Volume 2

CHAPTER 14

Lifecycle Costs and Economic Justification

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

- Quantify the full financial burden of CBTC: capital expenditure, operating cost, and lifecycle implications
- Build defensible business cases aligned with FTA Capital Investment Grant evaluation criteria
- Translate costs into benefit-cost metrics that survive public, board, and PMOC scrutiny
- Survey federal, state, and local funding sources — including BIL-era expansions
- Present ROI analysis and monetize capacity, safety, reliability, and environmental benefits

14.1

Capital Expenditure (CAPEX) Breakdown

The Six Canonical CAPEX Categories

- (a) Onboard & Vehicle Equipment (VOBC): $250K–$450K per train cab
- (b) Wayside Infrastructure & Interlockings: $1.5M–$3M per route-mile (brownfield up to $5M)
- (c) Communication Systems: 12–18% of total project cost
- (d) Central Operations & Control (OCC/ATS): 10–15% of total project cost
- (e) Engineering, Systems Integration & PM: 20–30% of total (soft costs)
- (f) Testing, Commissioning & RSD: 8–12% (brownfield 15–18%)

Representative CAPEX Allocation

CAPEX Category	Typical %	Low %	High %
Onboard & Vehicle Equipment	12–18	10	22
Wayside Infrastructure	25–35	20	40
Communication Systems	12–18	10	20
Central Operations & Control	10–15	8	18
Engineering & Program Mgmt	20–30	18	35
Testing, Commissioning, RSD	8–12	7	15

US Benchmark Costs Per Route-Mile

$8–10M

/mile

NYC L-Line (greenfield-era)

$25M

/mile

BART TCMP (extensive integration)

$15-30M

/mile

Rule of thumb: US brownfield

Cost Drivers Unique to US Projects

- Davis-Bacon prevailing wages add 30–50% to installation labor ($1.5M–$5M on a typical project)
- Buy America / BABA domestic content premiums: 5–15% above international prices
- Union labor and Project Labor Agreements (PLAs) add 10–20% to installation costs
- FRA/FTA oversight extends design and testing schedules, adding 2–5% to cost
- Insurance, bonding (2–5%), and NEPA environmental review ($500K–$3M) further inflate budgets

