Scientific models for seismic risk assessment and resilience enhancement of road and aerodrome infrastructure in Uzbekistan

Inomjon Gulomovich Ganiev
Dilnavo Khamdamova
Jizzakh Polytechnic Institute

Abstract: *The seismic performance of transport infrastructure must be evaluated not only through structural resistance, but also through the probability of service disruption and the ability of the network to recover after an earthquake. This study develops an integrated risk- and resilience-based methodology for road and aerodrome infrastructure in Uzbekistan. The framework combines normalized seismic hazard, local ground conditions, asset vulnerability, functional criticality, failure consequences and post-event recovery in a single decision architecture. Two principal indicators are introduced: the Integrated Seismic Risk Index (ISRI) and the Transport Infrastructure Resilience Index (TIRI). Hazard explicitly incorporates peak ground acceleration, spectral demand, site amplification, liquefaction susceptibility and permanent ground deformation; vulnerability accounts for pavement, geotechnical, structural, deterioration and drainage components. A GIS workflow links the indices with asset inventories, condition surveys, traffic or airport function, alternative routes and emergency accessibility. An eight-asset synthetic demonstration, used solely to test the logic of the method, identifies a primary runway on potentially liquefiable fill and a bridge corridor on soft alluvium as the highest-priority archetypes. In a targeted intervention sensitivity test, a 20% reduction in vulnerability combined with a 25% reduction in recovery time decreases ISRI by about 5-6% while increasing TIRI by about 6-9%. The results show that resilience-oriented measures can provide substantial functional benefits even when the change in a conventional risk score is moderate. The framework is intended for calibration with field inventories, site-specific hazard data, fragility functions and post-earthquake restoration records in Uzbekistan.*
Keywords: *seismic risk, resilience, road infrastructure, aerodrome, vulnerability, liquefaction, GIS, criticality, Uzbekistan*

1. Introduction

Transport systems are lifeline networks: their performance after an earthquake controls emergency access, evacuation, supply chains, medical response and the restoration of other infrastructure. For this reason, the engineering question is broader than whether an individual pavement, bridge or runway satisfies a prescribed strength requirement. The decision problem is to identify where strong shaking and adverse ground conditions coincide with vulnerable assets, where failure would generate the greatest network consequences, and how rapidly essential functionality can be restored. This shift from component safety to system risk and resilience is consistent with the development of quantitative resilience theory and infrastructure-network assessment [12-16].

Uzbekistan is situated within the seismically active Central Asian region. Regional and national studies have developed probabilistic hazard models, seismic microzonation approaches and risk assessment procedures for Tashkent, Jizzakh and broader parts of Uzbekistan [1-8]. Recent work has also emphasized the importance of local soil conditions, including Vs30-based characterization and revised soil classification for seismic design [9,10]. A 2026 scenario study for Tashkent demonstrates the practical integration of local ground conditions, spatial exposure and loss modeling within a

GIS/OpenQuake environment [11]. These developments provide a strong scientific basis for extending seismic risk analysis from buildings to transport assets.

Road and aerodrome systems have specific failure mechanisms that are not fully represented by building-oriented risk models. Roads may lose serviceability through embankment settlement, slope instability, fault-related ground deformation, bridge damage, culvert failure or loss of access. Aerodromes may remain structurally intact yet become operationally unavailable because of localized runway deformation, liquefaction-induced differential settlement, taxiway discontinuity, drainage failure or disruption of the airport access corridor. Airport resilience therefore requires simultaneous consideration of airside pavement performance, geotechnical conditions and landside connectivity [23-25]. Uzbekistan-focused studies of cement-concrete pavements likewise show that pavement type, long-term deterioration, maintenance demand and repairability should be represented in asset-level vulnerability and continuity assessments [26,29].

The current regulatory corpus of Uzbekistan includes SHNQ 2.01.03-19 for construction in seismic areas and sectoral design standards such as SHNQ 2.05.02-23 for highways, SHNQ 2.05.03-22 for bridges and culverts, and SHNQ 2.05.08-21 for aerodromes. The methodology proposed here is not a substitute for code-based design or verification. It is a screening and prioritization layer intended to organize inspections, detailed analyses, strengthening programs and recovery planning across many heterogeneous transport assets.

The objective of this article is to formulate a unified scientific model for seismic risk assessment and resilience enhancement of road and aerodrome infrastructure in Uzbekistan. The specific tasks are to: (i) define hazard, vulnerability, functional criticality and consequence indices; (ii) construct an Integrated Seismic Risk Index; (iii) quantify post-earthquake recovery through a Transport Infrastructure Resilience Index; (iv) demonstrate the logic on transparent synthetic scenarios; and (v) define a GIS-based workflow for subsequent calibration and operational implementation.

2. Materials and Methods

The proposed methodology is an asset-level multi-criteria framework that can be implemented for road sections, bridge corridors, runways, taxiways, aprons and airport access links. Each object is represented by a digital record containing location, geometry, structural type, geotechnical setting, condition, service function, network role and recovery-related attributes. All component indicators are normalized to the interval [0,1], where larger values represent greater hazard, vulnerability, criticality or consequence. Weighting coefficients in the present demonstration are methodological starting values rather than normative constants; calibration should use local expert elicitation, analytical hierarchy methods, observed damage, fragility analyses and restoration data.

