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Review article

Understanding state-of-the-art situation of transport planning strategies in earthquake-prone areas by using AI-supported literature review methodology

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A R T I C L E I N F O

Keywords:
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A B S T R A C T

Aim: This review aims to explore earthquake-based transport strategies in seismic areas, providing state-of-the-art insights into the components necessary to guide urban planners and policymakers in their decision-making processes.
Outputs: The review provides a variety of methodologies and approaches employed for the reinforcement planning and emergency demand management to analyze and evaluate the impact of seismic events on transportation systems, in turn to develop strategies for preparedness, mitigation, response, and recovery phases. The selection of the appropriate approach depends on factors such as the specific transport system, urbanization level and type, built environment, and critical components involved.
Originality and value: Besides providing a distinctive illustration of the integration of transportation and seismic literature as a valuable consolidated resource, this article introduces a novel methodology named ALARM for conducting state-of-the-art reviews on any topic, incorporating AI through the utilization of large language models (LLMs) built upon transformer deep neural networks, along with indexing data structures (in this study mainly OPEN-AI DAVINCI-003 model and vector-storing index). Hence, it is of paramount significance as the first instance of implementing LLMs within academic review standards. This paves the way for the potential integration of AI and human collaboration to become a standard practice under enhanced criteria for comprehending and analyzing specific information.

1. Introduction

Over the past decades, urbanization in developing countries has rapidly increased, with a substantial portion (1/5) of the world's population residing in earthquake-prone areas (94 countries) [1]. The unique challenges faced by these regions require a comprehensive understanding of the impacts of seismic activity on transportation planning, requiring both resilience to seismic activity and the provision of safe and efficient transport options for residents after seismic events. The availability of functional transportation infrastructure is crucial for emergency services, enabling them to reach affected areas swiftly while the transportation of essential goods, such as food, water, and medical supplies plays a vital role in disaster response and recovery.

Past seismic events underscore the significance of seismic-based urban and transport planning. The neglect of seismicity-induced

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outcomes in Türkiye led to devastating consequences when two consecutive earthquakes (magnitudes 7.8 and 7.6), struck on February 7, 2023. The resulting loss of over 50,000 lives, 107,000 injuries, and extensive damage to infrastructure, including a $6.3 billion loss in the transport system, highlighted the urgency of addressing seismic risks [2,3]. Similar transport-related loss can be found in the aftermath of the Hanshin earthquake, where the transport port system of Kobe City, contributing significantly to the city's industrial output and employment, suffered severe damage. This led to $10 billion economic impact due to the loss of logistic facilities and transportation infrastructure [4]. Also, the direct damage caused by seismic events to railway infrastructure has resulted in substantial economic losses globally as observed for the Wenchuan earthquake's $10.2 billion direct damage, railway service disruptions following the Eastern Japan earthquake, and numerous earthquake-induced rail service disruptions in China from 2012 to 2019 [5].

An inadequate transport planning does not only result in economic consequences for seismic areas but also impedes rescue and relief operations. The emergency response capability of transport networks after seismic events is of utmost importance, given the rapid decline in survival rates as time passes. For example, victims of the 1976 Tangshan earthquake and the 1995 Hanshin earthquake experienced significantly reduced survival rates on the following day, highlighting the need for quick response and transportation assistance [6]. The accessibility of critical facilities, such as hospitals has a direct impact on earthquake-related fatalities. Inadequate seismic transport planning has resulted in higher mortality rates after earthquakes, as observed in instances where hospitals faced accessibility issues [7]. For example, severe Wenchuan earthquake in some cities of China led to delayed emergency responses (mobility of rescue workers, medicines and supplies) and further losses, underscoring the need for better evaluation and improvement of transport strategies [10]. Also, the 2003 earthquake in Bam resulted in significant traffic congestion, leading to substantial delays in rescue and relief operations, emphasizing the urgent requirement for demand management strategies in earthquake-prone areas [8].

Inadequate city and transport planning can result in devastating consequences for urban roads and other transportation infrastructure when earthquakes occur. Ports, bridges, airports, rail services, and tunnels are particularly susceptible to damage, leading to disruptions in transportation and economic activities. Seismic events worldwide, the ones in Central Italy 2016, Kaikoura (New Zealand) 2016, Kumamoto (Japan) 2016, Palu (Indonesia) 2018, and Sendai (Japan) 2011, have revealed the inadequate seismic capacities of transport systems in certain cities [9]. This does not only disrupt emergency response efforts but also poses risks to public safety. The neglect of seismic considerations in urban transport planning can cause significant costs, both in terms of economic vitality and human lives as discussed above. Therefore, it is crucial to develop a transport system that is resilient to seismic events, ensures accessible routes, and has effective emergency demand management after earthquakes. This review aims to explore earthquake-based transport strategies in seismic areas, providing state-of-the-art insights into the components necessary to guide urban planners and policymakers in their decision-making processes. The present review differs from the existent ones in the research field by.

1 Unlike previous review studies [11–15] that provide generalized views, scopes, methods, or definitions of disasters, this review specifically concentrates on earthquakes and incorporates more on practice considering case-oriented studies. By delving deeper into the dynamics and parameters unique to each disaster, a comprehensive understanding of the topic is achieved, supported by general subject matter.
2 This review primarily considers research studies that focus on transportation systems, an area that is not extensively understood [16]. Instead of focusing solely on individual transport elements, as seen in the previous works of [17–20], this review considers the broader parameters, interactions, and dynamics within the transportation system.
3 Presenting and using a novel review methodology incorporation artificial intelligence (AI).

The article organization is as follows, the next section presents the framework of the novel review approach by providing in detail how AI is integrated and utilized in the present study. Thereafter section 3 provides the state-of-the-art of transport planning in earthquake prone areas under three main headlines: conceptual background, reinforcement planning, and emergency demand management. Lastly, section 4 discusses the review outputs while section 5 provides the fundamental gains of the present article.

2. Review methodology

2.1. Background

In recent years, significant advancements have occurred in the development of Large Language Models (LLMs), transforming the landscape of natural language processing (NLP). These models, comprised of deep artificial neural networks (DNNs) utilizing billions of parameters, undergo training using unsupervised, supervised, or semi-supervised learning techniques on extensive text datasets. This approach mirrors certain aspects of human brain function, particularly language learning and processing [21]. The human brain, with its billions of interconnected neurons, processes and transmits information [22]. Artificial neural networks mimic this structure, utilizing interconnected nodes to process input data and generate output responses through mechanisms like feed-forward propagation [23]. While synaptic plasticity in the brain allows for the modification of neuron connections based on experience [24], DNNs achieve a similar effect by adjusting connection strengths through backpropagation during the learning process [25]. Despite being inspired by the structure and function of biological neural networks, artificial neural networks currently exhibit limitations in information processing and storage compared to the highly parallel and distributed system of the human brain [26]. Nonetheless, LLMs, exemplified by models like GPT (Generative Pre-trained Transformer) and BERT (Bidirectional Encoder Representations from Transformers), showcase remarkable efficiency in learning human language complexities and generating coherent, contextually relevant output [27–29]. The effectiveness of these models dependent on the architecture of transformer deep neural networks, as introduced by Ref. [30]. Since then the field has progressed significantly with the use of better-designed transformer networks and training with more data. Transformer neural networks utilize a self-attention mechanism, enabling them to simultaneously focus on different parts of the input sequence, capturing dependencies and proving efficient for long-range relationships. This capability contributes to their robust performance in various NLP tasks. The naturalness and versatility of language produced by these models present exciting prospects for the future of NLP, including advanced chatbots, automated content generation, and language-based virtual assistants like ChatGPT, Copilot, and Gemini. However, limitations persist, particularly in addressing complex questions or tasks within specific fields or relying on private knowledge not included in their training data. Answers provided by these models may be overly general, hallucinatory, or inaccurate, as they rely on statistical patterns without a true comprehension of underlying concepts. For instance, users of the ChatGPT tool, powered by the GPT 3.5 LLM, encounter a cautionary message from the OPENAI team at the bottom of the page, alerting them to the potential for ChatGPT to produce unreliable information regarding individuals, locations, or factual details.

