggers for action. This section defines the automated workflows that replace the TTE's proactive enforcement. This system manages exceptions, resolves conflicts, and provides self-service tools for passengers to manage their own revenue transactions.

7.1. Workflow 1: The "Occupied But Unbooked" Alert (Ticketless Traveller)

1) Trigger: MISMATCH: OCCUPIED_UNBOOKED

(from Table 1).

- 2) System Action: The system logs the discrepancy and automatically sends a real-time alert to personnel. This is modelled on "Gateline Detection" solutions, which send real-time alerts to staff when security gates are left open, inviting ticketless travel.
- 3) Resolution (Human-in-the-Loop): This is the primary resolution path. The alert is pushed to the on-board 'Passenger Host's handheld device, with a message like: "Seat 4B, Car 3: Occupied, Unbooked. Please verify." This allows for a targeted, non-intrusive intervention, replacing the need to "check everyone" with a precise, data-driven check of a single passenger.
- 4) Resolution (Remote): In a truly "unstaffed" model (e.g., a short-hop commuter line), this alert could be sent to a remote operations centre.

- 5) Resolution (Automated Enforcement): An extreme model could leverage automated camera enforcement (similar to bus-lane enforcement) [1] to identify the passenger (if not an anonymous system) and automatically issue a "ticket-by-mail" or fine. This approach carries significant privacy, data security, and customer-relations risks and is not recommended for passenger service.

7.2. Workflow 2: The "Wrong Seat" Alert (Seat Squatter / Confused Passenger)

- 1) Trigger: MISMATCH: VAL-ID_PASSENGER_WRONG_SEAT
- 2) The Problem: This is one of the most common sources of passenger-to-passenger conflict. A passenger with a reservation finds their seat occupied, leading to an "awkward seat moment" or "seat altercation." [4]
- 3) Automated Resolution (System-to-Passenger):
 - a) Passive Empowerment: The LNER-style LED indicator above the seat turns RED. [8] This "empowers" the rightful passenger (Passenger A). They no longer need to argue; they can simply point to the light, which acts as the system's objective "authority."
 - b) Active Notification: If the "squatting" passenger (Passenger B) is logged into the app, the system can push a polite notification directly to their device: "Welcome! We see you're in Seat 4A. Your reserved seat is 8C. Please move to 8C at your convenience."

This workflow reveals a critical implication of the TTE-less system. It *shifts the burden of conflict*. In the traditional model, the TTE proactively resolves the conflict. The automated system, by design, is reactive. It empowers the *rightful passenger* to manage their own conflict, using the seat's LED indicator [8] as their "authority." This creates a high probability of *increasing* passenger-to-passenger conflict. [34] This, in turn, *proves the necessity* of the 'Passenger Host' as a highly-trained *mediator* and *de-escalator* who can be summoned to manage these exact situations.

7.3. Workflow 3: Passenger-led Changes (Self-service Revenue)

This workflow replaces the TTE's role in handling on-board sales, managing upgrades, and collecting fares. The system must provide self-service tools for passengers to "legalise" their own discrepancies, such as moving from an unbooked to a booked seat.

- 1) Technology 1: In-App Purchases & Upgrades:
 - a) The passenger's mobile app must be in real-time sync with the "Intelligent Carriage" sensor grid
 - b) The passenger opens the app, which displays a live occupancy map of their carriage. [36] The app may show its own location (from a BLE beacon [7]) and all *Green* (available) seats. [8]

- c) The passenger can then select an empty seat and "buy this seat" or "upgrade to this seat" mid-journey. Upon payment, their PSR is updated instantly, and the LED above their new seat turns RED. The ticket must auto-activate. [1]

- d) This self-service model avoids the punitive on-board surcharge or penalty fare that is common in today's systems

2) Technology 2: On-Board Unattended Kiosks:

- a) To serve the "digital divide", the train must be equipped with self-service kiosks
- b) These would be "unattended retail" solutions [10] located in a vestibule or cafe car. They would allow a passenger to use a credit card or cash to buy a ticket, pay a fare, or process an upgrade, printing a simple receipt or QR ticket

8. The New Human Element: The 'Passenger Host' Staffing Model

This section is the linchpin of the entire TTE-less framework. It directly solves the problem identified (the loss of the TTE's safety, security, and service functions) and addresses the new conflicts created by automation.

The TTE-less train is *not* an *unstaffed* train. The critical human-in-the-loop functions of the TTE cannot be automated. The only viable solution is to *re-staff* the train differently, shifting the human role from enforcement to high-value service.

8.1. From Enforcement to Service: Unbundling the TTE Role

The core premise of this model is to "unbundle" the TTE's current job description. [24].

