RESEARCH NOTE

O&M Note 2
Operating costs for high-speed rail

Cost structure, methodology, and sensitivity to service frequency

Annual cost (MID)	Per train-km	Variable share	40-year PV
$700M	**$24**	**69%**	**$9.3B**
CAD, real	*at 80 trains/day*	*scales with traffic*	*7% real discount*

Worked example: 1,000 km dedicated HSR corridor, Canadian climate, 80 trains/day baseline. Companion to the maintenance costs note; combined cost recovery is the subject of Note 3.

Purpose

This note is the companion to the research note on infrastructure maintenance costs. It sets out a defensible methodology for estimating the steady-state operating cost of a high-speed passenger rail corridor — the "O" in O&M — and applies it to a 1,000 km ALTO-scale alignment under Canadian operating conditions.

Combined cost recovery, including the comparison of total O&M with fare revenue and the identification of break-even service frequency, is the subject of Note 3 in this series.

The methodology follows the cost-category structure used by the California High-Speed Rail Authority's 2020 Business Plan O&M model, the Federal Railroad Administration's HSIPR Best Practices toolkit, the SNCF Réseau operating cost framework, and the Riyadh-Dammam HSR total social cost study (Almujibah and Preston).

1. Cost structure

Operating cost for an HSR corridor decomposes into eight categories. Unlike infrastructure maintenance, which is dominated by fixed-asset patrol, inspection, and renewal, most operating cost categories scale with service volume — train-km, passenger volume, or both.

Category	Primary driver	Scope
Train operations	train-km	Drivers, on-board staff, traincrew dispatching, rostering.
Traction energy	train-km × kWh × $/kWh	Electricity for traction, regenerative braking offset, station and facility energy.
Rolling stock maintenance	train-km (light) and time (heavy)	Daily servicing, intermediate maintenance, heavy overhauls, wheel turning, traction equipment refurbishment.
Station operations	per-station fixed cost	Staffing, cleaning, ticketing, security, passenger handling, building maintenance.
Network control (OCC)	fixed	Operations Control Centre staff, dispatching systems, incident management.
Commercial	share of revenue or per-passenger	Reservations, customer service, marketing, distribution fees, on-board catering.
Insurance	fixed (rises with revenue)	Third-party liability, property and asset cover, business interruption.
General & administrative	markup on direct costs	Executive, finance, HR, legal, IT, regulatory affairs. Typically 15–20 per cent of direct costs.

> *Where infrastructure cost is dominated by the existence of assets, operating cost is dominated by the act of running trains. The two cost streams have opposite sensitivity to traffic: infrastructure is largely fixed, operations is largely variable.*

2. Calculation formula

The total annual operating cost for the corridor is the sum of the eight category costs:

$$C_{\text{op}} \;=\; C_{\text{crew}} + C_{\text{energy}} + C_{\text{RS}} + C_{\text{stat}} + C_{\text{OCC}} + C_{\text{comm}} + C_{\text{ins}} + C_{\text{GA}}$$

Train-km-driven categories

Three categories — traincrew, traction energy, and rolling stock maintenance — share a common form: cost is a unit rate per train-kilometre multiplied by annual train-km on the corridor.

$$C_j = c_j \cdot N_{\text{tkm}} \quad \text{for} \;\; j \in \{\text{crew, energy, RS}\}$$

Traction energy is the simplest specific case:

$$C_{\text{energy}} = e \cdot N_{\text{tkm}} \cdot p_{\text{kWh}}$$

where:

C_energy	annual traction energy cost ($/year)
e	specific consumption (kWh per train-km)
N_tkm	annual train-km on the corridor
p_kWh	effective electricity price ($/kWh, including delivery and carbon)

Station, OCC, insurance — fixed categories

Three categories scale negligibly with traffic over the operating range. Station operations cost is the sum across staffed stations; the Operations Control Centre is a single facility supporting the whole network; insurance is largely time-based with secondary scaling on revenue.

Commercial and G&A — partly variable

Commercial cost (reservations, customer service, marketing) is typically modelled as a share of revenue, in the four to six per cent range for mature HSR operations. General and administrative overhead is applied as a markup on direct costs, typically 15 to 20 per cent.