One approach to overcome limitations in such AI models for specific tasks is the integration of structured private knowledge into LLMs. This injection allows models to better understand concept relationships, offering accurate answers to specific questions. Diverse indexing data structures (IDSs), including b-trees, hashing, vector storing, skip-lists, and graphs, can facilitate the incorporation of private datasets into LLMs for information retrieval purposes (see information retrieval related details in Ref. [31]). The choice of an index structure depends on factors like dataset size, query types, and efficiency requirements. Commonly used for sorted data, binary trees and linked indexes excel in exact-match retrieval. Hash tables, on the other hand, efficiently handle exact-match retrieval with unique keys, yet may lack coverage for similarity-based retrieval in complex contents [32,33]. Vector store data indexes, known for versatility, represent data elements as high-dimensional vectors, facilitating similarity calculation using distance metrics [31]. These indexes precompute and store vector representations, enabling efficient holistic retrieval through similarity metrics like cosine similarity. They are particularly good in accuracy, proving valuable for indexing scientific literature and books. As they are resilient to noise and variations in the data, making them suitable for similarity-based retrieval in deep chatting scenarios. Moreover, vector store data indexes support various search algorithms like k-nearest neighbor (KNN) and support vector machines (SVM) for diverse query purposes [31,34]. The subsequent subsection explores the application of LLMs and IDSs in state-of-the-art review studies.

2.2. *ALARM: AI-supported literature review methodology*

This paper presents a novel review framework called ALARM, which aims to explore and understand the state-of-the-art in any scientific topic. The methodology, depicted in Fig. 1, requires close cooperation between an expert in the given field and AI tools. Its purpose is not to create a black box that can be used without any understanding of the field. Step 1 involves collecting literature from academic databases by an expert. While this step is universal, for the purpose of this review, only the Web of Science (WoS) database has been utilized. Many recent review studies in the field focus on WoS database due to its rigorous selection process, higher quality content, extensive coverage (e.g. Refs. [35–37]), and reputation as a principal source for state-of-the-art research in the field (e.g. Refs. [38–40]). The review focuses on studies conducted since 2000 and primarily identifies relevant literature through specific keywords related to transportation systems in earthquake-prone areas. These keywords encompass synonyms for “transport” (e.g., mobility, transportation, road, rail, metro, airport, logistics) in conjunction with topic terms (system, network, planning, strategy, service, functioning), as well as synonyms for “seismic” (e.g., earthquake, earthquake-prone, seismicity) in conjunction with topic terms (hazard, risk evaluation, emergency, preparation, mitigation, response, recovery).

The data collection process involves reading the abstracts to filter for relevance to the topic to select relevant literature. The literature investigation resulted in a collection of 79 articles. Among these, 36 articles provide general information about the investigated topic components, while 43 articles specifically focus on the practice considering the transport system and seismic events. Note that during the review, additional important citations not included in the initial search are also discovered and added. Within step 2, an expert prepares key research questions based on the abstracts including comparative inquiries to be used for a starter of deep level chatting with each article.

Step 3 defines the structured specific knowledge by indexing the selected papers and injects this semantic meaning into a LLM while step 4 is a dynamic process of converting the expert queries into vector representations and the selection of a search algorithm. In the step 4, the research queries prepared in step 2 are fed into the LLM as starter and literature chat is conducted with the papers. In this study, we employ LlamaIndex[1] (version_5.21) as a toolkit for generating IDSs in conjunction with the LLMs. LlamaIndex utilizes the Langchain[2] pack to define an LLM model and create an IDS based on the provided data. Both tools are written in Python and are MIT-licensed. To define the LLM, we utilize the author’s personal OPENAI-API, specifically used the DAVINCI-003 model. Although we also tested the recent GPT-4-0314 model, we found that it produced similar answers with minor nuances. Therefore, we decided to keep with mainly the DAVINCI-003 model for cost-efficiency reasons, as utilizing the API of each OPENAI LLM incurs costs for data indexing and querying (see details in OPENAI page). LlamaIndex offers vector-store indexing capability, which we employ in this study. For each collected article, we create a vector store index that incorporates the LLM and store it as a JSON file. LlamaIndex provides several search algorithms such as KNN, SVM, linear regression, and logistic regression for analyzing the input data. After testing all the options, we prefer KNN, a non-parametric model, due to its robustness against outliers and noise in the data, resulting in clearer and more reliable querying. In the KNN algorithm, the choice of the parameter k directly impacts the number of nearest neighbors used to estimate the similarity between the query and the data points [34]. In this study, we set k as 2 for most cases, occasionally using higher to obtain a more comprehensive perspective. Last step is the harmonization and integration of extracted information by an expert to

[1] https://github.com/jerryjliu/llama_index.
[2] https://github.com/hwchase17/langchain.

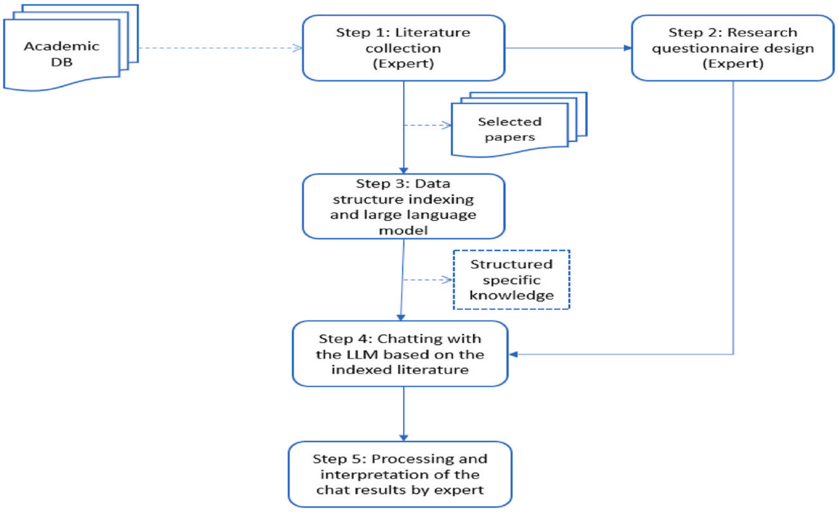

Fig. 1. Alarm framework.

produce the state-of-the-art analysis as demonstrated in the next section.

Supplementary materials include additional details and example conversational means generated by the AI in response to the expert queries using the collected literature as well as how the video abstract of this study is created by using knowledge graphs and GPT-4. Given that the focus of the present review is a complex and multifaceted process with various dimensions to consider, it is crucial to test the proposed approach within this context to assess its scientific capability. The obtained results from the chats are highly promising. Upon reviewing the articles alongside the AI-generated answers, experts would observe the quality and level of detail provided by the AI in retrieving relevant information. Each answer is thoroughly cross-checked against the outputs and articles by the authors, ensuring usability and correctness. The information provided by AI in this specific topic is correct, useful, and sufficiently detailed, enabling a professional review with harmonizing these outputs by experts, that facilitates an understanding of the state-of-the-art situation in transport planning strategies for earthquake-prone areas in this study, as presented in the subsequent section. Furthermore, it is important to emphasize the time-saving aspect of this approach. Obtaining an answer to a query can now be accomplished within seconds, depending on the complexity of the query. The ability to access such high-quality integrated information in such a short period is immensely valuable, especially when processing critical information efficiently.

