Volume 2

CHAPTER 9

Operating Modes and Mode Transitions

Communications-Based Train Control
A Comprehensive Guide for US Transit Professionals
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Chapter Overview

- If GoA answers "how much automation is designed in," operating modes answer "how does the system behave when conditions change?"
- Six primary modes: Normal CBTC, Restricted Manual, Non-CBTC Bypass, Territory Entry/Exit, Degraded, Emergency
- Modes form a continuum from maximum capacity/automation to minimum capacity/maximum human control
- Operators and dispatchers must be trained on ALL modes — system design must degrade gracefully
- Boundary transitions account for 15–20% of CBTC operational anomalies despite being 2–3% of track

9.1

Normal CBTC Operation (ATP/ATO)

Defining Normal Mode

- Full ATP/ATO coverage with continuous communication to Zone Controller (RTT <500 ms)
- Healthy onboard systems: VOBC, odometry, localization sensors, door/propulsion interfaces
- Healthy wayside: Zone Controller, ATS, interlocking logic, traffic databases all functioning
- Initialization sequence: power-up BIT (30–60 sec) → position acquisition → comm handshake → MA grant → ready
- Typical initialization: 2–5 min normal; 10–30 min if comm/sensor issues cause retries

Train Initialization Sequence

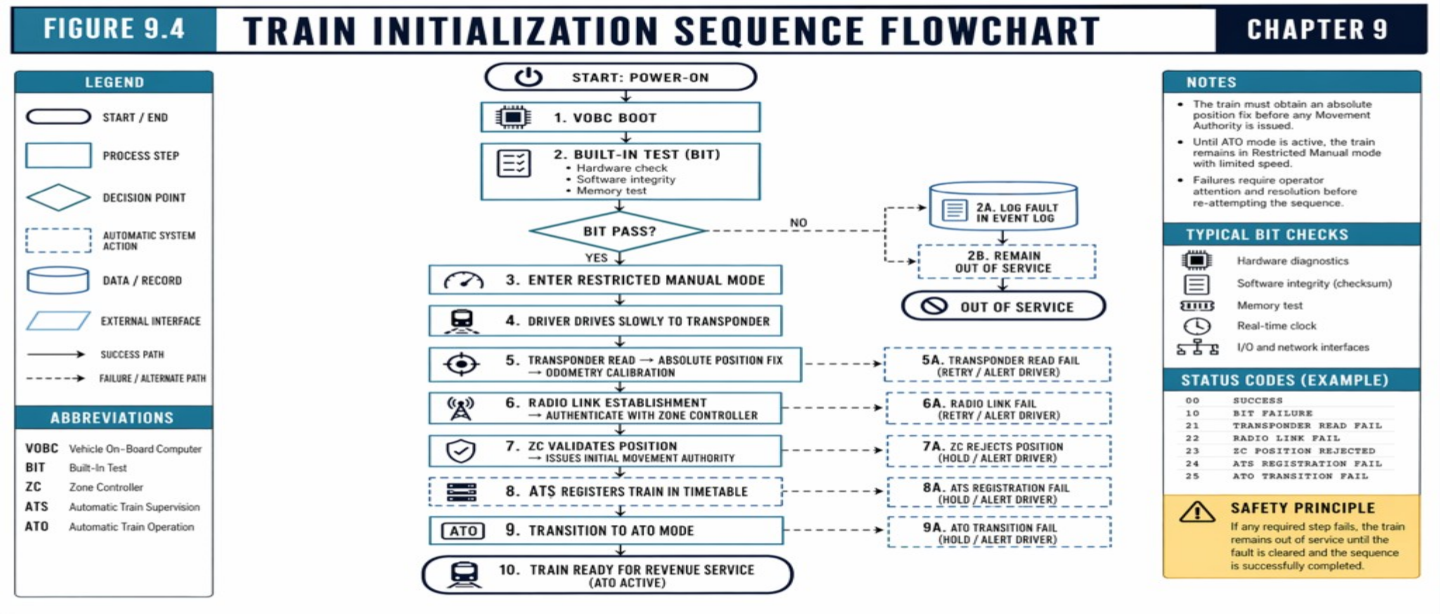

Figure 9.4 — From power-up through self-diagnostics, position acquisition, and MA grant to revenue service.

