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The Economic Feasibility of (Re-)Introducing Tram-Trains in Canada: Okanagan Valley Electric Regional Passenger Rail

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Abstract: Population and tourism growth has increased congestion, collisions, climate harming emissions, and transport inequities in the Okanagan Valley, British Columbia (B.C.), Canada. Surveys indicate a willingness among residents to switch from cars to public transit featuring better service levels and connections. We conducted an analysis on the economic feasibility of an Okanagan Valley Electric Regional Passenger Rail (OVER PR) powered by zero-emission (ZE) Fuel Cell/Battery Hybrid Rail (Hydrail) technology along a 342-km route between Osoyoos, B.C., at the US Border and Kamloops, B.C., the Canadian VIA rail hub. Hydrail passenger light-rail has operated successfully since 2018 in Germany and was demonstrated in Quebec, Canada, in 2023. Technical analyses have confirmed the feasibility in B.C. on steep Highway (Hwy) 97 grades and mountainous weather, with mode shift forecasts in the range of 30%. OVER PR economic analyses were also favorable, with net present value (NPV) = CAD 40 billion (CDN, base year 2023), benefit–cost ratio (BCR) = 9:1, and Return on Investments (IRR) = 33% over 30 years. Subject to additional stakeholder consultations and final design reviews, these results were tested against risks using Monte Carlo Simulation (MCS) and Reference-Class Forecasting (RCF), including worst-case risks such as 70% cost over-runs. OVER PR promises an economic transition to clean energy, sustainable transportation, and more livable communities, benefiting all Valley communities through greater transportation equity.

Keywords: passenger rail; hydrail; Okanagan Valley; sustainable transportation; Okanagan Valley electric regional passenger rail; economic feasibility; reference-class forecasting; Monte Carlo simulation



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1. Introduction

The transportation sector accounts for one quarter of Canada’s greenhouse gas (GHG) emissions, second only to Canada’s carbon-based energy sector, and has increased by 14% since 2018, with the majority being emitted by private vehicles [1,2]. To reduce vehicle emissions and increase transport equity in Canada, zero-emission electric passenger rail, patterned after the successful Karlsruhe tram-train model in Europe, has been proposed for inner and inter-city trips. Figure 1 illustrates one possible route that has been assumed in this analysis, a 342-km rail route paralleling Highway 97 in the Okanagan Valley of British Columbia, Canada.

Known as one of Canada’s premiere tourism destinations due to its arid, desert-like climate and ubiquitous Okanagan Lake beaches, the Valley contains 13 cities that range in size from a few thousand residents (such as Osoyoos at the US border) to over 150,000 residents in its economic center, Kelowna, all connected solely by Highway 97. The booming technology and tourism sectors have fueled population growth and created one of Canada’s hottest housing markets in Kelowna, with many employees being forced to live in, and commute from, neighboring communities along Highway 97. Limited travel choices and long distances between communities means that the vast majority of inter-city trips, and over 85% of inner-city trips, are auto-based, thus increasing Highway 97

congestion. Booming year-round tourism growth further compounds traffic congestion, leading to frequent gridlock and collisions. Seven of the ten worst crash locations in BC's interior occur on Highway 97 in this valley, with multiple crashes weekly contributing to massive delays for local, commercial, and through traffic as emergency responders deal with on-site injuries and clearing of debris. Traffic congestion solutions have been studied, with widespread calls from residents and businesses alike for improved safety and more equitable travel choices for all ages and abilities in order to sustain the valley's world-famous quality-of-life (QoL) and tourism-based economy. After extensive analyses and public engagement processes (including First Nations communities, businesses, and all levels of government), a major provincial transportation study has concluded that traditional auto-oriented solutions such as road widenings and/or bypasses would be both ineffective and cost prohibitive in the region, due to excessive property costs, environmental impacts, and negative community QoL impacts [3]. Instead, they have recommended high-capacity, high-quality transit improvements, which would not only address congestion, safety, and equity problems, but also support federal and provincial climate action targets to reduce climate-damaging emissions [4]. Consequently, researchers have been studying the technical and economic feasibility of an Okanagan Valley Electric Regional Passenger Rail (OVER PR) service. If feasible, this valley-long passenger rail service could significantly enhance transport equity, safety, and congestion while also providing a more affordable, resilient, and environmentally friendly choice for valley residents, businesses, and tourists.

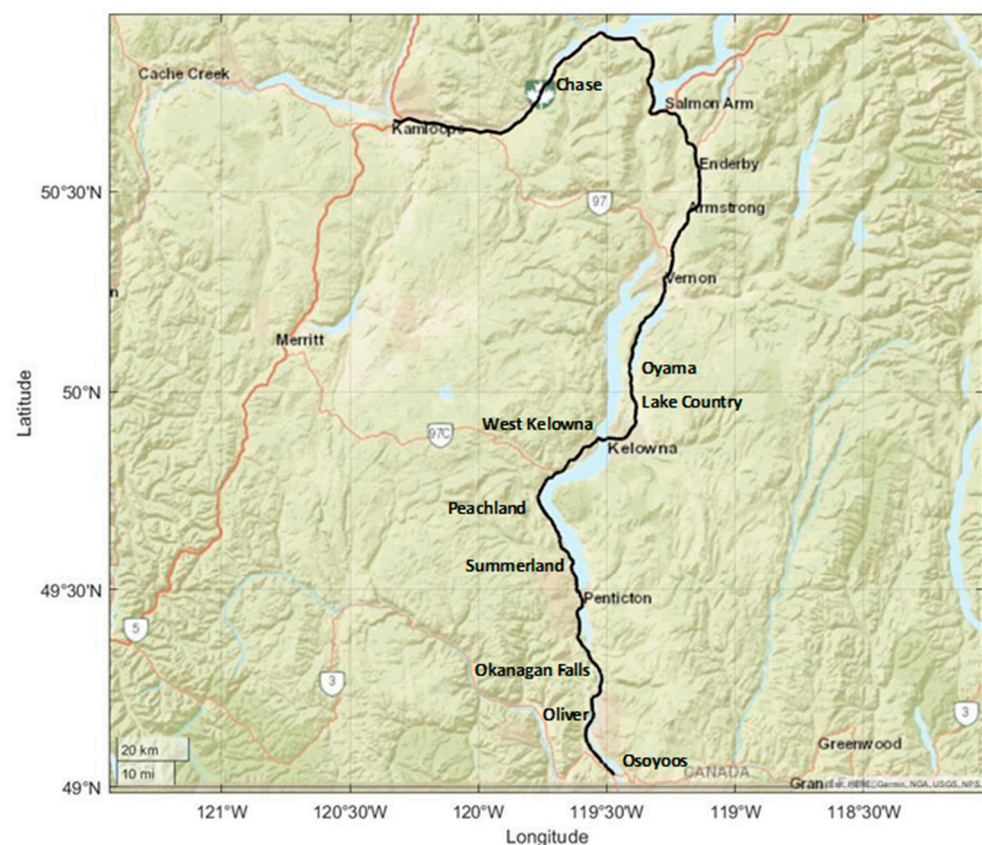


Figure 1. Possible Route—Okanagan Valley Electric Regional Passenger Rail (OVER PR). OVER PR would run on rails between Osoyoos (US Border) and Kamloops (CDN rail hub).

Researchers began by studying the technical feasibility of OVER PR and those results have recently been published [5]. The results confirmed the technical feasibility of an inter-city passenger tram-train on rails, powered by onboard zero-emission hydrogen fuel cell/battery hybrid drives (Hydrail) comparable to traditional (i.e., non-hydrail) tram-trains used in Europe, over a surface route paralleling Highway 97. Specifically, hydrail

tram-trains could traverse the Highway 97 route and its steepest (8%) hills in all weather and all seasons, all while maintaining safe stopping and starting in mixed traffic, much like streetcars in many North American and European cities (e.g., Toronto, Camden, and Karlsruhe) [6–11]. In cities, the tracks would be sunk into travel lanes, flush with road surfaces on city streets, with the tram-trains travelling at city speeds and sharing traffic lanes with regular traffic (e.g., in high-occupancy-vehicle (HOV) lanes). For inter-city travel at higher speeds, OVER PR could run in the median of, or beside, Highway 97 or on an abandoned parallel rail corridor known as the Okanagan Rail Trail. Both corridors contain ample width, meaning that additional property acquisition would not be needed. Thus, OVER PR would operate in a similar fashion to non-hydrail tram-trains that have operated in Karlsruhe, Germany ('the Karlsruhe tram-train model'), and other leading European tourism regions for over 40 years.

Given OVER PR technical feasibility, researchers have begun studying its economic feasibility. This analysis is being conducted at a strategic level before any approved budgets for more detailed planning and design studies are needed to confirm routes, stations, costs, and service levels. Consequently, many assumptions have been made, based on available research findings and industry data, while using Highway 97 grades and alignment as a conservative route proxy. Full community engagement must occur in order to confirm exact routing and station locations, but this proxy route was considered a reasonable transit planning assumption given its direct connections to all existing communities and their bus services. We present the following results of our research on the economic feasibility and social cost benefit analysis of a North American hydrogen powered (hydrail) passenger tram-train, which, if implemented, would be the first hydrail-powered tram-train in the world, including:

1. An overview of the OVER PR's associated:
 - a. Ridership fares and forecasts;
 - b. Community benefits and costs;
 - c. Congestion and GHG emission reductions;
 - d. Investment opportunities.
2. Detailed OVER PR economic feasibility results:
 - a. Benefit/cost metrics;
 - b. Limitations;
 - c. Risk analyses.
3. Recommendations on next steps toward:
 - a. Stakeholder engagement;
 - b. Route planning;
 - c. Business case development.

2. Ridership Analysis

The ridership analysis below sets out identified target markets and ridership forecast methods, which have been critical in constructing service designs and estimating associated capital costs (CAPEX), operating costs (OPEX), and resulting benefits.

