

Preparing Canada for High-Speed Rail: Global Integration and Cold Climate Operations

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Abstract

Canada's next phase of transportation based on intercity travel demand and increased congestion highlight the need for high-capacity and efficient system, primarily high-speed rail (HSR). However, challenges related to system integration, culture, policy, engineering technical frameworks and cold-climate operations continue to shape feasibility discussions. The analysis draws on firsthand observations of eleven high-speed rail systems, supported by a wider range of regional and metropolitan transit systems across Europe, Asia, and Africa, including Morocco's Al Boraq.

Observations were conducted in the following systems pertaining to these regions: Japan, France, Italy, South Korea, Switzerland, United Kingdom, and Türkiye including the whole Nordic region. The Nordic region comprising of Norway, Sweden, Denmark, Finland and Iceland is complemented by technical insights from Nordic engineering bodies including Bane NOR, Trafikverket, Banedanmark, and the City of Oulu. These inputs provide expertise in ETCS signalling, winter railway operations, and cold-climate infrastructure practices, informing a systems-level framework for "building around HSR" that emphasizes feeder integration station accessibility, operational reliability, and lifecycle asset performance.

Key findings indicate that successful HSR implementation depends not solely on speed, but on early integration with surrounding mobility networks, including regional rail, metro, active transportation, and station-area circulation. Nordic case studies further demonstrate that cold-climate operations such as snow management, extreme temperature performance, signaling reliability, and maintenance strategies must be embedded in planning and asset decisions from the outset.

These findings can be applied to the Canadian context, particularly for cold climate, where winter reliability and long-term asset performance are critical. Rather than proposing a single design solution, this paper presents a planning-oriented framework to support agencies, planners, and asset managers in reducing implementation risk and improving long-term outcomes as Canada advances toward high-speed rail delivery.

Introduction

On February 19th, 2025, the Canadian government announced that high-speed rail plans are in motion for the Toronto-Québec City corridor called Alto[1] with Toronto-Windsor portion still yet to be determined. In Alberta, the provincial government announced on June 5th, 2026, that it would advance planning for a Calgary-Edmonton high-speed rail corridor as part of the Alberta Passenger Rail Master Plan[2], moving the concept beyond earlier unsolicited proposals such as EllisDon's Prairie Link. The broader Alberta rail plan also considers additional passenger rail connections, including Calgary-Banff. Furthermore, the Cascadia HSR corridor between Vancouver and Seattle remains under study through cooperations involving British Columbia, Washington State, and Oregon.

Research Objectives

Accordingly, this paper has four objectives:

1. **Establish the systems-level fundamentals relevant to Canadian HSR**, including digital delivery, signaling, infrastructure integration, and operational requirements.
2. **Identify transferable international practices for integrating HSR with surrounding transportation networks**, including regional rail, public transit, active transportation, airports, and station-area mobility.
3. **Assess cold-climate transportation and railway practices**, observed in Japan, Switzerland, and the Nordic Region, with emphasis on snow management, ice accretion, electrification, signalling, and winter mobility.
4. **Translate these international findings into prioritized and context-sensitive recommendations for Canadian HSR planning and implementation**, recognizing differences in climate, urban form, governance, infrastructure, and transportation behaviour.

Research Approach and Methodological Framing

This paper applies a comparative, observation-informed case study approach combining literature and technical-source review with firsthand transportation-system observations. Eleven high-speed rail systems were experienced in revenue service, alongside regional rail, urban transit, active transportation, airport access, and station environments across Europe, Asia, and Africa. Observations focused on recurring systems-level characteristics relevant to Canadian HSR, including feeder connectivity, station accessibility, passenger information, multimodal integration, winter operations, signalling, electrification, and infrastructure performance.

Cold-climate findings were further informed by observations in Japan, Switzerland, and the Nordic region and by technical discussions with transportation and railway organizations including Bane NOR, Trafikverket, Banedanmark, and the City of Oulu. Photographs and field observations are used as observational evidence rather than as substitutes for independently verifiable technical sources. Where broader engineering or operational conclusions are drawn, observations are supplemented by agency publications, technical documentation, and other external references where available.

The cases are therefore treated as contextual comparisons rather than directly replicable solutions. Lessons are assessed according to their potential transferability to Canadian climatic, geographic, operational, governance, and transportation conditions.

1 – High-Speed Rail System Fundamentals

1.1 – HSR Overview

High-Speed Rail (HSR) is a railway system that achieves speeds at 250 km/h or more on dedicated infrastructure or upgraded conventional track running at 200 km/h or more according to International Union of Railways (UIC)[3] .Table 1 displays the definition furthermore based on EU and UIC definitions.

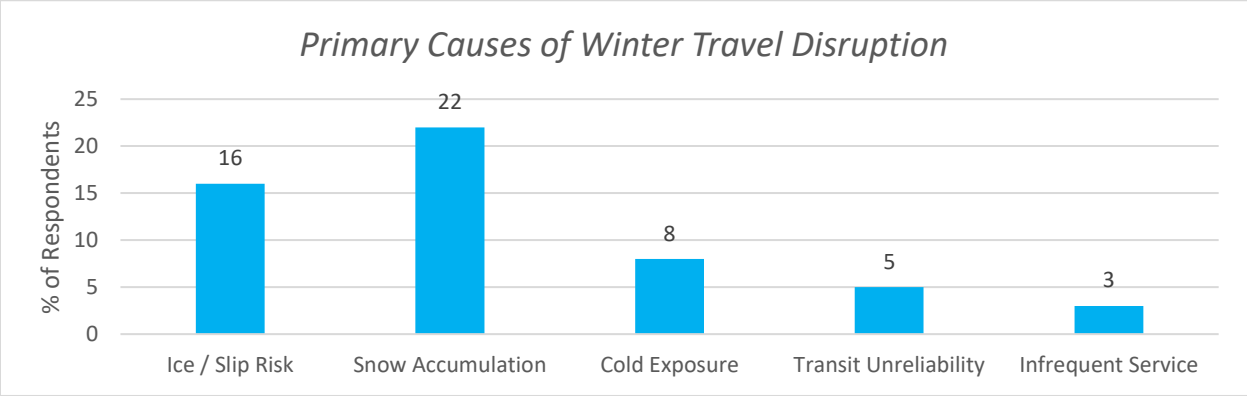
Table 1. International Definition of High-Speed Rail (HSR) (UIC)

