Volume 1

CHAPTER 5

Wayside Equipment

Communications-Based Train Control
A Comprehensive Guide for US Transit Professionals
Francisco Wang

Chapter Overview

- Zone Controller (ZC): the wayside 'brain' — MA generation, conflict detection, zone boundary handover
- Interlocking Interface: CBTC-to-EI coordination for switch control, route locking, and signal management
- Wayside Transponders and Beacons: passive balises providing absolute position references for localization
- Platform Screen Doors (PSD): safety interlock with CBTC for berthing accuracy and door sequencing
- Track Vacancy Detection: fallback systems for broken-rail detection and non-CBTC train support

5.1

Zone Controller / Wayside ATP

Zone Controller: Dividing the Network

- Track divided into zones (2–5 km each) — each controlled by its own SIL 4 Zone Controller
- Distributed architecture: fault isolation (one ZC failure affects only that zone), scalability, reduced latency
- Each ZC handles 10–20 trains simultaneously; MA updates every 1–3 seconds
- Zone boundaries at strategic locations: stations, junctions, equipment rooms
- NYC L Line: 3 zones for 15 km; BART: ~30–35 zones planned for 120 km network

Movement Authority Generation

- MA = min(preceding train rear - safety margin, next restriction, zone boundary, max distance)
- Safety margin: 300–500m buffer between trains — varies by braking performance and system reliability
- Conflict detection: continuous scan of all trains; predictive conflict detection 30–60 seconds ahead
- MA update cycle: Receive (200ms) → Compute (200–500ms) → Transmit (100ms) = 500ms–1s total
- Shorter cycles → smaller safety margins → higher capacity; but require faster processors and better radio

Zone Controller Territory and Overlap

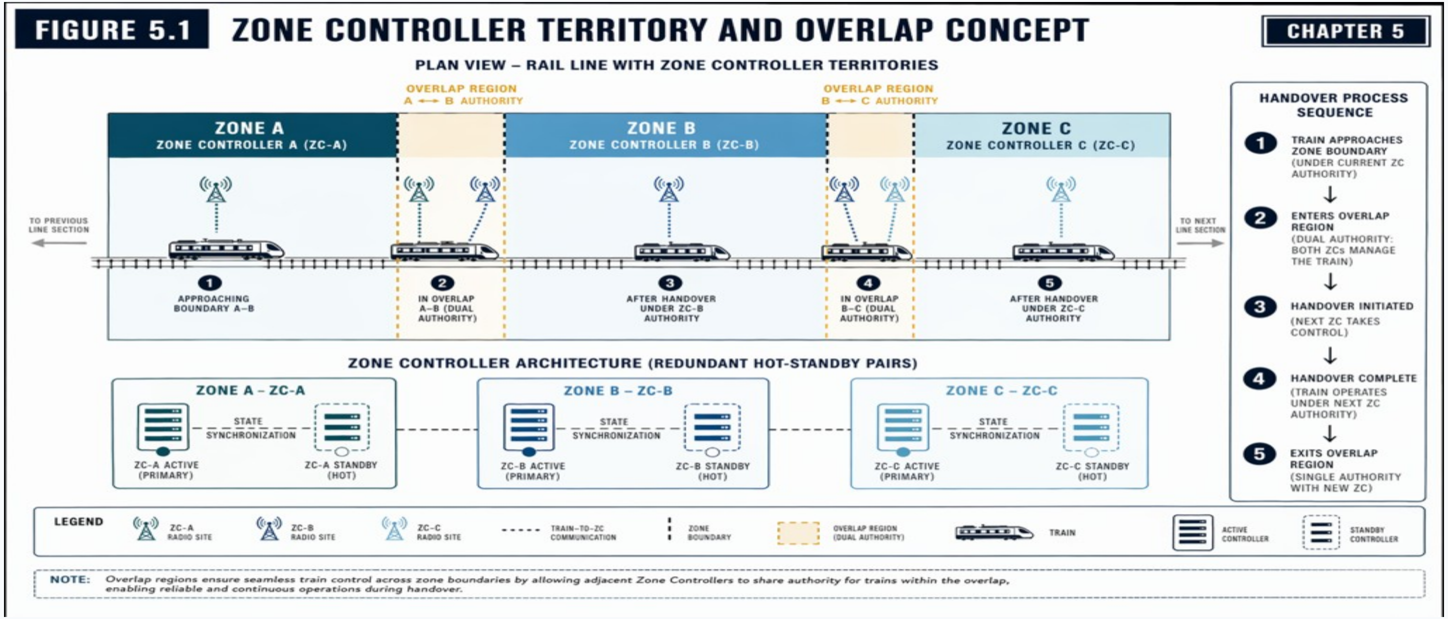

Figure 5.1 — Zone Controller territory division with overlap zones for seamless train handover.