Movement Authority and Precision Stopping

- Zone Controller recalculates MA every 500 ms–1 sec with updated EOA, speed profile, and acknowledgment
- Safe-brake distance at 60 km/h: ~50–70 m (perception + braking + safety margin)
- Moving-block headway: 90–150 m separation vs. 200–400 m for legacy fixed-block
- Precision stopping: ±0.3 m at platform — eliminates operator-induced variability
- Dynamic headway regulation: 90–150 sec achievable vs. 180–300 sec with legacy systems

CBTC vs. Legacy Performance in Normal Mode

Metric	Legacy (Fixed-Block)	CBTC (Normal Mode)	Improvement
On-time performance	85–90%	97–99%	+12–14 pp
Typical headway	180–300 sec	90–150 sec	40–50% reduction
Capacity (tph)	20–25	30–40	+50–100%
Energy per pax-km	1.0 (baseline)	0.70–0.85	15–30% savings

Operating Modes Continuum

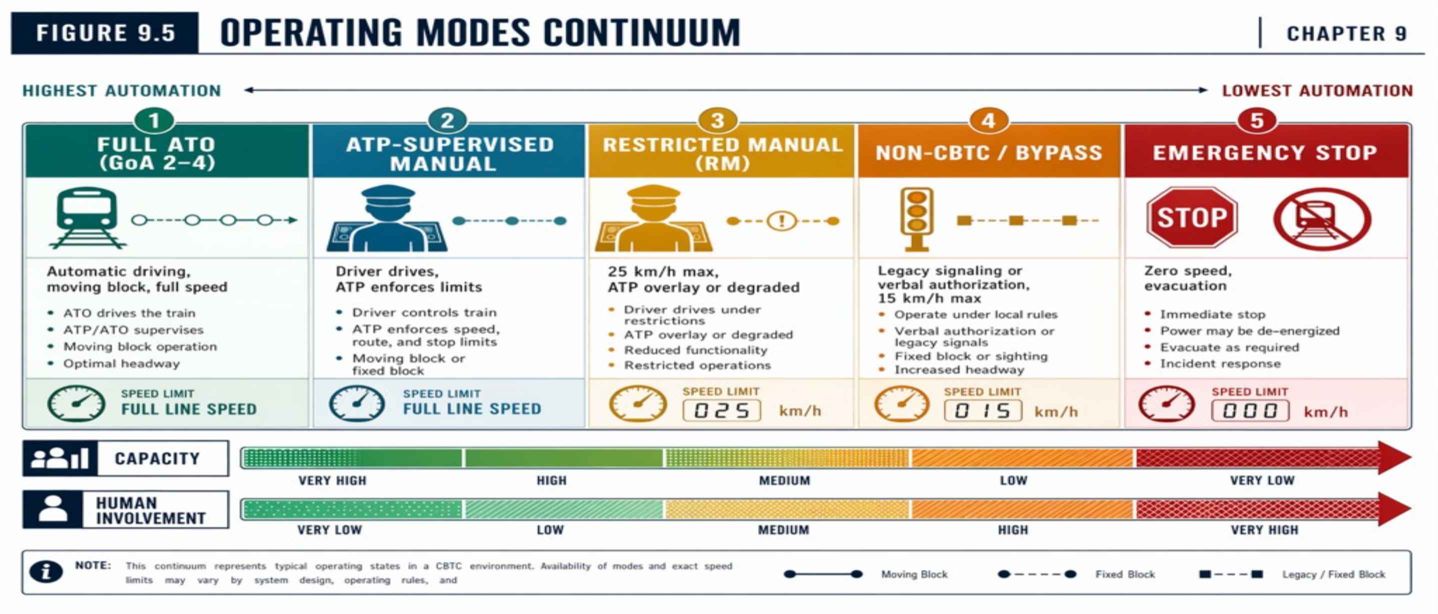

Figure 9.5 — From full automatic (Normal CBTC) through RM to Non-CBTC: trading capacity for resilience.

