Volume 2

CHAPTER 11

International Benchmarks with US Relevance

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

Chapter Overview

- Extract pattern-recognition lessons from five international CBTC systems spanning three continents
- Paris Métro Lines 1 & 14: the gold standard for GoA 4 greenfield and brownfield conversions
- London Crossrail & Jubilee Line: multi-operator complexity and CBTC/ETCS integration
- Beijing & Shanghai Metro: massive-scale deployment and cost optimization through standardization
- Singapore, Dubai, Copenhagen: UTO showcase cities with 15+ years of driverless operation

11.1

Paris Métro: Lines 1 and 14 (GoA 4)

Paris Métro: GoA 4 Performance

85 sec	1.5M	€700M+
headway	**daily trips**	**total cost**
Line 14 peak — 42 tph	Line 1 ridership (brownfield conversion)	Line 1 conversion (signal + fleet + PSDs)

Line 14 (Greenfield) vs. Line 1 (Brownfield)

- Line 14: opened 1998 — world's first fully automated heavy-metro line
- Extended to Orly Airport (Dec 2024) — Europe's first driverless rail-to-airport link
- 17.5 km, 13 stations, 650,000 daily trips
- Full-height PSDs at all stations from day one

- Line 1: opened 1900, converted 2007–2012 — largest brownfield UTO conversion
- Siemens Trainguard MT overlay on legacy track-circuit signaling
- 3-sector phased cutover — no heroic one-shot events
- 250 drivers redeployed (zero layoffs) via union agreement

International CBTC Benchmark Comparison

FIGURE 11.1 INTERNATIONAL CBTC BENCHMARK COMPARISON MATRIX — CHAPTER 11

CITY/SYSTEM	YEAR	GoA	SUPPLIER	LENGTH	MIN HEADWAY	INNOVATION
Paris Line 14	1998	4	ALSTOM	14 km	85 s	First driverless metro in revenue service (GoA 4)
Paris Line 1	2012	4	ALSTOM	16 km	95 s	High-capacity automation with moving block and ATO
London Elizabeth	2022	2	ALSTOM	118 km	150 s	Advanced ETCS Level 2 with CBTC overlay on mainline railway
Singapore Circle	2009	4	ALSTOM	36 km	100 s	Fully automated metro with high reliability and energy efficiency
Beijing	2010+	2–4	VARIOUS	400+ km	—	Large-scale CBTC deployment across multiple lines
Dubai	2009	3	THALES	75 km	100 s	High-performance CBTC in extreme climate conditions

GoA LEGEND
- 4 — GoA 4 Driverless
- 3 — GoA 3 Driverless (Attended)
- 2 — GoA 2 Semi-Automated
- 2–4 — GoA 2-4 Mixed Deployment

★ **INNOVATION** Key differentiators and notable advancements for each system.

Note: Length indicates route length in operation. Min headway refers to typical achievable headway under normal operations.
Sources: Public transport authority publications, supplier documentation, industry reports.

Figure 11.1 — International CBTC Benchmark Comparison Matrix.