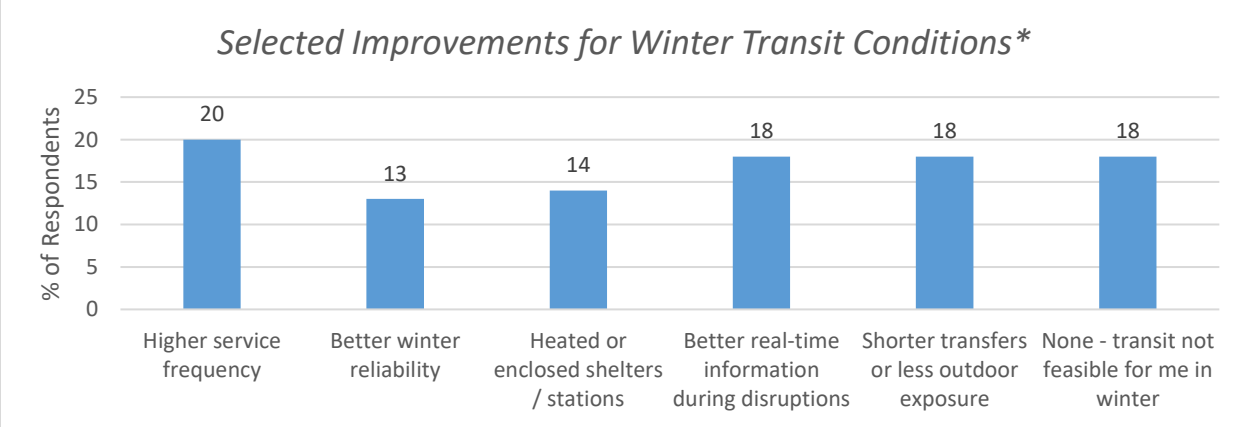
250 km/h or more	200 km/h or more (upgradeable line)
Dedicated high-speed infrastructure	Upgraded conventional corridors
Fully grade-separated	Mixed / Interoperable alignment
ETCS / Advanced Signaling	Legacy + Upgraded Signaling

Source: UIC (2026)[3]

High-Speed Rail (HSR) implementation in Canada is influenced not only by rail technology but by the reliability of winter feeder access systems; evidenced by Canadian winter travel mobility graduate survey[4].

Figure 1. Winter mobility impacts on transit accessibility based on graduate research survey (n = 37 respondents, Canada, 2026); Primary Causes of Winter Travel Disruption (Top); Selected Improvements for Winter Transit Conditions (Bottom).*





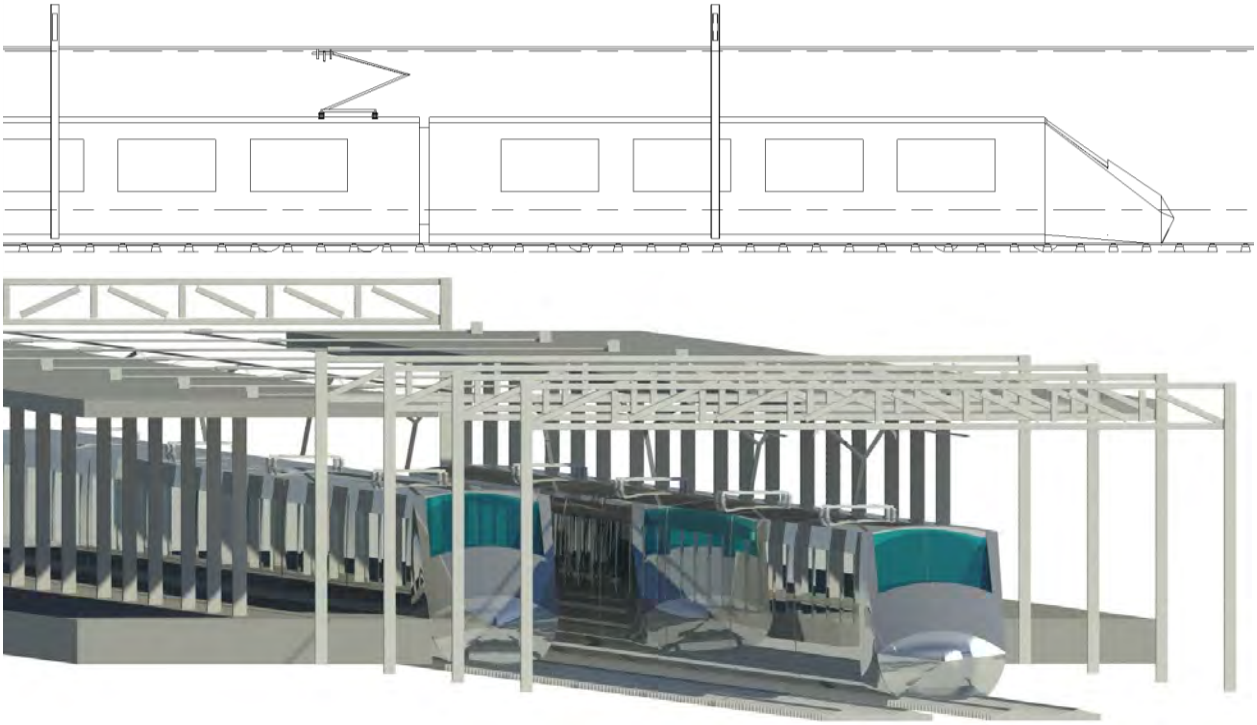
Source: Author (2026), Winter Mobility Under Extreme Cold Graduate Course Project[4]
**Respondents could select up to two options; percentages are not mutually exclusive.*

1.2 – Digital Delivery (BIM)

The recommended design delivery for high-speed rail and life cycle assessment would be BIM (Building Information Modelling). BIM allows for integrated system modeling which unifies many disciplines of engineering together ranging from electrical, civil, structural, transportation, signaling, etc. Multidisciplinary coordination can be used in BIM software such as Autodesk Revit which has extensively been used to model 4D/5D works of Ontario Line's Exhibition Station based on Parsons Corporation experience in design and modeling. BIM software that delivers rail related projects typically fall under the following software: Revit, CAD, Civil 3D, Navisworks, OpenRail and Infraworks. Navisworks was used extensively to detect clashes and coordination gaps for Exhibition concourse station in correspondence to the Revit model itself which can be communicated and effectively reviewed in a centralized structure.