2.1. Target Markets

2.1.1. Tourism and Commuting Context

The largest OVER PR target markets involve tourists and commuters. Tourism is one of the main economic drivers for the Okanagan Valley, as, historically, visitor spending in the Greater Kelowna area reached nearly CAD 1.4 billion in 2018 and, in Kamloops, CAD 449 million in 2017 [12–14]. As observed in other leading tourism regions, many visitors prefer rail transit due to its affordability, convenience, and reliability. Over two million tourists fly into the valley via Kelowna's International Airport (YLW) per year, and then must use Highway 97 to reach their final destinations. A similar number of visitors arrive to the valley using personal vehicles, driving in via Highway 97, which averages roughly

40,000 vehicles per day. The Thompson Okanagan Tourism Association (TOTA) forecasts that these numbers will double by 2050 and is concerned that, without auto-alternatives, visitors may choose to avoid Highway 97 and valley congestion by choosing other tourist destinations altogether. Rather than put the valley's reputation as a key tourism hub at risk, this forecast population and tourism growth instead represents a key OVER PR target market. For example, half of all YLW travelers come from, or are destined for, destinations outside of Kelowna, such as Big White Ski Resort, Penticton, Vernon, and Kamloops, each of which could conveniently be reached via OVER PR tram-trains.

Over 85% of valley residents use personal vehicles due, in large part, to auto-oriented community growth management and funding decisions. These auto-centric planning decisions have resulted in transit service levels that have not kept up with growth. Moreover, this has been further compounded by current governance models that keep bus services, for the most part, city-focused, with limited regional and inter-regional connections [15]. Additionally, last mile problems continue to plague transit ridership even in cities. Despite ongoing pleas for improvement, transit authorities in a post-COVID-19 climate have been slow to expand inter-city Bus Rapid Transit (BRT) and hesitant to extend service beyond regional district boundaries. Introducing a Valley-long passenger tram-train service would provide a high-quality, high-capacity transit connection between all valley communities integrated at station hubs with city bus services in each community. Figuratively speaking, this is termed a 'backbone and rib transit service model', as it would help connect all these disparate city bus systems (i.e., the ribs) and allow travelers more convenient transit access up and down the valley via the hydrail tram-train (i.e., the backbone). For example, such a spine-and-rib transit service model resulted in ridership quadrupling in the 1980s in Karlsruhe and its neighboring communities. Karlsruhe's example is especially noteworthy, given that its density and population in the 1980s matches the Okanagan Valley density and population today. The Karlsruhe model worked by promoting inclusive, barrier-free, low-floor tram-trains with embedded rails on city streets in mixed traffic. It was also well integrated at stations, with city buses being re-focused to increase hours and coverage, increasing convenience and attracting more commuters [16,17]. Another example relevant to Okanagan Valley wine sector tourism is the Napa Valley wine train, which safely shuttles imbibing visitors and reduces congestion, multiplying community tourism benefits and economic spin-offs [18].

2.1.2. Productivity, Resiliency and Health Access Context

OVER PR could provide several other ridership-attracting benefits and thereby tap into several other markets, including business productivity, community resiliency, and health service access. Productivity benefits would accrue in two ways: first, as OVER PR is given priority to queue jump and/or pre-empt signals to bypass congestion and reduce travel time; and, second, as mode shift occurs and reduces Highway 97 congestion, crashes, and delays due to crashes. Although economic estimates for safety benefits are provided in a later section, ridership boosts due to public perception of rail transit as a safe, affordable, and convenient mode is a common finding by researchers [19].

Another potential market for ridership involves community resilience, particularly in emergency evacuations and re-housing during climate-related crises and other natural disasters, such as wildfires and floods. There are examples in North America where rail travel could have or did benefit community resilience, including VIA Rail evacuating stranded motorists from Highway 1 washouts during the November 2021 atmospheric river events in BC [20] and BNSF rail transporting crews, water, power, food, and equipment to rebuild New Orleans after Hurricane Katrina in 2005 [21]. Sadly, rail evacuations were not available during the Fort MacMurray wildfires of 2016, where one person died, at least in part, due to the traffic chaos and congestion during wildfire evacuations, with an estimated damage cost of over CAD 3 Billion making it the costliest disaster in Canadian history [22]. There are many such examples that demonstrate how rail lines take less time and resources to repair, operate, and control securely after disaster events (e.g., Ukraine).

The third resiliency-related market segment identified is related to how OVER PR might improve equity and access to health services for all ages and abilities. Equity refers to the rights and abilities of all socio-economic demographics in a community to safe, affordable, and convenient mobility, especially when unable to drive themselves, including:

- Impoverished people who cannot afford to own/operate their own vehicle;
- Seniors wanting to age in place that can no longer drive themselves;
- Youth that cannot yet drive themselves;
- Those in remote communities too health-compromised to drive themselves.

Preliminary discussions with B.C.'s Interior Health Authority suggest that the value in improved health outcomes alone from this fourth group (i.e., remote communities) would be significant; however, they have not, as yet, been researched for confirmation [23].

In addition to equal and improved access for all of these groups, there are equity benefits related to First Nations (FNs) in Canada, many of whom are located in remote rural communities. For example, improved access to, and availability of, health services (equitable access) has been identified in Canada's federal Truth and Reconciliation Commission 94 Calls to Action (TRC) [24]. The TRC was commissioned in 2014 to better understand the 'truths' of the trauma that FN people have suffered due to past and present colonial governance practices in Canada. Truths that have been acknowledged included traumas related to forceful family separations and children were sent to residential schools where abuses were suffered and mortality rates were high over several generations. Other traumas relate to unlawful exploitation of traditional unceded FN territory. Consequently, many FNs today continue to experience high rates of mental illness, addictions, and suicides. As part of the healing and reconciliation process across Canada, a series of 94 calls to action were made in the commission's final report, with a call to improved access to health services being among them. How much a hydrail tram-train would help in this situation remains to be researched.

Based on these contexts and global examples where passenger rail and/or tram-train services have been in place, together with the noted regional commuter and tourism data, ridership forecasts were prepared.

2.2. Ridership Estimation

Valley light rail has long been studied for the Okanagan Valley, repeatedly showing not just significant tourism/commuter ridership demand but also strong economic development potential [25,26]. Moreover, international studies confirm significant environmental and social benefits in general. Specifically, at one-fifth of the energy-per-passenger km as compared to automobile travel, rail transit would also provide considerable energy conservation and significant noise and GHG emission reductions [27,28]. The most recent passenger ridership forecast for an Okanagan Railway was researched by Boozarjomehri [29], who drew data from four sources, including the following: (1) the valley's transportation planning model (OVTP) [30]; (2) valley traveler surveys [31,32]; (3) Canadian auto operating costs [33]; and, (4) internationally recognized passenger rail demand models [34]. The OVTP provided the forecast 2020 Origin-Destination (O-D) table for the total travel demand between cities (i.e., all modes, all trip purposes), as shown in Table 1. The traveler surveys and auto operating costs provided data to derive input values and parameters for the calibrated OVER PR mode choice model, following standard research methodology [35]. Tables 2–4 show the percentage breakdown of the above O-D trip numbers according to trip purpose derived from the above O-D table.

Table 1. Inter-city O-D trips (OVTP model 2020 forecast, all modes, all trip purposes) [29].

From/To	Osoyoos	Penticton and Summerland	Peachland, Westbank	Kelowna	Vernon
Osoyoos	2012	3882	158	500	11
Penticton and Summerland	4368	1696	2309	6164	70
Peachland and West-bank	133	3713	2911	29,482	923
Kelowna	292	6370	29,631	15,133	8670
Vernon	20	108	1762	6364	3363

Table 2. Home-Based Work (HBW) share [29].

Figure	Osoyoos	Penticton and Summerland	Peachland, Westbank	Kelowna	Vernon
Osoyoos	17.06%	36.48%	37.15%	37.15%	37.15%
Penticton and Summerland	36.48%	17.06%	36.48%	37.15%	37.15%
Peachland and West-bank	37.15%	36.48%	13.69%	43.11%	36.36%
Kelowna	37.15%	37.15%	34.41%	19.59%	32.06%
Vernon	37.15%	37.15%	37.93%	36.36%	17.91%

Table 3. Home-Based Other (HBO) share [29].

From/To	Osoyoos	Penticton and Summerland	Peachland, Westbank	Kelowna	Vernon
Osoyoos	57.07%	37.72%	37.36%	37.36%	37.36%
Penticton and Summerland	37.72%	57.07%	37.72%	37.36%	37.36%
Peachland and Westbank	37.36%	37.72%	68.05%	40.83%	33.33%
Kelowna	37.36%	37.36%	46.01%	50.44%	31.76%
Vernon	37.36%	37.36%	41.38%	32.26%	52.73%

Table 4. Non-Home-Based (NHB) share [29].

From/To	Osoyoos	Penticton and Summerland	Peachland, Westbank	Kelowna	Vernon
Osoyoos	25.86%	25.80%	25.50%	25.50%	25.50%
Penticton and Summerland	25.80%	25.86%	25.80%	25.50%	25.50%
Peachland and Westbank	25.50%	25.80%	18.26%	16.06%	30.30%
Kelowna	25.50%	25.50%	19.59%	29.97%	36.18%
Vernon	25.50%	25.50%	20.69%	31.38%	29.36%

Given the predominance of auto-based trips, together with the lack transit-based trips between valley cities, the OVER PR mode choice model used a single nested structure, as shown in Equation (7) below. Okanagan input values used for calibration are shown below in Table 5.

Table 5. Mode choice typical values for the OVER PR model [29].