30-Year CBTC Lifecycle Cost Stack

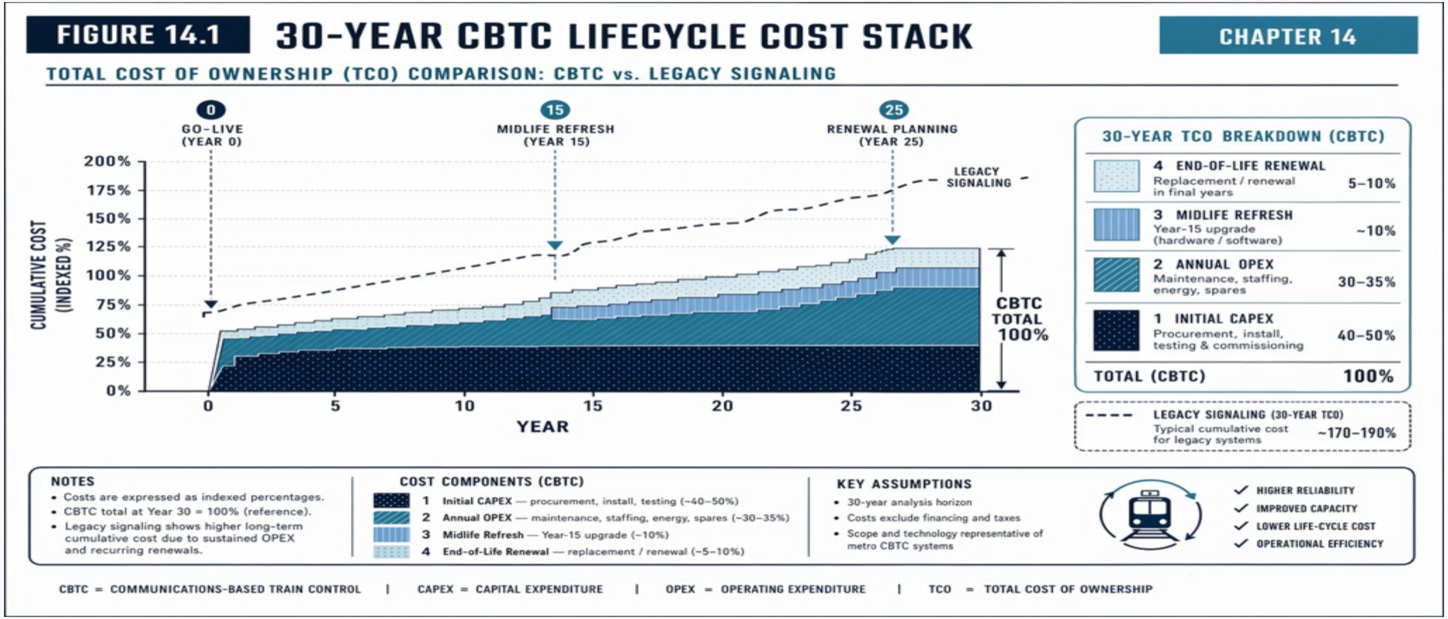

Figure 14.1 — Lifecycle cost stack showing CAPEX, OPEX, and technology refresh phases over 30 years.

14.2

Operating Expenditure (OPEX) and Maintenance

The OPEX Iceberg

$1.2–1.8B
O&M

Over 25–30 years for a $1B CBTC CAPEX

1.2–1.6×
staff

Signal maintenance headcount (years 1–5)

8–15%
/yr

Software CAPEX as annual support cost

Maintenance Philosophy Evolution

- Time-Based Preventive (TBM): Fixed-interval inspections — inherited from legacy practice
- Condition-Based (CBM): Real-time telemetry from VOBC, ZC, radios to schedule maintenance before failure
- One avoided outage can justify months of monitoring infrastructure

- CBTC-specific roles: software engineers, network admins, cybersecurity analysts, RF engineers
- Training pipeline: $50K–$100K per person (first cohort); $10K–$20K/yr refresher
- Spare parts: 5–10% critical on-site; 2–3% CAPEX/yr obsolescence fund

Annual OPEX: Legacy vs. CBTC

Category	Legacy	CBTC (Yrs 1–10)	CBTC (Yrs 11–25)
Labor	60–70%	40–50%	45–55%
Spare parts	15–25%	20–30%	25–35%
Software/OEM	2–5%	35–45%	20–30%
Cybersecurity	0–2%	8–12%	10–15%
Facilities/training	10–15%	8–12%	8–12%

