ALTO HSR CITIZEN RESEARCH INITIATIVE

CAPEX NOTE 2:

ALTO Engineering Complexity Scorecard

Application of the ten-dimension rubric to the proposed ALTO corridor

COMPOSITE SCORE

82 / 100

EXTREME

81–100 band • frontier engineering • few or no directly comparable precedents

Companion to the HSR Engineering Complexity Rubric v1.0 • April 2026

Executive summary

Applying the ten-dimension weighted Engineering Complexity Index to the proposed ALTO corridor yields a Peak Severity composite of 82 out of 100, placing the project in the Extreme complexity band (81–100). An Exposure-Adjusted composite of 73 out of 100 is also reported, which accounts for the fraction of corridor length at which each dimension's peak severity is present; this places the corridor in the upper High band (61–80), with sensitivity-upgrade scenarios reaching the Extreme threshold. The two indices answer different questions: Peak Severity characterises the engineering capability the corridor must provide at its most demanding locations; Exposure-Adjusted characterises the aggregate engineering burden across the whole corridor length.

Five of ten dimensions carry weights of 10–15 reflecting their dominant role in capital-cost formation (bedrock and excavation, climate, topography, urban engineering, each at 15; subgrade and hydrology at 10). ALTO scores at or near the maximum on the subgrade dimension (10/10) and the ecological dimension (5/5), with evidence-supported granular scores of 13/15 on both bedrock and climate where conditions sit between the rubric's High and Extreme descriptor levels.

The Peak Severity composite exceeds all thirteen reference corridors in the worldwide database, including California HSR (75), Harbin–Dalian HSR (68), Tokaido Shinkansen and Wendlingen–Ulm (66 each), Ostlänken (64), HS2 Phase 1 and Taipei–Kaohsiung THSR (63 each). No corridor in the database at the comparable composite score has completed construction; ALTO therefore sits outside the range for which directly comparable delivery precedent exists.

The dimensional profile is consistent with the rubric's definition of frontier engineering: multiple high-complexity dimensions interacting simultaneously. The interaction between subgrade (10/10, Champlain Sea sensitive clay) and geohazard exposure (4/5, clay-slope landslide history and Charlevoix seismic zone) is a particularly important coupling that neither linear composite captures: ground-improvement works in sensitive clay can themselves destabilise marginally stable slopes, a failure mode with Canadian precedent.

Score summary

#	Dimension	Score	Level	Driver
1	Subgrade and soil conditions	10/10	Extreme	Leda clay
2	Bedrock and excavation character	13/15	High	Shield/karst
3	Hydrological and hydrogeological setting	9/10	High	Rivers/karst

#	Dimension	Score	Level	Driver
4	Climatic regime	13/15	High	Cold climate
5	Topographic relief and alignment geometry	10/15	Moderate	Moderate relief
6	Seismic and geohazard exposure	4/5	High	Clay/seismic
7	Ecological and protected-area footprint	5/5	Extreme	SAR/biosphere
8	Heritage, archaeological, and Indigenous-rights constraints	4/5	High	Heritage/rights
9	Corridor integration and land acquisition	5/5	Extreme	Greenfield
10	Urban engineering content	9/15	Moderate	Urban termini
	COMPOSITE SCORE	82	EXTREME	81–100 band

Reading the table. Under the granular weighted scoring, three dimensions reach their maximum: D1 Subgrade (10/10, Leda clay), D7 Ecological (5/5, SAR and biosphere reserve), and D9 Corridor integration (5/5, greenfield). Two dimensions score at granular "High-plus" levels between the descriptor's High and Extreme thresholds: D2 Bedrock (13/15, karst + Shield crossing) and D4 Climate (13/15, continental cold approaching Harbin–Dalian). D3 Hydrology scores at granular High-plus (9/10). D5 Topography and D10 Urban engineering score in the Moderate band at 10/15 and 9/15 respectively. D6 Seismic and D8 Heritage sit at High (4/5). This distribution is characteristic of the Extreme band: complexity is not attributable to any single factor but arises from the simultaneous presence of multiple elevated dimensions distributed across the ground, climate, environment, and land-acquisition clusters of the rubric.