- 1) Tasks to Automate (Low-Value): The repetitive, low-value tasks of "checking every ticket" and "collecting fares" are automated by the systems. These roles, like "ticketing offices" and "station staff at ticket barriers," are "jobs under pressure" and declining globally. [42]
- 2) Tasks to Retain (High-Value): The high-value, high-skill tasks of "Emergency Handling" [24], "Passenger Assistance," and "Conflict Resolution" [34] are retained and expanded. These service-oriented, technology-adjacent roles are "jobs on the rise." [42]

This model proposes eliminating the TTE role and replacing it with a new, specialised 'Passenger Welcome Host'.

8.2. Defining the 'Passenger Welcome Host' / 'Car Host'

This new role is distinct from a "Conductor." In many rail operations, the Conductor is responsible for safety-critical

train operations, such as managing train movements, adhering to signals, and coordinating with the engineer. The 'Host' is a *customer-facing* and *cabin-focused* role.

This role is known in various forms as a "Passenger Service Attendant", "Train Attendant", "Railroad Passenger Agent" [26], or "Customer Welcome Host."

The primary duties of the 'Passenger Welcome Host' are:

- 1) Passenger Service: Their first duty is hospitality. They act as "goodwill ambassadors," assist passengers with boarding, seating, and deboarding, provide travel information, and are responsible for "creating a welcoming atmosphere."
- 2) Accessibility: They are the primary human contact for the 'Passenger Assist' program. [33] They proactively identify and assist passengers with disabilities, elderly travellers, and those with special needs, replacing the TTE's ad-hoc assistance duty. [26].
- 3) Safety & Security: They "monitor the safe operation of onboard systems." In an emergency, they are the designated "Person In-Charge" [41] responsible for executing evacuation plans. They are the "principal contact" for coordinating security matters [21] and are the visible human presence that deters anti-social behaviour.
- 4) Automated Exception Handling: They *do not* check every ticket. Their tablet device receives the discrepancy alerts. They only intervene when the system flags a "ticketless traveller" or when they are called to "manage passenger seat assignments" to resolve a conflict.

8.3. Essential Competencies: The New Training Mandate

This new role requires a fundamentally different skillset and training regimen from the traditional TTE model.

- 1) Conflict De-escalation: This is the paramount new skill. The Host will be the human mediator for the passenger-to-passenger conflicts [34] that the automated system will inevitably create. They must be "trained to defuse tension, communicate calmly under pressure" and prioritise "care before position or policy enforcement." This is an essential, core competency for this role.
- 2) Emergency Response: This is the most critical, non-negotiable function. The 'Host' is the safety-critical staff member for the passenger cabin. They must receive "on-train instruction on the location, function, and operation/use of on-board emergency equipment." [12] This includes passenger evacuation procedures [18], basic firefighting [18], and coordinating with remote operations centres and first responders. [18] This training must include railroad-specific incident response.
- 3) Security & Observation: The Host is the human sensor. Their presence is a proven deterrent. Incidents where staff intervention has "undoubtedly saved lives" [23] demonstrate that a human presence is vital to passenger

safety. The Host is trained to be the eyes and ears of the on-board security system, coordinating with remote operations and law enforcement. [6].

The "TTE-less" train is therefore not an "unstaffed" train. A fully unstaffed model is operationally unviable, as it creates an unsafe, unmanaged, and high-conflict environment. The only workable solution is to *re-allocate* the TTE labour force. The business case is not "cutting labour" but "optimising labour"—shifting employees from low-value (ticketing) to high-value (service, safety, and de-escalation). This transition requires a new career path, new collective bargaining agreements, and a new focus on hospitality and safety.

9. An Equitable and Accessible System: Ensuring Service for All Passengers

A fully automated system that serves only tech-savvy, fully-abled, and banked passengers is an operational, legal, and social failure. A "complete solution" must be inclusive by design, providing mandatory "on-ramps" and support systems for 100% of the travelling public. Automation risks creating a "dual-track" system: a seamless experience for the 90% and a hostile, exclusionary one for the 10%.