Benefit Realization and ROI Framework

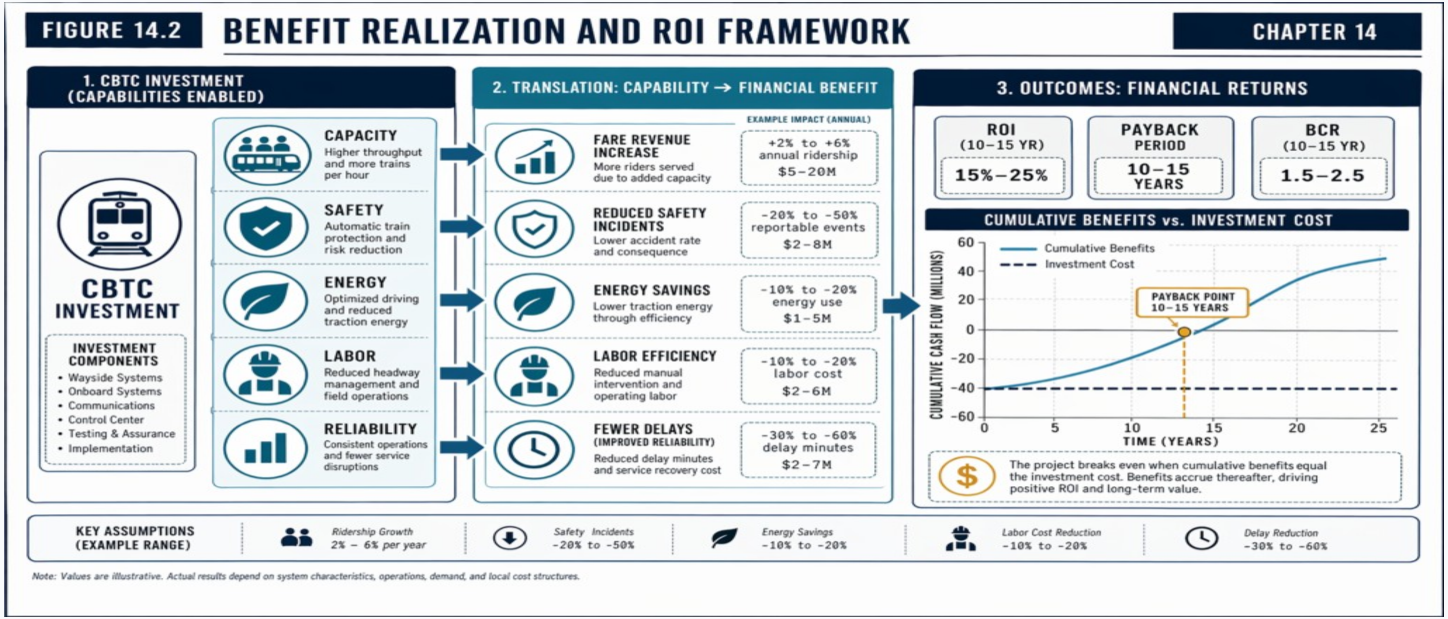

Figure 14.2 — Framework connecting CBTC investment to measurable benefit streams and ROI.

14.3

Total Cost of Ownership over 30-Year Lifecycle

30-Year Lifecycle: Four Phases

- Phase 1 (Yrs 0–5): Design, procurement, installation, testing — 35–50% of undiscounted cost
- Phase 2 (Yrs 5–15): Stable ops, first midlife upgrades — OPEX 2–4% of initial CAPEX/yr
- Phase 3 (Yrs 15–25): Major tech refresh — VOBC (15–20%), ZC/RBC (10–15%), OCC (8–12%)
- Phase 4 (Yrs 25–30): End-of-life planning, replacement system design, decommissioning
- Discount rate per OMB A-94: 2.0% real (10–30 yr horizon); sensitivity ±1.5 pp essential

Worked Example: 25-Mile Brownfield TCO

Cost Category	Nominal ($M)	Share	Discounted ($M)	Share
Initial CAPEX (Yrs 0–5)	185	35.0%	169	42.5%
Annual OPEX (Yrs 5–30)	210	39.8%	135	34.0%
Yr 10 Radio Refresh	24	4.5%	18	4.5%
Yr 15 VOBC/RBC Replace	52	9.8%	32	8.0%
Yr 22 OCC Re-Platform	28	5.3%	13	3.3%
Total Lifecycle Cost	530	100%	398	100%