3. STATE–OF–THE-ART review: transport planning strategies in earthquake prone areas

3.1. *Conceptual background*

The term “vulnerability” and “resilience” within the context of transportation systems has led to confusion due to the abundance of available indices (see Ref. [48] for terminologies) in which vulnerability is conditional for seismic scenarios, closely related to the concept of risk, encompassing two essential components: probability and consequence [41,42]. Transport-related consequences or costs of a seismic risk involve losses in terms of life, health, environment, or their combination resulting from the vulnerability state of transport components after a specific earthquake magnitude [7,16,43]. Therefore, seismic performance assessment of transport systems is crucial for evaluating ability to mitigate failure probabilities, risk consequences, and recovery time [13].

The vulnerability or exposure state of a transport system can be determined by estimating physical losses or significant degradation of system components [11,41]. Seismic vulnerability directly impacts consequences and recovery time, influenced by the design and construction quality of transport infrastructure [10,16–20,44,45]. Identifying critical elements within the system and developing strategies to mitigate seismic risk is crucial for ensuring system resilience in the face of seismic hazards. Moreover, it should be noted that the consequences of transport-related seismic risk can vary widely depending on urban fabric conditions [46], operational performance, and demand patterns [47]. For instance, a damaged bridge or a collapsed tunnel can lead to significant transportation-related costs, resulting in obligatory operational pattern changes and emergency delays. Meanwhile, the obstruction of urban roads near residential zones can cause severe accessibility issues for a large population trying to reach critical locations. In this article, we focus on a comprehensive exploration of seismic risk evaluation in transport planning based on the existing WOS literature. We address factors involved, challenges faced, methodologies employed, and how transport-related seismic risk is assessed to create transport strategies in the WOS literature. Understanding these strategies can assist urban planners and policymakers in decision-making and the development of new methods.

The state-of-the-art situation regarding the seismic risk evaluation of transport systems was examined from simplistic to complex under the following two main topics. By synthesizing the responses obtained from the literature chat with the AI, a comprehensive overview of the topic providing a holistic understanding of the seismic risk evaluation of transport systems was achieved.

1. Reinforcement Planning: This aspect primarily focuses on estimating transport system damage following potential earthquakes to identify component fragility and critical elements. It involves the development of preparedness, mitigation, and recovery plans to enhance system resilience by considering various approaches such as urban fabric, economy, population exposure, and combined perspectives.
2. Emergency Demand Management: This perspective enhances disaster response by incorporating operational resilience and changes in demand patterns into risk evaluation. It emphasizes the management of emergency situations, including resource allocation, emergency route planning, evacuation planning, and response actions to effectively address post-quake demands through reinforcement planning.

3.2. Reinforcement planning

This section focuses on estimating earthquake-induced damage to transportation systems, aiming to identify component fragility and critical elements. It involves developing plans for preparedness, mitigation, and recovery to enhance system resilience, considering factors like urban fabric, economy, population exposure, and holistic perspectives. Table 1 provides a summary of reinforcement planning studies, which are further explained below.

Table 1
Summary of studies primarily focused on reinforcement planning.

Study	Main Factors	Main Challenges	Methodologies	Seismic Risk Evaluation
[19]	Road geometry, built environment	Road disruptions, old dense cities, networks dependent of critical infrastructures	Object-oriented modeling, Monte-Carlo simulation (MCS), joint probability models	Impact distribution of road network's seismic performance
[76]	Road hierarchy and proximity of main resource centers	Rural system	Topology-based simulations (GCC), MCS	Recovery behavior and serviceability
[77]	Road network, built environment	Road disruptions, big cities	Topology-based simulations (GCC)	Network resilience
[58]	Transport systems and lifelines	Big cities, interdependencies between systems	Fragility functions (FF), GIS simulator	Damage state mapping and indirect economic impact
[78]	Road network, built environment	Road disruptions, big cities	FF, MCS, Bayesian network	Spatial distribution map of system-level resilience loss
[17]	Bridge oriented network, schools, hospitals, and civil protection centers	Regional system, network dependent of critical infrastructures	FF, vector-valued attenuation law	Accessibility and rescue ability
[68]	Road classification and geometry, built environment	Road disruptions, old dense cities	FF	Accessibility risk and response capacity indexes
[64]	Circular tunnels, soil types	Critical system	FF	Vulnerability index for metro system design and construction
[43]	Bridge oriented network	Network dependent of critical infrastructures	FF, GIS-based software tool	Damage state mapping
[63]	Bridge oriented network	Network dependent of critical infrastructures	FF, ArcGIS software	Integrity index based on CPIM
[6]	Road network, built environment	Budget constraints, historical city centers	Link failure model, MCS, investment model	Accessibility and economic impact
[65]	Port components, terminal operation	Critical system	FF, simulation models	Damage state mapping of seaport transportation systems
[74]	Bridge-oriented network	Budget constraints, network dependent of critical infrastructures	FF, MAEViz package for repair cost model	Damage and economic state mapping
[73]	Road network, origin-destination pairs	Budget constraints, big cities	FF, two-stage stochastic program	Traversal cost optimization
[69]	Road geometry, built environment	Road disruptions, old dense cities	Fuzzy multi-criteria decision-making analysis, centrality measures	Damage intensity mapping, betweenness centrality index
[72]	Road network, built environment	Road disruptions, historical city centers	Weighting approaches (Modified Cherubini's approach, expert judgement approach, and analytical hierarchy process)	Seismic risk & intervention priority maps
[70]	Road geometry, built environment	Road disruptions, historical city centers	Indexing based on macro damage levels (EMS-98)	Vulnerability index, blink Index
[66]	Urban areas, BRT network	Highly vulnerable areas	Macro-level design approach utilizing multi-agent programming and meta-heuristic solution procedure	Transit oriented development performance and rescue ability
[11]	Road network	Rare strong earthquakes, big cities	FF, MCS, GIS tools	Damage state mapping
[75]	Railway system components	Budget constraints, critical system	FF, binary nonlinear stochastic programming, MCS, genetic algorithm	Minimization service loss
[71]	Road geometry, built environment	Road disruptions, historical city centers	Fuzzy logic	Functionality of urban road networks

3.2.1. Basement

Choosing seismic reinforcement strategies for transport systems involves a crucial decision-making process, requiring a deep understanding of seismic hazard levels and the vulnerability of transport elements. In earthquake-prone regions, effective transport planning depends on a thorough understanding of local geological conditions and the specific effects of seismic events at various intensity and frequency parameters, including peak ground acceleration (PGA), peak ground velocity (PGV), peak ground deformation (PGD), and spectral acceleration (SA) [49,50].

Seismic impact on transport systems is commonly assessed through fragility analysis, utilizing both analytical and empirical approaches (see Refs. [51,52] for details). Empirical fragility curves, based on past seismic event data, estimate damage probabilities at different ground motion intensities. Analytical fragility curves, derived through dynamic analysis, model the behavior of transport structures to predict responses to future earthquakes, proving valuable for complex geometries and limited empirical data situations [53]. Soil-structure interaction significantly affects the reliability of these analytical curves, making it crucial to account for it in their construction [54]. Some studies integrate local soil characteristics (see [53,55,56]) and secondary hazards such as landslides and liquefaction [see 42,57] in their analytical frameworks.