Mega projects like Kayas-Yerkoy High Speed Rail System played an important role in BIM with Kirikkale High Speed Train Station modeling and delivery via Autodesk Revit[5]. Additionally, BIM has been applied to South Korea's GTX-B HSR[6] and design of Chuo Shinkansen tunnels, maintenance planning and interference checks[7] which furthermore displays BIM's capabilities on reducing soft costs (design phase) which can help save for more hard costs (construction phase) when executing project delivery for these mega projects. Revit for Structural Design based on experience and academia has steel and concrete modeling features[8] which was used extensively for Ontario Line's Exhibition Station. As shown in Figure 2 below, a conceptual BIM model was developed in Autodesk Revit to illustrate the integration of high-speed rail systems within a station environment. This model demonstrates coordination between rolling stock, standard gauge track (1435 mm) with concrete sleepers, platform interfaces, canopy structures, and the overhead contact system (OCS) displaying role of electrification. BIM can support multidisciplinary integration, system visualization, and early-stage design coordination for high-speed rail infrastructure.

Figure 2. Conceptual BIM Model of High-Speed Rail Station Integration Showing Rolling Stock, Track System, Platform, Canopy, and Overhead Contact System in 2D (Top) and 3D Rendering (Bottom)



Source: Author (2026), Autodesk Revit Model

1.3 – Signalling (ETCS)

Efficient signalized blocks with efficient relay communication are required for high-speed rail development when it comes to frequency, reliability and serviceability. A type of signalized system that is widely used in Europe with GO Expansion having plans to implement would be ERTMS (European Rail Traffic Management System). It is deployed across conventional, high-speed, and mixed-traffic networks globally. Greater Toronto Area's (GTA) GO train network is stated to be the first train system in the North American continent to implement ERTMS related systems.

ETCS (European Train Control System) is one of the three systems comprising ERTMS and provides train control through in-cab equipment that supervises train movements and maximum permitted speeds. Track information is transmitted to the train through Eurobalises or radio depending on the operational level, allowing ETCS to calculate and continuously supervise permitted speed and apply emergency braking when required. ERTMS also incorporates Railway Mobile Radio (RMR), comprising GSM-R and the future FRMCS, to provide radio communication between trains and traffic control centres. Automatic Train Operation (ATO), the third ERTMS system, can automate train operation up to Grade of Automation 2 (GoA2), with ETCS providing the underlying automatic train protection functions[9]. Canada's Alto team has discussed potential ETCS deployment research regarding the Toronto-Quebec City HSR corridor.

ETCS is broken down into two levels. ETCS Level 1 uses track-mounted balises for intermittent train-track communication, automatic train protection and speed control. Balises transmit lineside signalling information to the train. On-board computer calculates maximum speed and braking curve of the train while the track circuits or axle counters detect the train's current location. Lastly, ETCS Level 2 has continuous communication between the train and track via GSM-R radio[9]. Figure 3 displays Eurobaliser and Axle-Counter components supporting ETCS connectivity and train detection. Unlike Level 1 lineside signalling, Level 2 uses a radio block centre connected to the interlocking to transmit movement authorities directly to trains. Suppliers of ETCS Level 2 are mainly by Siemens, Alstom, and Hitachi regarding ETCS trackside equipment based on technical discussions with Bane NOR, Trafikverket and Banedanmark[11]. ETCS capacity also depends on governance-based track-sharing agreements, which determine how effectively train paths accommodate multiple services and operators respectively.

Figure 3. Eurobaliser (Left) and Axle Counter (Right) in Bane NOR Lab, Oslo illustrating components essential for ERTMS (ETCS) development and deployment in railway modernization



Source: Author (2026), Building High Speed & Electrified Rail Systems Technical Report[11]

2 – Global Integration

Global transportation practices around the world have been observed across 17 countries through firsthand experiences with technical insights gained. Countries ranging from Europe, Asia, South America and Africa which have been researched and analyzed that apply as international contextual lessons for Canada's current transportation landscape in terms of cultural, climatic and modal shift solutions. These global case studies have been conducted in a policy conference ready paper, Global Transit Mobility – Building Around High-Speed Rail as an aid to policy makers, engineers, transit planners and general public to see systems perspective regarding transportation modes playing a role towards high-speed rail. The following subsections delineate and breakdown the international case studies that demonstrate how integrated transportation systems overcome the constraints of extreme climate, geographical limitations, cultural transition, behavioural resistance, population density and modal shift based contextual constraints. Photographic and video still based evidence through observations are used in this paper which is derived from the author's Global Transit Mobility – Building Around High-Speed Rail conference ready-research document, based on field documentation across multiple international case studies.[12]

2.1 – Feeder Systems to HSR

Global feeder systems display multifaceted solutions to ridership demand for HSR services. Spanning from Switzerland's lowly populated Alpine areas, South Korea's airport LRT integration, Iceland's bus feeders, Italy's pedestrian plazas, France's multimodal corridors and Türkiye's ferry water-based transport as solutions for feeder systems to HSR. Italy's historic urban landscape imposes hard physical limits when it comes to underground expansion, particularly Metro Line C as shown in the left of Figure 4. Walkability allows for free flow of users even in archaeological layered historic sites with metro construction taking place. These observations provide relevant context for Toronto's Ontario Line construction, particularly regarding maintenance of pedestrian movement and surface transit during major transit construction. Furthermore, as referenced in the right of Figure 4, France's multimodal street corridors for automobile, bus and cycling systems all take place on an economic corridor, the Champs Elysees which can parallel to Greater Toronto Area's Dundas Street requiring more middle housing and mixed-use development.

Figure 4. Pedestrian activity with construction in Rome (Left) and Champs-Élysées, Paris corridor (Right)



Source: Author (2024), field observations, Rome, Italy & Paris, France

As shown in Figure 5 (left), Zermatt is a largely car-free Alpine community supported by walking, local electric mobility and rail access. Similar rail and transit accessible Alpine settlements include Bettmeralp, Mürren, and Braunwald. These examples illustrate how relatively small communities can maintain effective public transportation connections despite limited population. Figure 5 (right) shows the Busan–Gimhae Light Rail Transit serving Gimhae International Airport, providing an observed example of airport rail integration and its potential relevance to HSR feeder networks.

Figure 5. Car-Free-Rail-Integrated Urban Form in Zermatt (Left) and Airport Rail Access in Busan (Right)



Source: Author (2024, 2025), field observations, Zermatt, Switzerland & Busan, South Korea

Figure 6 illustrates contrasting feeder approaches observed in Istanbul and Reykjavik. Istanbul's ferry network demonstrates how water-based transportation can connect major urban districts across a geographic barrier, providing comparative context for Canadian waterfront communities. Reykjavik demonstrates how scheduled bus and airport-coach services can provide regional connectivity in the absence of an urban rail network. Together, these cases illustrate that HSR feeder systems do not need to rely on rail exclusively and can incorporate transportation modes suited to local geography and demand. For Canada, these cases demonstrate that HSR ridership depends not only on the rail corridor itself, but on reliable feeder connections extending its effective catchment area.

