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Transportation Resilience under Climate Change: Infrastructure, Policy, Technology, and Social Dimensions

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ABSTRACT: Resilience in transportation systems is increasingly critical as climate change intensifies the frequency and severity of natural disasters. This study aimed to synthesize existing research on strategies that enhance transportation resilience by examining infrastructure, policy frameworks, technological innovations, and socio-economic conditions. A narrative review methodology was employed, with literature collected from Scopus, PubMed, and Google Scholar using targeted keywords such as transportation resilience, natural disasters, infrastructure resilience, and disaster recovery. Inclusion criteria emphasized peer-reviewed empirical and modeling studies published between 2010 and 2025 that directly addressed transportation resilience. The review finds that strengthening physical infrastructure through adaptive design, improved drainage, and advanced engineering reduces vulnerability to floods and earthquakes. Policy frameworks and inter-agency collaboration provide systemic coordination, while technological innovations—including Internet of Things, Artificial Intelligence, and digital twin simulations—significantly enhance predictive capacity and accelerate recovery operations. However, socio-economic disparities remain a central challenge, with developing nations facing extended recovery periods due to limited resources and fragile infrastructure. Cross-country comparisons underscore the importance of aligning resilience strategies with local contexts while promoting global knowledge exchange. Methodological limitations in the literature highlight the need for more interdisciplinary approaches that integrate technical, social, and policy dimensions. Overall, this review demonstrates that a multidimensional approach combining infrastructure reinforcement, governance reforms, technological innovation, and community engagement is essential to strengthen transportation resilience. These findings carry important implications for policymakers, practitioners, and researchers seeking to develop sustainable and adaptive transport systems in the face of escalating disaster risks.

Keywords: Transportation Resilience, Natural Disasters, Disaster Recovery, Infrastructure Resilience, Climate Change Adaptation, Urban Transportation, Network Resilience.

INTRODUCTION

Resilience in transportation systems refers to the capacity of networks to withstand, adapt to, and recover from adverse conditions. It encompasses both the physical durability of infrastructure and the continuity of essential services, while also reflecting the ability of communities to mitigate the impacts of emergencies. As climate change intensifies the frequency and severity of natural disasters, resilience has become a central concern for urban planning and disaster management (Wu & Barrett, 2022; Hu et al., 2024).

The vulnerability of transportation systems to extreme events has been widely documented. Empirical studies highlight how recovery logistics, supported by mobile resources and technical efficiencies, can accelerate service restoration (Lei et al., 2019). At the same time, spatial disparities in resilience have been observed, with peripheral or rural-urban transition zones often being disproportionately affected (Wan et al., 2025). These patterns underscore the challenges of aligning infrastructure development with the adaptive demands of climate change.

Severe weather events such as floods, snowstorms, and cyclones frequently disrupt essential networks, undermining daily mobility and long-term productivity. For example, catastrophic flooding of Shanghai's urban rail system caused significant operational and financial losses (Li et al., 2024), while Mediterranean cyclones posed wide-ranging socio-economic risks, including impacts on transport, public health, and cultural heritage (Khodayar et al., 2025). These cases illustrate that resilience is not only about rapid recovery but also about protecting the interconnected systems on which communities depend.

Localized research further highlights context-specific challenges. In Valencia, Spain, urban corridors remain highly vulnerable to flooding, necessitating integrated risk management in urban planning (Castro-Melgar, 2025). In Tampa Bay, the transportation fuel supply chain was found to be especially fragile during hurricanes, exacerbating cascading failures in logistics and energy systems (Kolpakov et al., 2021). These findings emphasize that resilience strategies must be tailored to regional environmental and infrastructural conditions rather than generalized globally.