9.2

Restricted Manual Mode (RM)

Restricted Manual Mode

- Driver manually controls traction and braking — ATP remains active enforcing safety envelope
- ATO is inoperative; platform stop precision degrades from ±0.3 m to ±0.5–1.0 m
- Triggers: ATO system faults, deliberate driver-initiated control, degraded communication, post-incident cleanup
- Max speed reduced to 25–40 mph (vs. 55–65 mph normal) — capacity drops 20–40%
- Transition alerts: visual + audible alarm, driver must acknowledge within 10–30 sec

Normal Mode vs. Restricted Manual Mode

Parameter	Normal Mode	RM Mode	Notes
Max speed	55–65 mph	25–40 mph	NYC L-line uses 25 mph
Speed enforcement	ATP at line speed	ATP at reduced RM limit	Driver brakes proactively
Stop precision	±0.3 m (ATO)	±0.5–1.0 m (manual)	PSDs may not align
Acceleration	Automatic, optimized	Manual, driver-controlled	No ATO profile

9.3

Non-CBTC / Bypass Mode

Non-CBTC Fallback Mode

- Complete absence of CBTC protection — ATP offline, no continuous headway calculation
- Relies on legacy wayside signals (overlay systems) or explicit dispatcher authorization
- Triggers: yard operations, maintenance windows, total CBTC failure, mixed-fleet legacy trains, weather damage
- Headway expands from 2–3 min (CBTC) to 5–10+ min — capacity drops 40–60%
- MTA L Line: legacy signals allow 40 mph under overlay fallback with ~6 min headway