Transit		Value
Transit Walk-Access Time		5 min
Transit Drive-Access Time		0 min
Transit Wait (average)		15 min
Transit Fare		200 ¢
Transit Transfer wait		0 min
Transit Number of Transfers		0
Auto		
Auto Terminal Parking Time		5 min
Auto Parking Cost		100 ¢
Auto Average Speed in City		30 km/h
Auto Operating Cost (per km)	Cobalt LT	Grand Caravan
Fuel	9.95 ¢	12.97 ¢
Maintenance	2.36 ¢	2.82 ¢
Tires	1.49 ¢	1.91 ¢
Total	13.80 ¢	17.70 ¢

The calibrated model is shown in Equations (1)–(6) below, with the transit share then being calculated using Equation (7), as follows:

$$U_{Tr,HBW} = -0.02IVT - 0.045FW - 0.023TW - 0.045WT - 0.02DAT - 0.003F - 1.25(DAT/IVT) - 1.98 \quad (1)$$

$$U_{Tr,HBO} = -0.015IVT - 0.035FW - 0.035TW - 0.035WT - 0.015DAT - 0.005F - 1.25(DAT/IVT) - 1.74 \quad (2)$$

$$U_{Tr,NHB} = -0.018IVT - 0.045FW - 0.045TW - 0.045WT - 0.018DAT - 0.005F - 1.25(DAT/IVT) - 0.69 \quad (3)$$

$$U_{Au,HBW} = -0.02IVT - 0.02TT - 0.045WT - 0.02DAT - 0.0021AOC - 0.003PC + 0.83 \quad (4)$$

$$U_{Au,HBO} = -0.015IVT - 0.015TT - 0.035WT - 0.015DAT - 0.0017AOC - 0.005PC + 0.93 \quad (5)$$

$$U_{Au,HBW} = -0.018IVT - 0.018TT - 0.045WT - 0.018DAT - 0.003AOC - 0.005PC + 0.9 \quad (6)$$

$$P_{Tr} = \frac{Exp(U_{Tr})}{Exp(U_{Tr}) + Exp(U_{Au})} \quad (7)$$

where:

U_{Tr} = Transit utility function, and U_{Au} = Auto utility function

IVT = Transit In-Vehicle Time; FW = Transit Walk-Access Time

DAT = Transit Drive-Access Time; TW = Transit Wait

WT = Transit Transfer Wait; F = Transit Fare

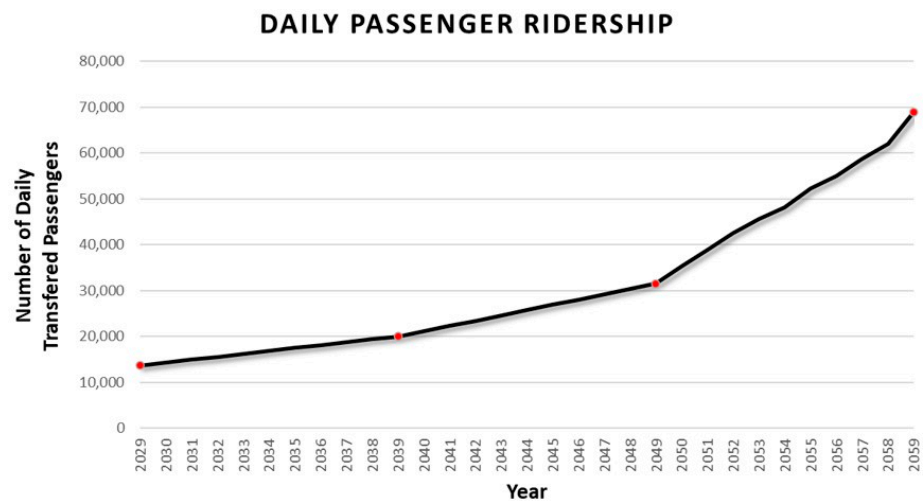
AOC = Auto Operating Cost; PC = Auto Parking Cost; TT = Auto Run Time

Performing sensitivity analysis, we found that the mode share results were very sensitive to three factors: Transit In-Vehicle Time (IVT), Transit Waiting Time (TW), and Auto Operating Cost (AOC). Using these above equations, passenger rail forecasts for OVER PR were calculated for every segment between the years 2009 and 2079, with the results being shown in Table 6.

Figure 2 presents two aspects related to expected ridership, including (a) OVER PR ridership forecasts for the years 2029–2059 by Boozarjomehri [29] (at 13,600 and 70,000 per day, respectively) and (b) average traffic volumes on Highway 97 at its busiest point in Kelowna for the years 2013–2022 from provincial counts, ranging from 52,000 to 57,000 per day (and 10% busier each summer).

Table 6. Forecast rail passenger demand for the OVER PR, years 2009 thru 2079 [29].

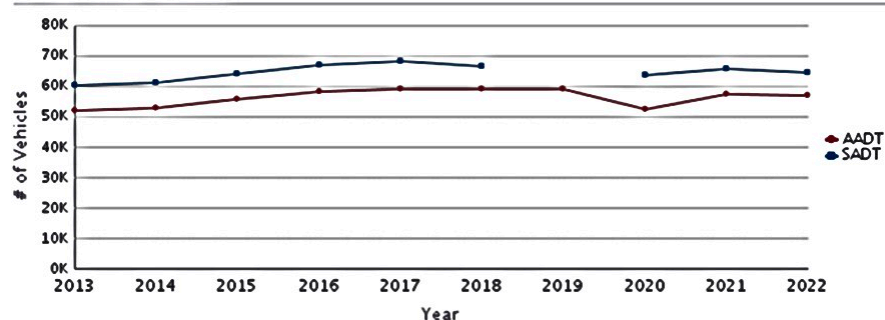
	2009	2019	2029	2039	2049	2059	2069	2079
Vernon—Lake County	1369	1697	2131	3123	4933	10,328	21,589	41,772
Lake County—Kelowna Airport	1414	1772	2226	3172	4840	9700	19,663	38,777
Kelowna Airport—Downtown Kelowna	1760	2207	2771	3949	6026	12,077	24,482	48,280
Downtown Kelowna—Westbank	2336	2918	3633	5096	7661	15,855	35,357	77,462
Westbank—Peachland	484	605	773	1239	2144	5571	15,777	39,939
Peachland—Summerland	437	545	698	1145	2023	5386	15,505	39,487
Summerland—Penticton	559	688	866	1351	2288	5804	16,162	40,681
Penticton—Osoyoos	392	463	570	911	1595	4257	10,226	19,992
Total (Transferred Passenger)	8751	10,896	13,669	19,985	31,511	68,978	158,760	346,390
Total (Transferred Trip)	5368	6684	8385	12,259	19,328	42,310	97,380	212,469



(a)

Average Daily Traffic Volumes

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
AADT	52,001	53,070	55,896	58,466	59,211	59,218	59,197	52,457	57,362	56,973
SADT	60,310	61,160	64,159	67,168	68,172	66,774		63,752	65,900	64,522

10 Year Annual Statistics

(b)

Figure 2. Expected OVER PR ridership. AADT = Annual Average Daily Traffic; SADT = Summer Average Daily Traffic. These ridership forecasts have previously been peer reviewed, presented at conferences, and were some of the first across North America in the past century [29]. (a) OVER PR Daily Passenger Ridership Interpolation [29]; (b) Highway 97 Daily Traffic over Okanagan Lake Bridge at Kelowna [36].

The 2029 ridership forecast in particular, at 15,000 passengers per day (nearly 400,000 passenger kilometers/day), fits within 25% and 30% of current Highway 97 traffic volumes shown above in Figure 2b, and it is consistent with commonly observed 30% mode shifts worldwide when light rail services have been introduced. However, as noted, there are significant additional ridership sources to consider.

In addition to expected the booming tourism growth discussed above, mode shift from cars to OVER PR could reasonably be expected to be bolstered by significant latent demand. Using internationally recognized polling consultants, local governments of the Okanagan Valley have commissioned several independent resident surveys to gauge this latent demand. Results across all resident surveys (drivers and non-drivers) have consistently shown that roughly one-third would prefer to drive less and that two-thirds want to use transit more, suggesting a latent transit demand of between 33% and 66%. Of these respondents, less than 25% reported using transit, while 65% favored reducing car use. These results suggested significant latent demand in the wider population, not just in drivers [15,37,38]. Conservatively, this economic analysis estimated between a minimum of 10%, an expected of 30%, and a maximum of 50% reduction in Highway 97 traffic volumes due to OVER PR. Similarly, latent ridership demand applied these min/max/expected forecast percentages to census population counts. Average travel distance travelled on OVER PR was conservatively assumed to be similar to reported Valley traveler diary surveys, which averaged 26 km across all demographics [38]. This was considered a conservative assumption, given that it ignored the observed mode shift that often occurs over longer inter-urban trips. To that end, our research found an interesting correlation between travel distance and commuter rail mode share, as shown in Figure 3 below.

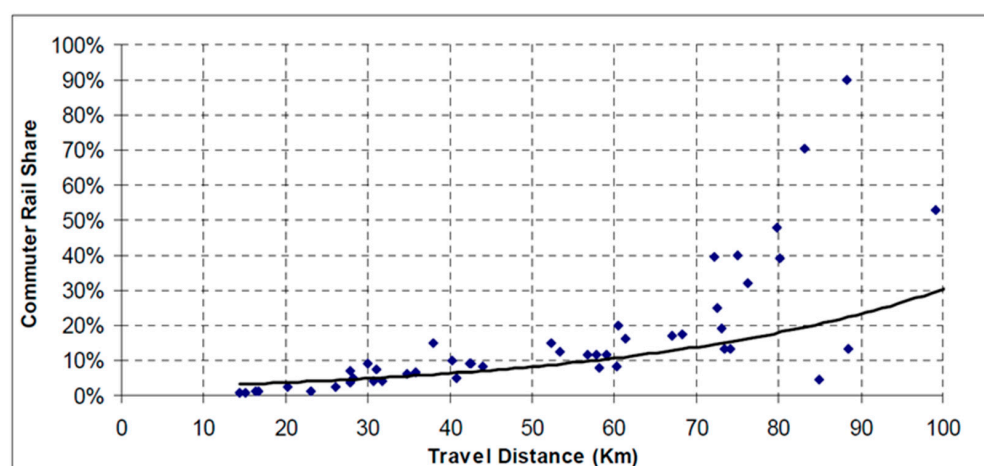


Figure 3. Travel Distance versus Commuter Rail Share [39–42].

3. Costs

We estimated the OVER PR project's costs, included capital (CAPEX) and operational (OPEX) expenditures, over the typical minimum 30-year life used for major infrastructure projects. Cost estimates presented have been calculated using base year 2023 constant dollars and a 6% discount rate. Moreover, all inputs involved minimum/maximum/expected values (and probabilities) in subsequent risk analyses. All input values and min/max ranges were based on peer-reviewed sources and vetted by industry experts. Specific published peer-reviewed sources are noted beside figures in each table below, with full citations in the reference list. In addition to this journal's independent, anonymous, peer-reviewers of this article, we directly engaged industry experts to critically review and provide estimates both locally and internationally [5,17,43]. The following tables and paragraphs summarize the valuations.

3.1. Capital Costs (CAPEX)

We estimated the OVER PR project's capital (CAPEX) expenditures as summarized in Table 7 and discussed in paragraphs following.

Table 7. OVER PR CAPEX Summary (CAD 000's, base year 2023).