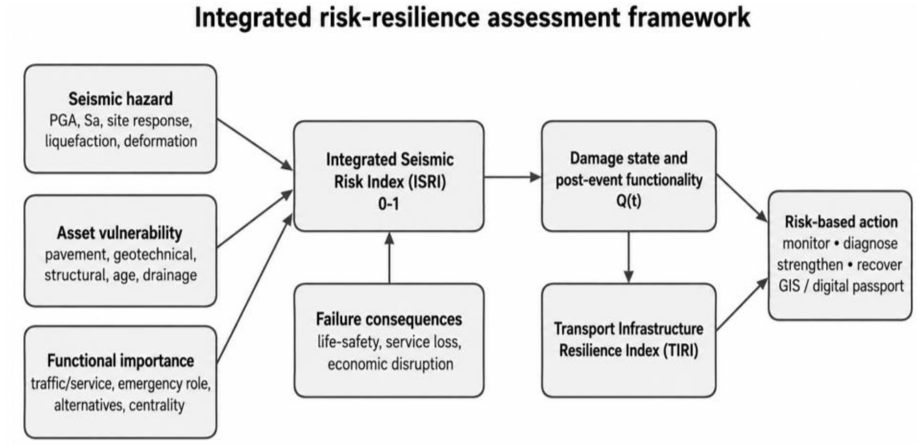

Figure 1. Integrated risk-resilience assessment framework proposed for road and aerodrome assets

2.1. Indicator architecture and data sources

Table 1.

Core indicator groups for the proposed assessment model.

Group	Representative components	Engineering meaning	Typical data sources
Hazard, H	PGA, Sa, site response / Vs30, liquefaction, permanent deformation	Intensity and ground-response demand	National/regional hazard models; microzonation; geotechnical investigation
Vulnerability, V	Pavement, geotechnical, structural, age/deterioration, drainage	Probability and severity of physical/functional damage	Condition surveys; NDT; design records; bridge/runway inspection; ground investigation
Criticality, C	Traffic/service intensity, emergency role, alternative routes, network centrality	Importance of the asset to continuity of transport service	Traffic counts; airport operations; network analysis; emergency plans
Consequence, F	Safety, service loss, economic disruption, isolation of critical facilities	Expected impact if the asset fails	Scenario analysis; user costs; emergency accessibility
Recovery	Immediate functionality Q0, restoration time constant τ	Speed and completeness of functional restoration	Repair scenarios; resources; contractor capacity; restoration records

2.2. Seismic hazard index

For transport infrastructure, a hazard index should include both shaking intensity and permanent ground effects. The site term is particularly important because Uzbekistan studies show that local soils can materially modify seismic demand [4,6,9,10]. A screening-level hazard index is written as:

$$H = 0.35\,PGA_n + 0.20\,S_a + 0.20\,F_s + 0.15\,L_q + 0.10\,D_g \qquad (1)$$

where PGA_n is normalized peak ground acceleration; Sa_n is normalized spectral acceleration representative of the asset response range; F_s is a normalized site-amplification measure derived, for example, from Vs30 or site-response analysis; L_q is liquefaction susceptibility; and D_g is the potential for permanent ground deformation. PGA and spectral demand may be derived from probabilistic or scenario hazard models, while L_q should reflect groundwater, density/state parameters, fines content and cyclic demand. Detailed project-level work should replace the screening score with site-response and liquefaction analyses appropriate to the facility.

2.3. Vulnerability index

Vulnerability is separated from hazard so that intervention benefits can be represented directly. The index is defined as:

$$V = 0.25\,V_p + 0.25\,V_g + 0.25\,V_s + 0.15\,V_a + 0.10\,V_d \qquad (2)$$

where V_p is pavement vulnerability; V_g is geotechnical vulnerability; V_s is structural vulnerability of bridges, retaining systems or other engineered components; V_a reflects age and accumulated deterioration; and V_d represents drainage and water-related vulnerability. For a runway, V_p may include slab or flexible-pavement condition, load-carrying capacity and surface regularity; for a road corridor, V_g may dominate where unstable slopes, weak embankments or liquefiable deposits control loss of service. Multiple-hazard bridge and aging-network studies show that deterioration and restoration assumptions can substantially alter network resilience [17-19]. For bridge assets, diagnostic condition assessment and reliability-based service-life modeling provide complementary inputs for V_s and V_a [27,33]. Drainage condition and saline-subgrade behavior can be represented explicitly within V_d and V_g because both mechanisms directly influence loss of road serviceability and post-event recovery [28,31].

2.4. Functional criticality and failure consequences

Assets with similar physical vulnerability can have very different system importance. A low-volume road with a parallel alternative should not automatically receive the same priority as the sole access link to an airport or a bridge on an emergency corridor. Functional criticality is therefore written as:

$$C = 0.30\,T + 0.25\,E + 0.25\,A^{-1} + 0.20\,N \quad (3)$$

where T is traffic or service intensity; E is the emergency-response role; A^(-1) measures the absence or inadequacy of alternative routes; and N is a normalized network-centrality measure. Failure consequence F is maintained as a separate variable so that safety, economic loss, network isolation and interruption of critical services can be incorporated without double-counting routine traffic. This separation is consistent with transportation resilience frameworks that distinguish physical damage from network performance and restoration scheduling [20-22].