Fixed / variable form for sensitivity analysis

Aggregating the eight categories, total operating cost can be expressed in fixed-plus-variable form parallel to the infrastructure formula:

$$C_{\text{op}}(N) = C_{\text{op, fix}} + c_{\text{op, var}} \cdot N$$

where:

$C\_op(N)$	annual operating cost as a function of trains/day
C_op,fix	traffic-independent component (OCC, stations, insurance, fixed overhead)
c_op,var	variable cost per train-per-day per year
N	service frequency (trains per day, both directions)

3. Worked example: 1,000 km HSR corridor

The formula is applied to the same configuration used in the maintenance note: 1,000 km dedicated double-track HSR, 300 km/h design speed, 80 trains per day baseline, 450-seat trainsets at 65 per cent load factor, 7 staffed stations.

3.1 Unit-cost parameters

Parameter	Value	Source / basis
Traincrew unit cost	**$4.00 / train-km**	*CHSRA, SNCF, HSIPR*
Specific energy consumption	**13 kWh / train-km**	*HSR at 300 km/h*
Effective electricity price	**$0.105 / kWh**	*Ontario industrial blended*
Rolling stock maintenance	**$4.00 / train-km**	*CHSRA, SNCF (light + intermediate)*
Heavy overhaul reserve	**$0.50 / train-km**	*amortised over cycle*
Station operations (avg)	**$18M / station / yr**	*7 stations, mixed sizes*
Operations Control Centre	**$28M / yr**	*single OCC*
Commercial cost	**5% of fare revenue**	*industry standard*
Insurance	**$12M / yr**	*HSR third-party + asset cover*
G&A markup on direct costs	**18%**	*industry mid-range*
Canadian climate uplift (ops)	**1.10**	*less sensitive than infrastructure*

3.2 Annual cost breakdown (MID scenario)

Category results for the central scenario at 80 trains per day baseline. All figures in millions of CAD per year, after climate uplift.

Category	$M / yr	$/train-km	Cost driver
Train operations (traincrew)	116.8	4.00	train-km
Traction energy	39.9	1.36	train-km
Rolling stock maintenance	116.8	4.00	train-km
Heavy overhaul reserve	14.6	0.50	train-km
Station operations	126.0	4.32	fixed
Network control (OCC)	28.0	0.96	fixed
Commercial / marketing	85.4	2.92	revenue-linked
Insurance	12.0	0.41	fixed
Direct subtotal	**539.5**	**18.47**	
G&A overhead (18%)	97.1	3.33	markup on direct
Climate uplift (1.10)	63.7	2.18	Canadian conditions
OPERATING TOTAL (MID)	**700.2**	**23.98**	

Three categories — traincrew, rolling stock maintenance, and station operations — account for 51 per cent of total operating cost. Energy is only 6 per cent. Commercial and G&A overhead together are 26 per cent.

3.3 Fixed / variable composition

Decomposing each category by its sensitivity to service frequency:

Component	$M / yr	Share of operating total
Fixed cost (traffic-independent)	220.6	31.5%
Variable cost (scales with N)	479.6	68.5%
TOTAL (MID)	**700.2**	**100.0%**
Variable per train-per-day	*$6.0M / yr*	*vs $3.6M for infrastructure*

Contrast with infrastructure maintenance: 77 per cent fixed, 23 per cent variable. The two cost streams have opposite traffic-sensitivity profiles.

4. Sensitivity to service frequency

Sweeping service frequency from 20 to 200 trains per day shows that operating cost has a different shape from infrastructure cost.