Global CBTC / UTO Maturity Map

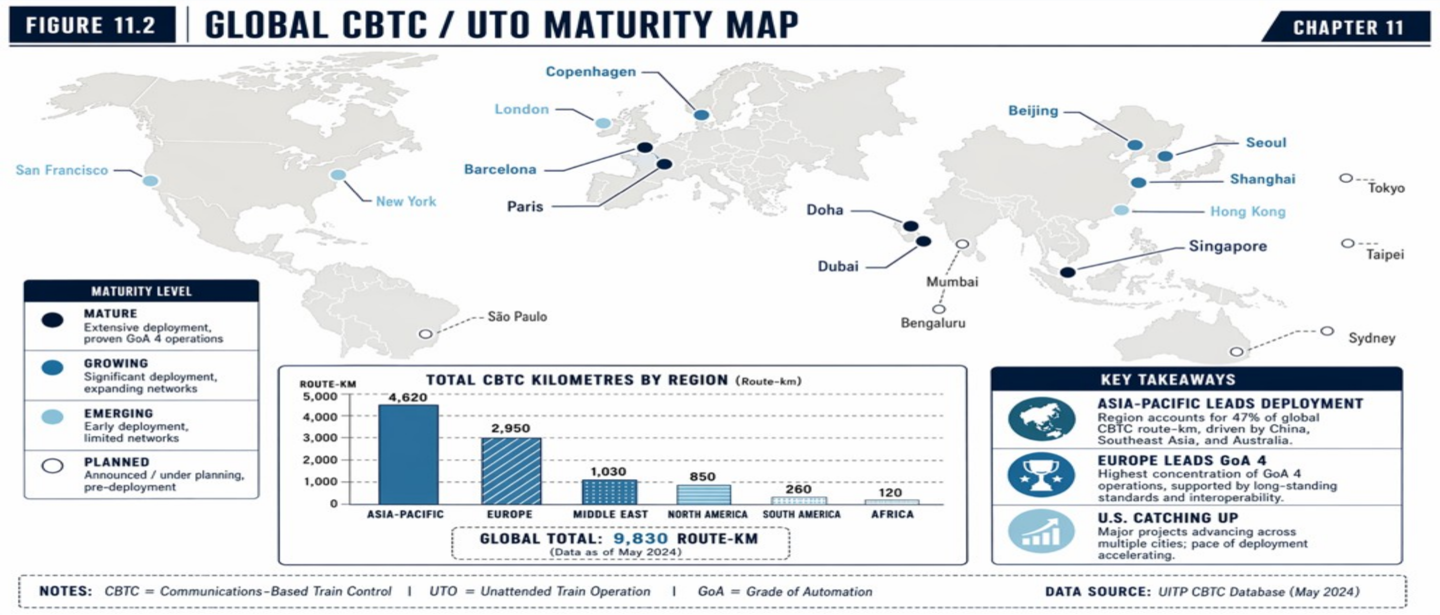

Figure 11.2 — Global CBTC / UTO Maturity Map.

Paris Lessons for US Agencies

- Brownfield automation is technically feasible — if RATP retrofitted a line opened in 1900, US systems are not beyond reach
- PSD retrofit is the pacing item, not CBTC — consumed >25% of budget and ~30% of duration
- Phased sector-by-sector cutover is operationally superior to one-shot conversion
- Labor transition is solvable if negotiated transparently before conversion begins
- Public acceptance is not a substantial barrier — Line 14 was received matter-of-factly by commuters

11.2

London: Crossrail (Elizabeth Line) and Jubilee Line

London CBTC Deployments

- Jubilee Line: Thales SelTrac, upgraded 2005–2011, 36 tph achieved
- Metronet PPP collapsed 2007 — cautionary tale for long-term fixed-price PPPs
- Contract restructuring cost 4-year delay
- Capacity uplift required signaling + rolling stock + driver retraining

- Elizabeth Line: 3-signaling-system architecture — CBTC + ETCS L2 + legacy
- Class 345 Aventra: dual-computer CBTC/ETCS handover while in motion (30–40 sec)
- Final cost £18.9B (~$24B USD), 41-month delay vs. original schedule
- US parallel: NEC, LIRR face identical multi-operator complexity