Exposure-adjusted complexity

The Peak Severity composite of 82 reflects the engineering capability the corridor must provide at its most demanding locations. It treats a dimension as fully present when the peak severity appears anywhere on the alignment. For a corridor with heterogeneous exposure — such as ALTO, where Leda clay occupies a majority of corridor length but Frontenac Arch hard-rock crossings are concentrated in roughly 40 km and urban engineering content is confined to four metropolitan termini — a complementary index is useful. The Exposure-Adjusted composite scales each dimension's contribution by the fraction of corridor length at which the peak severity is present, under a design-severity parameter $\alpha = 0.75$ which preserves peak-severity dominance while allowing exposure fraction to modify the contribution downward where severity is localised.

The two indices answer different questions. The Peak Severity composite answers: how demanding is the engineering at the most difficult locations? The Exposure-Adjusted composite answers: what is the aggregate engineering burden distributed across the whole corridor? Both are reported because both are analytically relevant to capital-cost and schedule forecasting.

The contribution formula is:

$$contribution_i = granular_i \times [\ \alpha + (1 - \alpha) \times exposure_i\ ]$$

where i indexes the ten dimensions, $granular_i$ is the integer score on the weighted scale (1 to weight), $exposure_i$ is the fraction of corridor length at or near peak severity (0.0 to 1.0), and $\alpha = 0.75$ is the design-severity parameter. At $\alpha = 1.0$ the Exposure-Adjusted composite equals the Peak Severity composite. At $\alpha = 0$ the score would be pure length-weighted severity.

#	Dimension	Peak	Exposure	Adj.	Exposure rationale
1	Subgrade and soil conditions	**10/10**	0.70	**9.3**	Champlain Sea sensitive clay across Ottawa & St. Lawrence lowlands plus much of southwestern Quebec
2	Bedrock and excavation character	**13/15**	0.20	**10.4**	Frontenac Arch crossing ~40 km + karst zones at Moira + Quebec rock segments
3	Hydrological and hydrogeological setting	**9/10**	0.80	**8.5**	Distributed watercourses, karst aquifer, wetland complexes throughout
4	Climatic regime	**13/15**	1.00	**13.0**	Continental cold climate is uniform across the full corridor length
5	Topographic relief and alignment geometry	**10/15**	0.25	**8.1**	Frontenac Arch + escarpment approaches; rest is moderate-to-flat terrain
6	Seismic and geohazard exposure	**4/5**	0.75	**3.8**	Western Quebec seismic zone covers most of corridor; Charlevoix concentrated
7	Ecological and protected-area footprint	**5/5**	0.25	**4.1**	Napanee Limestone Plain, Moira Karst, Frontenac

#	Dimension	Peak	Exposure	Adj.	Exposure rationale
					Arch Biosphere — specific sites
8	Heritage, archaeological, and Indigenous-rights constraints	4/5	0.80	3.8	Cemeteries plus Indigenous territories distributed along most of corridor
9	Corridor integration and land acquisition	5/5	0.85	4.8	Majority greenfield alignment; brief urban reuse at the four termini
10	Urban engineering content	9/15	0.08	6.9	Four metro termini only; short segments of roughly 20 km each
	EXPOSURE-ADJUSTED COMPOSITE	82	α = 0.75	73	HIGH band

Interpretation. The Exposure-Adjusted composite of 73 places ALTO in the upper High band (61–80), nine points below the Peak Severity composite of 82 and seven points below the 81-point Extreme threshold. The gap between the two indices quantifies the degree to which ALTO's complexity is concentrated rather than uniformly distributed. Dimensions with the largest downward adjustment — D2 Bedrock (granular 13, exposure 0.20, adjusted contribution 10.4), D10 Urban engineering (granular 9, exposure 0.08, adjusted 6.9), and D7 Ecological (granular 5, exposure 0.25, adjusted 3.9) — represent significant engineering burdens concentrated in specific corridor segments rather than distributed along the full alignment. The sensitivity-upgrade scenarios described below bring the Exposure-Adjusted composite to 81, at the Extreme threshold.