CBTC Operating Mode State Machine

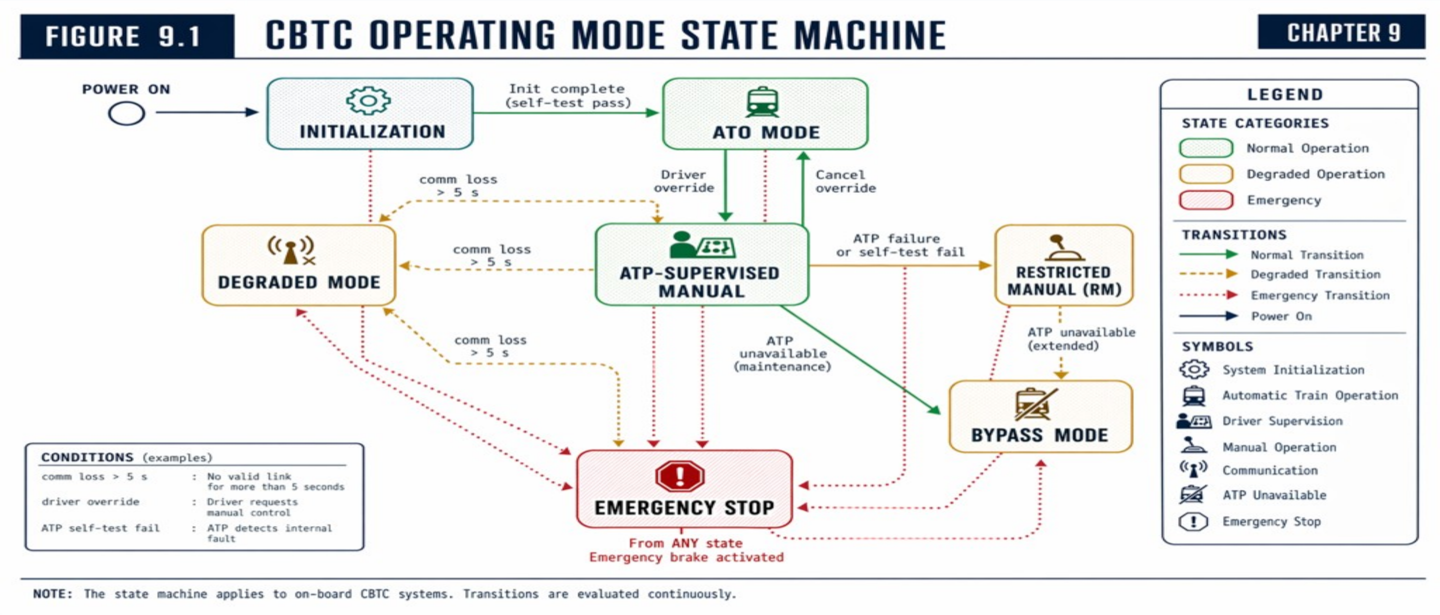

Figure 9.1 — State transitions between Normal, Restricted Manual, Non-CBTC, and Emergency modes.

9.4

Territory Entry and Exit

CBTC Territory Boundary Challenges

- Boundaries between CBTC and non-CBTC zones create complex handoff scenarios
- 15–20% of operational anomalies occur at boundaries despite being only 2–3% of track
- Four boundary types: mainline ↔ yard, CBTC ↔ legacy segment, mixed-fleet overlap, phased deployment
- Entry sequence: speed conditioning (15–25 mph) → transponder read → comm establish → MA grant
- Graduated speed increase: 15–25 → 25–35 → full CBTC speed over ~90 seconds of stable operation