Elizabeth Line Cross-Rail Zones

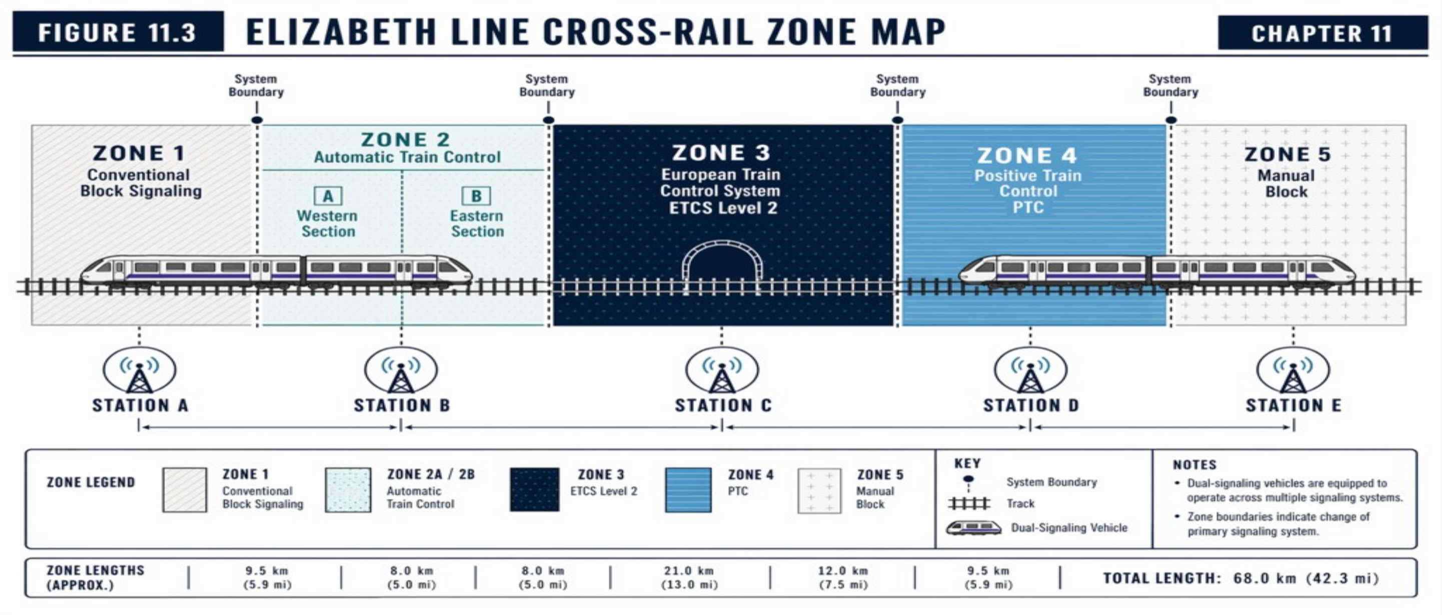

Figure 11.3 — Elizabeth Line three-signaling-system zone architecture.

Jubilee vs. Crossrail Cost Comparison

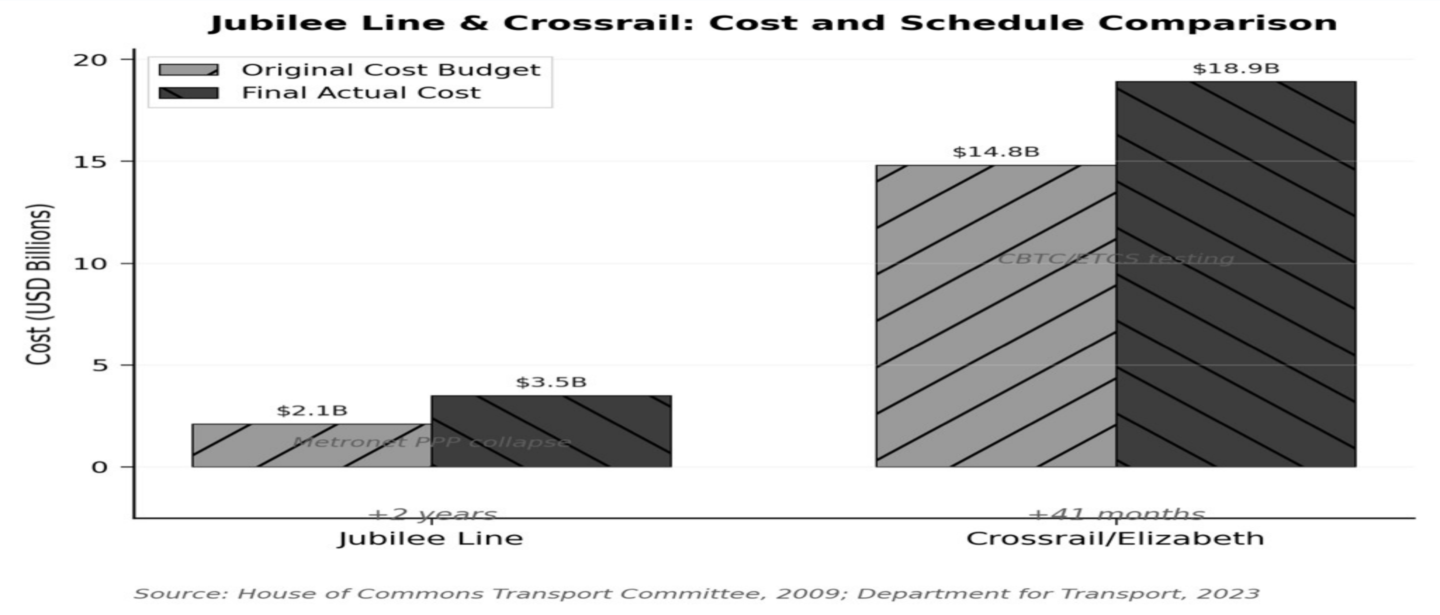

Figure 11.4 — Jubilee Line vs. Crossrail cost trajectory comparison.