3.1 Capital Cost Components	Unit Costs		# of Units	Capital Cost
	Minimum/Maximum (\$ @ Probability, P)	Expected (P = 0.5)		
3.1.1 Tracks	3 @ 0.2/10 @ 0.3	CAD 5000	342 km	CAD 1,710,000
3.1.2 Stations	5 @ 0.1/20 @ 0.4	CAD 10,000	16	CAD 160,000
3.1.3 New Apt Units at Stations	200 @ 0.4/400 @ 0.1	CAD 300	1500	CAD 450,000
3.1.4 H2 Refueling Depot	10 @ 0.2/25 @ 0.3	CAD 15,000	1 Depot	CAD 15,000
3.1.5 Tram-train vehicles (i.e., rolling stock)	8 @ 0.25/12 @ 0.25	CAD 10,000	16 TUs	CAD 160,000
3.1.6 Maintenance Depot	15 @ 0.25/30 @ 0.25	CAD 20,000	1 Depot	CAD 20,000
Sub Total:				CAD 2,515,000
(Deduct New Apartment Costs at Stations):				CAD 450,000
Resulting CAPEX Class C estimate sub-total:				CAD 2,065,000
3.1.7 Add Engineering and Contingency		Value		Design Cost
Engineering		10%		CAD 206,500
Contingency		30%		CAD 619,500
CAPEX Total				CAD 2.9 Billion

3.1.1. Tracks

Railway track infrastructures consist of all the physical components needed to support and guide tram-trains. In cities, tram-trains (also known as street cars in North America (N.A.)) use tracks embedded into the roadway. Imbedded rails reduce costs and tripping hazards, and they can be integrated into existing roadways without removing traffic lanes and reducing highway capacities. Moreover, imbedded rails provide improved reliability, efficiency and noise reduction [44,45]. While they cost less to maintain and have many benefits, these embedded rails do cost more to install than standard rails. Nonetheless, in this analysis embedded rails were assumed to allow seamless integration and convenient, barrier-free connections through the valley. The deciding factor was that no additional property would be needed to accommodate tram-trains if they shared public roadway lanes and/or followed the Highway 97 right-of-way.

Table 8 lists the tram-train track costs used in this analysis, which rely heavily on European Union (E.U.) track construction experience over the past 25 years [46]. The reason for this E.U. reliance is that the most recent and reliable tram-train track installation estimates found in the research come from the E.U. Regardless, as noted above, North American industry track experts were also consulted to confirm that the European values were appropriate; however, no long-distance (i.e., beyond 100 km length) inter-city tram-train track projects have been built in N.A. in the last 50 years. All figures have been converted from euros to Canadian dollars and inflated using construction indices to 2023 base year.

Table 8. Summary of EU Tram-train rail construction costs [46].

City	Length (km)	Converted Cost/Km (CAD Millions, 2023)	Comments
Bremen	3.5	2.4	Only track; 1998 prices
Angers	9.8	15.0	Incl 3rd rail power; 2005 prices
Bern	6.8	13.5	Only track; 2006 prices
Bordeaux	27.0	17.5	Incl veh's and roads; 1998 prices
Bydgoszcz	9.5	7.5	Incl new veh's, roads, stns; 2016
Plock	20.4	3.6	Only track; 2008 prices

Notes: 1. Costs were taken from double track projects; OVER PR would be 95% single track. 2. Euros converted to CAD using a conversion rate of 1.5:1 and historic inflation rates.

The rail infrastructure costs of the train-tram systems examined in Bremen, Germany; Bern, Switzerland; and in Plock, Poland were averaged to estimate railway construction costs. These transport systems' cost per kilometer-track assessments included relevant railway infrastructure components only, all of which were much shorter double-track routes than OVER PR's 342-km route. Other CAPEX associated with turnouts, railway signals, and communications were taken from peer reviewed sources [46–49]. Consistent with the Karlsruhe tram-train implementation history, initial track costs assumed a single dedicated set of rails (single track) running the entire 342-km route between Osoyoos and Kamloops, with double tracks where needed (i.e., passing sidings and at stations) to permit opposing tram-trains to pass mid-route.

From Table 2 and industry sources, adjusting for inflation for 2023 and economies of scale, an expected centerline cost of CAD 5 million per kilometer was used for this study, ranging from CAD 3 million ($P = 0.2$) to CAD 10 million (CAD 0.3). Admittedly, these costs appear low relative to shorter length, in-city track sections. For example, a 3.3 km tram segment in Hannover City was just built for EUR 90 million (roughly CAD 45 million/km), reflecting significant property acquisition and high costs of retrofitting streets in cities, versus in rural areas outside of cities [17]. Economy of scale, use of modular construction techniques, and staying within the highway right-of-way over the much longer 342-km tram segment in this case, most of which is outside cities, could reasonably be expected to lead to significant cost savings in this range [48]. Regardless, all numbers were subjected to Class-reference forecasting and Monte Carlo Simulation risk analyses using the min/max values listed in Table 1 above [48].

3.1.2. Stations

Sixteen OVER PR stations were assumed, averaging one in each community, and two in larger communities. The American Federal Transit Administration (FTA) Capital Cost Database (CCD) was researched and identified CAPEX for numerous bus rapid transit, passenger rail, light rail, heavy rail, and trolley transportation projects [49]; however, no tram-train station costs were found. Instead, this analysis averaged costs of those built as part of larger, longer projects similar in distance and function to OVER PR, including: (1) Minneapolis–NorthStar Passenger Line (64 km); (2) Portland–Wilsonville to Beaverton (24 km); (3) Salt Lake City–Weber Co. Passenger Rail (71 km); and, (4) Fort Lauderdale Tri Rail Segment 5 (116 km). These estimates are high relative to typical EU tram-train station costs, but they also provide a min/max range, whereby the expected average station cost used was CAD 10 million, with range from CAD 5 million ($P = 0.1$) to CAD 20 million ($P = 0.4$).

3.1.3. New Apartment Units at Stations

Station sites were expected to trigger redevelopment of surrounding lands in keeping with official community plan (OCP) processes by local governments, which respect existing land uses while promoting long term community goals. Station area redevelopment costs related to increased housing units (i.e., new apartments) and office spaces were included in this analysis only in order to internalize the associated external (i.e., community) benefits. In this analysis, neither CAPEX nor OPEX were included, with only expected *net* revenues from station area redevelopment being taken into account, as exact configuration and costs and benefits would be dependent on each community's context and bylaws. As such, net benefits from redevelopment were used as follows: (i) apartment sales were expected to net 10% of construction costs; (ii) office rentals were expected to net CAD 25 per square meter monthly. Local BC (Vancouver) data reported in the Canadian Cost Guide was used as follows: (i) an averaged construction cost of CAD 3000, CAD/m²; (ii) an average unit size of 100 square meters; (iii) 1500 apartments in total dispersed across all stations according to city size [50,51]. For example, the three largest cities, Kamloops, Kelowna, and Vernon, were assumed at 200 new residential units each, while the rest were stepped down to a minimum of 50 units at the other main stations based on population statistics [51].

3.1.4. Hydrail Tram-Train Vehicles

Virtually all inter-city, rail-based vehicles now use electric traction motors, with most in Europe historically relying on overhead wires for power and those in North America using diesel-electric generators. Technologic advancements since the 1990s have made hydrail power trains not only viable but also the economically and environmentally superior options [17,52,53]. The lowest cost path to hydrail passenger vehicles is to retrofit existing diesel trains, under CAD 6 million each, which is a sound business case given the typical 30-to-50-year life of railcar chassis [53]. Regardless, figures in the CCD were also sourced for procuring new trainsets in North America [49]. These peer reviewed sources were used along with prices quoted in recent industry disclosures, giving an expected CAD 10 million per new hydrail vehicle, ranging from CAD 8 million to CAD 20 million [54,55].

3.1.5. Hydrogen Refueling Depot

The tram-train vehicles were expected to use trackside re-fueling facilities at the maintenance depot. Highway 97 parallels a natural gas/hydrogen pipeline that could provide trackside hydrogen by 2030, subject to regulatory approvals and construction. For contingency, this analysis added in costs for an on-site ‘green’ hydrogen electrolysis refueling station using electricity from excess renewables (e.g., wind, solar, hydro) at an expected CAD 15 million CAPEX with a range from CAD 10 million to CAD 25 million [56].

3.1.6. Maintenance Yard/Depot

One maintenance depot would be needed to fuel, maintain, and store the sixteen hydrail tram-train vehicles. A central location was assumed, at an expected cost of CAD 20 million, with a range from CAD 15 million to CAD 30 million [49], including property acquisition.

3.1.7. Class B Engineering and Contingency

Given the conceptual level of design detail, this feasibility analysis used a 30% CAPEX contingency and 10% CAPEX engineering fee values, in keeping with industry practices [49].

3.2. Operating Costs (OPEX)

Table 9 below summarizes OPEX, with explanations following below. These operating costs were adapted from a table found in [57] that references Harris et al. [58]. These are internationally recognized sources, both of which note how difficult it is to get detailed breakdowns, especially as they are often proprietary and held confidential to protect individual corporate competitiveness. To quote [57] (page 118), ‘Since 2005, accurate numbers have been difficult to obtain as they are seen as commercially sensitive data’.

Table 9. OVER PR OPEX Summary (CAD 000’s, CDN, 2023 base year) [57,58].

Operating Cost Components	Industry Norm	Resulting OPEX
Onboard Staff	0.20	CAD 41,240
Rolling Stock Maintenance	0.20	CAD 41,240
Fuel Costs	0.05	CAD 10,310
Management and Other Staff	0.25	CAD 51,550
Rolling Stock Financing	0.30	CAD 61,860
OPEX Sub-total (Check = 10% of CAPEX)		CAD 207 million/yr
Adjustment 1: DEDUCT Rolling Stock Financing		(CAD 61,950)
Adjustment 2: DEDUCT Green H2 Fuel Savings		(CAD 1185)
Adjustment 3: ADD Track System Maintenance (10% OPEX)		CAD 20,650
Adjusted OPEX Total (Base year 2023)		CAD 164 million/yr

In the absences of final tram-train corridor and service model designs, a planning-level analyses was used to set OPEX. Based on industry norms for planning level analyses,

Johansen et al. [57] suggested setting OPEX at 10% of CAPEX, or CAD 207 million/year. Three adjustments were needed, affecting: (1) rolling stock financing, (2) fuel costs, and, (3) track maintenance. First (Adjustment 1), rolling stock costs (i.e., tram-train vehicles) were included in CAPEX (Table 7) above as part of initial capital costs, and, as such, there was no need to include rolling stock financing costs (i.e., OPEX) for the same item in Table 9. Second (Adjustment 2), hydrail uses hydrogen fuel, not diesel fuel. The US ‘Hydrogen Shot’ program expects the price of hydrogen fuel to drop below the cost of diesel fuel by 2030 [52,56,59,60]. Hence, the second adjustment reduced annual fuel costs to an expected price of CAD 5 per kilogram H₂ [60]. Daily fuel consumption assumed five tonnes of hydrogen for the OVER PR expected 16 tram-train fleet, as previously documented in a related technical feasibility study [17]. Finally, the third adjustment added a 10% annual track maintenance allowance. As a result of these three adjustments, the present value over 30 years of operations totaled PV(OPEX) = 2.3 Billion (CAD, base year 2023). For context and comparison, the PV(OPEX) nearly matched (i.e., within a 25% planning error) the PV(CAPEX) = CAD 2.9 Billion. This near match was consistent with expectations and industry norms observed in infrastructure lifecycle cost analyses (i.e., over the lifecycle of infrastructure projects, typically OPEX nearly matches CAPEX).