CBTC Territory Entry and Exit Sequence

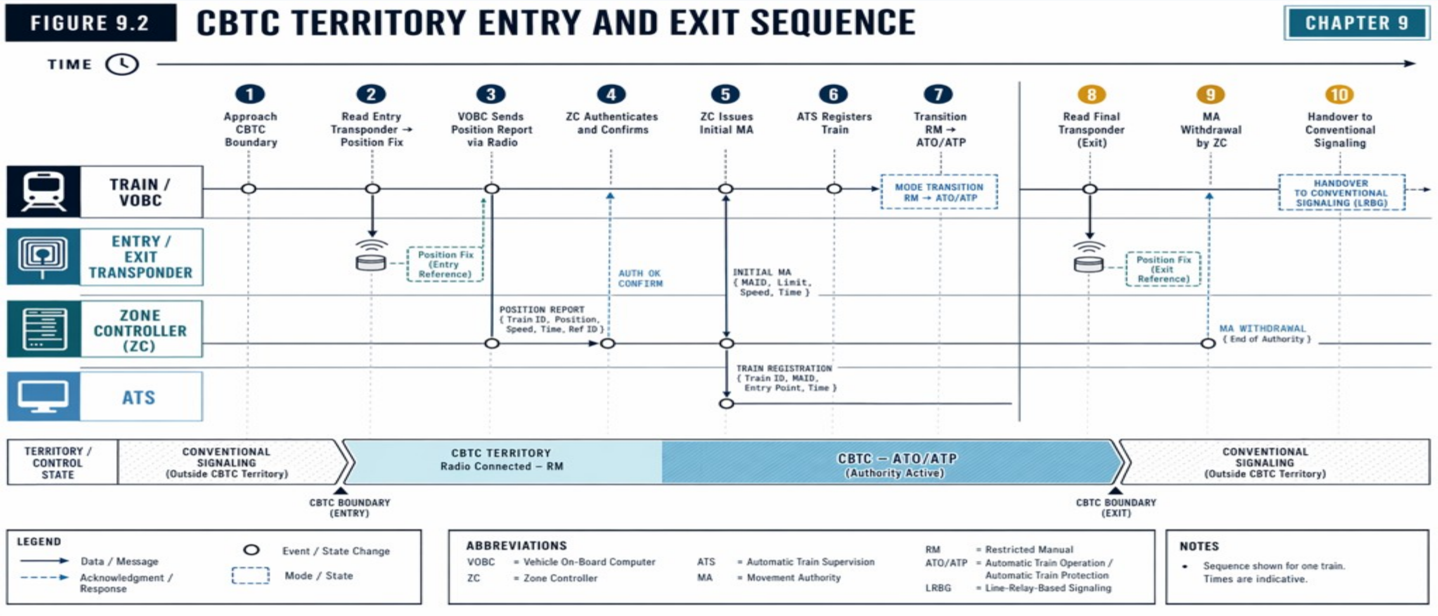

Figure 9.2 — Step-by-step handoff protocol at the boundary between CBTC and non-CBTC territory.

Mixed-Fleet Phantom Occupancy

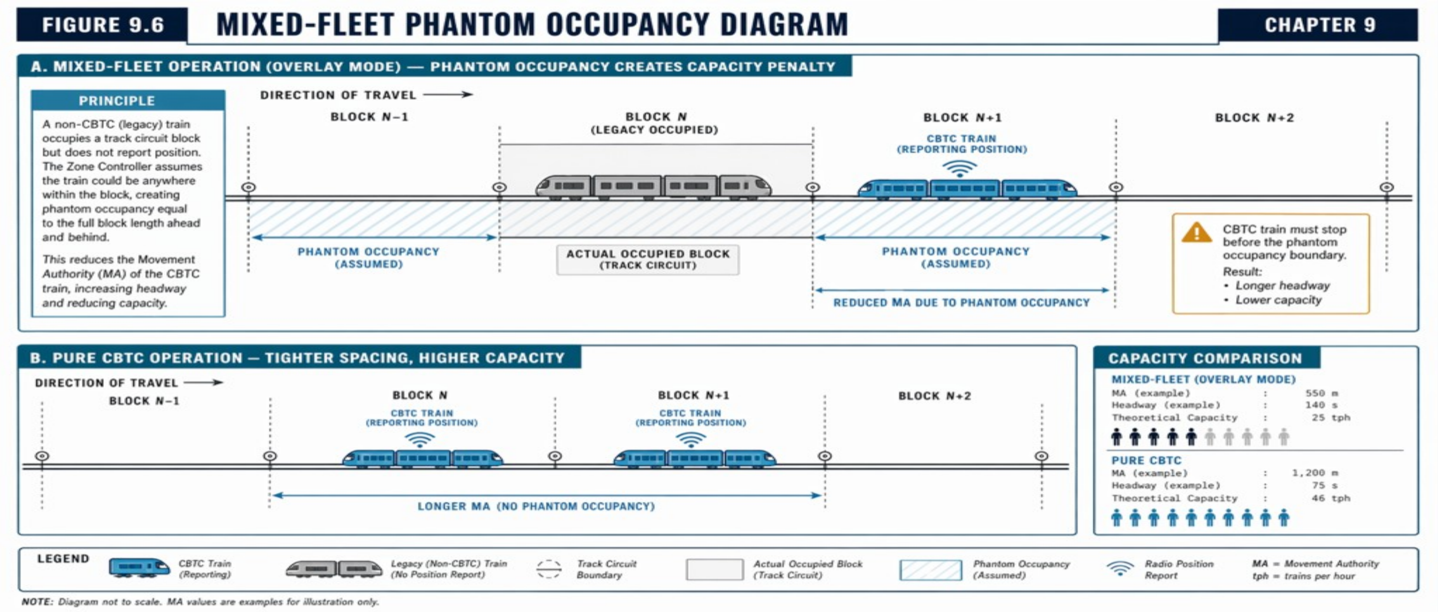

Figure 9.6 — Legacy trains appear as phantom occupancy to Zone Controllers, reducing capacity 20–30%.