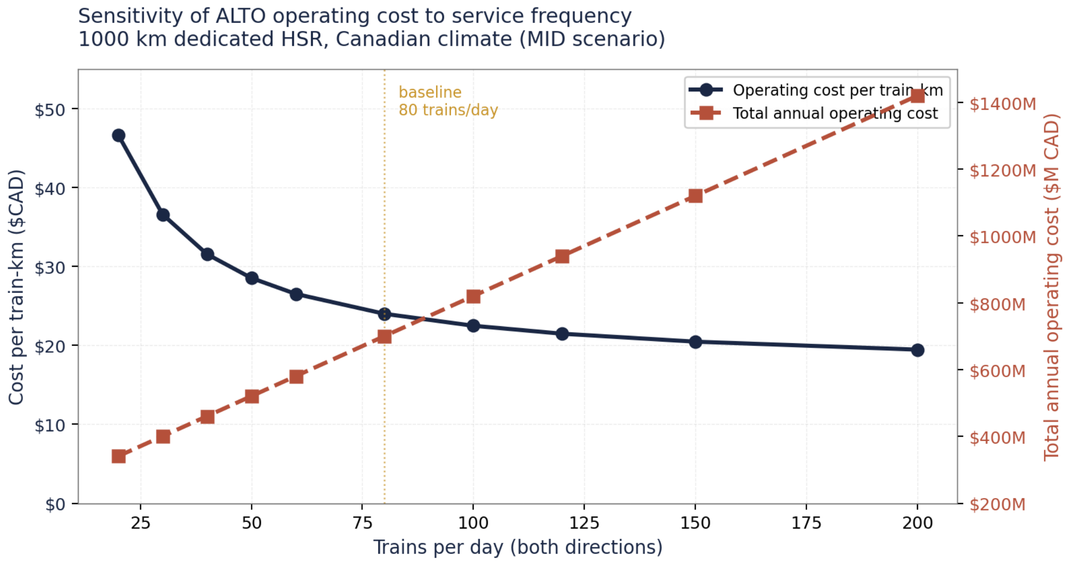

Figure 1. Sensitivity of unit and total annual operating cost to service frequency. Total cost rises near-proportionally; unit cost falls more gradually than for infrastructure.

4.1 Sensitivity table

Trains/day	Total $M/yr	$/train-km	Fixed $M	Variable $M
20	340.5	46.65	220.6	119.9
30	400.5	36.57	220.6	179.8
40	460.4	31.54	220.6	239.8
50	520.4	28.51	220.6	299.7
60	580.3	26.50	220.6	359.7
80	**700.2**	**23.98**	**220.6**	**479.6**
100	820.1	22.47	220.6	599.5
120	940.0	21.46	220.6	719.4
150	1,119.9	20.45	220.6	899.2
200	1,419.6	19.45	220.6	1,199.0

Baseline 80 trains/day row highlighted. Fixed cost stays at $221M across the range; variable cost scales linearly with frequency.

4.2 Elasticities — operations vs infrastructure

Metric	Operations	Infrastructure
Fixed share of total cost	**32%**	**77%**
Elasticity of total cost to N (40→80)	**+0.52**	**+0.13**
Elasticity of $/train-km to N (40→80)	**−0.24**	**−0.44**

Operations scales more strongly with traffic than infrastructure — but its unit cost falls less steeply. The combined O&M cost curve and the cost-recovery analysis are the subject of Note 3.

5. Implications and diagnostic framework

5.1 Implications for operations cost

1. **Operations cost scales near-linearly with service frequency.** Total annual operating cost rises from $341M at 20 trains per day to $1.42B at 200 trains per day — a 4.2-fold increase for a 10-fold increase in service. The elasticity (+0.52) sits between the infrastructure value (+0.13) and a fully proportional response (+1.00). Operations cost forecasts should therefore be expressed with explicit reference to the assumed service frequency.
2. **Three categories dominate.** Traincrew, rolling stock maintenance, and station operations together account for 51 per cent of total operating cost. Any cost-reduction strategy that does not address these three categories addresses only half of operating cost.
3. **Energy is a small share of operating cost.** Traction energy is only 6 per cent of total operations. Aggressive energy efficiency or grid decarbonisation will not materially move the operating cost line. The carbon argument for HSR rests on modal shift and embodied emissions, not on operating energy savings.
4. **Station operations are the largest fixed-cost line.** At $18M per staffed station per year, the seven assumed stations contribute $126M annually regardless of service frequency. Each additional intermediate station adds approximately this much to the fixed-cost floor. Station count decisions should be tested against their incremental ridership contribution, not assumed to be cost-free.
5. **The HPR alternative does not change the operating cost picture materially.** Operating cost per train-km is largely independent of whether the corridor is dedicated HSR or shared with freight or conventional passenger services. The structural cost advantage of shared-corridor approaches such as the High Performance Rail (HPR) framework lies in the infrastructure cost line, not the operations cost line.