2.5. Integrated Seismic Risk Index (ISRI)

The four dimensions are aggregated into an Integrated Seismic Risk Index:

$$ISRI = 0.35\,H + 0.30\,V + 0.20\,C + 0.15\,F \quad (4)$$

ISRI ranges from 0 to 1. It is intended as a transparent screening score rather than a replacement for probabilistic loss calculations. Higher values identify assets where seismic demand, susceptibility to damage and system consequences overlap. For early implementation, the preliminary decision bands in Table 2 can be used to organize follow-up actions. These thresholds are methodological and must be calibrated before any regulatory or contractual use in Uzbekistan.

Table 2.

Preliminary methodological interpretation of ISRI

ISRI	Risk level	Recommended management response
0.00-0.20	Very low	Routine inspection and ordinary maintenance
0.21-0.40	Low	Periodic monitoring; verify inventory and condition data
0.41-0.60	Moderate	Detailed seismic assessment and targeted diagnostics
0.61-0.80	High	Strengthening / reconstruction planning; recovery preparation
0.81-1.00	Critical	Priority intervention; contingency and continuity measures

Note: the bands are proposed for methodological screening only; they are not limits established by an Uzbek construction standard.

2.6. Functionality recovery and Transport Infrastructure Resilience Index (TIRI)

Risk ranking alone does not quantify how quickly service returns. Post-earthquake functionality is described by an exponential recovery curve:

$$Q(t) = Q_0 + (1 - Q_0)\,[1 - \exp(-t/\tau)] \quad (5)$$

where Q(t) is the fraction of normal functionality at time t, Q_0 is functionality immediately after the event, and τ is a restoration time constant. Q can represent traffic capacity, passability or operational airfield capacity, depending on the asset. A normalized resilience measure over a selected horizon T_h is then:

$$TIRI = \frac{1}{T_h}\int_0^{T_h} Q(t)\,dt \quad (6)$$

TIRI approaches 1 when functionality remains high or is restored rapidly. The analysis horizon should reflect the decision objective; 90 days is used here to demonstrate short- to medium-term transport recovery. The formulation follows the general concept that resilience combines loss of performance and recovery through time [12-16].

2.7. GIS implementation and assessment workflow

Operational implementation requires a georeferenced asset inventory. Hazard and geotechnical layers are spatially joined with road, bridge and aerodrome objects; condition and operational data are then attached to each asset. After normalization, H, V, C, F, ISRI and TIRI are calculated and stored in a digital passport. The output is a priority map rather than a single hazard map: an asset can become critical because of high ground-motion demand, poor soil, degraded condition, lack of alternative access, slow recovery, or a combination of these factors. This approach extends the GIS-based regional exposure and risk methods already demonstrated in Central Asia [6-8,11].

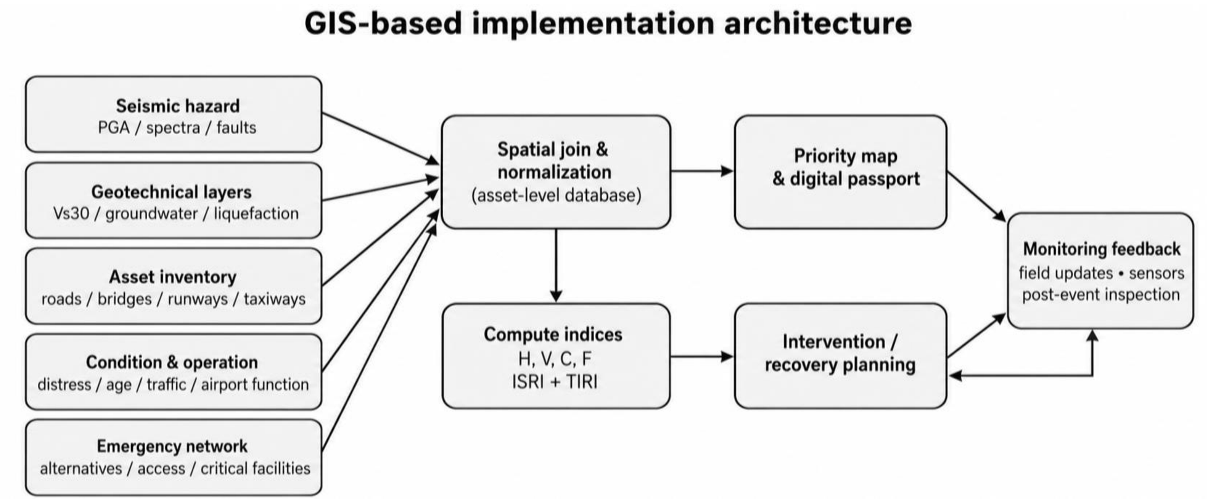

Figure 2. GIS-based implementation architecture for seismic-risk and resilience management.

3. Results and Discussion

3.1. Synthetic demonstration dataset

To test the internal logic of the framework without presenting unverified field measurements, eight synthetic transport-asset archetypes were constructed (Table 3). The values are deliberately illustrative; they are not observations from a named road, bridge or airport in Uzbekistan. Their purpose is to show how hazard, vulnerability, criticality and consequences interact, and how a decision-maker can distinguish between physically vulnerable assets and system-critical assets. Q0 and τ were assigned as scenario restoration parameters, and TIRI was calculated over T_h = 90 days using Eqs. (5)-(6).