TCO Sensitivity Tornado Diagram

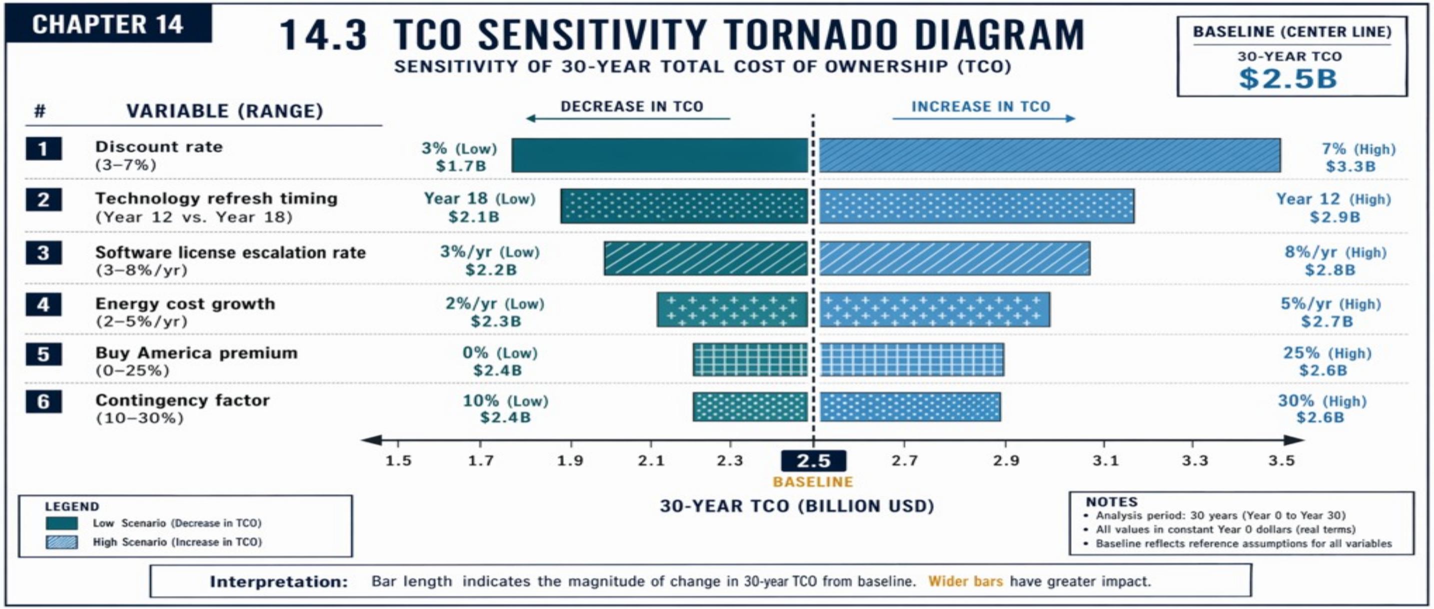

Figure 14.3 — Discount rate, refresh timing, and contingency drive the largest TCO variance.

14.4

Funding Sources for US Transit CBTC Projects

Federal Funding Sources

- FTA Core Capacity Grants: ~$2.2B/yr (BIL era); 80% federal share; BCR > 1.5 required
- FTA Small Starts: Capped $300M total / $75M federal — suits single-line CBTC
- TIFIA Loans: Up to 49% of cost; 2–4% real interest; requires dedicated revenue stream

- State Bond Programs: CA Prop 1A, NY, IL — CBTC competes with other modes
- Local Transit Authority Debt: Bonds backed by farebox, sales-tax, property-tax
- P3 Structures: Private finance + design-build-operate for 25–35 years (e.g., Honolulu HART)

Typical Funding Stack for Large Brownfield CBTC

- FTA Core Capacity Grant: ~60% ($1.2–1.6B of a $2–3B project)
- TIFIA Loan: ~15–25% ($300–500M), repaid over 20–30 years from farebox/dedicated revenue
- State Bond or Grant: ~10–15% ($200–300M)
- Local Agency Debt or Cash: ~5–10% ($100–200M)
- P3 / Private Equity (if applicable): $0–200M