Having calculated these minimum, maximum, and expected PV(CAPEX) and PV(OPEX), the next steps in our economic feasibility analysis involved calculating the OVER PR estimated benefits and final economic metrics, including Net Present Value (NPV), Benefit/Cost Ratio (BCR), Payback Period (PBP), and Return on Investments (IRR).

4. Benefits

The estimated benefits of OVER PR have been summarized in Table 10 below, along with citations, with minimum, maximum, and expected values being used in risk analyses. For reference in risk analyses, several input assumptions were also made concerning population, and discount rate. Expected valley population = 550,000 (P = 0.5; min = 450,000 @ P = 0.2; max = 650,000 @ P = 0.3). Expected discount rate = 0.06 (P = 0.5; min = 4% @ P = 0.25; max = 8% @ P = 0.25). Fractions in brackets represent probabilities used for MCS risk analysis. Further explanations of each have been given in the following table and paragraphs:

Table 10. Min/Max/Expected Benefits for OVER PR (See Notes below).

Direct (One Time)	Value Ranges CAD 000's (@ Prob'y)		Source	Expected Values (CAD 000's 2023)
	Min	Max		
Net Apt. Rev. @ Stns	22,500 (0.25)	67,500 (0.25)	Local data ¹	CAD 45,000 (0.5)
Salvage Value	15,000 (0.25)	196,000 (0.25)	After 30 years ²	CAD 105,499 (0.5)
Sub Total DIRECT (one time):				CAD 150 Million
Indirect (Ongoing)	Value Ranges CAD 000's (@ Prob'y)		Source	Expected Annuity (CAD 000's 2023)
	Min	Max		
Fares	CAD 0.15/km (0.25)	CAD 0.30/km (0.25)	CAD 0.20/pass km ³	CAD 24,684 (0.5)
Concessions	2% (0.25)	8% (0.25)	5% of fare revenue ⁴	CAD 1234 (0.5)
Advertising	2% (0.25)	8% (0.25)	5% of fare revenue ⁴	CAD 1234 (0.5)
Sub Total INDIRECT (recurring):				CAD 27.2 Million/yr

Table 10. Cont.

External (Ongoing) (i.e., Community)	Value Ranges CAD 000's (@ Prob'y)		Source, CAD/km- vehicle	Expected Annuity (CAD 000's 2023)
	Min	Max		
Station Office Rentals	20,000 (0.25)	54,000 (0.25)	Local data ⁵	CAD 34,000 (0.5)
Carbon Tax Savings	20,000 (0.15)	30,000 (0.35)	30% red'n ⁶	CAD 25,000 (0.5)
Safety	430,000 (0.2)	860,000 (0.3)	30% shift ⁷	CAD 645,000 (0.5)
Tourism	CAD 70,000 (0.25)	CAD 350,000 (0.25)	15% boost ⁸	CAD 210,000 (0.5)
Water Pollution	0.001 (0.2)	0.026 (0.3)	0.018 ^{9,10}	CAD 40,000 (0.5)
Waste Disposal	0.000 (0.2)	0.001 (0.3)	0.0006 ^{9,10}	CAD 1000 (0.5)
Local Air Pollution	0.001 (0.2)	0.093 (0.3)	0.061 ^{9,10}	CAD 137,000 (0.5)
GHG Emissions	0.006 (0.2)	0.140 (0.3)	0.098 ^{9,10}	CAD 219,000 (0.5)
Noise	0.002 (0.2)	0.075 (0.3)	0.051 ^{9,10}	CAD 113,000 (0.5)
External Crash	0.034 (0.2)	0.149 (0.3)	0.127 ^{9,10}	CAD 283,000 (0.5)
Parking	0.051 (0.2)	0.233 (0.3)	0.197 ^{9,10}	CAD 438,000 (0.5)
Travel Time	0.048 (0.2)	0.317 (0.3)	0.246 ^{9,10}	CAD 548,000 (0.5)
Sub Total EXTERNAL (recurring):				CAD 2.7 Billion/yr

Notes: 1. Expected net revenues of CAD 3000/m² cost (min = CAD 200 @ P = 0.25; max = 400 @ P = 0.25) for 1500 condo units at 16 stations, one-time sales at initial station construction. 2. Declining balance depreciation, expected 4% rate (P = 0.5; min = 2% @ P = 0.35; max = 10% @ P = 0.15). 3. Transit fare range derived from: E.U.; local tour buses; and, recent travel surveys. 4. Conservative estimate from industry norms. 5. Kelowna office rental revenues, ongoing. Expected rate = CAD 2.50/sq ft; (P = 0.5; min = CAD 1.50 @ P = 0.25; max = CAD 4/sq ft @ P = 0.25). 6. Expected CAD 50/tCO₂, 10 L/100 km; 16,150 km/yr (P = 0.5; min = 13,100 @ P = 0.25; max = 19,100 km @ P = 0.25). 7. Expected safety benefit reflects expected 30% modal shift from driving to transit (i.e., min = 10% @ P = 0.2; max = 50% @ P = 0.3), with valuation using local, ICBC data [61]. 8. Expected boost due to OVER PR = 15% (P = 0.5; +/- 10% @ P = 0.25) was provided by local tourism experts, and then applied to the existing valley tourism revenue of CAD 1.4B annually [62]. 9. Todd Litman provides mileage-based estimates of benefits in his TDM Encyclopedia, based on an extensive, well-updated research database compiled over decades of case studies [63]. 10. Expected auto ownership = 0.92 (P = 0.5; min = 0.85 @ P = 0.25; max = 0.95 @ P = 0.25).

Similar to estimating costs, for estimating benefits, this analysis used peer reviewed, published research sources to derive project (i.e., direct and indirect) and community (i.e., external to the project) valuations. Similarly, all benefit calculations used the previously derived expected 30% (+/-20%) mode shift from 2023 traffic volumes, together with a discount rate of 6% (min 4%/max 8%), to calculate the present values of benefits over 30 years = PV(Benefits). Recurring benefits were extended as annuities (base year 2023) over the assumed project lifespan of 30 years (min 25/max 50). While a myriad of other community benefits was researched during the analysis, no methodology was found in the literature to calculate benefits related to light freight, productivity, healthcare access, affordable housing, or livability.

4.1. Direct Benefits

4.1.1. Salvage Value

This analysis used a 4% (min 2%/max 10%) declining balance depreciation rate for capital assets, with an expected CAD 105.5 million 'salvage' value of OVER PR assets and a one-time benefit value at 30 years.

4.1.2. Station Area Redevelopment—Net Revenues from Housing Sales

Stations catalyze area re-development, subject to local planning authorities, and generate commercial, residential, and employment opportunities while the local tax base increases. A conservative 10% return on capital investments is assumed, with a minimum range of 5% and a maximum of 15%. This analysis suggests that home sale revenues could range from 1.05 to 1.15 times their construction cost, with an expected value of 1.10 or an expected CAD 45 million in net revenues above cost (a one-time benefit).

4.2. Indirect Benefits

Indirect benefits would occur over the full 30 year assumed project life yet still accrue to the project, including passenger fares, concession revenues, and advertising revenues, as noted below.

4.2.1. Fares

OVER PR passenger fares would form another significant contribution to financial sustainability. There is no directly comparable, transit-based, Valley-long travel option. One limited-service private bus company, E-Bus, runs only twice daily and connects between Vancouver, Kamloops, Kelowna, Salmon, Arm, and Vernon. Referencing the E-bus website, which books trips around our Okanagan Valley, we explored the length and cost of several inter-city excursion origin destinations in the valley, along with several in-city trip distances and rates for valley city buses, taxis and driving personal vehicles [33,64]. Rates for driving, taking a taxi, city buses, and tour buses connecting the Okanagan Valley average CAD 0.68, CAD 0.20, CAD 2.26, and CAD 0.27 (CAD/pass km), respectively. At the time of our analysis, the cost of trips averaged CAD 0.27/passenger km. This analysis used a conservative expected fare revenue value of CAD 0.20/passenger km, with a bound range of minimum CAD 0.15/passenger km and a maximum CAD 0.30/passenger km. As seen in Table 6, 13,669 passengers per day were taken over the project life. This volume was combined with travel distance data from recent Okanagan travel surveys at 25.8 km per day [15]. Given this analysis was conducted in 2023 base year dollars, which, by definition, ignores inflation, ridership growth was also ignored. Although longer trips on OVER PR could be reasonably expected, no data were found pending fuller transportation planning analyses; hence, this constant ridership level was considered to be a reasonably conservative assumption.

4.2.2. Concession, Couriers and Advertising Revenues

Publicly available data are limited, as they are typically confidential industry data. The US Transportation Research Board found in a 1998 report [65] that transit agencies typically leased or sold advertising on transit vehicles for as low as CAD 1000/year, up to as high as CAD 17 million/year in New York, with an average in the range of CAD 3 million/year. A more recent 2017 article found that advertising revenues in Toronto and Hong Kong total 2.33% and 4.7%, respectively, of total operating revenues. Moreover, Hong Kong station retail revenue (i.e., concession revenue) was found to be roughly 3.4 times that of advertising revenue [66]. For this analysis, a conservative estimate of concession and advertising revenue was used at 5% of fare revenues, with a range of minimum at 2% and maximum at 8%. Additionally, courier revenues from transporting minor freight (postal services, packages, regional goods, express letters) within the tram-trains could also reasonably be expected; however, estimates were not available at the time of this analysis.

4.3. External Benefits

External benefits accrue to the broader community and are considered ongoing. Estimates were directly calculated where local data were available. Otherwise, estimates were sourced from the Victoria Transport Policy Institute and are calculated in units of CAD/Vehicle km travelled [63]. Expected light and medium duty vehicle mileages of 16,150 (min 13,100/max 19,200) km per year were used based on Canadian statistics [67].