Table 3.

Synthetic scenario results for eight transport-asset archetypes

ID	Asset archetype	H	V	C	F	ISRI	Q0	τ, d	TIRI
R1	Urban arterial / firm soil	0.45	0.35	0.80	0.50	0.498	0.552	15	0.926
R2	Mountain highway / slope instability	0.70	0.65	0.75	0.70	0.695	0.375	30	0.802
B1	Bridge corridor / soft alluvium	0.78	0.72	0.90	0.80	0.789	0.290	40	0.718
R3	Regional highway / medium soil	0.58	0.50	0.60	0.55	0.555	0.500	25	0.865
A1	Primary runway / potentially liquefiable fill	0.80	0.68	0.95	0.90	0.809	0.272	45	0.685

ID	Asset archetype	H	V	C	F	ISRI	Q0	τ, d	TIRI
A2	Taxiway-apron / dense soil	0.60	0.45	0.70	0.55	0.568	0.489	20	0.888
A3	Airport access road-bridge	0.68	0.60	0.85	0.75	0.701	0.370	35	0.774
R4	Low-volume local road	0.50	0.55	0.30	0.30	0.445	0.600	18	0.921

All values in Table 3 are synthetic and are used only to demonstrate the method. They must not be interpreted as measured condition or seismic risk for an actual facility.

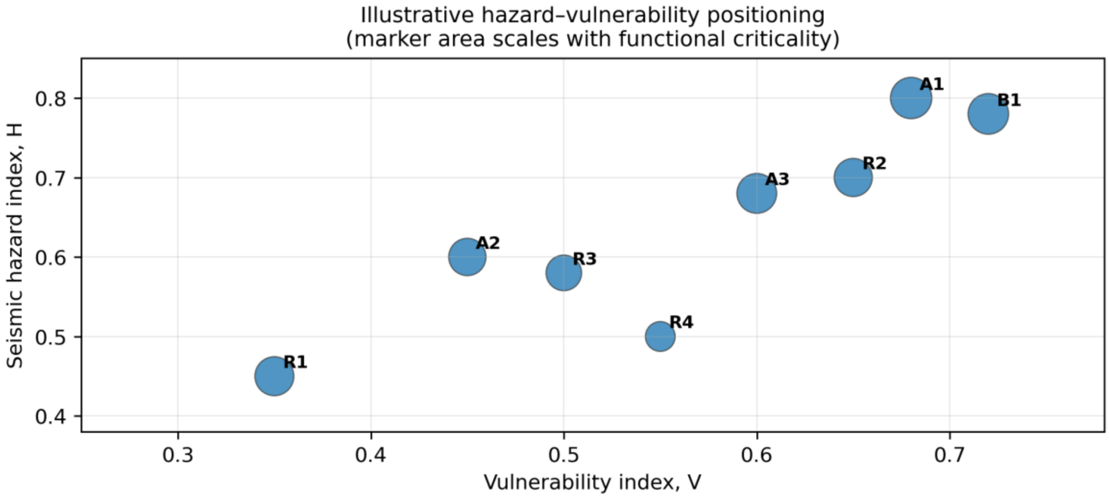

Figure 3. Illustrative hazard-vulnerability positioning of the synthetic assets; marker area scales with functional criticality

3.2. Risk ranking and systemic interpretation

The primary runway archetype A1 produces the largest ISRI (0.809), followed by the bridge corridor B1 (0.789), airport access corridor A3 (0.701) and mountain highway R2 (0.695). The ranking is important because A1 is not only exposed to high seismic demand and liquefaction susceptibility; it also has very high functional criticality and consequence. B1 remains nearly as important because soft alluvium, structural vulnerability and the centrality of the bridge corridor combine to create a system bottleneck. These patterns reflect the general finding of transportation-risk research that network significance and restoration cannot be inferred from component damage alone [17-22].

The low-volume road R4 provides a useful counterexample. Its vulnerability score (0.55) exceeds that of several other assets, yet its ISRI is 0.445 because criticality and failure consequences are lower. This does not imply that R4 is safe; it means that, under a constrained regional strengthening budget, assets with similar or higher physical risk but much greater network consequences may need to be addressed first. The model therefore separates engineering condition from investment priority rather than merging them implicitly.

For aerodromes, the comparison between A1, A2 and A3 shows why the assessment unit should extend beyond the runway itself. A taxiway/apron on dense soil can have a moderate risk score, while the airport access road/bridge remains high-risk because loss of landside access can reduce the airport's emergency value even if the runway is operational. Studies of airport disaster resilience and earthquake-related runway damage similarly emphasize restoration, alternative operating modes and geotechnical failure mechanisms [23-25].