The choice of anti-seismic reinforcement strategies for transport systems is contingent upon the nature of the infrastructure. For instance, bridges may require seismic bearings, isolation systems, and damping devices to absorb and dissipate seismic energy while tailored track bed and ballast designs could be beneficial for railways to mitigate the impact of ground motion. On the other hand, tunnels may demand special lining materials to avert collapse or buckling. Numerous reviews have been conducted on the fragility of specific transport elements, encompassing highways (see Ref. [17]), railways (see Ref. [19]), and underground systems (see Ref. [20]). Analytical and/or empirical fragility curves for transport components are commonly constructed using two prominent software tools in the literature: SYNER-G and HAZUS versions. SYNER-G, designed primarily for European and Mediterranean countries, integrates diverse models and methods for risk assessment, covering physical and social vulnerability, hazard analysis, and consequence analysis [58,59]. On the other hand, HAZUS, specifically tailored for the United States, places greater emphasis on physical damage and loss estimation, incorporating US-specific data and models [60,61].

Addressing earthquake losses is a multifaceted and stochastic challenge, demanding an examination of the intricate interconnections among the economy, social dynamics, and transportation networks [42]. The evaluation of acceptable risk in transportation systems involves weighing the advantages of implementing anti-seismic reinforcement measures against the potential consequences of seismic events. Various criteria, such as population exposure, economic consequences, and urban fabric-induced impacts, are taken into account when assessing seismic risk in transportation systems. These elements play a pivotal role in the decision-making processes associated with transport planning. The following overview presents a spectrum of approaches, ranging from basic methods to comprehensive strategies.

3.2.2. Simplistic approach

Several studies have addressed seismic risk assessment in transportation systems, adopting a one-dimensional approach. This involves creating damage state maps through fragility functions and GIS tools to evaluate the intrinsic vulnerability of these systems. The primary goal is to pinpoint critical elements for reinforcement strategies in the face of seismic uncertainties. For instance, Wang et al. [10] applied fragility functions (based on empirical data and HAZUS) and Monte-Carlo simulation (MCS) to assess seismic risk in Tangshan's roadway system. Through simulating the road network under various ground-motion intensities, they generated damage state maps, allowing for a quantitative analysis of potential damage. The study highlighted a significant seismic risk for Tangshan's road network during rare strong earthquakes, while indicating its functionality for earthquakes with a 10 % probability within a 50-year timeframe.

In another study, Kappos et al. [42] analyzed the seismic risk of Western Macedonia's inter-urban highway system. They developed fragility curves specific to Greek bridge types, factoring in local soil conditions. Introducing a GIS-based software, the team mapped damage conditions, aiding in seismic risk management for decision-making in design, construction, and maintenance of highway systems. This tool was particularly beneficial for emergency response planning, especially for transport systems relying on critical elements like bridge-oriented roadway systems. Meanwhile, a study [62] proposed an integrity index for seismic risk assessment in bridge-oriented networks, utilizing ArcGIS to model Los Angeles. Employing damage estimations and analytical fragility functions, they calculated conditional probability importance measure (CPIM) values for each link. Analyzing the CPIM range, the study assessed the network's recover ability to seismic hazards. The integrity index yielded crucial insights for identifying critical components and formulating retrofit strategies, ultimately minimizing network disruption.

Huang et al. [63] focused on the seismic risk evaluation of the Shanghai metro system. They developed analytical fragility curves to assess damage probability and formulate a vulnerability index for circular tunnels at various depths, accounting for different soil types. This proposed vulnerability index offers valuable insights for designing and constructing metro systems in seismic urban areas, aiding in the development of strategies to mitigate earthquake-induced damage. In another investigation [64], a study assessed seismic risk in seaport transportation systems by integrating simulation models for terminal operation with analytical fragility curves of port components. Using the ARENA software package, they developed a simulation model considering probabilistic seismic hazard and damageability of port facility components, validated with actual seaport records from South Korea. The study's outcomes contribute significantly to improving seismic retrofit projects in coastal cities.

3.2.3. Urban fabric approach

Extrinsic vulnerability approaches are commonly employed in the literature to address the high susceptibility of transportation systems to specific seismic events cause of urban fabric conditions, particularly in densely populated cities, city centers, and historic districts. For instance, one study [65] focused on enhancing seismic resilience in earthquake-prone old metropolitan areas, using Ahvaz City as a vulnerable case study. Recognizing the pronounced vulnerability, the study offered a macro-level approach to reshape city design. The study proposed a transit-oriented development, involving the renovation of deteriorated urban areas and the establishment of a bus rapid transit network. To facilitate collaboration among the government, private investors, and residents, a multi-agent programming framework was employed, along with a meta-heuristic solution procedure to address the associated challenges. The findings indicated that the suggested investments were anticipated to significantly reduce travel time, increase transit ridership, and enhance earthquake safety, potentially rescuing over 150,000 inhabitants from the threat of severe earthquakes.

Argyroudis et al. [66] used an object-oriented modeling approach to analyze seismic risk effects on dense city road networks. They used an object-oriented modeling approach to break down the problem into interacting objects representing the road network, built environment, and other relevant systems. MCS and joint probability models assessed system performance, accounting for uncertainties. Their approach, applied to Thessaloniki's road network, assessed the impact of building collapses and damaged bridges, highlighting vulnerabilities in older structures lacking seismic design, providing crucial insights for preparedness strategies. Another study [67] focused on seismic risk assessment in other dense city, Tehran's urban road network. They developed accessibility and response capacity indexes based on road classification, fragility curves, road blockage forecasts caused by potential debris; aiding identification of high-risk areas for road disruption and informing alternative route planning and evacuation strategies in urban centers.

Pouryari, Ardakani, and Hassani [68] proposed a framework to assess seismic risk in Tehran's central street networks. Their method integrated fuzzy multi-criteria decision-making with centrality measures based on expert judgment, considering factors like building characteristics, earthquake intensity, and road geometry to determine the road blockage index. The betweenness centrality index measured traffic potential at different network links and nodes. The study produced intensity maps, identified regional vulnerabilities, and highlighted critical paths, aiding pre-quake reinforcement strategies. One study focusing also central streets [69] employed a macro-seismic approach to evaluate road seismic risk in Civitanova Marche's city center, introducing the Blink index to assess link blockages and enhance emergency and evacuation routing information in historic areas. The study utilized readily detectable data on the geometry and vulnerability features of streets and nearby buildings. Calculating vulnerability indexes for both buildings and links, they assessed potential street blockages influencing street accessibility resulting from critical damage levels. Another study [70] used fuzzy logic to assess post-earthquake road network functionality in the historical Conegliano district. They examined residual road geometry, evaluating its impact on accessibility due to building collapses. The study found overall good network functionality after a simulated earthquake (Mw 6.3), but also identified specific connectivity issues in certain main street segments, useful for highlighting privileged areas for reinforcement.

Quagliarini et al. [71] developed a holistic methodology to assess the seismic risk of evacuation routes in city centers, considering factors like intrinsic vulnerability, seismic hazard, and exposure conditions. Different weighting approaches (modified Cherubini's approach, expert judgement approach, and analytical hierarchy process) were used to evaluate the factors, and the risk index was normalized based on a selected case study for Offida. The methodology effectively applied to paths in earthquake-damaged historical urban areas, displaying its potential for generating seismic risk and intervention priority maps. This enables a nuanced understanding of risk variations between routes, offering valuable input for developing emergency routing strategies in city centers.

3.2.4. Economic approach

When formulating anti-seismic reinforcement strategies, the economic consequences play a crucial role. Azevedo et al. [57] focused on the seismic vulnerability of urban transport systems (highways and railways) considering other bonded lifeline systems (such as water supply systems, electric power supply systems, and liquid and gas fuels) in the greater Lisbon area which economic activities cannot be operated without. The study employed the HAZUS99 methodology and a GIS simulator to assess the structural damage of transport systems and bonded lifelines, as well liquefaction potential. The study indirectly assessed economic impact by examining interdependencies among various lifeline systems (e.g., disruptions in the power network affecting the railway network). While it is a rare example of incorporating bonded lifeline systems in transport risk assessment, the authors did not delve deeper into economic relations using economic models.