Class 345 Aventra Onboard Architecture

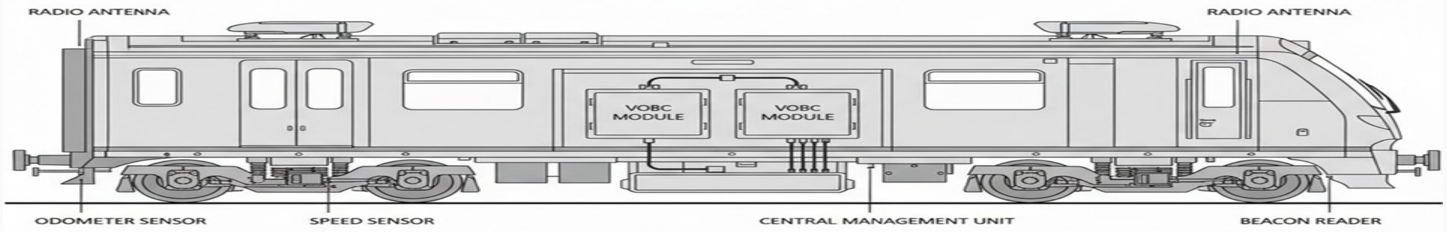

Figure 11.5 — Aventra dual-computer signaling architecture for CBTC/ETCS switching.

11.3

Beijing and Shanghai Metro: Massive-Scale Deployment

China CBTC: Scale Without Parallel

1,700+

km

Combined Beijing + Shanghai track mileage

$0.8–1.5M

/km

Chinese CBTC cost vs. $4–8M/km in US

3–4

vendors

Domestic CBTC suppliers driving competition

China Lessons for US Agencies

- Standardization and design reuse drive cost reduction — CRSC reuses 70–80% across lines
- Greenfield vs. brownfield cost gap is structural, not technology-driven
- Domestic second-source competition improves operator bargaining power
- Interoperability across operator's fleet is achievable and worth pursuing (common VOBC specs)
- US agencies cannot procure from Chinese suppliers (49 USC §5323(j)), but engineering lessons transfer