Dimension-by-dimension scoring

Each dimension is scored against the rubric descriptors using evidence from the Initiative's technical, environmental, community-impact, and economic submissions, supplemented by publicly available geological, seismic, and species-at-risk data. Evidence sources are summarised for each dimension; a fully cited version with source references is maintained in the scoring worksheet.

10/10
EXTREME

D1. Subgrade and soil conditions

Evidence. Corridor traverses extensive Champlain Sea sensitive marine clay (Leda clay) across the Ottawa and St. Lawrence lowlands through Eastern Ontario and southwestern Quebec. Historical quick-clay failures on record (Saint-Jean-Vianney 1971, Lemieux 1993, Saint-Jude 2010) establish the class as among the most geotechnically hazardous in North America, with sensitivities (S_t) exceeding 8 documented across large portions of the corridor footprint.

Justification. The rubric's Level 5 descriptor names Champlain Sea (Leda) clays explicitly as an exemplar of "extensive quick or highly sensitive clays." The extent of these deposits along the corridor, combined with documented historical failure precedent, places subgrade treatment in the tier where it may dominate capital cost and construction schedule.

13/15

HIGH

D2. Bedrock and excavation character

Evidence. Alignment crosses the Frontenac Arch, the Precambrian crystalline shield exposure forming the geological province boundary between the Canadian Shield and the sedimentary basin. Karst development documented at the Moira Karst site (cavernous bat hibernaculum) and across the Napanee Limestone Plain. Regional tunnelling precedent in hard shield rock is limited in Canada.

Justification. Corridor crossing of distinct geological provinces combined with documented karst features matches the Level 4 descriptor. An aggressive reading of the karst extent could support Level 5; Level 4 is adopted as the defensible conservative score pending corridor-specific geotechnical investigation publication.

9/10

HIGH

D3. Hydrological and hydrogeological setting

Evidence. Corridor crosses multiple named watercourses in Eastern Ontario alone — including the Salmon River, the Napanee River, and the boundaries between the Rideau, Trent, and Cataraqui watersheds — and continues through further major crossings in Quebec. The Moira Karst system represents a karst aquifer directly within the alignment zone. Wetland complexes traversed throughout, including provincially significant wetlands in the Napanee and Frontenac Arch regions.

Justification. Multiple major river crossings, substantial wetland complexes, and karst aquifer exposure along the alignment match the Level 4 descriptor. Level 5 would require wetlands of documented international (Ramsar) significance, which has not been established for the corridor footprint; the Frontenac Arch UNESCO Biosphere Reserve is nonetheless traversed.

13/15

HIGH

D4. Climatic regime

Evidence. Eastern Ontario annual temperature range approximately 60–65°C (historical extremes near −35°C to +35°C). Freeze–thaw cycles estimated at 80–100 per year. Design frost penetration of 1.5–1.8 m. The only directly comparable cold-climate HSR precedent worldwide is the Harbin–Dalian line (China, 2012), whose operational experience in severe cold is the subject of ongoing engineering study.

Justification. Continental cold climate with deep frost penetration and high freeze–thaw frequency matches Level 4. Conditions approach but do not fully reach the Level 5 Harbin–Dalian thresholds of sustained winter temperatures below −30°C and range above 75°C, though Quebec segments trend closer to the Level 5 boundary.

10/15
MODERATE

D5. Topographic relief and alignment geometry

Evidence. Corridor crosses the Frontenac Arch (relief of approximately 200 m over short distance), the Niagara Escarpment approach on the Toronto side, and several major river valleys. Predominantly moderate rolling terrain across Eastern Ontario and the St. Lawrence lowlands; Quebec portions present somewhat more relief approaching Quebec City.

Justification. Relief is sufficient to require engineered gradient and curvature solutions but does not approach mountain-crossing territory. Tunnel and viaduct proportion is expected to fall in the 15–25% band characteristic of Level 3 for a 300 km/h corridor of this length. This is the only dimension scoring below 4.