Zone Controller Specifications

SIL 4

Safety integrity level (IEC 61508)

<500ms

Hot-standby failover time

$400K–700K

per zone

Hardware + installation cost

Zone Boundary Handover

- Challenge: transfer control between ZCs without interrupting motion or creating authority gaps
- T-30s: Zone A sends handover initiation (train ID, position, velocity, MA history) to Zone B
- T-10s: Zone B prepares MA for incoming train; sends 'handover ready' confirmation
- T=0: Train crosses boundary; Zone B begins issuing MAs; brief 10–100ms overlap for continuity
- Failure safeguard: if Zone B is offline, train receives no MA at boundary → ATP emergency brake

5.2

Interlocking Interface

Interlocking and CBTC Interface Logic

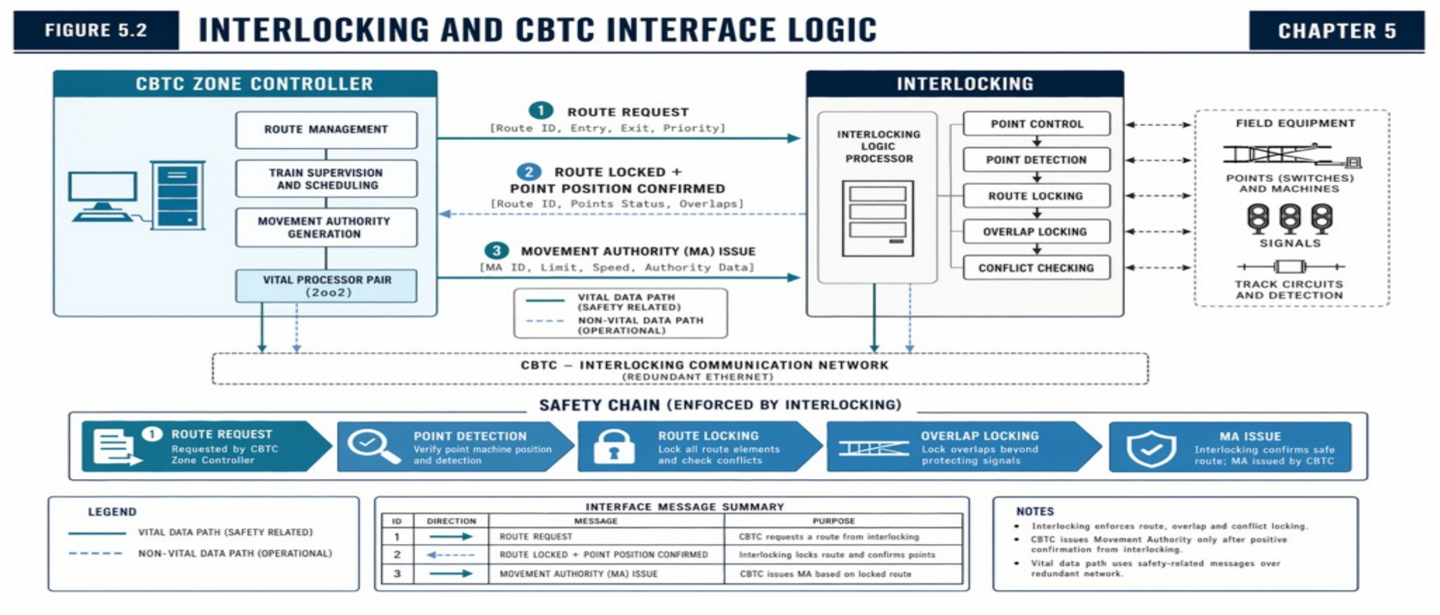

Figure 5.2 — CBTC Zone Controller and Electronic Interlocking coordination model.