Li and Zhou [6] focused on cost-effective risk mitigation strategies for historical city centers considering budget constraints, proposing an empirical method to optimize investments based on post-earthquake road network resilience in Shanghai. Their study utilized a predictive model considering debris effect to calculate link connectivity probability, assessing accessibility through MCS. The findings suggested that matching the investment budget with the inflection point significantly improved network accessibility (e.g., a ¥1,500,000 investment resulted in a 3.83 % resilience improvement). Another study [72] presented a two-stage stochastic program for strategic planning in seismic management of transportation networks under budget constraints. Their model, applied to the urban highway system in Istanbul, minimized expected traversal costs considering fragility curves and stochastic network behavior, effectively addressing investment decisions and trade-offs.

Padgett, DesRoches, and Nilsson [73] conducted a seismic risk assessment of bridge-oriented networks in the Charleston region, focusing on economic losses. They employed the MAEViz seismic risk assessment package, utilizing fragility curves for the Central and Southeastern U.S. to estimate probabilities of different damage states. The study incorporated repair cost models to assess direct losses and identified critical elements for retrofit investments, such as emergency routes, by evaluating various damage states and economic losses through multiple scenario events. Yan et al. [74] investigated seismic risk in the Chinese railway system considering budget constraints. They employed a comprehensive methodology, calculating ground motion intensities, estimating failure probabilities using HAZUS fragility curves, and conducting MCSs to assess affected trains and service loss. The study introduced a binary nonlinear stochastic programming optimization model, solved with a Genetic Algorithm, to identify critical railway stations and edges for

Table 2
Summary of studies focused on demand management.

Study	Main Factors	Main Challenges	Methodologies	Seismic Risk Evaluation
[93]	Highway system, operational transport performance, recovery period	Interurban systems	Aimsun traffic simulation software	Simulation model evaluating system resilience and accessibility based on static pre-quake demand
[97]	Roadway system, emergency services, demand patterns	Dense urban areas, modeling post-earthquake demand patterns	Two-stage stochastic programming model, multi-commodity & multi-modal network flow problem	Model quantifying information value for emergency response
[4]	Road network, emergency facilities, demand patterns	Modeling post-earthquake mobility patterns	Trip distribution and assignment model, variable demand model (VDM) analysis	Simulation model considering post-earthquake demand changes
[7]	Logistics, bridge-oriented highway network, logistic demand patterns	Budget, network dependent of critical infrastructures, modeling post-earthquake demand patterns	FF, comprehensive regional transport and economic model	The model considering post-earthquake logistic demand changes and spatial distribution of economic impacts
[47]	Roadway system, operational performance	Old cities	FF, MCS, Quake Engine, traffic micro-simulator (SUMO)	Simulation model evaluating system resilience and accessibility based on static pre-quake demand
[86]	Roadway system, operational SAR performance	Old big cities	Developing a heuristic algorithm	Death toll
[96]	Bridge oriented highway network, demand patterns	Network dependent of critical infrastructures, Modeling post-earthquake mobility patterns	Agent-based model, equilibrium model, real-time dynamic traffic model	Simulation model considering post-earthquake demand changes
[90]	Bridge-oriented network, operational performance	Network dependent of critical infrastructures, big cities	Decision support framework based on two-stage stochastic programming	Strategy optimization based on minimizing travel time
[89]	Bridge-oriented network, operational performance	Network dependent of critical infrastructures, big cities, extreme earthquakes	USGS Shake-Maps and vulnerability surface (VS) approach	VS tool combining network damage conditions, betweenness centrality, and accessibility, and trip change statue.
[98]	Roadway system, demand patterns	Old dense cities, modeling post-earthquake mobility patterns	Traffic assignment techniques, accessibility indexes, expert judgments	Redundancy-based isolation index
[95]	Bridge oriented highway network, demand patterns	Budget, network dependent of critical infrastructures, modeling post-earthquake travel patterns	FF, VDM	Simulation model considering post-earthquake demand changes and repair costs
[8]	Road network, hospital availability and proximity, operational transport performance	Dense city	FF, system dynamics simulation	Simulation model evaluating system resilience and accessibility in terms of expected loss of human life based on static pre-quake demand
[94]	Logistics system, railways, recovery period	Budget constraints, critical and large System	Two-stage stochastic program, MCS, L-shaped method	Network resilience as the expected fraction of logistics demand satisfying the post-disaster situation
[48]	Highway system, operational transport performance, recovery period	Urban and interurban systems, budget constrains	FF, GIS-based analysis, ASR	Social life cycle costs
[9]	Roadway system, emergency services, demand patterns	Designing emergency transportation networks	Lexicographic and weighted approaches, branch-and-cut algorithm, reliability-based resource-allocation model	Critical routes considering trade-offs between conflicting objectives
[10]	Transportation system (roads, bridges, tunnels, metro stations, and railway systems), operational transport performance	Dense cities, multimodality	FF, data envelopment optimization (DEA) model, dynamic traffic modeling (DTA)	Simulation model evaluating system resilience and accessibility based on static pre-quake demand
[88]	Bridge-oriented network, operational performance	Network dependent of critical infrastructures, big cities	System risk curves and MCS	Travel delays, annual probability of exceeding seismic impacts on system operation
[100]	Bridge-oriented roadway systems, hospital functionality (structural, service staff, demand points)	Network dependent of critical infrastructures, modeling post-earthquake geographic and service accessibility	FF, attenuation model, urban traffic capacity analysis, modified 2SFCA methods	Health-care service accessibility under travel time thresholds.
[91]	Bridge-oriented highway system, operational SAR and transport performance	Regional systems, network dependent of critical infrastructures	FF, MCS, holistic framework quantifying urgency of emergency medical service, operational & transport time.	Search-and-rescue activity performance and the decay of life vitality
[92]	Highway system, operational transport performance, recovery period	Interurban Systems	Microscopic traffic flow model, Statistical methods (poisson regression, negative binomial regression, cellular	Resilience indicator combining traffic efficiency and safety, assessing the time-progressive system performance

(continued on next page)

Table 2 (*continued*)

Study	Main Factors	Main Challenges	Methodologies	Seismic Risk Evaluation
			automata model), MCS, Greedy algorithm	
[5]	Rail system, operational performance	Critical and large system	Experimental fragility curves and MCS	Seismic risk maps combining damage and operational performance

strengthening within a limited budget. This approach aimed to minimize expected service loss from earthquake hazards, showcasing its superiority over topology-based methods in addressing seismic impacts on the railway system.

3.2.5. Population exposure

Certain studies take a people-centered approach when assessing seismic risk in transportation networks, especially in areas with low accessibility and limited access to rescue centers, like rural regions. Franchin et al. [16] focused on Italy's Apennine region, evaluating seismic hazard in its roadway system. Using fragility curves for infrastructure components like bridges, schools, hospitals, and civil protection centers, the study aimed to determine failure probabilities and assess rescue losses in a specific earthquake scenario. By incorporating vector-valued attenuation law and fragility curves, the research estimated potential challenges for people attending schools and those requiring medical treatment due to road closures or unavailable hospitals. The results emphasized the critical role of a reliable road network in facilitating rescue operations and providing timely access to medical facilities. This information is valuable for prioritizing road and bridge upgrades, effective allocation of maintenance resources, and identifying areas in need of additional infrastructure. Another study [75] focusing on seismic risk in rural road networks proposed a framework that combines intuitive decision-making and analytic modeling for improved understanding of recovery behavior and serviceability. Using topology-based simulations like the Giant Connected Component (GCC), they assessed various road recovery strategies based on metrics such as mean recovery time, recovery efficiency, and uncertainty magnitude through MCSs. Considering factors like road hierarchy and proximity to resource centers, the study aimed to develop effective strategies mitigating earthquake and landslide impacts on rural roads. The research, applied in earthquake-affected Sindhupalchok, Nepal, after the 2015 Gorkha earthquake, demonstrated the practicality of their proposed methodology.