9.5

Degraded Mode Operations

Failure Taxonomy and Response

- Single VOBC failure: affects one train → RM mode or withdrawal; 60% recoverable via software reset
- Zone Controller failure: affects all trains in zone → hot-standby failover in 200–500 ms; dual failure <5/year on NYC L
- Communication loss: most frequent trigger (~25% of degraded events); graduated deceleration → safe stop within 60–120 sec
- Track circuit failure: false occupancy restricts MAs, reduces throughput 15–30% until maintenance verifies
- Environmental: flooding, snow, heat — hours to days; temporary bypass to Non-CBTC while repairs proceed

Degraded Mode Response Ladder

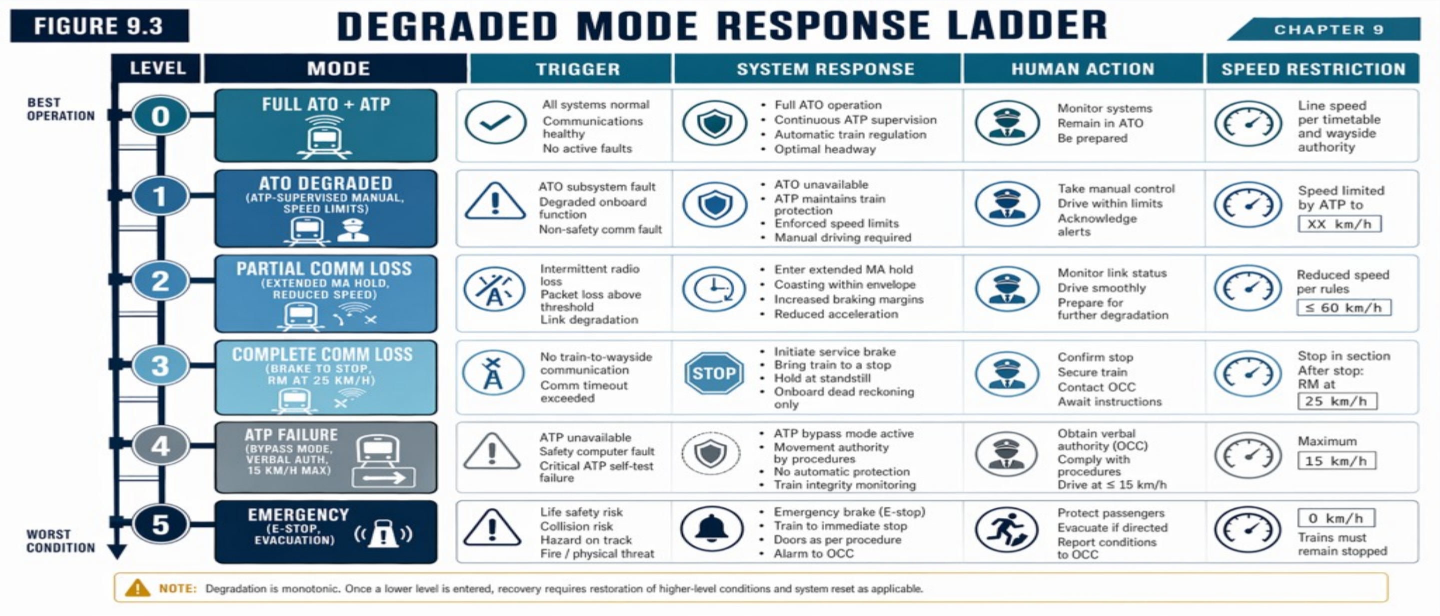

FIGURE 9.3 DEGRADED MODE RESPONSE LADDER CHAPTER 9

LEVEL	MODE	TRIGGER	SYSTEM RESPONSE	HUMAN ACTION	SPEED RESTRICTION
BEST OPERATION 0	FULL ATO + ATP	All systems normal; Communications healthy; No active faults	• Full ATO operation • Continuous ATP supervision • Automatic train regulation • Optimal headway	Monitor systems; Remain in ATO; Be prepared	Line speed per timetable and wayside authority
1	ATO DEGRADED (ATP-SUPERVISED MANUAL, SPEED LIMITS)	ATO subsystem fault; Degraded onboard function; Non-safety comm fault	• ATO unavailable • ATP maintains train protection • Enforced speed limits • Manual driving required	Take manual control; Drive within limits; Acknowledge alerts	Speed limited by ATP to XX km/h
2	PARTIAL COMM LOSS (EXTENDED MA HOLD, REDUCED SPEED)	Intermittent radio loss; Packet loss above threshold; Link degradation	• Enter extended MA hold • Coasting within envelope • Increased braking margins • Reduced acceleration	Monitor link status; Drive smoothly; Prepare for further degradation	Reduced speed per rules ≤ 60 km/h
3	COMPLETE COMM LOSS (BRAKE TO STOP, RM AT 25 KM/H)	No train-to-wayside communication; Comm timeout exceeded	STOP • Initiate service brake • Bring train to a stop • Hold at standstill • Onboard dead reckoning only	Confirm stop; Secure train; Contact OCC; Await instructions	Stop in section; After stop: RM at 25 km/h
4	ATP FAILURE (BYPASS MODE, VERBAL AUTH, 15 KM/H MAX)	ATP unavailable; Safety computer fault; Critical ATP self-test failure	• ATP bypass mode active • Movement authority by procedures • No automatic protection • Train integrity monitoring	Obtain verbal authority (OCC); Comply with procedures; Drive at ≤ 15 km/h	Maximum 15 km/h