Figure 6. Ferry-Based Feeder Systems and Airport Shuttle in Istanbul (Left) and Reykjavík (Right)



Source: Author (2025, 2026), field observations, Istanbul, Türkiye & Reykjavík, Iceland

2.2 – Behavioural Urban Shift

Behavioural shift requires three types of frameworks in order to transition the pathway towards transit-oriented development. These three cases have been observed in the following countries: Netherlands, Morocco and Finland. Netherlands presents a 'Culture-led' based framework that has culture lead to infrastructure change. Morocco shifts based on 'Infrastructure-led' framework based on built infrastructure. Lastly, Finland demonstrates 'Policy-led' framework that uses policy with the addition of behavioural elements in order to result in a utilized transit system. These frameworks combined or used interchangeably provide useful lessons on Canada's current transportation culture which is crucial for policy makers, planners, designers and engineers.

Netherlands proved change as evidenced back in the 1970s to the present day, from automobile dominance to cycling capital of the world. The shift was 'Culture-led' based on widespread public concern and organized civic pressure on local municipal governments due to automobile collisions resulting in child deaths. Advocacy movements helped drive policy changes toward safer streets, particularly for children, contributing to greater recognition of cycling as a safe and practical transportation mode. These changes supported Amsterdam's gradual development of protected cycling routes, traffic-calmed streets, and continuous cycling infrastructure, integrating cycling with transit, retail, and cultural destinations[13]. Firsthand observations of analyzing the cycling infrastructure (refer to Figure 7) and tram systems under rainy conditions furthermore proves the effectiveness of deprioritized automobile dominance.

Figure 7. Amsterdam cycling infrastructure under wet conditions, demonstrating continuous right-of-way and weather-resilient design (Left) and bicycle parking density within historic streetscape (Right)

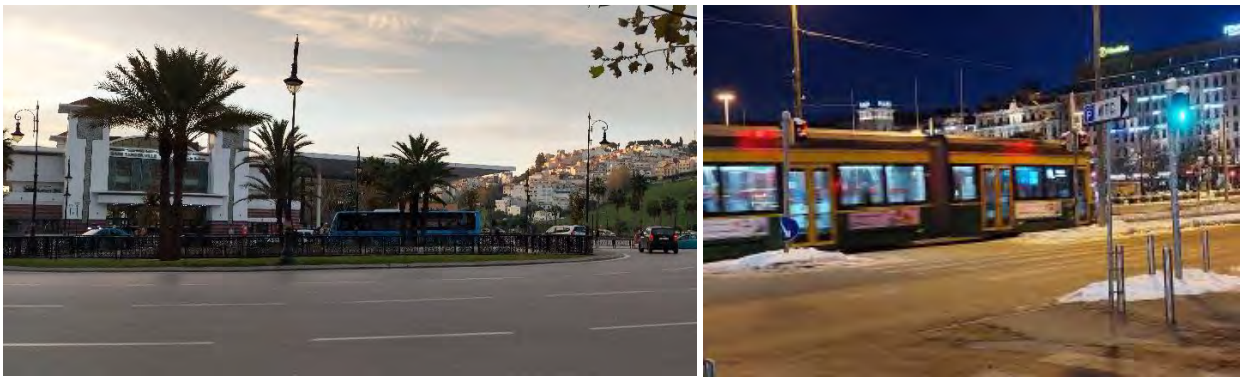


Source: Author (2024), field observation, Amsterdam, Netherlands

Moreover, Morocco displays a crucial case for Canada's Alto high-speed rail system based on its transit feeder integration systems adapting. Despite multimodal transit option and feeder integration not being ready, Al Boraq HSR was still constructed and deployed successfully. Observing Casablanca's tram and walkability compared to Tangier's limited transit displays 'Infrastructure-led' framework, showing the automobile dominant cities adapting to the HSR service (refer to Figure 8) Casablanca Airport to Casablanca's HSR station still required driving services furthermore displaying Al Boraq still being a success despite no existing transit corridors to help feed the HSR service. Morocco displays building priority for high-speed rail which parallels to Egypt's upcoming high-speed rail service being 'Infrastructure-led' framework despite the automobile dominance being present based on past observations there.

Lastly, Finland demonstrates a 'Policy-led' framework through Helsinki's urban planning policies aimed at reducing car dependence and prioritizing walking, cycling and public transport. Helsinki integrates land-use and transportation planning through measures including transit-oriented development (T.O.D.), higher densities around rail corridors and reduced parking requirements near railway, metro and light-rail stations[14]. These policies can support gradual behavioural shifts toward car-lite mobility, as further reflected in the Helsinki observations shown in Figure 8. Similar policy-led and T.O.D.-based approaches could be considered for shifting transportation culture in the Canadian context.

Figure 8. Adaptation to High-Speed Rail in Morocco through Car-Oriented Station Access in Tangier (Left) and Car-Lite Urban District Development with Tram Integration in Helsinki (Right)



Source: Author (2024, 2026), field observations, Tangier, Morocco & Helsinki, Finland

2.3 – Policy and Governance Tools

Land-use and traffic management are policy and governance-based tools that provide effective solutions to existing sprawling conditions. Luxembourg showcases free-transit policy as observed and experimented, yet car congestion remained in certain urban pockets. This case concludes that land-use policy is key, implementing economic zones with mixed-use development in order to generate more ridership as shown in Figure 9 with streetscape displaying tram right across Luxembourg rail station. Traffic management in the United Kingdom is done through signal management and zones discipling the automobile dominance as referenced in Figure 9. This provides a valuable lesson in Canada's current traffic congested cities, requiring more transit options like London, United Kingdom managed to execute. Additionally, UK track-sharing coordinates passenger and freight access to maximize shared rail capacity.