4.3.1. Station Office Rentals

Many of the OVER PR stations would offer office rental opportunities for commercial activities (e.g., we-work, and retail). The revenue generated would promote financial sustainability. Annual revenue was computed using publicly available local lease rates data, which suggested expected = CAD 25/sq m-month (min = CAD 15/max = CAD 40) [68,69]. The analysis assumed a conservative 75% occupancy rate, well below historic occupancy rates that exceed 90% [70].

4.3.2. Carbon Tax Savings

The Province of B.C. implemented one of North America's first broad-based carbon taxes on all fuel sales as part of its CleanBC climate action plan. This analysis used a CAD 50/tCO₂e expense that local drivers pay as part of valley travel [71]. This CAD 50 rate was set by the Province of B.C. based on their internal policy analyses, and it included escalation clauses for future years. This analysis included a conservative assumption that this rate would remain constant over the 30-year analysis period. OVER PR would provide an economic substitute to driving, and thus reduce that expense for passengers that formerly drove. Available data from national databases [72] provided this analysis with an average fleet automobile fuel economy of 10 L/100 km, as well as tailpipe emissions at 2.66 kg of CO₂e per liter of fuel combusted. When combined with the average distance driven for the B.C. vehicle fleet of 16,150 km/year, and the expected mode shift [51,67], the product of these numbers calculated a CAD 25 million expected benefit (min CAD 20/max CAD 30) in carbon tax savings from burning approximately half a million fewer tonnes of CO₂e per year by Okanagan Valley drivers. Approaching the 2050 Net Zero deadline for Canada, annual CO₂e emissions can be expected to reduce as the EV fleet composition shifts; however, the dollar value of this climate benefit would likely not diminish given the aforementioned carbon tax increases that this analysis has ignored. Regardless, the potential estimating error due to this diminishing benefit is low relative to other external benefits (e.g., safety).

4.3.3. Safety

The greatest external benefit, or community benefit, that OVER PR would generate, at an expected value of CAD 645 million (min CAD 430/max CAD 860) annually, was found to be road safety improvements. These benefits accrue through reducing the use of private vehicles (i.e., an expected 30% mode shift) and thereby reducing the associated exposure risk to collisions and injuries. According to the provincial Insurance Corporation of British Columbia (ICBC), over 56,000 road crashes occurred annually from 2018 to 2022 in the valley, resulting in over 12,000 injuries and 150 lives being lost each year [61]. The Government of Canada has set the social cost of traffic collisions according to collision severity as follows: CAD 7.5 million (min CAD 5/max CAD 10), and CAD 265,000 (+/−33%), for fatal and injury, respectively [73]. It is commonly known that the majority of serious crashes in the valley occur on the Highway 97 corridor. This is the same corridor where a 30% mode shift from private vehicles to OVER PR ridership was expected. Hence, this analysis used an expected 30% reduction in fatal and injury crashes, which is consistent with the research and follows from the inherently safer nature of public transportation, whereby transportation is commonly referred to as a 'social determinant of health' [74,75].

4.3.4. Tourism

Current annual direct economic output due to tourism in the valley have been estimated based on surveys conducted by the Thompson Okanagan tourism industry—hotels, restaurants, retail, tours and other tourist attractions—at CAD 1.4 Billion [12,13,76]. Based on observations after the introduction of passenger rail transit services around the world, it is reasonable to expect that OVER PR would offer an attractive and sustainable transportation choice for, and increase the number of, tourists visiting the valley. Numerous before and after studies have shown that accessible and convenient rail travel boosts tourism by attracting more visitors to explore the region's attractions, wineries, and recreational areas. Moreover, there have also been economic spin-offs, as increased tourism activities along the railway route contribute to local businesses, accommodations, and the overall economy, with a 20% increase in new tourism-related revenues observed with the introduction of high-speed rail [77,78]. The Thompson Okanagan Tourism Association (TOTA) [62] confirmed that it was reasonably conservative to use an expected 15% (min 5%/max 25%) increase in annual tourism economic output due to OVER PR supporting the growth and development of the tourism industry in the Okanagan Valley.

The remaining discussion below of external benefits (i.e., Sections 4.3.5–4.3.11) relied heavily on data from the Victoria Transport Policy Institute (vtpi.org) and its minimum/maximum/expected estimates of passenger km metrics. Where additional data were found, VTPI estimates were augmented (i.e., vehicle ownership, annual mileage, and auto occupancy) [63,75,79–85]. The Transportation Association of Canada's Urban Transportation Indicators report found Kelowna vehicle ownership stood at 0.92 vehicles for every city resident [86]. This 0.92 factor (min 0.85/max 0.95) was used in calculations going forward, together with the expected 30% (min 10%/max 50%) mode shift, annual driven mileage of 16,150 (min 13,100/max 19,200) kilometers, 550,000 (min 450,000/max 650,000) valley population, and average 1.1 (min 1.05/max 1.2) auto occupancy data from valley surveys [31,32].

4.3.5. Reduced Water Pollution

Carbon-fueled, internal combustion engine (ICE) use has been associated with increased water pollution and hydrologic disruptions. These harmful impacts occur via the introduction of harmful substances (e.g., fluid leaks, particulate emissions, petroleum spills, road salts) into the surface or groundwater and/or changes in the surface and groundwater flows of streams, rivers, and wetlands, as well as habitat destruction. Water quality impacts have been directly associated with vehicle maintenance and usage practices, while hydrologic impacts have been correlated with the extent of lane miles and parking infrastructure. Water quality and the hydrologic impacts of ICE vehicles include habitats, bio-diversity, and livability [79].

4.3.6. Waste Disposal

Environmental and economic damages have been incurred due to improper disposal of used cars and their used tires, batteries, oil and other fluids. While approximately 80% of car parts have been found to be recycled, the remaining 20%—plastics, and glass—have amounted to roughly five million tonnes per year being landfilled in BC [75].

4.3.7. Reduced Air Pollution and GHG Emissions

Over 30% of GHG emissions in the Okanagan Valley have come from driving ICE vehicles, many of which also exhaust fine particulates (PM10, PM2.5) that cause cancer. Over the life of a vehicle, from its manufacturing to disposal, air pollution and GHG emission impacts arise not just from exhaust emissions, but also from road dust, tire and brake wear, lifecycle emissions from fuel extraction and refining, and transportation facility construction. While ICE vehicles could reasonably be expected to transition to EVs by 2050, other lifecycle emissions and environmental impacts would continue (e.g., brake linings, material extractions, and maintenance facilities). The vehicle cost for pollution included an estimate for local air pollution due to indirect pollution caused by vehicles and an estimate for GHG emissions directly emitted from fuel combustion by ICE vehicles [82].

4.3.8. Noise Reduction

Noise, characterized as unwanted sounds and vibrations, is a result of various factors related to motor vehicles, including engine acceleration, tire/road contact, braking, horns, and vehicle theft alarms. Motorcycles, trucks, and buses are prominent contributors to traffic noise, with different sources dominating at various speeds. Noise can deter outdoor activities, render certain locations unfavorable for housing or other quiet-dependent land uses (e.g., farming), and disrupt sleep patterns, causing heart disease. Noise disproportionately affects the health of residents living near highways. This analysis assumed that mitigating noise by reducing the number of vehicles on the road would significantly benefit communities [83].

4.3.9. External Crash Reductions

Internal crash costs were previously estimated above under ‘safety’ at being over CAD 644 million annually in regard to injuries to individuals traveling by vehicle. External crash costs refer to those uncompensated damages on other people and/or infrastructure, including traffic congestion delays at crash sites; diminished quality of life; and mental health implications. This analysis assumed that external crash benefits would accrue to the community via reduced disruptions and delays to other travelers on the Highway 97 corridor (i.e., due to reduced collisions as more travelers use OVER PR to travel instead of driving in personal vehicles) [80,81].

4.3.10. Less Parking Required

Parking incurs land and construction costs, including on-street and surface stalls, and off-street, structured parking facilities. Moreover, parking lanes and road shoulders occupy valuable road space that could be used for active travel modes (e.g., bus, bike, walking) and/or tree canopy to address climate change. This analysis assumed both internal parking (private/residential) and external parking (public/commercial) benefits [84].

4.3.11. Travel Time Savings (Reduced Congestion)

Increased traffic congestion has been associated with increased impacts in terms of travel delays, collision and injury risks, and lost productivity resulting from interactions among road users. These costs were measured by considering additional travel time, increased vehicle operating costs (i.e., fuel and wear), and wage rates. Alleviating congestion would improve mobility and accessibility, providing significant economic benefits to all road users. Moreover, all road users benefit from one less vehicle on the road. In this analysis, travel time stood out as a major impact and the highest external benefit next to safety [81,85].

As detailed in Table 10 above, the benefits of OVER PR can be summarized as follows:

DIRECT, one-time benefits = CAD 150 Million;

INDIRECT, recurring benefits = CAD 27 Million per year;

EXTERNAL (community), recurring benefits = CAD 2.7 Billion per year.

Taken together and discounted at 6% over 30 years to present value (PV), these benefits totaled PV(Benefits) = CAD 45 Billion. The bulk of OVER PR benefits would be derived from CAD 27 million in annual benefits over 30 years (i.e., fares, advertising, concessions, station office rentals), and, an even larger contribution, from CAD 2.7 Billion in annual community benefits over 30 years (i.e., reduced crashes and injuries, GHG emissions, congestion, pollution, travel time, noise, parking, and increased tourism). The value of these benefits was tested using Monte Carlo Simulation (MCS) and Reference-Class Forecasting (RCF) risk analyses, with the results being given in Table 5 below.

5. Results and Discussion

5.1. Economic Indicators (NPV, BCR, Payback Period, IRR)

Table 11 summarizes results of this economic feasibility analysis, pending comprehensive community engagement, final design, and service design.

Each of these figures—costs and benefits—has been peer-reviewed by local and international industry experts, and each rely on the best available peer-reviewed research. Construction over the entire 342 km route, including stations, vehicles, and maintenance depots, was estimated at a present value of PV(CAPEX) = 3 Billion (CAD, base year 2023) and expected to take four years to complete. No benefits would accrue until after completion, including CAD 45 million (one time) in station area net revenues from apartment sales; CAD 27 million per year in fare, concession, and advertising revenues; and nearly CAD 3 billion in recurring annual community benefits, all of which translated to a CAD 45 billion present value (in 2023 base year CAD). Operating costs (OPEX) of CAD 164 million annually translate to a present value of PV(OPEX) = CAD 2 billion over 30 years.