CBTC-Interlocking Control Model

- ZC requests a route → Interlocking locks switches, verifies position, confirms → ZC extends MA
- Interlocking enforces three core rules: no conflicting routes, verified switch position, safe signal aspects
- Object Controller (OC): physical bridge translating ZC commands to 24VDC hardware control signals
- Route-setting cycle: 5–15 seconds (switch movement 2–5s + detection 0.5–2s + validation + confirmation)
- CBTC does NOT replace interlocking — they work in concert; both are independently SIL 4 certified

US Integration: Legacy vs. Modern Interlocking

- Legacy Relay Interlocking (NYC, CTA, WMATA):
- 40–60 year old electromechanical systems
- Interface via custom gateway modules
- Protocol translation: 100 baud serial → Ethernet
- NYC L Line: 3+ years of interface engineering
- Cheaper upfront but adds complexity and failure modes

- New Electronic Interlocking (BART):
- Deployed in parallel with CBTC ZC
- Standardized interfaces (moving toward IEC)
- Eliminates decades of relay system tech debt
- Larger budget ($500M+) and longer timeline (5+ years)
- Cleaner, safer, more maintainable long-term

5.3

Wayside Transponders and Beacons

Transponders: Anchoring Train Position

- Passive balises (Eurobalise standard): unpowered inductive loops energized by train antenna at passage
- Provide absolute position reference with ±0.5m precision — resets accumulated odometric drift to zero
- Key specs: 210-bit telegram, 20–40cm read range, >99.99% first-attempt reliability, IP67 rated
- Zero scheduled maintenance; 20+ year design life; installed cost $200–$500 per unit
- Spacing: 50–200m depending on accuracy needs — denser at stations, switches, speed restrictions

Transponder Deployment Strategy

- Station entrances and platform centers: enables precise ATO stopping control
- Track switches and junctions: confirms which route was taken after divergence
- Speed restriction zones: position confirmation before curves and grade changes
- Chicago Red Line: 100m intervals on mainline; WMATA Green Line: 150m with denser at switches
- US agencies increasingly demand Eurobalise compatibility to reduce vendor lock-in

5.4

Platform Screen Doors (PSD) Integration

PSD Types and CBTC Berthing Interlock

- Full-height PSD: floor-to-ceiling; standard for GoA 4 driverless systems (Hong Kong, Singapore, Seoul)
- Half-height PED: waist-height compromise; gaining traction in US retrofit and mixed-fleet environments
- Berthing accuracy: ±30cm tolerance — misalignment risks passenger entrapment or ADA violations
- CBTC achieves ±15–20cm stopping repeatability via ATO brake curve control
- Safety interlock: train stop confirmed → CBTC signals PSD → PSD verifies independently → doors open

Platform Screen Door Types Comparison

Type	Height	Use Case	Cost	Maintenance
Full-Height PSD	2.5–3.5m	GoA 4, new metros	Higher	Complex HVAC integration
Half-Height PED	1.1–1.5m	Retrofits, mixed fleets	Moderate	Simpler, fewer parts
Rope/Cable Barrier	0.6–1.2m	Light rail, heritage	Lower	Minimal mechanical

5.5

Track Vacancy Detection as Fallback

Track Vacancy Detection: Safety Net

- In pure CBTC, track circuits are optional — trains self-report position via radio
- Track circuits often retained in overlay CBTC for: non-CBTC trains, broken-rail detection, fallback positioning
- Broken-rail detection: interrupted track circuit alerts maintenance before catastrophic failure
- Axle counters: alternative to track circuits — count axles entering/exiting a section to confirm vacancy
- Track-circuit-free CBTC saves $1–2M per mile but requires higher onboard sensor investment

Track Circuits: Retain or Remove?

- Retain (Chicago Red Line, most US retrofits):
- Supports non-CBTC trains on same line
- Provides broken-rail detection capability
- Safety fallback if CBTC localization fails
- Higher ongoing maintenance cost

- Remove (Paris Line 14, new-build driverless):
- Saves $1–2M per mile in infrastructure
- No track circuit failures or recalibration
- Requires 100% CBTC-equipped fleet
- Demands proactive rail inspection program

Key Takeaways

1. The Zone Controller is the SIL 4 wayside brain — it divides the network into 2–5 km zones, generates Movement Authorities, detects conflicts, and manages zone boundary handovers in <500ms

1. Interlocking and CBTC work in concert, not in replacement — the ZC requests routes, the interlocking locks switches and confirms, then the ZC extends the MA (5–15 second cycle)

1. Passive transponders provide absolute position references at $200–$500 per unit with zero maintenance and 20+ year life — the cost-effective anchor for train localization

1. PSD integration requires ±30cm berthing accuracy from CBTC, with independent safety verification — essential for GoA 4 driverless operation

1. Track vacancy detection is optional in standalone CBTC but commonly retained in US overlay deployments for broken-rail detection and mixed-fleet compatibility

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End of Chapter 5

Next: **Chapter 6: Communication Systems**

Questions & Discussion