Figure 9. Streetscape multimodal activity outside Luxembourg Gare Centrale (Left) and Multimodal Street Function in Knightsbridge, London displaying cars being disciplined at a traffic intersection (Right)



Source: Author (2024), field observations, Luxembourg, Luxembourg & London, England, United Kingdom

2.4 – Performance & Operations

As forementioned in South Korea's LRT rail to airport integration, Norway displays an effective case of HSR connected to the airport. Railway integrated to airports functions as a core ridership generator for high-speed corridors rather than a supplementary feature. Oslo's Flytoget Airport Express showcases high-frequency link between Oslo Airport (OSL) and Oslo Central Station, operating within the same coordinated station environment via regional and intercity services. This high-speed airport rail service runs at top speed of 210 km/h but falls under the definition of HSR based on conventional upgraded track able to run over 200 km/h. As shown in Figure 10, Flytoget HSR service (far left) and real-time passenger information interface board displays reduction of transfer friction for passengers based on user friendly display of alignment's stops. This information display can provide lessons towards Alto's HSR to help users have ease when boarding and alighting off the service within the corridor. Furthest conception of Alto service connecting to Toronto Pearson airport resulted in discussions based on questions asked in National Capital Commission conference. Toronto-Windsor corridor having Toronto Pearson as a stop would allow Alto to have an airport rail corridor similar to Flytoget in terms of seamless and smooth transfer.

Figure 10. Flytoget Airport Express with Regina SJ3000 Intercity Service (Left) integrated within Oslo Central Station platform geometry, paired with onboard real-time passenger information interface (Right) demonstrating end-to-end airport-city connectivity



Source: Author (2026), field observations, Oslo, Norway & Oslo Airport Express

Another useful operations lesson is bilingual signage displaying real-time as observed in Amsterdam Centraal station using Eurostar HSR services (refer to Figure 11). Alto's potential bilingual signage can adapt from Eurostar's in order to reduce dwell time for passengers for English and French languages.

Figure 11. Bilingual Electronic Signage for Eurostar's HSR services in Holland



Source: Author (2026), field observation, Amsterdam, Netherlands

3 – Cold Climate Operations

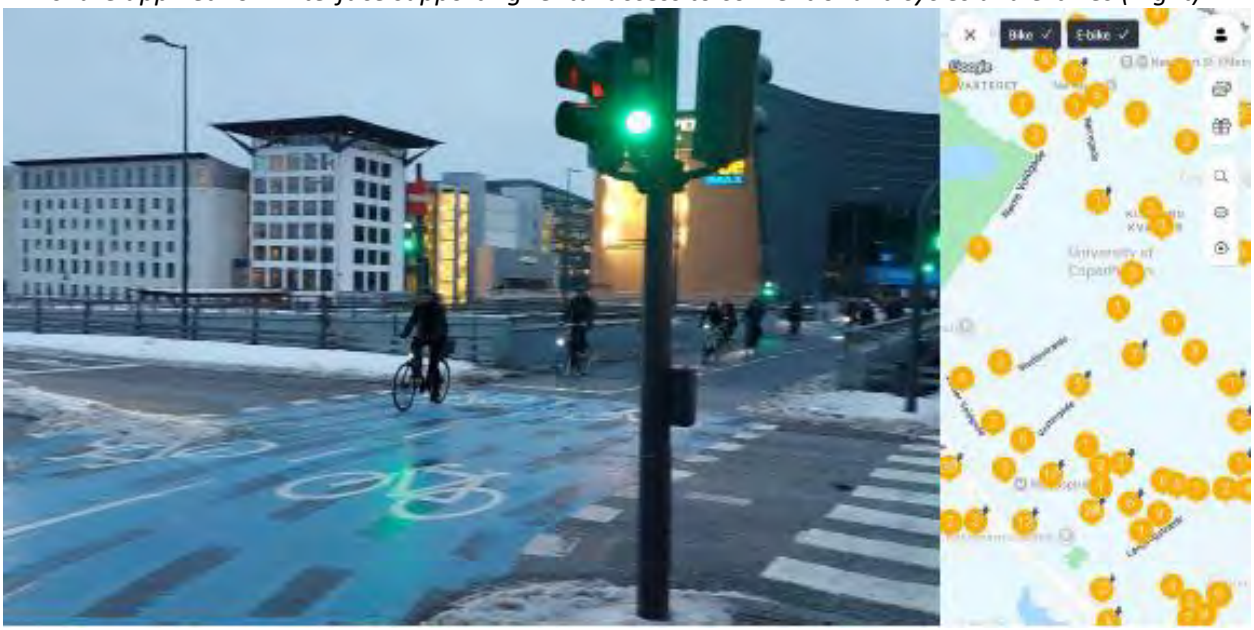
Variety of different winter operational methods have been observed, studied and analyzed in Switzerland, Japan and Nordic region ranging from high-speed rail, regional transportation and cycling infrastructure in snowy and arctic based climatic conditions. These working examples illustrate climate not being a deterrence for the transportation systems, concluding that it all comes down to proper design, equipment and policies in place for effective execution of these winter mobility systems.

3.1 – Winter Cycling

Winter cycling case studies observed in Copenhagen, Denmark and Oulu, Finland have demonstrated remarkable results in efficient and sustainable cycling infrastructure in slush, freeze-thaw, extreme cold (snowpack) conditions including arctic temperatures as low as -40°C. Copenhagen displays slush and freeze-thaw conditions which is highly applicable to the Ontario corridor (i.e. Toronto, Peterborough, Ottawa). Maintaining year-round cycling access to rail stations can help retain ridership for intercity and future HSR services by preserving reliable first and last-mile connectivity during winter conditions.

As referenced in Figure 12, protected cycling infrastructure takes place with traffic lights dedicated for cycling all year round in Copenhagen enabled with micro mobility bike-share app supporting rental access for bicycles and e-bikes. This case represents Copenhagen functioning as a 'resilient city', representing alternative viable modes of transportation being active even during times of crisis and emergencies based on bicycle bridge corridors such as the Cykelslangen ("Bicycle Snake"). This bicycle bridge allowed even electric wheelchair users to have mobility across the Cykelslangen in winter conditions based on firsthand observations with a rental ebike using the public bike-share mobile app. Toronto possesses bike-share program but requires infrastructure designed for all year-round cycling based on drainage and dedicated bike corridors. Copenhagen's resilient design and winter conditions parallel's closely to Toronto's climatic landscape, making this case study a transferable lesson in terms of winter cycling mobility.