3.3. Recovery behavior and resilience

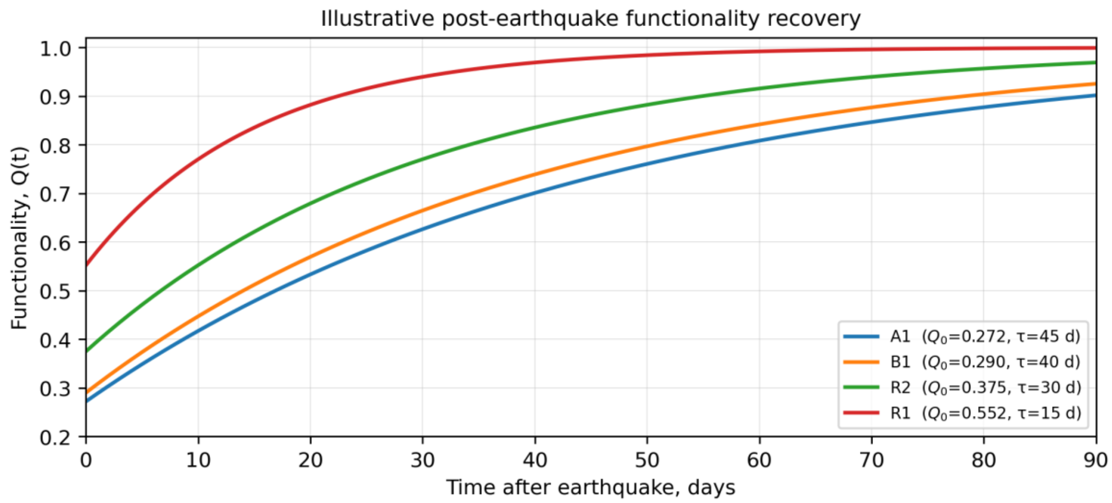

Figure 4. Ninety-day functionality recovery curves for representative synthetic assets using Eq. (5)

The recovery curves reveal a different ranking dimension. A1 has the lowest TIRI (0.685) because it combines a low initial functionality Q0 = 0.272 with a long restoration time constant of 45 days. B1 follows at 0.718. By contrast, R1 reaches TIRI = 0.926 because initial service remains above one-half and restoration is relatively rapid. Thus, two assets may have comparable hazard but different resilience if emergency traffic management, repair logistics, redundancy or access to materials and contractors changes the recovery trajectory.

This distinction is especially relevant for airports and major road corridors. Seismic strengthening reduces expected physical damage, but resilience can also be improved through pre-positioned repair resources, emergency inspection protocols, rapid pavement-repair technology, traffic detours, spare bridge components and predefined minimum-operability criteria. The resilience literature supports treating preparedness and restoration capacity as engineering decision variables rather than as external assumptions [12-16,20-23]. A recent Uzbekistan-focused synthesis of seismic effects on transport infrastructure similarly identifies soil conditions, liquefaction susceptibility, structural detailing, drainage efficiency, monitoring and corridor-level recovery planning as interdependent determinants of seismic performance [30].

3.4. Sensitivity to a targeted intervention package

A simple sensitivity experiment was performed for the four highest-ranked assets. The illustrative package assumes that preventive strengthening and condition improvement reduce V by 20%, while preparedness and repair planning reduce τ by 25%. All other indices are held constant so that the effect is transparent. The resulting changes are shown in Table 4.

Table 4.

Illustrative sensitivity of risk and resilience to a targeted intervention package

ID	ISRI before	ISRI after	ΔISRI	TIRI before	TIRI after	ΔTIRI
A1	0.809	0.768	-5.0%	0.685	0.746	+8.9%
B1	0.789	0.746	-5.5%	0.718	0.775	+8.0%
A3	0.701	0.665	-5.1%	0.774	0.822	+6.3%
R2	0.695	0.656	-5.6%	0.802	0.847	+5.6%

Sensitivity assumption: vulnerability V reduced by 20% and restoration time constant τ reduced by 25%. The exercise is methodological, not a forecast of a specific project.

The risk score decreases by approximately 5.0-5.6%, whereas TIRI increases by about 5.6-8.9%. The difference is expected: Eq. (4) distributes risk among several dimensions, so changing vulnerability alone produces a bounded ISRI reduction, while the resilience metric responds directly to faster restoration across the whole analysis horizon. This shows why a program evaluated only through pre-event risk reduction may undervalue measures that substantially improve continuity and recovery. A balanced portfolio should therefore combine physical strengthening with operational recovery measures.

3.5. Implications for implementation in Uzbekistan

A practical national or regional implementation can be organized in three tiers. Tier 1 is network screening using existing seismic zoning, asset inventories, condition ratings, traffic data and readily available geotechnical proxies. Tier 2 applies detailed geotechnical investigation, structural analysis and fragility assessment to assets in the high and critical bands. Tier 3 develops project-specific strengthening and continuity plans, including recovery targets and post-event inspection routes. This tiered structure concentrates expensive investigation on locations where the combination of H, V, C and F justifies it. Digital monitoring approaches discussed for underground construction and for the technical-condition monitoring of underground hydraulic structures are also applicable to continuous condition-data acquisition, threshold-based warning and evidence-based maintenance within such a tiered infrastructure-management system [32,34].

The method is compatible with the direction of recent Uzbek seismic-risk research. Regional studies already integrate ground conditions and spatial exposure [6-8], while Tashkent-focused work demonstrates Vs30 mapping, updated soil classification and scenario-based risk modeling [9-11]. For roads and aerodromes, the next data-development step is a unified georeferenced inventory that links pavement condition, bridge attributes, subgrade and groundwater conditions, slope instability, drainage, traffic/service data, emergency routes and restoration resources. Such a database would permit the weighting coefficients and threshold bands to be calibrated empirically rather than selected by expert judgment alone.