9.1. Bridging the Digital Divide: The Unbanked and Non-smartphone Users

- 1) The Problem: A "digital-only" system will exclude a large and vulnerable passenger segment. A significant number of riders (~30% in one study) currently pay with cash on board. [20] Approximately 10% of adults in the U.S. lack a bank account or credit card. [20] Furthermore, the "digital divide" is multi-layered; it is not just a lack of a smartphone, but also a "lack of interest," a "lack of skills," or a reliance on "restrictive cell-phone data plans." [20] "Older and lower-income riders are more at risk of exclusion." [20]
- 2) The Solution: A "Cash On-Ramp" Strategy: The goal is not to eliminate cash, but to *move its point of collection* from the (human) TTE to an (automated) point-of-sale. This is critical for retaining riders. [20]
 - a) Retail Networks: Allow passengers to use cash to buy tickets or load re-usable smartcards at third-party retail partners (e.g., convenience stores, post offices). [20]
 - b) Cash-Accepting Ticket Vending Machines (TVMs): All station-based kiosks *must* continue to accept cash for ticket purchases. [20]
 - c) On-Board Kiosks: The self-service kiosks *must* also accept cash. This is the direct replacement for the TTE's cash-handling duty. This will be critical as some transit operators plan to remove on-board cash sales. [17]
 - d) Non-Digital Media: The system cannot be app-only. It must fully support non-digital media, such as sim-

ple paper QR tickets [43] or reloadable RFID/NFC smartcards that do not require a phone. [49]

9.2. Ensuring Accessibility: Passengers with Disabilities and Reduced Mobility

- 1) The Problem: An automated, TTE-less system risks dehumanising accessibility. A passenger in a wheelchair cannot "self-serve" a boarding ramp, and a visually impaired passenger cannot navigate an unfamiliar, unstaffed station
- 2) The Solution: Integrating 'Passenger Assist' with the 'Passenger Host'
 - a) The 'Passenger Assist' System: The existing industry-wide reservation system for assistance [33] must be the *single source of truth* for accessibility. When a passenger books assistance (for a ramp, sighted guidance, luggage, etc.), this request is automatically flagged in their Passenger Service Record (PSR)
 - b) The 'Passenger Host' Role: This is the *primary* solution. The 'Passenger Host' receives the 'Passenger Assist' manifest on their handheld device. Their duties explicitly include proactively meeting the passenger, assisting with luggage, and ensuring safe boarding and deboarding with all necessary equipment. [26] This formalises and replaces the TTE's ad-hoc assistance duty. [31]
 - c) Station Infrastructure: At unstaffed or automated stations, ticket gates present a physical barrier. The policy *must* be that "automatic or manual ticket gates... [with] no employees attending... will lock the gates open." [33] An alternative, default-open accessible gate must be provided. All infrastructure must comply with size requirements for wheeled mobility devices [40] and aim for level-entry boarding where possible. [46]

This analysis reveals a critical, unavoidable conflict in the TTE-less model. To make the perimeter *secure*, the system must have closed, automated gates. But to make the perimeter *accessible*, the system must *lock those same gates open* at unstaffed stations. [33].

This paradox *proves* that a perimeter-only solution is an absolute failure. It is the final piece of evidence demonstrating that *both* the "Intelligent Carriage" and the "Passenger Host" are non-negotiable, essential components. The in-transit sensors are required to catch the fare-evaders who will inevitably walk through the (intentionally) open accessible gates. The 'Passenger Host' is required to be the human element that *manages* the accessible gate and provides the mandated service to the passengers who need it.

10. Implementation Pathways, Costs, and Concluding Recommendations

This report has detailed an end-to-end framework for a

TTE-less railway. The final analysis synthesises these components into a strategic, actionable implementation plan, assessing the economic framework and proposing a "best-of-breed" model.

10.1. The Economic Framework: Cost vs. True Value

The transition to a fully automated verification system requires significant capital expenditure. However, the return on investment (ROI) is not found in labour savings, but in a radical improvement in operational efficiency and revenue capture.

- 1) Costs: The initial capital expenditure (CAPEX) is high.
 - a) Infrastructure: This includes the installation of smart turnstiles [50], a fleet-wide deployment of on-board IoT sensors [9], and the installation of accessible, cash-accepting kiosks at stations and potentially on-board. A single, related EU project had a total cost of €3.8 million. [14]
 - b) Data Architecture: This includes the significant software development cost of building the high-concurrency, real-time PSR database [47] and licensing or developing the AI algorithms for APC and sensor fusion
 - c) Labour: This includes the cost of a mass retraining and re-skilling program to transition the existing TTE workforce into a new 'Passenger Host' corps, with new training in de-escalation and emergency response. [18]
- 2) Return on Investment (ROI): The business case is *not* a reduction in TTE headcount, as this role is proven to be essential for safety and service. The true ROI is found in four other areas:
 - a) Operational Efficiency: This is the primary value driver. The rich data from "Intelligent Carriage" sensors [37] and APCs allows for data-driven optimisation of fleet schedules, route planning, cleaning schedules, and energy consumption ("why heat... empty carriages"). [37]
 - b) Revenue Protection & Growth: The system provides near-100% revenue protection, eliminating casual fare evasion. Furthermore, the self-service, in-app upgrade tools create a frictionless new revenue stream, capturing value that was previously lost
 - c) Safety & Accident Prevention: On-board sensors are not limited to passengers. Integrated IoT systems can also monitor rolling stock and track conditions. [51] A Benefit-Cost Analysis (BCA) for related technologies showed that a positive ROI can be achieved by preventing a single, costly accident like a derailment. [32]
 - d) Passenger Throughput & Capacity: Automated systems are dramatically faster. China's e-ticketing system "reduced the average time for passengers to pass