Figure 12. Protected Copenhagen cycling corridor under winter slush (Left) and Donkey Republic bike-share app network interface supporting rental access to conventional bicycles and e-bikes (Right)



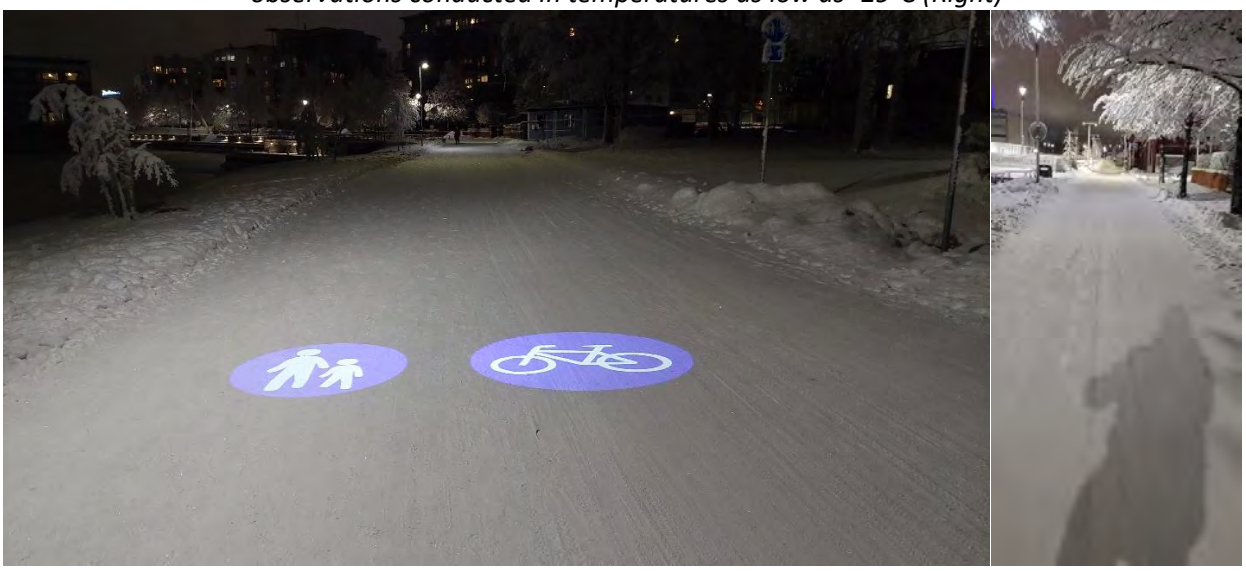
Source: Author (2026), field observation, Copenhagen, Denmark

Furthermore, Figure 13 displays Arctic cycling conditions near the arctic circle in Oulu, Finland with snowpack pathways. This case study is a transferable lesson towards Canadian cities like Edmonton, Fort McMurray, Yellowknife and Québec corridor portion of Alto based on snowfall accumulation and arctic temperatures. Based on technical discussions with a local traffic engineer in Oulu, it all comes down to cultural behavioural framework in order for winter cycling in extreme conditions to grow more. Adaptation needs time, preparation and patience for winter cycling culture to be integrated. Although, it requires a crucial initial step to kickstart the culture; **safe, reliable and efficient winter cycling infrastructure**.

Operational success of Oulu's cycling system is based on corridor geometry and snow management strategy. Along the outer urban corridors, peripheral bicycle paths take place which allows for reductions of vehicles and intersection frequencies to be reduced, minimizing conflict exposure. This allows for adjacent grass buffers be a spot for snow to accumulate when plowing without encroaching roadway cross-sections. This can be done with bicycle paths being on the outer parts of the urban areas, this spatial allocation preserves both cycling continuity and vehicular capacity during winter months. Oulu's winter cycling design allows for riding surfaces to be usable with varying bicycle tire types, reducing the need for specialized equipment which furthermore lowers behavioural barriers to winter mode continuity. Snowpack is compacted and compressed in order to maintain smoothness of snow in arctic temperatures that can go down to -30°C or lower[12].

Overall, further municipal discussions with the local traffic engineer in Oulu concludes that direct replication is not key to engineering solutions but rather require contextual adaptation through a framework to interpret and recalibrate based on existing local governance structures, urban form, political systems, and cultural expectations in the Canadian context. Edmonton is a case that proves that adaptation of winter cycling is possible for the Canadian climatic landscape. Recent Canadian winter ridership in Edmonton has grown, indicating that severe cold is not a barrier to active commuting based on users' opinions correlating to infrastructure being available and perceived as safe[15].

Figure 13. Plowed, compacted snow-maintained pathways in Oulu operating in arctic temperatures with projected lights to display pedestrian and cycling signage on top of snow layer (Left), firsthand observations conducted in temperatures as low as -29°C (Right)



Source: Author (2026), field observation, Oulu, Finland

3.2 – Winter Operations for Urban and Regional Transit

Light Rail Transit (LRT) and tram related systems operate in snow and ice conditions based on observations in Helsinki, Finland. As displayed in Figure 14, an old tram car has been converted for de-icing purposes in Helsinki. Operations of this de-icing tram has been witnessed when performing snow and ice removal of the tracks. This utilizes efficient cold climate operations for LRT systems that Toronto could use as a contextual lesson pertaining to the Finch West Line 6 LRT system. Constant de-icing and plowing by a de-icing based tram car are key to prevent ice accumulation and snow buildup within the narrow crevices of the LRT tracks. Solely relying on consistent operations from the LRT rolling stock alone would not suffice in efficient winter operations due to overnight ice and snow buildup. Helsinki de-icing LRT operations were observed as early as 7-8 a.m. during winter conditions.

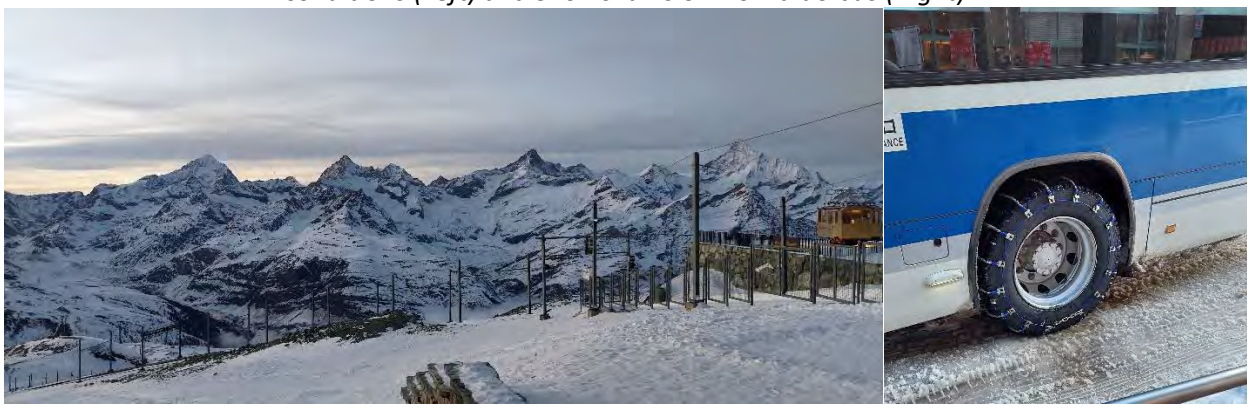
Figure 15 showcases an electrified alpine railway operating at elevations up to 3,089 m (10,135 ft) in Switzerland, providing a useful contextual lesson for Canada's alpine regions (i.e. Banff, Whistler-Blackcomb and Valemount). The Gornergrat Bahn demonstrates railway reliability under high-altitude winter conditions despite persistent snow exposure. Figure 15 also shows snowchains used on a public transit bus in Hokkaido, a practice also implemented in British Columbia[16].