From a geotechnical perspective, liquefaction and permanent ground deformation deserve explicit treatment in airfield and corridor screening. The consequences of localized differential settlement can be disproportionately large for runway operability, and earthquake case histories show that repairability and surface geometry may control restoration even when catastrophic structural collapse does not occur [24,25]. For mountain highways, slope and retaining-system instability may dominate. For bridge corridors, foundation/approach deformation, bearing systems and aging-related deterioration must be included alongside superstructure fragility [17-19]. In addition, an Uzbekistan-focused ecological-safety framework for highway operation emphasizes continuous monitoring, drainage and runoff-water management, and climate-resilient operation; these considerations are consistent with treating environmental and water-related condition as part of long-term transport resilience [35].

3.6. Limitations and further validation

The principal limitation of the present article is intentional: it establishes a transparent methodological framework but does not claim field-calibrated risk values for specific facilities. The synthetic dataset is not a substitute for site measurements. Before operational use, the weights in Eqs. (1)-(4), the ISRI decision bands, Q0-damage relationships and restoration parameters must be validated with Uzbek inventory data, site-specific hazard, laboratory and field geotechnical testing, bridge and pavement fragility functions, airport-operability criteria and observed repair durations. Correlation among indicators should also be tested to avoid double counting. A subsequent probabilistic implementation can propagate uncertainty by Monte Carlo simulation or logic-tree methods and express results as expected loss, downtime distributions and confidence intervals rather than deterministic index values alone.

3.7. Scientific novelty and practical significance

The principal methodological contribution is the coupling of pre-event seismic risk and post-event functional recovery within one asset-level decision model. Conventional screening commonly ranks facilities using hazard and physical vulnerability, while resilience studies often begin after a damage state has already been defined. The proposed architecture links these stages explicitly: H, V, C and F determine the pre-event priority expressed by ISRI, and the expected damage/service state is then interpreted through Q(t) and TIRI. This allows a strengthening option to be evaluated twice—first by the reduction of vulnerability and risk, and second by the acceleration of functional recovery.

A second contribution is the explicit separation of functional criticality from failure consequence. This is especially important for transport systems because traffic volume alone does not identify all strategic assets. An airport access bridge, emergency corridor or unique mountain pass may be critical even when ordinary daily demand is lower than on an urban arterial. By retaining C and F as separate indices, the framework can represent network topology, emergency accessibility, lack of alternatives and socioeconomic disruption without treating all of them as physical vulnerability. The same structure can therefore be applied to roads, bridges and aerodrome elements while preserving their different operational roles.

The practical output is a GIS-based digital passport containing the component scores, supporting evidence, calculated indices, risk class, recovery target and recommended follow-up action. For infrastructure owners, this creates a traceable path from network screening to detailed investigation and then to project selection. The framework is intentionally modular: as higher-quality Uzbek data become available, simple normalized indicators can be replaced by probabilistic hazard curves, site-specific response analyses, fragility functions, measured deterioration models and empirically derived restoration distributions without changing the overall decision logic. In this form, the method can support preventive maintenance, seismic strengthening programs, emergency planning and post-earthquake inspection prioritization while remaining compatible with project-level verification under the applicable national standards.

4. Conclusions

1) A seismic-safety assessment for transport infrastructure should move beyond component resistance and integrate hazard, local ground conditions, vulnerability, network criticality, failure consequences and recovery capacity.

2) The proposed Integrated Seismic Risk Index (ISRI) provides a transparent screening mechanism for heterogeneous road, bridge and aerodrome assets, while the Transport Infrastructure Resilience Index (TIRI) captures service loss and restoration through time.

3) The synthetic demonstration shows that the highest priorities are not necessarily the physically weakest assets. A critical runway, bridge bottleneck or airport access corridor can rank higher because of its system role and consequences.

4) Resilience-oriented interventions can produce functional benefits larger than suggested by the change in a conventional risk index. In the illustrative sensitivity test, a 20% reduction in vulnerability and a 25% reduction in restoration time lowered ISRI by about 5-6% but increased TIRI by about 6-9%.

5) GIS integration is essential for implementation because it connects seismic hazard and soil layers with asset condition, operational importance, alternatives and emergency access in a common digital passport.

6) The framework is compatible with recent seismic hazard, microzonation, ground-condition and risk studies in Uzbekistan, but it requires field calibration before regulatory or investment use. Priority

future work is the creation of a verified transport-asset database and development of local fragility and restoration functions for highways, bridges, runways and airport-access systems.

Data and methodological note

No field dataset is reported in this methodological article. Numerical values in Tables 3-4 and Figures 3-4 are synthetic scenario values created to demonstrate calculation logic. They should not be cited as measured seismic-risk indicators for any real road, bridge or aerodrome in Uzbekistan.

References

1. Erdik M., Rashidov T., Safak E., Turdukulov A. Assessment of seismic risk in Tashkent, Uzbekistan and Bishkek, Kyrgyz Republic. Soil Dynamics and Earthquake Engineering. 2005;25(7–10):473–486. doi:10.1016/j.soildyn.2004.11.002.

2. Bindi D., Abdrakhmatov K., Parolai S., Mucciarelli M., Grünthal G., Ischuk A., Mikhailova N., Zschau J. Seismic hazard assessment in Central Asia: Outcomes from a site approach. Soil Dynamics and Earthquake Engineering. 2012;37:84–91. doi:10.1016/j.soildyn.2012.01.016.