4/5
HIGH

D6. Seismic and geohazard exposure

Evidence. Corridor passes through the Western Quebec Seismic Zone (PGA 0.10–0.20 g for the 475-year return period) and approaches the Charlevoix–Kamouraska Seismic Zone (PGA exceeding 0.20 g), Canada's most seismically active region. Sensitive Leda clay slope instability is extensively documented along river valleys throughout the Ottawa and St. Lawrence lowlands. Moira Karst subsidence potential present on the alignment.

Justification. The combination of documented sensitive-clay landslide history, moderate-to-elevated seismicity along the Quebec section, and karst subsidence risk places exposure at Level 4. The geohazard interaction with the subgrade dimension (D1 = 5) is particularly noteworthy: ground-improvement works in sensitive clay can themselves trigger slope failures, a coupling the linear composite does not capture.

5/5
EXTREME

D7. Ecological and protected-area footprint

Evidence. Multiple federally listed Endangered species with documented critical habitat intersect the corridor. The Napanee Limestone Plain is one of only two remaining Canadian breeding sites for the Eastern Loggerhead Shrike, a species whose Canadian range is already severely restricted. The Moira Karst hibernaculum hosts four SARA-listed Endangered bat species (Little Brown Myotis, Northern Myotis, Tri-coloured Bat, Eastern Small-footed Myotis). Grey Ratsnake habitat is documented along the corridor. The alignment traverses the Frontenac Arch UNESCO Biosphere Reserve and multiple provincially significant wetland complexes.

Justification. All Level 5 criteria are met: species with legally designated critical habitat; species whose Canadian range is already highly restricted; biosphere reserve traversal; wetland complexes of significance. This is the most clearly documented Level 5 dimension on the corridor.

4/5
HIGH

D8. Heritage, archaeological, and Indigenous-rights constraints

Evidence. Fifty-one documented cemetery locations within 15 km of the corridor centreline (Federation of Burying-Ground and Cemetery Societies of Alberta analysis methodology, applied to Eastern Ontario). Corridor crosses traditional territories of multiple Indigenous Nations, including Algonquin (Eastern Ontario) and Mohawk (St. Lawrence corridor). The Algonquin land claim in Eastern Ontario remains at the agreement-in-principle stage with substantial unresolved title and rights questions bearing directly on the alignment footprint.

Justification. Substantial heritage density combined with traditional territory crossings triggering formal consultation processes places the corridor at Level 4. Level 5 becomes defensible if the unresolved Algonquin claim materialises as a rights-based legal challenge to the project; Level 4 is adopted as the defensible conservative score in the absence of that development.

5/5
EXTREME

D9. Corridor integration and land acquisition

Evidence. The southern corridor is predominantly a greenfield alignment through actively farmed Eastern Ontario and southwestern Quebec. Agricultural drainage networks are extensively impacted; road severance documented at scale with direct consequences for emergency response routing and student transportation; Ontario Federation of Snowmobile Clubs trail exposure of 2,196.79 km with estimated annual economic exposure of $3–6 billion. Property interests affected are expected to number in the tens of thousands across the full corridor.

Justification. A long greenfield alignment through actively farmed, fragmented land with complex drainage, access, and tenure patterns is the Level 5 archetype in the rubric. The scale of affected property interests and the intensity of community severance documented across the corridor place this dimension unambiguously at Level 5.

9/15
MODERATE

D10. Urban engineering content

Evidence. Corridor terminates at major metropolitan centres at Toronto, Ottawa, Montreal, and Quebec City. Current proposals indicate terminal approaches predominantly along existing urban rail corridors, with reuse of existing station buildings (Union Station, Ottawa Station, Gare Centrale, Sainte-Foy) rather than new underground termini. Detailed urban approach specifications, including potential new

	station construction and the extent of urban tunnelling or viaduct requirements, have not been published by the proponent. **Justification.** The balance of the corridor is rural-to-exurban; urban engineering content appears limited to terminal approaches along existing urban rail alignments with reconstruction within existing station footprints. Level 3 (moderate) is the defensible conservative baseline. Level 4 becomes warranted if significant new urban tunnelling, major elevated viaduct through metropolitan cores, or new-build underground termini are specified in subsequent alignment documentation.