Figure 14 – Helsinki aging tram converted into de-icing vehicle (Left) and typical Helsinki streetcar corridor under winter conditions (Right)



Source: Railway Gazette (2025)[17] and Author (2026) field observation, Helsinki, Finland

Figure 15 – Gornergrat Bahn electrified alpine railway in Switzerland at 3,089 m (10,135 ft) under winter conditions (Left) and Snowchains on Hokkaido bus (Right)



Source: Author (2024-2025), field observations, Zermatt, Switzerland & Hokkaido, Japan

3.3 – Arctic High-Speed Rail Systems

Prominent arctic climate-based countries such as Norway, Sweden, Denmark, Japan, China and Russia currently operate dedicated or HSR-ready operations reaching above 200 km/h with examples shown in Figure 16. The design of high-speed rail requires to take the most extreme absolute temperature as its datum for climatic design throughout the corridor. The entirety of the corridor should be designed homogenously rather than selectively having portions designed for different parameters and tolerances of climatic design based on Trafikverket (Swedish Transport Administration) technical expertise[11].

Figure 16. Jōetsu Shinkansen operating at Gala Yuzawa Station during active snowfall (Left) and Arctic-rated high-speed rolling stock (SJ3000) engineered for sustained operations in temperatures approaching –30°C to –40°C (Right)



Source: Author (2026), field observations, Gala Yuzawa Station, Japan & Stockholm, Sweden

3.3.1 – Snow Mitigation

A number of methods for snow clearing differ from region to region based on engineering practices spanning from Japan to the Nordic region. Beilhack (operated by Aebi Schmidt Group) is a railway snowblower used to clear up to 10,000 tonnes of snow per hour[18] (information provided by Bane NOR)[11]. Trafikverket deploys snow clearing as required to reduce operational delays, while axle-counter impacts must also be considered[11]. Trafikverket's winter-maintenance practices include weather monitoring, snow clearance, anti-slip treatment and extensive use of automatically controlled switch heating to maintain railway operations during winter conditions[19]. Methods for snow clearing are as listed in Table 2 based on Alto's analysis which pertains to Japanese and Nordic region practices as observed firsthand. Snow accumulation is displayed in Figure 16 illustrating Joetsu Shinkansen's capabilities to cold-climate operations in the Niigata Prefecture of Japan.

Table 2. Methods on Track Clearance and Winter Operations

Method	Description
Mechanical Snow Removal	Specialized snowplows and blower-equipped machines will clear snow from the right-of-way, keeping the passage open.
Preventive Treatments	Anti-icing products and sand can be applied to improve traction and reduce the likelihood of ice formation along the rail.
Thermal Blowers	Direct warm air onto the switch points.
Electrical or Gas Burners	Positioned beneath switches to melt accumulating frost.
Compressed Air Systems	Designed to blast away snow or ice from moving components.
Chemical De-icing	Applying glycol-or saline-based solutions, manually or automated nozzles

Source: Alto (2026)[20]

3.3.2 – Ice Accretion

Ice accretion (solid state) for railway systems should be taken into heavy consideration when it comes to operations and overall system performance. Humidity creates challenges, especially pertaining with rail connectors creating issues due to ice build up being imminent. Wheels of the train should be maintained regularly during times of cold temperatures which is critical for cold climate operations. Discussions with Trafikverket concludes that maintenance of the wheels is crucial since it helps prevent derailment based on their practices in northern Sweden railway projects. Signaling of the railway system should be conducted in non-winter half of the year as further corroborated by Trafikverket technical insights. Additionally, Bane NOR uses 5 kV iron cast automated switches based on detection of cold temperatures which leads to activation[11]. Ice accretion should be treated as a system-wide reliability risk, requiring coordinated maintenance of wheels, switches and signalling components to maintain winter operations.

3.3.3 – Electrification in Cold Climate

Electrification is a crucial subsystem of railway systems that contain power reliability interfaces with signaling and operations. Setup of wires that deliver electricity to electric trains through a pantograph is defined as a catenary system. Contact is made toward the lower wire to draw power through a mechanical arm known as the pantograph. Overall, the catenary system must remain clear and conductive in order to seamlessly continue operations with ease despite ice being an interference with electrical power delivery[11].

Based on technical discussions with Bane NOR technical expertise, overhead contact system is designed to withstand subzero temperatures down to -40°C theoretically. Although, field observations by Bane NOR confirm that continued functionality still remained as low as -42°C in operational working conditions. Electrical power output which Canada primarily uses which is 25 kV with 50 or 60 Hz AC power. These parameters are confirmed to be adequate for ice mitigation operations based on Bane NOR discussions. Norway and Sweden use 16 kV with a third of 50 Hz AC respectively, although ice accretion is dependent on the level of humidity based on the region's climatic context which plays a major factor based on de-icing the catenary systems. Tunneling is a major factor of ice build up due to high humidity creating a steam effect as the train exits the tunnel which plays a prominent role in Alto's HSR development in the Canadian climatic context. De-icing maintenance crew are required based on ice build up above the catenary systems which is critical as the icicles elongate down. Short circuit can be caused by icicles for the train's overall electrification system, furthermore, leading to full power outage for the train itself[11].

Continuous operations are key with short windows of ice buildup based on further technical insights from Trafikverket. Goal is to avoid long interruptions in order to prevent ice buildup, otherwise de-icing crew is required. A frequent and operational service should seamlessly run as often due to heated wire and catenary able to de-ice on its own before build-up accumulates at a point which causes short circuiting. Based on rural northern Sweden arctic railway practices, Trafikverket shuts down rail service when temperatures hit below -30°C due to remoteness and isolation based on power loss risk. An electric arc effect is a plasma effect that is created specifically on the pantograph when contact is made with ice on the electrification wiring. It is a common occurrence based on brief untimed durations. Furthermore, this electric arc effect has been explained by Trafikverket and observed in Finland via the Santa Claus Express operated by VR. An electric arc continuously emitting for long periods of time should be a cause for concern based on the amount of ice accretion which requires inspection on the pantograph's contact with the wiring is sufficient enough to continue its operational run[11]. Cold-climate electrification reliability requires continuous operations, de-icing and reliable pantograph-catenary contact under icy conditions.