3.2.6. Multi-dimensional approaches

In the analysis of seismic risk in complex urban environments, some studies consider multidimensional metrics to assess the resilience of transport systems. One study [76] introduces a methodology that combines graph theory and stress testing to evaluate transportation network resilience during seismic events. The study utilizes graph-based metrics (using GCC) to analyze the system's response and to manage risks. Resilience is evaluated based on network efficiency, robustness, node criticality, and road blockage data. The methodology includes creating seismic damage scenarios, assessing resilience with graph metrics, conducting topology-based simulations, evaluating metric changes, and examining critical nodes and network topology. When applied to the Kathmandu Road network, this method reveals a noteworthy decline in network resilience concerning efficiency and robustness, even with the loss of just 2 % of intersections. Byun and Ayala [77] conducted a comprehensive seismic resilience analysis of Istanbul's transportation network. The study assessed resilience loss at origin vertices, estimating system functionality loss through probabilistic analysis. Structural damage to roadways was evaluated using fragility curves from SYNER-G and HAZUS-MH26, along with additional disruption from debris potential. The analysis incorporated various models and assumptions, including data acquisition, harmonization, Bayesian network quantification, and MCS. Bayesian network graphs encompassed seismic hazard, physical damage, structural repair, debris clearance, and traffic disruption models. MCS involved numerous random variables to capture diverse distributions of resilience loss values. Results included spatial distribution of system-level resilience loss, kernel distributions for edges affected by direct and indirect disruptions, and percentage differences in resilience loss measures with and without indirect disruptions. The study presented a resilience measure map to examine disruption inequality, identify critical factors influencing system resilience, estimate functionality loss, and guide decision-making for enhanced community resilience and equality among neighborhoods.

3.3. Emergency demand management

The effective and secure transportation of individuals and goods after seismic events are of paramount importance in earthquake-prone areas. To comprehensively delve into the concept of emergency demand management, it is essential to pinpoint key areas of investigation. This involves developing flow models for networks facing degradation and congestion to comprehend operational dynamics and establishing routing and allocation strategies under uncertain conditions (see Refs. [78–83] for general view of the topics). This section delves into the subject matter through two main headings, each with two subsections. The primary approach for incorporating demand into the seismic risk evaluation of transport systems is scenario analysis. Typically, empirical operational records, surveys, and OD matrices reflecting actual demand patterns disrupted by seismic-related transportation disturbances are manipulated (e.g. Ref. [46]) to comprehend operational performance. Understanding how individuals or goods are likely to distribute during earthquakes involves the integration of stochastic approaches and variable demand models (e.g. Ref. [84]) or more advanced simulation tools. Employing both approaches aids in formulating strategies, including the development of alternative transportation routes, especially to critical facilities [8], establishing evacuation plans and emergency shelters [85], and mobilizing services and industrial flows for the post-quake situation [7,87]. Table 2 shows a summary of studies focused on emergency demand management, which is detailed below.

3.3.1. Operational performance

This subsection examines the evaluation of operational performance in transportation networks during seismic events, focusing on methodologies and their impact on overall system functioning. Shiraki et al. [88] developed an approach combining seismic hazard analysis and mobility disturbance expectation (utilizing S. California OD survey data for traffic zones). The study created system risk curves by integrating bridge and link damage indices to estimate changes in link capacity and free-flow speed. Through MCSs, they assessed travel delays, offering insights into the annual probability of exceeding seismic impacts on system operation. Zhu et al. [5] evaluated seismic risk in the Chinese rail system by generating earthquake catalogs and intensity maps using MCSs. They built a failure fragility curve based on earthquake-induced train disruption records. Such modeling the Chinese railway system as a network allowed for a comprehensive assessment of direct physical damage and affected train flows. The results, presented as seismic risk maps, assist in resource allocation, safety measures, and emergency response planning for public transport systems. Another study [94] proposed a two-stage stochastic program for optimizing preparedness and post-disaster recovery in intermodal freight railways within limited time and resource budgets for the Western U.S. disaster scenarios. They measure network resilience as the expected fraction of logistics demand satisfying the post-disaster situation. The study employs MCSs and the L-shaped method to address uncertainties and solve the stochastic program (assuming as freight travel times increase in proportion to capacity decrease). The results demonstrate the effectiveness of implementing both preparedness and recovery activities resulted in improving resilience 18 %.

Kermanshah and Derrible [89] evaluated the operational vulnerability of transportation networks in Los Angeles and San Francisco through a comprehensive vulnerability surface (VS) approach. They integrated various metrics like network damage condition, betweenness centrality, accessibility, and trip change status by utilizing surveys of longitudinal employment & household dynamics into a spider diagram. By employing USGS ShakeMaps, vulnerable roads were identified and subjected to simulation of extreme earthquake conditions. The findings revealed that Los Angeles road network is more susceptible to extreme earthquakes compared to San Francisco, leading to significant operational losses. The proposed VS approach can be useful as a quick system operation assessment tool especially for extreme seismic scenarios. Another study [90] proposed a decision support framework for managing seismic risks in complex transport networks. The study framework prioritizes retrofit and repair decisions based on travel time as a performance metric. Using two-stage stochastic programming to address uncertainty, the optimization process involves a master problem and sub-problems dedicated to minimizing repair costs while achieving performance targets by using optimality cuts and the L-shaped approaches. The study demonstrated the framework's success in identifying optimal retrofit strategies for the San Francisco highway system, minimizing costs and consequences while meeting operational performance targets, specifically preventing travel time delays between selected origin-destination pairs. Costa et al. [47] conducted a seismic risk assessment of the Messina roadway system, integrating dynamic functionality and traffic conditions through earthquake and traffic simulation tools like Quake Engine and SUMO. The study addressed uncertainties related to exposure models, seismic hazard models, and fragility/vulnerability functions using MCSs. They evaluated road network disruption and its impact on mobility demand, exploring various traffic demand models to assess system resilience and accessibility to essential services during emergency response. One related work [10] proposed an integrated seismic risk and resilience assessment methodology for urban transport systems in the southwest district of Mexico City, taking travel demand into account. The study considered diverse elements such as roads, bridges, tunnels, metro stations, and railway systems, incorporating factors like structural characteristics, soil properties, and mobility patterns. Employing SYNER-G analytical fragility curves, they modeled the structural vulnerability of the transport system. The study utilized data envelopment optimization (DEA) to evaluate operational network efficiency and dynamic traffic modeling (DTA) to simulate damage-induced road closures and changes in mobility patterns. While providing valuable insights for managing emergency demand during the response phase, important to note that the study assumes only a constant trip among origins and destinations.