U.S. CBTC Funding Stack Waterfall

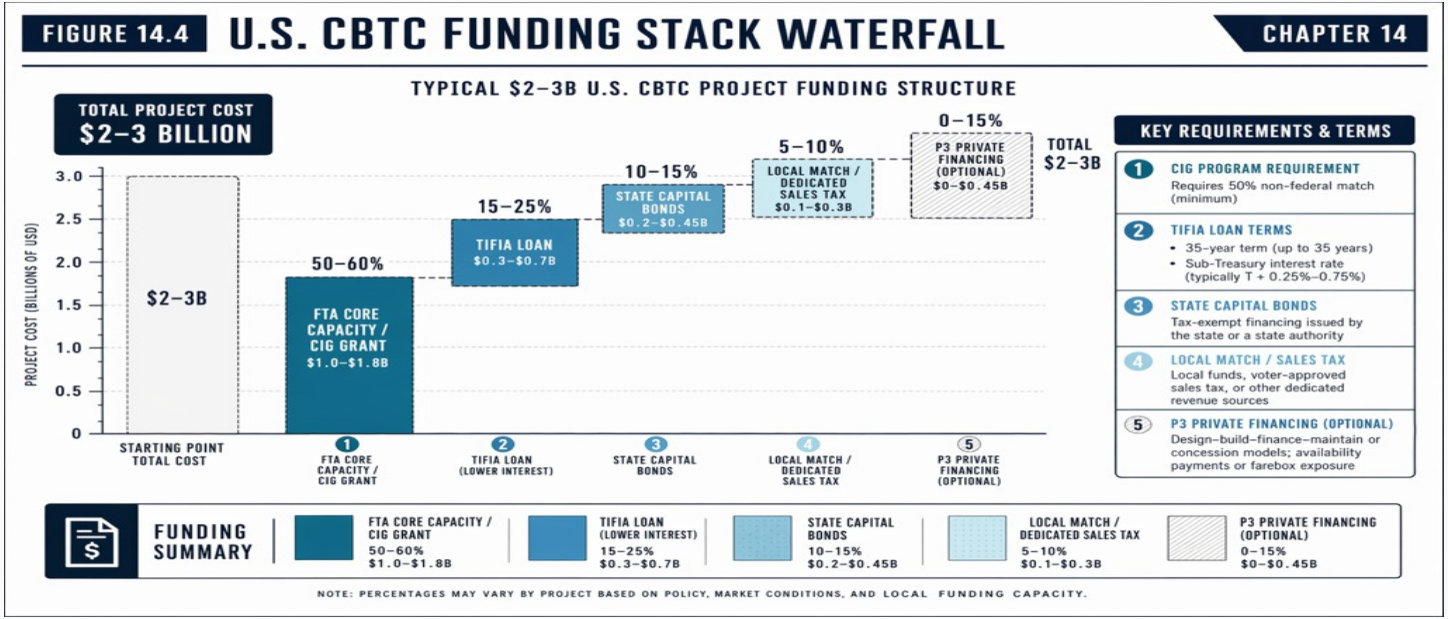

Figure 14.4 — Representative funding stack combining federal grants, credit, state/local sources, and P3.

14.5

Return on Investment — Quantifying CBTC Benefits

Monetizing CBTC Benefits

- Capacity value: Typically 40–70% of total discounted benefits — the largest and most contested
- Three approaches: avoided capital expansion, passenger throughput × VoT, induced economic development
- Safety benefits: VSL = $13.2M (2024); monetize avoided collisions, injuries, work-zone incidents
- Reliability benefits: Reduced delays → lower lost-revenue and passenger-minute costs
- Environmental benefits: Energy savings from eco-driving, regenerative braking, fleet optimization

CBTC Capacity Gains — Real-World Evidence

20-45%

gain

MTA L-Line: 20 → 24–29 tph

53%

gain

Paris Line 1 (GoA 4): 42 tph

≥ 1.5

BCR

FTA threshold for federal funding

Key Takeaways

1. US brownfield CBTC costs \$15M–\$30M per route-mile, with Davis-Bacon, Buy America, and union agreements adding 20–40% above international benchmarks
1. OPEX is not an afterthought — a \$1B CBTC CAPEX generates \$1.2–\$1.8B in O&M over 25–30 years; lifecycle cost, not annual cost, tells the true economic story
1. TCO over 30 years structures into four phases; discount-rate and refresh-timing assumptions drive the largest sensitivity — always present ±1.5 pp ranges
1. The BIL era expanded FTA funding substantially — Core Capacity grants at ~\$2.2B/yr, TIFIA loans, and state/local sources combine into layered funding stacks
1. ROI hinges on capacity value (40–70% of benefits); BCR ≥ 1.5 is the federal threshold — operational constraints must be honestly modeled to survive PMOC review

End of Chapter 14

Next: **Chapter 15: Vendor Landscape and Technology Trends**

Questions & Discussion