through the automatic ticket gates... from 3 seconds to 1.3 seconds." [47] This 57% reduction in processing time can dramatically increase the practical capacity of a busy station, delaying the need for costly physical expansion.

10.2. Synthesised "Best-of-breed" Case Studies

No single rail operator has implemented this entire framework perfectly. The optimal solution is a "best-of-breed" hybrid that combines the proven successes of multiple global systems:

- 1) Perimeter Control (Japan Model): Adopt Japan's model for perimeter access. Prioritise high-speed, reliable, and privacy-respecting NFC/Smartcards (e.g., Suica) as the primary validation medium. [30]
- 2) Data Architecture (China Model): Adopt China's model for the *backend architecture*. Build the system on a high-concurrency, real-time "Passenger Service Record (PSR)" database that can fuse heterogeneous data streams (sensors, tickets, location). [47]
- 3) Reserved Cabin (LNER Model): Adopt the LNER "traffic light" sensor grid for all reserved-seating carriages. This system is passenger-centric, reduces conflict, and is operationally proven. [8]
- 4) Unreserved Cabin (Parquary Model): Adopt the APC model for all unreserved/commuter cars. This model *must* be built on "privacy-by-design" principles, using edge computing to ensure video data never leaves the train, and only anonymous counts are transmitted. [36]

10.3. The Final Framework: The "Intelligent Train" Conceptual Model

The TTE-less train is, in fact, an "Intelligent Train." [3] The final conceptual model [38] is a fully integrated, cyber-physical system [28] where all components are in constant communication:

- 1) The Train (its sensors, location, and systems)
- 2) The Passenger (their mobile app and digital ticket). [7]
- 3) The Staff (the 'Passenger Host' and their handheld device). [26]
- 4) The Control Centre (the central PSR database). [47]

This integrated system creates a resilient, data-driven operation that is safer, more efficient, and provides a better passenger experience

10.4. Concluding Recommendations

The query for a "solution to checking... tickets" without TTEs is answered. The solution is not a single piece of technology but a comprehensive, four-part, integrated socio-technical framework.

PERIMETER (Station): Deploy a hybrid access-control perimeter. Use NFC as the primary standard for speed and

reliability, QR codes as a low-cost, app-based option, and cash-accepting kiosks to ensure 100% equity and inclusion. Avoid biometric facial recognition until the profound ethical, legal, and data-security risks are resolved.

CABIN (Train): Deploy a *service-specific* sensor matrix.

For Reserved Cabins: Implement an IoT seat sensor grid with a passenger-facing "traffic light" indicator (the *LNER model*).

For Unreserved Cabins: Implement anonymous, edge-computed Automated Passenger Counting (the *Parquary model*) to ensure privacy.

DATA (Cloud): Re-architect the backend around a real-time, high-concurrency Passenger Service Record (PSR) database (the *China model*). This system must be capable of instantly fusing sensor data, ticketing data, and train location data to flag exceptions.

HUMAN (Service): This is the most critical component. The TTE-less train *cannot* be an unstaffed train. The entire TTE workforce must be redeployed and retrained. The "enforcer" role must be eliminated and replaced with a new, highly-trained 'Passenger Welcome Host' corps. This role is non-negotiable and is focused *exclusively* on the high-value tasks of safety, security, accessibility, and customer service, responding only to the exceptions flagged by the automated system.

Abbreviations

ACLU	American Civil Liberties Union
AI	Artificial Intelligence
APC	Automated Passenger Counting
BCA	Benefit-Cost Analysis
BLE	Bluetooth Low-Energy
CAPEX	Capital Expenditure
GDPR	General Data Protection Regulation
HITL	Human-in-the-Loop
HVAC	Heating, Ventilation, and Air Conditioning
IoT	Internet of Things
LED	Light Emitting Diode
LNER	London North East Railways
NFC	Near-Field Communication
PSR	Passenger Service Record
QR	Quick Response (Code)
RFID	Radio Frequency Identification
ROI	Return on Investment
TCMS	Train Control and Management System
TTE	Train Ticket Examiner
TVM	Ticket Vending Machine

Author Contributions

Partha Majumdar is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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