Deducting costs from benefits produced a favorable net present value (NPV) = CAD 40 billion, a benefit–cost ratio (BCR) = 9:1, a payback period (PBP) < 7 years, and an Internal Rate of Return or return on investment (IRR) = 33%. It is reasonable to expect that these benefits would be distributed across the entire valley, including not only communities from Osoyoos to Kamloops, but also visiting tourists and Highway 97 travelers. Notwithstanding risks inherent to all such mega-projects, these initial results suggest that OVER PR is economically feasible with high confidence, as well as that the next steps of public engagement and planning would be warranted to further confirm the community business case.

Table 11. OVER PR Economic Feasibility Results (rounded CAD, base year 2023)¹.

Item	Base Case (BC) (All Benefits)	Adjusted BC Incl Only TT and Safety Benefits	Reference-Class Forecasts
PV (Benefits)	CAD 45 Billion	CAD 20 Billion	CAD 20 Billion
PV (CAPEX)	CAD 3 Billion	CAD 3 Billion	CAD 6 Billion
PV (OPEX)	CAD 2 Billion	CAD 2 Billion	CAD 4 Billion
Net Present Value	CAD 40 Billion	CAD 15 Billion	CAD10 Billion
Benefit/Cost Ratio (BCR)	9:1	4:1	2:1
Internal Rate of Return (IRR)	35%	19%	7%
Payback Period (PBP)	7 years	9 years	18 years

Note: Reference-Class Forecasts taken from [48], Appendix A, and assume 116% cost overrun across all cost estimates. The Adjusted BC CAD 20B benefits (as opposed to the full CAD 45B) approximate a similar 116% reduction in estimated benefits, although Flyvberg et al. [48] did not posit such a conservative adjustment when estimating benefits (they only recommended adjustments for costs).

5.2. Limitations

At this early level of analysis, there are several limitations to be acknowledged, including:

- (1) Proportion of direct, indirect, and external benefits;
- (2) Confidence of estimates (risk analyses).

First, regarding proportion of benefits, it was observed that most benefits (in this case 99%) are derived from external (community) benefits and not from direct or indirect project-specific, financially tangible benefits, a result consistent with many public infrastructure projects. In an era of growing public concerns over the environment, climate and community resilience, governments are more and more realizing that externalities (i.e., community benefits) must be fully accounted for (i.e., internalized) in recognition that transportation is fundamentally a social determinant of public health [87]. Recognizing that some debate occurs on exactly which externalities should and should not be internalized, the analysis was also adjusted to include just two of the twelve externalities (i.e., community benefits) based on their widely accepted inclusion in traditional economic feasibility analyses—safety and congestion benefits (results for this Adjusted BC have been listed in Table 11 above). However, this adjusted economic feasibility analysis still produced strongly positive results, with NPV = CAD 15B, BCR = 4, PBP < 10 years, and IRR = 18%. As noted previously, this limitation would be further reduced through ongoing efforts to confirm route and design.

The second limitation, level of confidence in estimates, was an inadvertent reality given the conceptual level of detail available (i.e., lack of final design and service model) from which to directly derive more accurate estimates. Every effort was made to consult the literature, consult with experts, and intentionally make estimates conservative. Nonetheless, to gauge the impact of this second limitation on the results, a detailed risk analysis was conducted using a Monte Carlo Simulation (MCS) and Reference Class Forecasting (RCF), with details given below in Section 5.3.2.

5.3. Risk Analysis

The risk analysis for the OVER PR involved assessing two categories of risk: (1) strategic risks (regulatory, operational, implementation, and market) which will be considered in the next steps toward business case development and were not part of this analysis (we

only touch on them below for future research reference). (2) Direct risks related to using Monte Carlo Simulation (MCS) and Reference-Class Forecasting (RCF) analyses to test how input values given in Table 4 above influenced the resulting economic metrics.

5.3.1. Strategic Risks

Regulatory

The OVER PR project faces strategic risks due to regulatory and permitting requirements that must be mitigated prior to implementation. Regional passenger rail is not new to Canada, but its introduction via inter-city hydrail tram-trains is entirely new [9,16,19,46–48]. This risk could be mitigated through a limited scope demonstration project. For example, Alstom conducted a demonstration in Canada of its iLint Coradia hydrail vehicle in Quebec, between Quebec City and the northeastern townships, in the summer of 2023 [8].

Operational

Operational risks relate to equipment, infrastructure, growth, and integration with existing transportation systems. This risk would be mitigated by proper service planning and community partnerships, and it should be prioritized in the next steps.

Implementation

This risk relates to timelines, community engagement, planning, partnerships, design, engineering, funding, approvals, construction, commissioning, and management (or governance). Comprehensive stakeholder involvement, including local communities, government agencies, and regulatory bodies, is critical for the success of large-scale infrastructure projects. The absence of a detailed stakeholder engagement plan raises concerns about the project's social and political acceptability. Another significant future research effort must investigate which governance structure would meet local needs and most effectively mitigate risks. One possible governance model might be an arms-length, crown-corporation. Moreover, such a governance model has had some local success in the valley. Known as the Okanagan Basin Water Board (OBWB), it was established in 1970 to coordinate, convene, and govern the valley's watershed for the benefit of all communities and all levels of government [88].

Markets

Market risks would relate to fuel prices, consumer preferences, economic substitutes, regulatory or policy changes, and macro-economic conditions. While recent community surveys suggest significant latent ridership demand and community support, the extent of these market risks underline the critical need for further research and comprehensive stakeholder engagement.

5.3.2. Direct Risks

Direct risks relate to estimating errors in inputs and ridership forecasts, and they were a part of this analysis, being analyzed in two ways: first, using conventional the Monte Carlo Simulation (MCS) methodology [89] and 20,000 trials; second using a 'Reference-Class Forecast' (RCF) technique recommended by Flyvbjerg et al. [48]. Each is discussed below.

Monte Carlo Simulation

Figure 4 below depicts ridership uncertainty over 20,000 samples from Monte-Carlo simulation, assuming pessimistic (10%), expected (30%), and optimistic (50%) mode shifts. Even in worst-case (i.e., 10% mode shift) ridership scenarios, the overall ridership was expected to grow fourfold in 30 years to over 30,000 rides per day on OVER PR.

Figure 5 below shows additional results from the same MCS analysis, focusing on Net Present Value (NPV) and on Benefit Cost Ratio (BCR) over the previously referenced min/max/expected value ranges of each input variable listed in Tables 7–10 above. Generally, at a 95% level of confidence, using best available data and our expert industry advisors,

the results of our analysis revealed strongly positive NPVs and BCRs above 1, and they also underscored the vast billion-dollar community benefits that would accrue immediately from OVER PR.

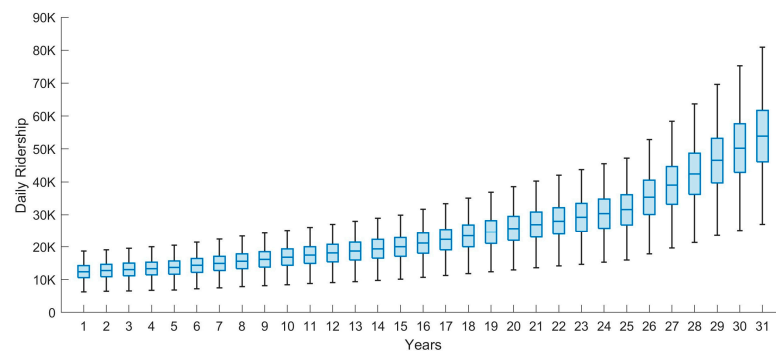


Figure 4. Risk in OVER PR Ridership. This figure shows results of 20,000 MCS trials on ridership levels over 30 years.

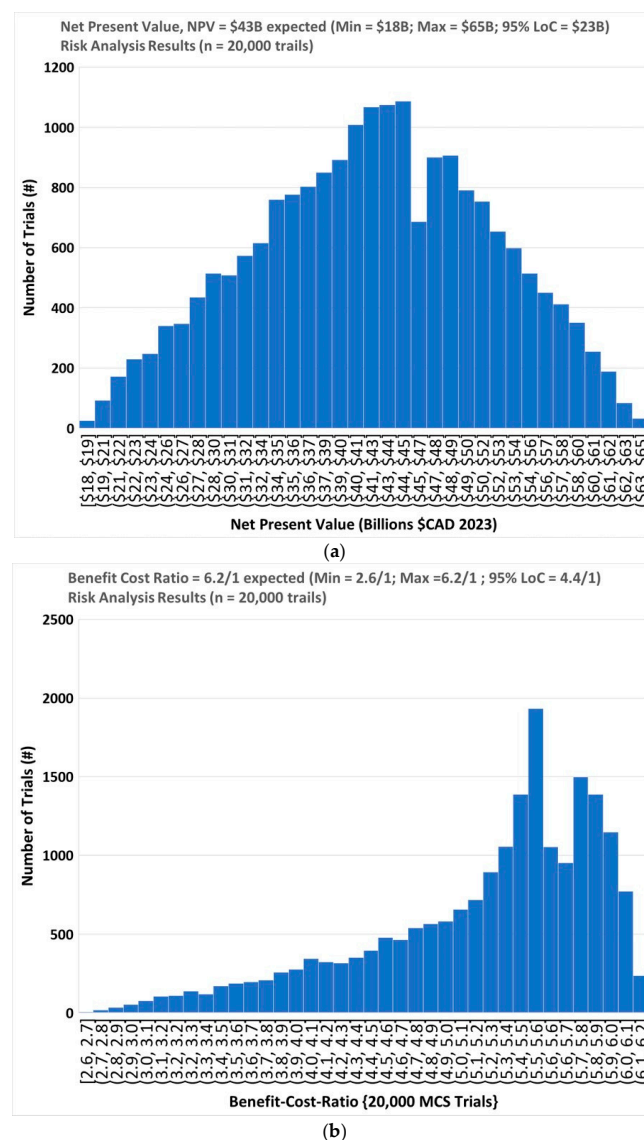


Figure 5. OVER PR Risk Analysis Results—BCR and NPV Histograms. Results suggest strong economic feasibility, NPV = CAD 23 Billion and BCR = 4.4:1 @ 95% LoC. (a) Net present value results of MCS trials. (b) Benefit–cost ratio of MCS trials.