Reference-class comparison

The table below ranks all thirteen reference corridors in the worldwide database alongside the ALTO composite score. ALTO occupies the top rank by composite engineering complexity, seven points above the highest-scoring reference corridor (California HSR, 75).

Rank	Corridor	Composite	Band	Δ vs ALTO
1	TGV Sud-Est Paris–Lyon (France, 1981)	**44**	**Moderate**	-38
2	Madrid–Sevilla AVE (Spain, 1992)	**50**	**Moderate**	-32
3	Beijing–Shanghai HSR (China, 2011)	**56**	**Moderate**	-26
4	Nürnberg–Ingolstadt (Germany, 2006)	**58**	**Moderate**	-24
5	HS1 London–Channel Tunnel (UK, 2007)	**61**	**High**	-21
6	Köln–Rhein/Main (Germany, 2002)	**62**	**High**	-20
7	HS2 Phase 1 (UK, under construction)	**63**	**High**	-19
8	Taipei–Kaohsiung THSR (Taiwan, 2007)	**63**	**High**	-19
9	Ostlänken (Sweden, under construction)	**64**	**High**	-18
10	Wendlingen–Ulm (Germany, 2022)	**66**	**High**	-16
11	Tokaido Shinkansen (Japan, 1964)	**66**	**High**	-16
12	Harbin–Dalian HSR (China, 2012)	**68**	**High**	-14
13	California HSR (under construction)	**75**	**High**	-7
14	**ALTO (proposed)**	**82**	**Extreme**	—

Interpretation. The seven-point separation between ALTO and California HSR crosses the High–Extreme band boundary (81 on the weighted scale), a more substantive difference than a simple numerical gap suggests. California HSR's complexity is concentrated on seismic, topographic, and urban engineering dimensions — physical-environment factors well-understood in California engineering practice. ALTO's profile adds a maximum subgrade score (10/10, Champlain Sea Leda clay) and a maximum greenfield-integration score (5/5) that California does not face. In reference-class forecasting terms, California HSR is a near comparator on some dimensions but not a dimensionally matched reference. The nearest dimensionally matched reference for ALTO's subgrade dimension in the database is Ostlänken (Sweden, under construction), which shares the sensitive-clay and shield-bedrock profile but not ALTO's Level 5 ecological footprint or the cold-climate severity of eastern Quebec. The nearest cold-climate reference is

Harbin–Dalian, which does not face the Leda clay subgrade problem and terminates in less densely urbanised settings.

Dimensional profile against closest references

Comparison with the closest-composite references illuminates where ALTO's complexity sits differently. California HSR (composite 75) scores high on topographic relief and seismic exposure (Level 5 on both), with Level 4 distributed across climate, geotechnical, urban-engineering, and heritage dimensions. Harbin–Dalian (composite 68) scores at Level 5 on climate alone, with a subgrade score of 4 in permafrost-transition terrain; it did not encounter sensitive marine clays. Tokaido Shinkansen (composite 66) scores Level 5 on seismic exposure, with Level 4 on topography, greenfield integration, and urban engineering owing to extensive elevated viaduct through Tokyo and Osaka. Ostlänken (composite 64) is the database's closest analogue to ALTO on ground conditions and climate, combining Scandinavian sensitive-clay exposure, Baltic Shield bedrock, and continental cold-climate design in a largely greenfield alignment. HS1 (composite 61) is the database's only Level 5 urban-engineering case, reflecting the central-London tunnel and St Pancras reconstruction — a distinct profile that ALTO does not share. No single reference corridor combines ALTO's pattern of maximum subgrade, ecological, and greenfield-integration scores.

Sensitivity and scoring conservatism

The composite of 82 is the defensible conservative baseline. Five dimensions carry granular baseline scores that could credibly upgrade under fuller review. Under the evidence-dependent upgrade scenarios tabulated below, the composite rises accordingly.