Kuwata and Takada [8] examined post-earthquake emergency transportation, focusing on Amagasaki City. They utilize a system dynamics simulation to model the movement of injured individuals, evaluating the reliability of roadway links in malfunctioning transportation systems by assessing the expected loss of human life. The simulation considers seismic vulnerability of the road network by using empirical fragility functions to estimate time delay uncertainty based on pre-earthquake OD demand, road link capacity, hospital availability, and proximity to accessible hospitals. The research underscores the significance of considering road network conditions, traffic congestion, and hospital accessibility when formulating emergency transportation strategies. In another study, Edrissi et al. [86] introduced the concept of an emergency response reliability network to evaluate overall transportation network operation during earthquake responses. This measure considers zonal travel times, supply and demand levels (evacuees and travelers at the earthquake onset), and sensitivity to the level of service. The researchers developed a heuristic algorithm to address the emergency response problem, calculating measures of effectiveness such as death toll. The study underscores the importance of selecting an appropriate level-of-service value to identify critical links in the network for retrofitting in emergency response scenarios. The results demonstrate that with a budget of 10 billion IRR, reinforcement efforts can significantly reduce transport-induced casualties in Tehran. A recent study [91] proposed an integrated framework that combines post-hazard emergency response and pre-hazard mitigation planning specifically tailored for bridge-oriented highway systems in the context of the Shelby County earthquake case. Their approach involves assessing the resilience of transportation networks by considering factors such as infrastructure fragility, seismic uncertainty by using MCSs, demand for search-and-rescue activities (which considers operational and transportation time for severely injured individuals requiring emergency medical services), and the deterioration of life vitality (quantifying the urgency of emergency medical service provision). The research underscores the importance of strategically allocating resources for the reinforcement of bridge networks to enhance the capacity for emergency medical response based on a thorough analysis of bridge retrofit costs and their corresponding effects.

Wu, Hou, and Chen [92] proposed a method to evaluate time-progressive resilience of transportation networks for the post-earthquake recovery period. Using a microscopic traffic flow model that accounted for varying origin-destination demand and lane closures conditions based on Centerville highway network fragility functions, the study introduced a resilience indicator blending traffic efficiency and safety. Employing statistical approaches like poisson regression, negative binomial regression, and cellular automata model, along with MCSs, they prioritized bridge restoration using the Greedy Algorithm to assess network resilience in the recovery period. Another study [93] focused on evaluating the seismic performance of road networks using the Aimsun simulation software. They assessed network accessibility, road vulnerability to closure, and restoration time estimations for a New Zealand earthquake scenario. The study analyzed supply and demand data considering adjusted origin-destination matrices and static path assignments. Through analyzing trip distribution in the region at various post-earthquake timelines, they provided a model into the influence of accessibility issues on trip patterns and costs, informing risk mitigation strategies for emergence response. Nagae et al. [48] introduced a practical approach to assess anti-seismic reinforcement (ASR) for transportation facilities in the Kobe region. They developed fragility curves considering seismic intensity and facility capacity, utilizing GIS-based analysis to compute transportation disutility and anticipated restoration costs. The study factored in traffic congestion and pre-quake travel patterns of route choice to evaluate ASR strategies' effectiveness. Applied to a test case network in Kobe's urban and suburban area, this method significantly reduced social life cycle costs by approximately 40 %, resulting in a minimum cost of 114.5 billion yen for reinforcing target bridges compared to a scenario without ASR implementation.

3.3.2. Demand patterns

This section explores the dynamics of demand patterns in transportation networks for the aftermath of earthquakes, examining post-earthquake mobility behavior, variations in traffic capacity, spatial-sectoral impacts, and the planning of emergency response trips. Chang, Elnashai, and Spencer [85] enhanced a comprehensive model encompassing both trip distribution and assignment to simulate mobility patterns in transportation networks following an earthquake. Their case study involves the Sioux-Falls network and takes into account the impact of structural damage, emergency facilities, and reduced network capacity on travel behavior and trip demand. The study employs the Variable Demand Model (VDM) analysis, assuming a reduction in post-earthquake traffic demand based on observed behavior from prior earthquakes. This integrated approach yields more realistic outcomes compared to conventional traffic simulation models, underscoring the significance of acknowledging changes in travel demand after an earthquake. Similarly, another study [95] investigated the seismic risk of highway networks in California considering mobility disturbances. The article evaluates the risk in terms of travel delays and direct loss from damage to highway bridges by using HAZUS99 fragility curves to estimate repair costs. The study considers different scenarios for post-event traffic analysis and observes a decrease in total vehicle hours when VDMs are used. Feng, Li, and Ellingwood [96] used an agent-based model to simulate post-earthquake traffic patterns in Tangshan, focusing on the influence of bridge-oriented network damage and traffic capacity impairment on network congestion and travel behavior. Individual drivers are represented as agents with features like mental state, travel time, and queue information. The study explores the impact on network congestion and travel behavior, utilizing an equilibrium model for pre-earthquake conditions and a dynamic traffic model for post-earthquake scenarios. Results emphasize the role of drivers' mental state and access to information in shaping network performance during response and recovery. Optimal delivery areas for injured individuals are identified, underscoring the importance of a functional transportation system for timely hospital transportation. One recent study [100] introduces a comprehensive post-earthquake accessibility assessment framework for medium-sized Chinese cities. It incorporates debris impact and transport network disruption through probabilistic seismic fragility analysis. The results are then used to calculate post-quake travel time between demand points (based on population distribution data related to injuries and deaths) and service supply points (utilizing hospital distribution data). The study establishes time thresholds, a time decay function, and assesses hospital service capacities. Notably, it provides one of the most detailed post-earthquake accessibility analyses in the literature, considering both geographic and service (medical staff and patient beds) accessibility. The modified two-step floating catchment area method (2FSCA) is applied to evaluate healthcare service accessibility under travel time thresholds. The presented scenarios prove useful in identifying demand points lacking access to healthcare services, especially in major earthquake scenarios causing significant accessibility disruptions, providing a convenient tool for post-earthquake emergency rescue planning.

One study [7] employs a comprehensive regional transport and economic model to analyze the spatial-sectoral impacts of seismic costs on the Los Angeles highway system, focusing on alterations in freight transportation after seismic events. The integrated model includes empirical fragility functions for bridge and structure performance, transportation network models, spatial allocation models, and interindustry demand models. The study investigates the impact of bridge closures on total travel cost for both passenger and freight transport, route selection, and industrial structure losses. It considers the spatial distribution of economic impacts resulting from transportation structure losses and changes in travel cost. The findings highlight the interconnectedness of the transportation network and the broader economy, offering deep insights into the economic consequences of seismic events. The model also incorporates endogenous distance decay relationships (destination choice) and facilitates the spatial allocation of indirect economic impacts. Barbarosoglu and Arda [97] present a two-stage stochastic programming model for efficiently coordinating the transport of critical first-aid supplies in emergency responses within Istanbul's Avcilar region. The study views the physical transportation network as a comprehensive structure, treating the resource mobilization system as a probabilistic, multi-commodity, multi-modal network flow problem. The model incorporates a fixed structural component (first stage) and a control component (second stage), addressing uncertainty in input data. Validation using 1999 Marmara earthquake data demonstrates the model's effectiveness, and the study quantifies the expected value of ideal and stochastic information. This research yields valuable insights for planning emergency commodity transportation in densely populated urban areas during crisis situations.

Khademi et al. [98] propose a vulnerability approach for assessing post-earthquake response routes, with a focus on developing countries with highly vulnerable networks. The study offers valuable insights into critical routes for emergency response. Using traffic assignment techniques, the research evaluates post-earthquake network performance in the greater Tehran area, employing accessibility indexes like the Hansen integral accessibility index and vehicle miles traveled to gauge the impact of disruptions on network accessibility. Expert judgments derive disaster response trip patterns, assigned to spatial units through nominal group technique sessions. The study also introduces a redundancy-based isolation index and exposure indexes to pinpoint zones prone to transport system disruptions and better understand the vulnerability of emergency response trips. Nikoo, Babaei, and Mohaymany [9] conducted a comprehensive study addressing the Emergency Transportation Network Design Problem (ETNDP) in both the Sioux-Falls and Tehran networks. They minimize total post-travel time using a novel approach that combines lexicographic and weighted methods to handle conflicting objectives. The study integrates a branch-and-cut algorithm for survivable network design and a reliability-based resource-allocation model for earthquake-affected networks. While seismic hazards are not directly incorporated, the researchers introduce a vulnerability assessment based on network link analysis, offering insights into the probability of link failures due to earthquakes. Stochastic optimization models and a multi-agent approach capture post-earthquake changes in mobility patterns for emergency response trips. The study successfully identifies critical routes and considers trade-offs between conflicting objectives under various budget constraints, providing practical insights for decision-makers involved in emergency transportation network design. An earlier ETNDP approach, utilizing a goal programming framework, was also presented by another study [99], offering a simplified approach to solving the maximal covering network design problem.