4 – Application to Canada

4.1 – HSR Corridor Logic

HSR Systems were observed in revenue service, including station access, onboard operations, and last-mile integration as shown in Table 3. Each global case provides useful contextual lessons for Canadian transportation landscape regarding HSR alignment, topography, political structure, transit culture, design, operations and climatic based parameters.

Table 3. HSR Systems Analyzed and Observed Globally with Operating and Climatic Parameters

HSR System	Country	Operating Speed**	Climatic & Operating Environment	Canadian Analogue
Haramain	Saudi Arabia	300 km/h	• Extreme heat durability • Desert corridor engineering	National climate adaptability benchmark
Frecciarossa	Italy	300 km/h	• Historic urban cores integration • Station-centric accessibility	Toronto-Montréal
TGV	France	300-320 km/h	• National high-speed network • Moderate winter reliability	Windsor-Montréal
Eurostar	UK-France-Benelux	~300 km/h	• Cross-border interoperability • Long-distance tunnel operations	Cascadia Corridor
Al-Boraq	Morocco	320 km/h	• First-stage HSR deployment • Semi-arid long-distance operations	Calgary-Edmonton
Shinkansen	Japan	240-320 km/h	• Seismic design integration • Snow resilience	Windsor-Québec City
KTX	South Korea	300-305 km/h	• High-demand linear corridor • Cost-efficient national rollout	Toronto-Montréal
Flytoget	Norway	210 km/h	• High-frequency airport express • Freeze-thaw operational resilience	Pearson–Union Airport Corridor
Regina / SJ3000	Sweden	180-200 km/h	• Arctic resilience • Flexible operations on mixed infrastructure	Calgary-Edmonton & Alto
X2	Sweden	200 km/h	• Tilting stock on legacy alignments • Snow and ice operations	Cascadia Corridor
Copenhagen-Ringsted Line	Denmark	200 km/h*	• Snowy resilience and freeze-thaw operational resilience • Highway-parallel alignment strategy	Highway-parallel HSR segments

Source: Author's synthesis based on firsthand field observations and cited operator, agency, and technical sources[12]
**High-speed capable infrastructure with constrained rolling stock*

4.2 – Phased Implementation

Global lessons and cold-climate practices can be adapted to Canadian transportation conditions through four phased implementation stages: Assess (P1), Structure (P2), Optimize (P3) and Integrate (P4) as shown in Table 4. This sequential hierarchy progresses from near-term planning and feeder-access priorities (P1) to land-use and multimodal structure (P2), operational, signalling, capacity and winter-reliability requirements (P3), and HSR integration with airports and broader regional networks (P4). Table 5 represents the proposed applied parameters for Canadian HSR.

Table 4. Phased Implementation toward HSR-ready mobility

Phase – Lesson	Application	Region
P1 – Behaviour Pilot	Voluntary car-lite pilot district in growth areas	Finland
P1 – Feeder Integration	Strengthen first/last-mile access to regional transit	Iceland, Türkiye
P2 – Land Use Intensification	Convert surface parking to mixed-use development	Luxembourg
P2 – Multimodal Corridors	Integrate cycling, transit, and pedestrian priority corridors	France, Italy, Netherlands
P2 – Suburban Retrofit	Transition car-oriented form to T.O.D.	Morocco
P3 – Corridor Discipline	Bus Priority & Signal Control	United Kingdom
P3 – Winter Cycling	All-season cycling design	Denmark
P3 – Reliability & Capacity	Regional rail expansion + modern signaling	Japan / Norway
P3 – Winter Rail Operations	Maintain service under snow and extreme cold conditions	Sweden
P4 – Airport Connectivity	Integrate airport rail into regional networks	South Korea
P4 – Regional Integration	Connect to broader network	Switzerland
P4 – Future HSR Integration	Prepare regional corridors for high-speed rail	Europe

Source: Author's synthesis of international case studies and field observations

Table 5. Proposed Applied Parameters for Canada's High-Speed Rail Corridors based on Systems Analysis

HSR	Operating Speed	Alignment	Climate Context	Signaling	Rolling Stock
Alto	300-320 km/h	Windsor–Québec City*	Cold, heavy snow, freeze-thaw	ETCS Level 2 benchmark	TGV Duplex-class (cold climate-capable EMU)
Calgary-Edmonton	300-350 km/h	Calgary-Edmonton	Extreme dry cold	ETCS Level 2 benchmark	E5-class (extreme-cold-capable high-speed EMU)
Cascadia	~300 km/h	Vancouver-Seattle	Coastal rain, seismic	Interoperable multi-system	Velaro-class (cross-border high-speed EMU)

Source: Author (2026), Building High Speed & Electrified Rail Systems Technical Report[11]

**Windsor-Toronto alignment portion not confirmed, still to be determined*

Conclusion

This research finds that successful Canadian HSR implementation depends on systems-level integration rather than operating speed alone. Digital delivery, signalling, electrification, infrastructure, rolling-stock performance and operational requirements should therefore be coordinated from the early planning and design stages.

International observations demonstrate that HSR performs as part of a wider mobility network. Regional rail, public transit, airport connectivity, active transportation, station accessibility and surrounding land use influence the ability of HSR infrastructure to generate accessible and reliable transportation benefits.

Cold-climate observations and technical insights indicate that winter conditions are manageable engineering and operational constraints when incorporated into system design. Snow management, ice accretion, turnout heating, OCS performance, maintenance access and defined operating thresholds should therefore form part of Canadian HSR requirements from the outset.

For Canada, these findings support a phased implementation framework beginning with P1 feeder access and behavioural preparation, followed by P2 land-use and multimodal structure, P3 technical and winter-operational readiness, and P4 regional and airport integration. International practices should therefore be contextually adapted rather than directly replicated.

The hardest high-speed rail corridor to deliver is often the first, as it defines the engineering standards, governance, and public trust that every future corridor depends on nationally. Canada’s entry into the high-speed rail era represents a significant shift in its transportation landscape, with the potential to deliver one of the first high-speed rail systems in the Western Hemisphere designed for operating speeds of 300-320 km/h under extreme cold-climate conditions, including temperatures approaching −40°C and heavy snowfall.

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