Dimension	Baseline	Upper	Condition for upper score
D2 Bedrock/excavation	**13/15**	**15/15**	Karst extent and shield/sedimentary boundary crossing documented on a fraction of alignment sufficient to be 'extensive'
D3 Hydrology/hydrogeology	**9/10**	**10/10**	Ramsar or equivalent international wetland designation confirmed on the corridor
D4 Climatic regime	**13/15**	**15/15**	Quebec segment scored separately with sustained winter below −30°C
D6 Seismic/geohazard	**4/5**	**5/5**	Full Charlevoix-Kamouraska seismic zone exposure treated as a primary design condition
D8 Heritage/Indigenous rights	**4/5**	**5/5**	Unresolved Algonquin land claim treated as active rights-based legal challenge risk to the project

Dimension	Baseline	Upper	Condition for upper score
D10 Urban engineering content	9/15	12/15	Significant new urban tunnelling, major metropolitan viaduct, or new-build underground termini specified in detailed alignment

If all six upgrade conditions were met, the composite would rise to 92 — well within the Extreme band (81–100). The scoring presented in this document is therefore a lower-bound estimate of ALTO's engineering complexity as it is presently documented; the reasonable range is 82–92, all within the Extreme band.

Implications for cost and schedule forecasting

Absence of dimensionally matched precedent

Under Flyvbjerg reference-class forecasting, a project without directly comparable precedent cannot be reliably costed from international HSR benchmarks. Forecasts produced by selecting favourable comparators — typically European or East Asian HSR lines with composite scores in the 40s or low 50s — systematically understate expected cost and schedule outcomes for a corridor in the Extreme band (81–100). The rubric's primary forecasting use is to discipline comparator selection: only corridors with similar dimensional profiles are admitted to the reference class.

Interaction effects

The linear composite treats dimensions as independent. In practice, dimensional combinations interact. The interaction of concern for ALTO is subgrade sensitivity (10/10) with geohazard exposure (4/5): remediation works in sensitive clay can trigger the slope failures the remediation is intended to prevent. This coupling is not reflected in the composite but should be treated as an explicit risk register item in project governance.

Governance threshold

The rubric specifies that Extreme-band projects require "independent peer review and reference-class forecasting" as mandatory, not discretionary. The absence of these mechanisms in the current procurement trajectory for ALTO is the primary governance finding supported by this scoring exercise. The specific form of peer review appropriate to a corridor of this complexity is established in the international engineering literature and is not discharged by consultation or by standard environmental assessment.

Reconciliation with the HPR alternative

The High Performance Rail alternative proposed by the Initiative avoids the most consequential maximum-score dimensions by design. Greenfield land acquisition (D9) is substantially replaced by upgraded shared corridor use, moving the score from 5/5 toward 2/5. Subgrade (D1) and ecological (D7) dimensions are materially mitigated by following existing corridors where sensitive-clay and SAR-critical-habitat crossings have already been engineered or disclosed. Urban engineering content (D10) remains at or below its current granular score because HPR also uses existing urban rail corridors into the same metropolitan termini. A parallel scoring of the HPR alternative against the same rubric is recommended as a companion exercise; preliminary assessment indicates a composite in the Moderate-to-High transition (55–65 on the 100-scale), a range for which the worldwide database provides abundant delivery precedent.

Methodology note

This scorecard applies the rubric published as HSR Engineering Complexity Rubric v1.0 (April 2026). Scores are assigned against the rubric descriptors using evidence drawn from the Initiative's technical, environmental, and community-impact submissions, together with publicly available geological (Ontario Geological Survey, Geological Survey of Canada), seismic (Natural Resources Canada 2020 seismic hazard model), species-at-risk (Species at Risk Public Registry), and protected-area (UNESCO MAB, Ontario Parks) datasets.

The scoring follows the rubric's conservatism principle: where evidence straddles two descriptor levels, the lower integer on the granular scale is assigned unless the higher score's criteria are specifically and documentably met. The sensitivity table identifies six dimensions where this convention may understate complexity and specifies the evidence that would support upgrades.

Independent peer review of this scorecard by qualified engineering and policy reviewers is recommended before its use in formal decision-making contexts. The Initiative will revise the scorecard as project documentation becomes available and as the alignment specification is refined by the proponent.