5.2 Diagnostic framework for proponent operating-cost claims

When reviewing any HSR operating-cost figure, the following questions should be applied.

1. **Is operations separated from infrastructure?** Bundled "O&M" figures hide the very different cost-driver structures and prevent independent verification of each.
2. **What is the per-train-km cost?** Operating cost should be in the $20–30 per train-km range at mature service levels for a dedicated HSR. Below $15 is implausibly low; above $40 indicates either a small system without economies of scale or an inflated estimate.
3. **Are the eight categories disclosed separately?** Aggregated direct-cost figures cannot be benchmarked. The proponent should disclose traincrew, energy, rolling stock maintenance, station operations, network control, commercial, insurance, and G&A as separate line items.
4. **What is the energy assumption?** Specific consumption should be in the 12–15 kWh per train-km range at 300 km/h. Effective electricity price should include delivery and carbon, typically $0.10–0.12 per kWh in Canada.
5. **What is the assumed station count and per-station cost?** Each staffed station adds approximately $15–25M per year to fixed cost. A proposal showing more than 5–7 staffed stations on a 1,000 km corridor should justify the additional ridership generated by each.
6. **Does the figure include rolling stock heavy overhauls?** Like infrastructure renewals, rolling stock heavy overhauls are periodic capital expenditure that must be annuitised into the operating line. Omitting them understates cost by approximately 10 to 15 per cent of rolling stock maintenance.
7. **Is G&A overhead included?** Some business cases quote "direct" operating cost only, omitting the 15 to 20 per cent G&A markup. Total operating cost should include this.

6. Caveats and limitations

- The model assumes steady-state mature service. Ramp-up years typically have higher per-train-km cost due to under-utilised fixed staffing.
- Unit costs are central estimates from CHSRA, SNCF, and HSIPR benchmarks. Firm Canadian unit costs require disclosure of rolling-stock OEM service agreements, Ontario electricity rate commitments, and station staffing models.
- The model excludes rolling stock acquisition capital, which for an ALTO-scale fleet (~30–35 trainsets at $60–80M each) is approximately $2 billion. This is properly treated as capital expenditure amortised separately, not as operating cost.
- Energy pricing assumes Ontario grid intensity and industrial rates. Cross-jurisdictional operation (Ontario / Québec) requires explicit treatment of inter-utility transmission cost and differential pricing.

- Climate uplift is applied as a network-level multiplier of 1.10. A more refined model would apply category-specific uplifts: energy 1.15 (winter heating, snow operations), rolling stock maintenance 1.10 (de-icing, longer turnaround), stations 1.20 (winter HVAC), other categories 1.00.
- The variable share is computed from European fixed-fraction coefficients adapted to the operating cost structure. Canadian-specific elasticities are not available in the public domain.

Sources

California High-Speed Rail Authority, 2020 Business Plan Operations and Maintenance Cost Model. Federal Railroad Administration, HSIPR Best Practices Operating Costs Toolkit (2011) and Operating Cost Best Practice Report. SNCF Réseau and SNCF Voyageurs, annual financial reports. Almujibah and Preston, "The Total Social Costs of Constructing and Operating a High-Speed Rail Line" (Frontiers in Built Environment, 2019). Bundesnetzagentur, Trassenpreissystem 2026 and associated rate publications. Office of Rail and Road (UK), European Benchmarking of GB Train Operating Companies (TOCBench). International Energy Agency, Future of Rail (2019) for energy intensity reference values. Independent Electricity System Operator (Ontario), industrial electricity rate benchmarking. Treasury Board of Canada Secretariat, Canadian Cost-Benefit Analysis Guide.