4. Discussion

The planning of transport strategies in earthquake-prone areas requires the consideration of specific risk conditions and characteristics of study areas. Factors such as urbanization level and type, built environment, transport infrastructure type, critical components involved influence the selection and application of appropriate methods and approaches for transport strategy-making.

Oldtowns often have historical structures, residential buildings, and transport infrastructure that may be more vulnerable to seismic events. Such historical city centers often have a distinct urban form, with narrow streets, limited accessibility, heritage buildings, and limited space for transport infrastructure upgrades posing challenges especially for emergency response and evacuation planning. Planning transport strategies in these areas requires a careful balance between seismic resilience, preservation of cultural heritage, and maintaining the functionality of the transportation network. Transport strategies need to account for these constraints and ensure that aged infrastructures are detected for retrofitting and evacuation routes are identified and accessible. In the other hand, modern city centers often serve as major economic, commercial, and cultural hubs, making them critical areas to consider in earthquake-resilient transport planning. One key aspect of city centers is their high population density and intense urban activities. These factors can lead to high risk and demand for transportation services during post-earthquake, therefore transport strategies should focus on enhancing capacity and efficiency of transportation systems in these zones to accommodate a high volume of seismic-induced transport demand. Furthermore, city centers often experience higher levels of socioeconomic activities and rely heavily on transportation systems for commerce and trade. Disruptions to transport networks can have significant economic consequences including potential losses in productivity, business closures, and disruptions to supply chains. Collaborative efforts between urban planners, transportation authorities, and business stakeholders are crucial to ensure that transport strategies align with the economic resilience goals of city centers. While city centers and historical areas are important, regional areas play a crucial role in ensuring the overall resilience and functionality of the transportation systems, especially for emergency logistic. Regional point of view also includes the seismic planning for the suburban or rural areas. Rural areas in earthquake-prone regions present specific challenges due to their dispersed population and limited infrastructure. Transport strategies for these areas should prioritize emergency response and recovery efforts, ensuring access to critical services and supplies, especially for health-care services. Developing alternative routes and diversifying transportation options, such as using off-road vehicles, can help overcome the challenges of rugged terrain and limited road networks.

Transport systems exhibit significant variations such as city road networks, oldtown networks, interurban road networks, bridge-oriented highway networks, railways, and freight transport networks. The differences in these systems necessitate distinct approaches in seismic risk assessment and planning strategies. Understanding the specific considerations and methodologies for each transport system is crucial for developing effective strategies to manage seismic risks in diverse settings. For oldtown networks require a unique methodology that considers the preservation and retrofitting of old structures and transport infrastructure. Seismic risk assessment in these areas often involves a combination of vulnerability assessments and structural evaluations of old buildings to detect the potential of road blockage and in turn emergency routes for SAR operations. For city road networks, seismic risk assessment often involves the use of advanced mathematical models that consider factors such as the conditions of various transport infrastructures, traffic and congestion patterns, and road blockage potential. These models can provide insights into the impact of seismic events on mobility and logistic flow and identify critical transport sections that may experience disruptions.

As evidenced in literature, assessments of critical infrastructure elements (bridges, seaports, railways, underground systems) are vital for comprehending the potential risks to urban and regional road networks, especially in areas with significant interdependency among systems. These critical infrastructure components often serve as lifelines, facilitating the movement of goods, services, and people during response phase. Assessing the seismic vulnerability of these infrastructure elements is crucial to understand their potential failure modes and plan for their retrofitting or replacement and the determination of emergency routes if necessary. For example, the cascading effects of bridge failures are commonly used to estimate the potential impact of seismic events on the network based on traffic flow, detour routes, and emergency response planning.

Ensuring the timely and efficient transportation of essential commodities, injured individuals, and emergency personnel is vital for effective emergency services aftermath of an earthquake. Nevertheless, there are limited studies focusing on understanding demand patterns under stochastic situation, supply and demand dynamics aftermath of earthquakes, and resource mobilization. The utilization of advanced modeling techniques, such as the integration of activity-based models, agent-based simulation tools, and traffic flow theories would allow for synthetic representation of post-earthquake mobility scenarios, therefore future studies should focus more on development of such approaches. That would enable transport planners and policy-makers to make more informed decision-making for reinforcement planning and emergency demand management.

5. Conclusions

This state-of-the-art review delves into the planning and assessment of transport strategies in earthquake-prone areas. The relevant literature underscores the significance of taking into account the distinct characteristics and challenges posed by diverse transport systems, areas, and components. The literature findings highlight the utilization of various methodologies and approaches for the reinforcement planning and emergency demand management to analyze and evaluate the impact of seismic events on transportation systems, in turn to develop strategies for preparedness, mitigation, response, and recovery phases. The selection of the appropriate approach depends on factors such as the specific transport system, urbanization level and type, built environment, and critical components involved. In essence, the effective planning of transportation, risk assessment, and emergency management in earthquake-prone regions relies on the incorporation of multidisciplinary approaches and careful consideration of context-specific factors, allowing policymakers to make more informed decisions regarding resource allocation and transport resilience enhancement.

This article serves as a valuable consolidated resource, not only for scholars specializing in or interested in the development of mitigation algorithms, the formulation of emergency response plans, and the design of resilient transportation networks in earthquake-prone regions but also for those seeking an integrated understanding of the intersection between transportation and seismic literature. Furthermore, this article introduced a pioneer methodology for conducting state-of-the-art reviews on any topic by incorporating AI through the utilization of LLMs (DAVINCI-003 LLM for this case developed by OPENAI, which is built upon one of the most extensive deep neural networks currently available) along with IDSs using vector-storing. To the best of our knowledge, this represents the first initiative outlining how these models can be effectively integrated within the context of academic review standards. The capacity to rapidly process, comprehend, and extract essential information from targeted research studies through conversational means proves highly advantageous in efficiently understanding a subject matter, thereby facilitating time-saving measures that hold great value for academicians. The power of such recent AI tools lies in good training of the number combinations orchestrated in the hidden layers of deep neural networks, however interpreting and explaining their decisions, and internal representations in a human-interpretable manner still remains a challenge today.

Considering the consistent upgrades and advancements of LLMs and relevant applications over the past few years, it is imperative to create academic standards for the integrated approaches involving both AI and expert input, therefore the significance of present work is high in order to guide upcoming works. The latest AI tools like GPT-4 Plus come equipped with valuable embedded plugins such as DALL-E 3 (a model for generating and interpreting images) and Bing (facilitating interactive internet browsing), albeit with some limitations. Also, the release of Gemini multimodal LLM (the enhanced version of Google Bard), Microsoft Copilot and GPT-4o, are also started to support various forms of information concurrently, encompassing text, audio, images. And eventually, all of these tools will also provide text-to-video generation soon. Future research endeavors could prioritize the standardization of these new features according to academic standards. For example, leveraging the interactive internet browsing capabilities of these tools presents a great opportunity to incorporate guidelines into the ALARM framework, such as PRISMA, for automating the screening of selected literature databases within a specified timeline, following eligibility and exclusion standards outlined by experts. This enhancement would significantly boost the transparency and efficiency of ALARM studies.

Data availability statement

No data was used for the review described in the article.

CRediT authorship contribution statement

Ali Enes Dingil: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Ondrej Pribyl:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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