Beijing & Shanghai Metro Network

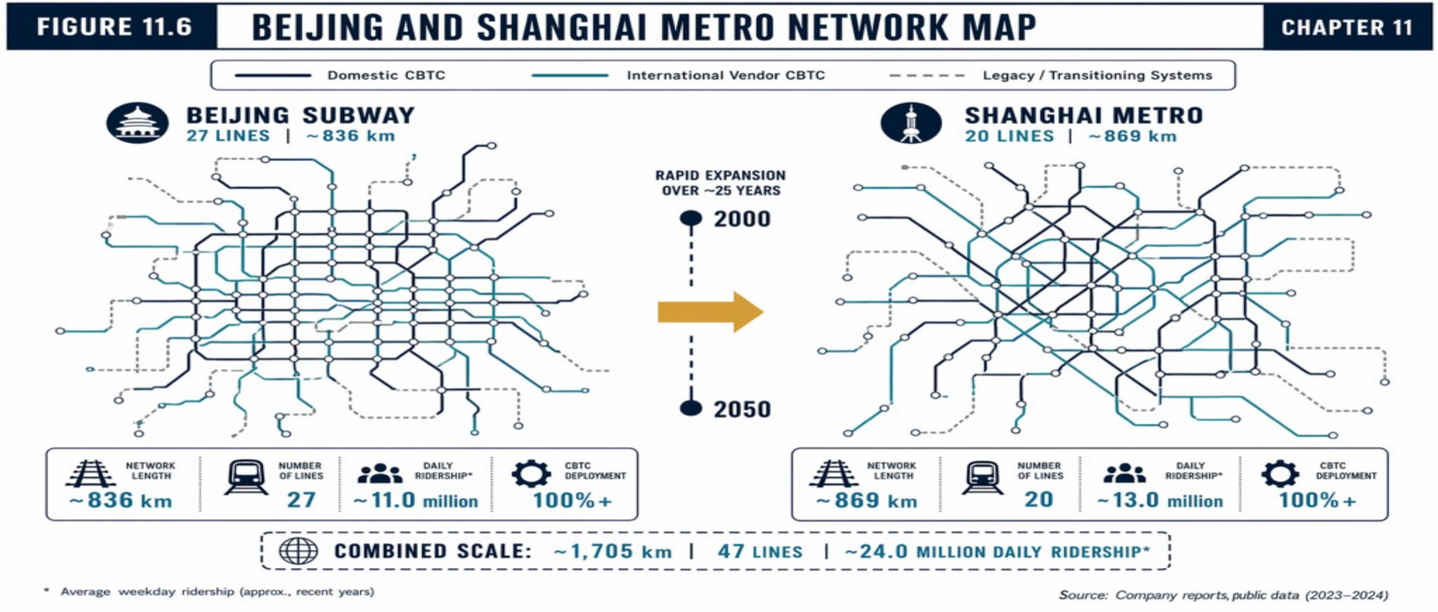

Figure 11.6 — Beijing and Shanghai Metro network map with CBTC-equipped lines highlighted.

International Headway Comparison

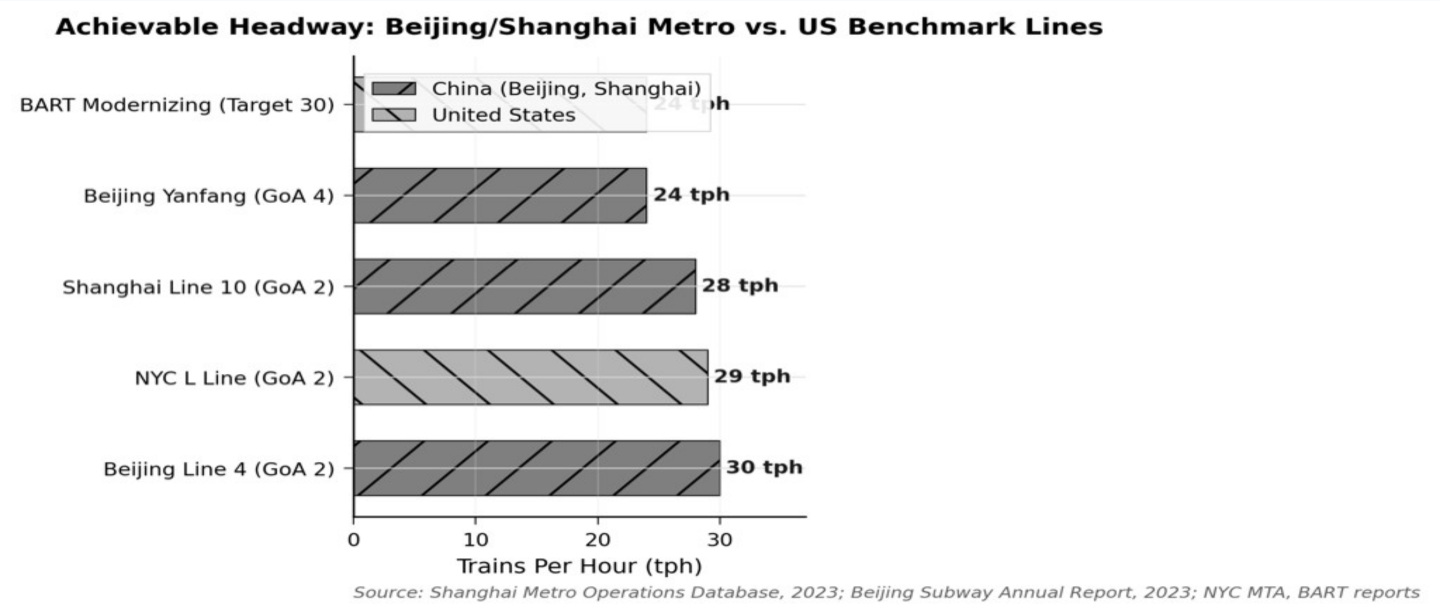

Figure 11.7 — Headway comparison across major international CBTC systems.