3. Ischuk A., Bjerrum L.W., Kamchybekov M., Abdrakhmatov K., Lindholm C. Probabilistic Seismic Hazard Assessment for the Area of Kyrgyzstan, Tajikistan, and Eastern Uzbekistan, Central Asia. Bulletin of the Seismological Society of America. 2018;108(1):130–144. doi:10.1785/0120160330.

4. Ismailov V.A., Yodgorov S.I., Allayev S.B., Mamarozikov T.U., Avazov S.B. Seismic microzoning of the Tashkent territory based on calculation methods. Soil Dynamics and Earthquake Engineering. 2022;152:107045. doi:10.1016/j.soildyn.2021.107045.

5. Ismailov V., Khusomiddinov S., Khusomiddinov A., Yodgorov Sh., Aktamov B., Avazov S. Seismic risk assessment of Jizzakh region. AIP Conference Proceedings. 2022;2432(1):030035. doi:10.1063/5.0089664.

6. Ismailov V.A., Yodgorov S.I., Khusomiddinov A.S., Yadigarov E.M., Aktamov B.U., Avazov S.B. Regional seismic risk assessment based on ground conditions in Uzbekistan. Natural Hazards and Earth System Sciences. 2024;24:2133–2146. doi:10.5194/nhess-24-2133-2024.

7. Scaini C., Tamaro A., Adilkhan B., Sarzhanov S., Ergashev Z., Umaraliev R., Safarov M., Belikov V., Karayev J., Fagà E. A regional-scale approach to assessing non-residential building, transportation and cropland exposure in Central Asia. Natural Hazards and Earth System Sciences. 2024;24:355–373. doi:10.5194/nhess-24-355-2024.

8. Salgado-Gálvez M.A., Ordaz M., Huerta B., Garay O., Avelar C., Fagà E., Kohrangi M., Ceresa P., Triantafyllou G., Begaliev U.T. Development of a regionally consistent and fully probabilistic earthquake risk model for Central Asia. Natural Hazards and Earth System Sciences. 2024;24:3851–3868. doi:10.5194/nhess-24-3851-2024.

9. Ismailov V., Yodgorov S., Khusomiddinov A., Mamarozikov T., Yadigarov E., Aktamov B., Allayev S., Teshayeva R. Seismic soil characterization of Tashkent using Vs30 mapping techniques. Journal of Applied Geophysics. 2025;239:105719. doi:10.1016/j.jappgeo.2025.105719.

10. Ismailov V.A., Yodgorov S.I., Khusomiddinov A.S., Yadigarov E.M., Aktamov B.U., Avazov S.B. New classification of soils by seismic properties for the building code in Uzbekistan. Geomechanics and Geoengineering. 2024;19(4):605–625. doi:10.1080/17486025.2023.2296975.

11. Ismailov V.A., Scaini C., Yodgorov S.I., Jumaev D.D., Aktamov B.U., Avazov S.B., Azamjonov A.T. Seismic risk assessment of Tashkent's residential buildings based on the 1966 earthquake scenario. Scientific Reports. 2026;16:19753. doi:10.1038/s41598-026-44585-3.

12. Bruneau M., Chang S.E., Eguchi R.T., Lee G.C., O'Rourke T.D., Reinhorn A.M., Shinozuka M., Tierney K., Wallace W.A., von Winterfeldt D. A framework to quantitatively assess and enhance the

seismic resilience of communities. Earthquake Spectra. 2003;19(4):733–752. doi:10.1193/1.1623497.

13. Cimellaro G.P., Reinhorn A.M., Bruneau M. Framework for analytical quantification of disaster resilience. Engineering Structures. 2010;32(11):3639–3649. doi:10.1016/j.engstruct.2010.08.008.

14. Reed D.A., Kapur K.C., Christie R.D. Methodology for assessing the resilience of networked infrastructure. IEEE Systems Journal. 2009;3(2):174–180. doi:10.1109/JSYST.2009.2017396.

15. Hosseini S., Barker K., Ramirez-Marquez J.E. A review of definitions and measures of system resilience. Reliability Engineering & System Safety. 2016;145:47–61. doi:10.1016/j.ress.2015.08.006.

16. Franchin P., Cavalieri F. Probabilistic assessment of civil infrastructure resilience to earthquakes. Computer-Aided Civil and Infrastructure Engineering. 2015;30(7):583–600. doi:10.1111/mice.12092.

17. Alipour A., Shafei B. Seismic resilience of transportation networks with deteriorating components. Journal of Structural Engineering. 2016;142(8):C4015015. doi:10.1061/(ASCE)ST.1943-541X.0001399.

18. Gidaris I., Padgett J.E., Barbosa A.R., Chen S., Cox D., Webb B., Cerato A. Multiple-Hazard Fragility and Restoration Models of Highway Bridges for Regional Risk and Resilience Assessment in the United States: State-of-the-Art Review. Journal of Structural Engineering. 2017;143(3):04016188. doi:10.1061/(ASCE)ST.1943-541X.0001672.

19. Capacci L., Biondini F., Titi A. Lifetime seismic resilience of aging bridges and road networks. Structure and Infrastructure Engineering. 2020;16(2):266–286. doi:10.1080/15732479.2019.1653937.

