Vancouver Island Rail Retrofit Project: Probabilistic Cost–Benefit Analysis

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***Abstract*—This paper presents a multi-layered cost–benefit analysis (CBA) of retrofitting Vancouver Island's 225 km dormant rail corridor with Battery-Electric Multiple Units (BEMUs). Using a sequential modeling framework built over fourteen weeks, the study integrates deterministic financial modeling, expanded environmental and social benefits, and probabilistic risk simulations. Deterministic results yield a baseline Benefit–Cost Ratio (BCR) of 1.15, while the probabilistic model produces a mean BCR of 1.18 and Net Present Value (NPV) of CAD 12.6 million. Monte Carlo simulation (1,000 iterations) indicates an 80% likelihood of positive NPV outcomes. By quantifying emissions savings, accessibility equity, and uncertainty, this study demonstrates that a BEMU retrofit aligns strongly with British Columbia's CleanBC 2030 targets and Sustainable Development Goals 9 and 11.**

***Index Terms*—Cost–Benefit Analysis, Battery-Electric Rail, Monte Carlo Simulation, Accessibility Equity Index, CleanBC 2030, Sustainable Infrastructure**

I. Introduction

Vancouver Island's 225 km railway has been inactive since 2011, despite its potential to connect Victoria, Duncan, Nanaimo, and Courtenay. Revitalizing the line with Battery-Electric Multiple Units (BEMUs) offers a viable path toward low-carbon transport and inclusive regional development. This study determines whether the retrofit is financially, environmentally, and socially justified under realistic uncertainty. Unlike prior assessments that emphasized engineering cost alone, this analysis integrates three complementary layers: deterministic evaluation, expanded environmental and social accounting, and probabilistic risk analysis. Such integration supports CleanBC's decarbonization goals and the Sustainable Development Goals (SDGs) 9 and 11 [2], [7].

II. Data and Assumptions

Model inputs were compiled from validated public and governmental sources. The parameters are summarized in Table I (Table I).

TABLE I
Primary Model Parameters and Sources

Parameter	**Value / Source**
Corridor Length	225 km (BC MoTI, 2014)
Baseline Ridership	115,000 riders/yr [4]
Fare Range	CAD 15–20 [3]
Elasticity (ε)	–0.4 to –0.6 [3]
CAPEX	CAD 155 M [4]
O&M Cost	0.20 CAD/pkm [5]
Discount Rate	3%, 30-year horizon
Carbon Price	65–125 CAD/t [2]
Grid Intensity	14→8 gCO_2/kWh [1]
Population within 10 km	710,000 residents [6]
First Nations Communities	17 along corridor [4]

III. Methodology

The methodology was executed in three progressive layers to evaluate technical and policy feasibility.

A. Deterministic CBA

A baseline cost–benefit model was developed using a 30-year horizon and 3% discount rate, consistent with federal guidance [7]. The Net Present Value (NPV) and Benefit–Cost Ratio (BCR) were computed as:

$$\mathrm{NPV} = \sum_{t=0}^{30} \frac{B_t - C_t}{(1+r)^t}, \quad \mathrm{BCR} = \frac{\sum B_t/(1+r)^t}{\sum C_t/(1+r)^t}.$$

B. Expanded CBA

Expanded benefits included avoided CO_2 emissions (valued at the carbon price from CleanBC [2]), avoided road maintenance, tourism benefits, and accessibility equity as quantified through the Accessibility Equity Index (AEI). These additions ensured the CBA reflected externalities aligned with CleanBC and UN SDG frameworks.

C. Probabilistic CBA

To capture uncertainty, a Monte Carlo model simulated 1,000 iterations with stochastic input variables. The input distributions and ranges are summarized in Table II (Table II).

TABLE II
Monte Carlo Input Distributions (1,000 Simulations)

Variable	**Distribution**	**Range / Mode**
Ridership Factor	Triangular	0.85–1.15 (1.0)
Elasticity	Triangular	–0.6–0.4 (–0.5)
O&M Cost	Triangular	0.18–0.25 (0.20)
CAPEX	Triangular	140–185 M (155)
Carbon Price	Discrete	65, 95, 125 [2]
AEI Delta	Triangular	–0.05–+0.05

Each simulation recalculated NPV, BCR, and AEI, summarizing mean, standard deviation, and P10/P50/P90 percentiles.

IV. Evaluation Metrics Framework

The Evaluation Metrics Framework (Table III, shown as Table III) established a normalized index to integrate financial, environmental, and social metrics, following Transport Canada [5] and the OECD/ITF [7].

TABLE III
Evaluation Metrics Definitions and Formulation

Metric	**Definition / Interpretation**
Emissions (E)	(Avoided tCO_2 × Carbon Price)/CAPEX
Cost (C)	(CAPEX + PV(O&M))/Passenger km
Accessibility (A)	AEI × (Ridership/Max Ridership)
Equity (Eq)	(Rural + Indigenous Benefits)/Total Benefits

The AEI weight structure was designed to prioritize geographic and Indigenous access, as shown in Table IV (Table IV).

TABLE IV
Accessibility Equity Index (AEI) Weight Structure

Dimension	**Weight (%)**
Geographic Reach	35
Indigenous Access	35
Affordability	20
Tourism Linkage	10

V. Results and Analysis

A. Deterministic and Expanded Outcomes

The deterministic baseline produced $\mathrm{BCR}_{base} = 1.15$ and $\mathrm{NPV}_{base} = 12.3$ M CAD, consistent with Island Corridor Foundation benchmarks [4]. Adding expanded benefits increased the BCR to 1.18, confirming moderate economic feasibility. Annual CO_2 savings were estimated at 350 t (equivalent to removing 100 cars), reflecting BC Hydro's decarbonized grid [1].

B. Monte Carlo Simulation Results

The probabilistic outputs are summarized in Table V (Table V). Results show an 80% probability that BCR ≥ 1, validating project resilience under uncertainty.

TABLE V
Monte Carlo Simulation Summary (1,000 Iterations)

Metric	**Mean**	**P10**	**P90**
BCR (Expanded)	1.18	0.94	1.39
NPV (M CAD)	12.6	–8.0	38.0
CO_2 Avoided (t/yr)	350	280	420
AEI Score	0.73	0.68	0.78
Pr(BCR $\geq$ 1.0)	0.80 (80% Feasible)		

C. Sensitivity Decomposition

Variance decomposition revealed that ridership and CAPEX uncertainty accounted for 68% of NPV variance, followed by O&M costs (12%) and carbon price (10%). AEI variation contributed less than 3%, indicating social benefits were stable relative to cost risk.

VI. Discussion

As indicated by Table V, probabilistic modeling confirmed the corridor's economic robustness under CleanBC policy conditions [2]. Carbon pricing significantly affects upside potential, improving mean feasibility by 8% in higher-price scenarios. Sensitivity results align with the OECD/ITF [7] recommendation to prioritize ridership and capital efficiency in infrastructure risk modeling.

Accessibility outcomes were equally compelling. Over 710,000 residents within 10 km of stations and 17 First Nations communities [6] benefit from improved regional connectivity. The AEI average of 0.73 demonstrates inclusivity consistent with Canada's reconciliation and SDG objectives.

VII. Conclusion

The Vancouver Island BEMU retrofit is financially feasible and socially equitable. With a mean BCR of 1.18 and 80% positive NPV probability, the project aligns with CleanBC 2030 targets and federal low-emission transport priorities [2]. Emission savings of 350 tCO_2/yr and high AEI values highlight environmental and equity impacts. Future work should introduce correlated risk modeling and lifecycle cost updates for implementation readiness.

References

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