Cumulatively, these results suggest strong economic feasibility for OVER PR. There are no negative NPV results, despite including the full range of industry recommended input cost (and benefit) values. Expected values for each metric are significant, with expected BCR = 6.5 (3.1, 6.9). Moreover, a 95% level of confidence test gives a BCR > 4.3:1, which is not only significantly greater than 1, but also exceeds the typical BCR level (1 to 1.5) of most urban light rail economic feasibility analyses. Similarly, there is the expected NPV = CAD 43 B (CAD 17B, CAD 64B), which is always greater than zero, with NPV > CAD 22 billion at a 95% level of confidence.

Reference-Class Forecasting

As an added and even more conservative risk analysis, a 'Reference-Class Forecast' (RCF) technique was employed, as recommended by Flyvbjerg et al. [48], which recognizes that major projects, such as OVER PR, can often be subject to a range of 'optimism biases' and 'blind spots' when estimating either costs and/or construction timeframes. Results were included in Table 11 above (i.e., see column labelled 'Reference Class Forecast'), whereby even with a 116% overrun added to all costs (i.e., CAPEX and OPEX), there was a strong positive BCR = 1.84. For context, this RCF result compared favorably with recent approved light rail projects in B.C. that had a BCR = 1.02 and an NPV = CAD 49 million in 2021 [90].

6. Summary and Conclusions

6.1. Summary

This paper provides an overview of:

1. The Okanagan Valley Electric Regional Passenger Rail (OVER PR);
2. Results of OVER PR economic feasibility analysis;
3. Recommendations on next steps toward stakeholder engagement, planning, and business case completion for possible OVER PR implementation.

The Okanagan Valley's booming population growth and tourism industry are exerting pressure on the capacity of Highway 97, raising concerns over livability, mobility, safety, housing, and climate. Survey results indicate a significant portion of residents would drive less if public transit and regional connectivity were enhanced. For decades there have been discussions around finding more convenient, affordable, and eco-friendly modes of transport that would enhance transportation equity, valley-long mobility, and tourism.

UBC Okanagan researchers have conducted an analysis of OVER PR running in the Valley between Osoyoos at the US Border and Kamloops at the Canadian rail hub along a route parallel to Highway 97, as shown in Figure 1. This analysis draws inspiration from the very successful Karlsruhe model passenger tram-trains running between cities in rural Germany and across the EU for the past 40 years. Building on the Karlsruhe model, OVER PR would be powered by an onboard zero-emission hydrogen fuel cell/battery hybrid rail power train, known as hydrail, which would reduce CAPEX significantly. Integrating with other transportation modes at station hubs (e.g., airports, buses, bicycles, cars) would enhance connectivity and bolster local bus services within each community. Prior studies have validated the technical feasibility of the hydrail passenger tram-trains [5] on rails and/or on imbedded rails sunk into the pavement running parallel to Highway 97. The analysis, reviewed by industry experts, indicates substantial economic viability for OVER PR and presents methodologies used to analyze social, economic, and environmental costs and benefits, including data ranges (min/max/expected).

6.2. Results and Conclusions of Economic Feasibility Analysis

Results were summarized in Table 11 and suggest significant economic feasibility for OVER PR. It would attract over 13,000 rides on opening day, shift 30% of highway traffic out of private cars and onto the passenger tram-train, and benefit all valley residents whether or not they rode it.

Figure 6 provides a proportional breakdown of capital (CAD 2.9 B) and operating (CAD 164 M/year) costs over the project’s 30-year lifecycle.

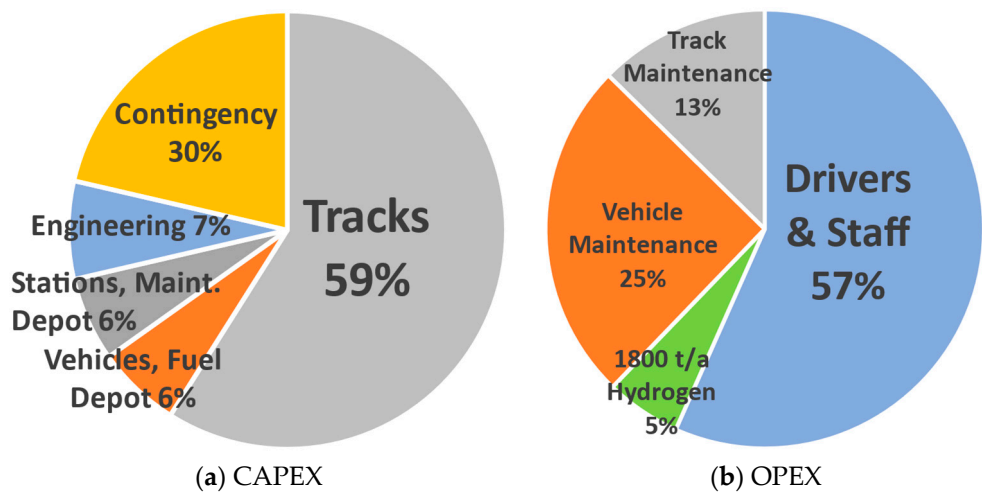


Figure 6. Proportional Breakdown of OVER PR Capital and Operating Costs over 30 years. (a) CAPEX (CAD 2.9 Billion) cost breakdown. (b) OPEX (CAD 164 Million/year) cost breakdown.

Figure 7 depicts graphically results presented in Table 11, indicating the amount by which the community benefits of OVER PR outweigh its costs.

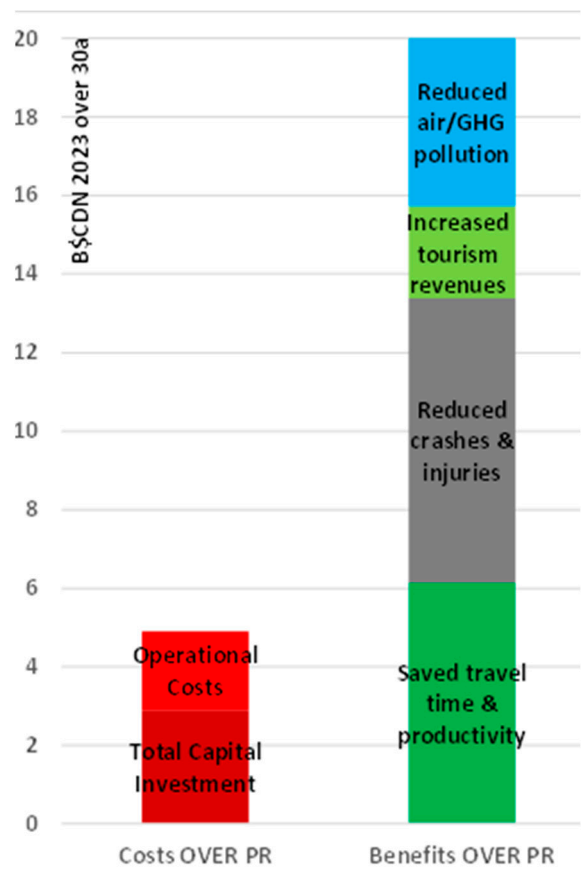


Figure 7. Community Benefits outweigh costs by far.

Detailed results were presented in four ways, as follows:

1. Expected net present value (NPV) = CAD 40 billion (CDN 2023 base year), meaning that, taken over the 30-year expected lifecycle of OVER PR, the value of benefits would exceed the value of costs by CAD 40 billion when converted to base year CAD 2023;
2. Benefit–cost ratio (BCR) = 9:1, meaning that those same calculated benefits are more than nine times the value of costs, again all calculated in 2023 base year dollars.
3. Rate of Return (IRR) = 35%, meaning that the CAD 45 billion in benefits are equivalent to a 35% rate of return on the CAD 5 billion invested over 30 years of OVER PR service.
4. Payback period (PBP) = 7 years, meaning that accrued benefits would more than pay back all initial investments within 3 years after the end of 4 years of construction.

Risk analyses were conducted in two ways. First, 20,000 Monte Carlo Simulation trials, which referenced best available industry data on pessimistic and optimistic estimating and confirmed that (at a 95% level of confidence) these results remained significantly positive, with NPV = CAD 19 Billion and BCR over 4:1, as shown in Figure 5. Second, using Reference-Class Forecasting (RCF), the analysis was performed again while assuming that expected costs and construction time doubled to CAD 11.1 Billion and to 9 years, respectively. Moreover, we effectively halved expected benefits. Yet, RCF results still showed significantly positive results with NPV = CAD 10 Billion, BCR = 2.1, IRR = 7%, and PBP = 18 years.

These results revealed enormous community-based benefits, findings that are consistent with many other public transportation infrastructure projects, and confirm that public transportation is indeed a social determinant of health. Community benefits where data were found and valued in this analysis include increased tourism revenue; improved road safety with fewer injuries and lives lost; more affordable and equitable access to health services; less congestion and improved productivity for freight trucks on Highway 97; reduced travel time from outlying areas for commuters. Consequently, these many and diverse social, economic, and environmental community benefits (i.e., externalities) favor continued exploration of OVER PR in the Okanagan Valley, as well as hydrail tram-trains generally elsewhere in North America.

6.3. Next Steps

The next steps in this research need to address identified risks, including strategic (stakeholder engagement, regulatory, permits, and business planning) and operational (confirming cost and benefit estimates) risks.

Specifically, the recommended next steps should include:

1. Setting up a conceptual scenario of the tram-train system that includes an initial timetable and integration considerations with local transportation systems in each community;
2. High-level regional and inter-regional surveys across the entire Valley from Osoyoos to Kamloops to engage residents, businesses and visitors, as well as to assess latent demand and level of support;
3. Based on survey responses, and in partnerships with all levels of government, conduct preliminary planning at the community level to confirm station locations, routes, costs, benefits, and implementation needs;
4. Develop a valley-long, community-approved OVER PR business case setting out precursors to formal planning, including service plans, governance models (e.g., Figure 3), funding pro forma, strategic partnerships, community benefits, and implementation plans;
5. Use the completed business case to advocate to senior governments (BC, Federal) by all Okanagan Valley communities (local, regional and the First Nation governments, residents, and businesses) to initiate funding and formal planning processes toward OVER PR implementation by 2050.

With proper consultation, engagement and partnerships, including through the collaboration of the federal, First Nation, provincial, regional, and local governments, OVER PR has significant favorable potential to foster green Okanagan Valley economic growth, effec-

tive climate action, improved transportation equity, and enhanced livability for generations to come.

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