WORST CONDITION 5	EMERGENCY (E-STOP, EVACUATION)	Life safety risk; Collision risk; Hazard on track; Fire / physical threat	• Emergency brake (E-stop) • Train to immediate stop • Doors as per procedure • Alarm to OCC	Protect passengers; Evacuate if directed; Report conditions to OCC	0 km/h; Trains must remain stopped

NOTE: Degradation is monotonic. Once a lower level is entered, recovery requires restoration of higher-level conditions and system reset as applicable.

Figure 9.3 — Graduated degradation from normal operation through RM to Non-CBTC fallback.

9.6

Emergency Scenarios

Emergency Response with CBTC

- CBTC provides automated protective actions + real-time situational awareness for human operators
- Fire/smoke: NFPA 130 mandates auto-deny train entry, emergency ventilation, controlled evacuation
- Medical emergencies: passenger alarm → emergency stop → OCC notification → coordinated response
- Security threats: CCTV integration, auto-camera selection, platform intrusion detection
- Power loss: ATS coordinates section isolation, controlled deceleration, passenger communication

Safety Verification During Mode Transitions

- Interlocking checks: switches locked, no conflicting routes, track circuits confirm expected occupancy
- ATP maintains full enforcement throughout transitions — no pause or relaxation during changeover
- Mode transition logic: formally verified via model-checking, exhaustive factory/site testing, shadow running
- SIL 4 target: probability of unsafe transition $<10^{-9}$ per hour
- Independent Safety Assessor reviews all transition hazard analyses before revenue service certification

Key Takeaways

1. Operating modes form a continuum from full automatic (Normal) through RM (GoA 1 fallback) to Non-CBTC bypass — each trading capacity for resilience
1. Normal CBTC achieves 97–99% OTP and 40–50% capacity gains through continuous MA updates and precision stopping (±0.3 m)
1. Restricted Manual preserves safety via active ATP while ATO is inoperative — capacity drops 20–40% but line stays operational
1. Territory boundaries (2–3% of track) cause 15–20% of anomalies — robust entry/exit protocols are critical
1. Degraded mode management proves a system's maturity: hot-standby failover (<500 ms), median recovery <30 min, and structured playbooks

End of Chapter 9

Next: **Chapter 10: CBTC in the United States**

Questions & Discussion