20. Aydin N.Y., Duzgun H.S., Heinimann H.R., Wenzel F., Gnyawali K.R. Framework for improving the resilience and recovery of transportation networks under geohazard risks. International Journal of Disaster Risk Reduction. 2018;31:832–843. doi:10.1016/j.ijdrr.2018.07.022.

21. Wu Y., Hou G., Chen S. Post-earthquake resilience assessment and long-term restoration prioritization of transportation network. Reliability Engineering & System Safety. 2021;211:107612. doi:10.1016/j.ress.2021.107612.

22. Zhang M., Yang X., Zhang J. Post-earthquake resilience optimization of a rural “road-bridge” transportation network system. Reliability Engineering & System Safety. 2022;225:108570. doi:10.1016/j.ress.2022.108570.

23. Comes T., Warnier M., Feil W., van de Walle B. Critical Airport Infrastructure Disaster Resilience: A Framework and Simulation Model for Rapid Adaptation. Journal of Management in Engineering. 2020;36(5):04020059. doi:10.1061/(ASCE)ME.1943-5479.0000798.

24. Grogan W.P., Vallerga B.A. Earthquake Damage and Repair of Oakland Airport Runway. Journal of Performance of Constructed Facilities. 2000;14(4):135–140. doi:10.1061/(ASCE)0887-3828(2000)14:4(135).

25. Taftsoglou M., Papathanassiou G., Valkaniotis S., Argyroudis S., Mitoulis S.-A. Airport infrastructure risk to liquefaction by deploying multi-modal data and remote sensing. Transportation Geotechnics. 2025;57:101849. doi:10.1016/j.trgeo.2025.101849.

26. Inomjon Gulomovich, Bozarboev A. Comprehensive Analysis of the Operational and Economic Advantages and Technological Limitations of Cement Concrete Pavements in Modern Road Construction. Multidisciplinary Journal of Science and Technology. 2026;6(4):182–192. Available at: https://www.mjstjournal.com/index.php/mjst/article/view/7191.

27. Ganiev I.G., Lapasov S.A. Theoretical Foundations of Diagnostics and Assessment of Existing Reinforced Concrete Bridges. American Journal of Research in Humanities and Social Sciences. 2026;47:18–26. Available at: https://americanjournal.org/index.php/ajrhss/article/view/3481.
28. Ganiyev I.G., Tog'ayev F.V. Engineering Solutions for the Modernization of Highway Drainage Systems. Western European Journal of Modern Experiments and Scientific Methods. 2026;4(04):14–22. Available at: https://westerneuropeanstudies.com/index.php/1/article/view/3488.
29. Ganiev I., Ergasheva D.A. Operational Experience of Cement Concrete Pavements in Developed Countries: International Practices, Statistical Trends, and Practical Lessons for Uzbekistan. Academicia Review-A Multidisciplinary Online Journal. 2026;2(04):51–64. Available at: https://academicia.org/index.php/journal/article/view/71.
30. Ganiyev I.G., Obloqulov D.I. Seismic Impact and Its Effect on Transport Infrastructure. FARS International Journal of Education, Social Science & Humanities. 2026;14(4):164–170. Available at: https://farspublisher.com/index.php/fars/article/view/710.
31. Ganiev I.G., Kamalov X.D. Methods for Strengthening and Stabilization of Saline Soils in Road Construction. European Journal of Pedagogical Initiatives and Educational Practices. 2026;4(4):20–26. Available at: https://europeanscience.org/index.php/4/article/view/1710.
32. Ganiev I., Juratova D. Advanced Technologies and Equipment Used in Underground Construction. Academic Journal of Science, Technology and Education. 2026;2(3):123–133. Available at: https://integrumpublication.org/index.php/ajste/article/view/193.
33. Ganiyev I.G., Alishova F.A. Assessment and Extension of the Service Life of Transport Structures Based on Reliability Theory under the Conditions of Uzbekistan. Technical Science Integrated Research. 2026;2(3):21–25. Available at: https://altumnova.com/index.php/tsir/article/view/59.
34. Ganiyev I.G., Eshpo'latova M.U. Underground Hydraulic Structures Technical Condition Monitoring Systems. International Journal of Advance Scientific Research. 2026;6(02):105–109.
35. Ganiyev I.G., To'xtaboyev E.Y. The Concept of Ecological Safety in Highway Operation and Its Basic Principles. Science and Education. 2026;7(4):127–133. Available at: https://openscience.uz/index.php/sciedu/article/view/8716.
Note. References 26–35 are additional Uzbekistan-focused sources cited for topical continuity. No DOI is stated where a DOI could not be verified; stable publisher URLs are provided when available.
36. SHNQ 2.01.03-19. Construction in seismic areas (Сейсмик худудларда қурилиш). Referenced in current official construction regulations of the Republic of Uzbekistan.
37. SHNQ 2.05.02-23. Highways. Design requirements (Автомобиль йўллари. Лойиҳалаш талаблари).
38. SHNQ 2.05.03-22. Bridges and culverts (Кўприклар ва қувурлар).
39. SHNQ 2.05.08-21. Aerodromes (Аэродромлар), approved/currently published through the official LexUZ legal database in the 2025 ministerial order