11.4

Singapore, Dubai, and Copenhagen: UTO Showcase

UTO Reliability Benchmarks

Metric	Singapore DT Line	Dubai Metro Red	Copenhagen Metro	US Metro (avg.)
MKBF (million km)	2.1	1.8	1.5	0.6–1.0
System Availability	99.85%	99.97%	99.92%	96–98%
Peak Headway (min)	3.0	2.5	3.0	2.5–4.0
Annual Passengers	850M	550M	200M	400–600M

UTO Availability Comparison

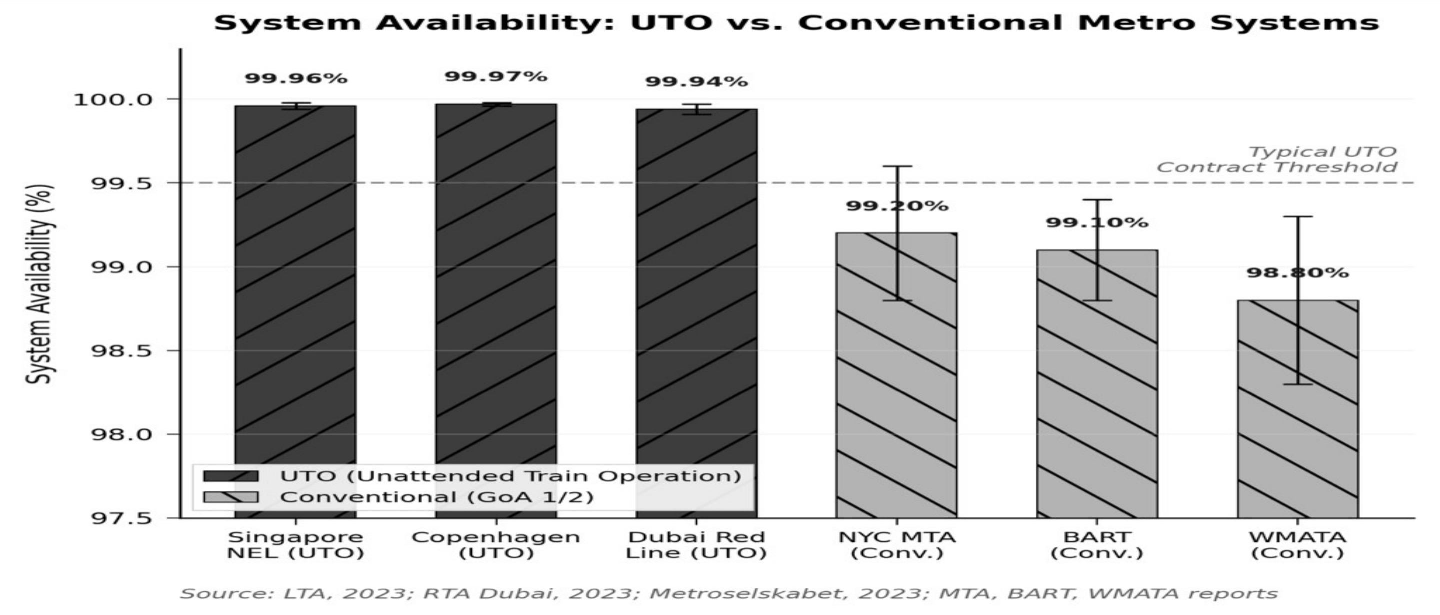

Figure 11.8 — UTO system availability vs. conventional US metro systems.

11.5

Lessons Learned: Common Pitfalls and Success Factors

International Success Factors

- Early alignment on functional requirements and GoA target before vendor selection
- Phased, sector-by-sector cutover reduces risk vs. big-bang conversion
- Transparent labor transition negotiated before conversion begins
- PSD retrofit is the pacing item — budget 25–30% of total cost

- Standardization and design reuse drive 40–50% cost reduction over time
- Dual-signaling vehicles (CBTC/ETCS) are feasible but add 15–25% to rolling stock cost
- Public acceptance follows reliability — passengers adapt quickly to driverless operation
- Contract structure matters — PPP failures (Metronet) can impose multi-year delays

Key Takeaways

1. International experience is a source of lessons, not a template for transplantation — US faces distinct constraints (FRA, Buy America, unions, heritage infrastructure)

1. Paris RATP proves brownfield GoA 4 conversion is feasible; PSD retrofit, not CBTC, is the pacing item and largest budget risk

1. London's Elizabeth Line demonstrates multi-signaling integration is technically possible but organizationally expensive — budget 24–36 months for interface testing

1. Chinese CBTC costs are 5–8× lower than US retrofits; the transferable lesson is standardization, design reuse, and competitive procurement

1. All three UTO showcase cities exceed 99.5% availability with zero fatalities over 15+ years — driverless systems are safer than conventional in practice

End of Chapter 11

Next: **Chapter 12: Project Lifecycle — From Planning to Revenue Service**

Questions & Discussion