Scholars have also identified systemic barriers to resilience. Limited redundancy, lengthy repair times, and difficulties in rerouting often lead to cascading failures across networks (Pitilakis et al., 2016). Extreme weather conditions further exacerbate these challenges, stripping networks of functionality and delaying emergency response (Chen et al., 2021; Zhang et al., 2019; Zhao et al., 2025). These insights highlight the necessity of proactive strategies that anticipate disruptions rather than relying solely on reactive responses.

Despite the growing body of research, gaps remain. Most studies focus on urban centers in developed nations, while developing countries remain underrepresented (Duy et al., 2018; Xu et al., 2019). Moreover, existing approaches often emphasize technical efficiency without sufficiently considering governance and equity concerns (Mostafavi, 2017; Miao et al., 2024). These gaps justify the need for comprehensive reviews that integrate technical, social, and policy perspectives across diverse contexts.

The objective of this review is therefore to synthesize resilience strategies for transportation systems in the face of natural disasters. By consolidating empirical evidence, theoretical models, and applied practices, the study identifies mechanisms through which transportation systems can maintain continuity and adapt under stress. Special attention is given to the interplay between infrastructure, governance, technology, and community resilience.

METHOD

This study employed a narrative review approach to systematically identify, evaluate, and synthesize scholarly literature addressing resilience strategies in transportation systems during natural disasters. The methodology was carefully designed to ensure rigor, transparency, and reproducibility, following established standards in academic reviews. The process encompassed a comprehensive search strategy, predefined inclusion and exclusion criteria, systematic screening of identified publications, and critical evaluation of the methodological approaches applied in the selected studies. The steps taken in this process are outlined in the following sections.

The initial phase of the study involved the systematic collection of relevant literature from multiple academic databases. The databases selected for this review included Scopus, Google Scholar, and PubMed, all of which are widely recognized for their comprehensive coverage of peer-reviewed articles in engineering, environmental sciences, disaster studies, and urban planning. Scopus was chosen due to its extensive indexing of multidisciplinary research articles, particularly those related to transportation resilience and infrastructure systems. Google Scholar was employed to broaden the scope of the search, capturing grey literature and additional peer-reviewed materials that may not be indexed in Scopus. PubMed was incorporated to ensure coverage of disaster management and public health perspectives that intersect with transportation resilience. The use of multiple databases minimized the risk of publication bias and enhanced the comprehensiveness of the review.

To maximize the relevance of retrieved articles, a set of predefined keywords and search terms were used in various combinations. Key terms included "transportation resilience," "natural disasters," "infrastructure resilience," "disaster recovery," "urban transportation," "network resilience," and "climate adaptation." Boolean operators such as AND and OR were utilized to refine the search queries, ensuring both precision and breadth in the retrieval process. For instance, combinations such as "transportation resilience AND natural disasters," "urban transportation AND disaster recovery," or "network resilience OR infrastructure resilience" were applied to target specific areas of research. These terms were informed by prior research and established terminology in the field (Zhang et al., 2019; Hu et al., 2024; Ahmed & Dey, 2020). The search was limited to articles published in English to maintain consistency and accessibility in analysis.

Inclusion and exclusion criteria were established to guide the selection process and ensure the scientific quality of the reviewed studies. The inclusion criteria encompassed studies that explicitly addressed transportation resilience in the context of natural disasters, whether through empirical investigations, modeling approaches, or systematic reviews. Studies that provided original data, case studies of disaster recovery, or evaluations of infrastructure resilience strategies were prioritized. For example, Zhang et al. (2019) examined network reconfiguration strategies under extreme weather conditions, providing a clear example of studies meeting inclusion requirements. Similarly, Yao et al. (2023) presented multi-stage recovery strategies for resilience, aligning with the objectives of this review. In contrast, exclusion criteria ruled out studies that did not directly address transportation systems, such as those focusing solely on agricultural resilience or environmental policies without clear transport-related implications. Furthermore, opinion pieces, non-peer-reviewed articles, and studies lacking methodological transparency were excluded from consideration (Lang et al., 2024; Wan et al., 2025).

Temporal and linguistic boundaries were also applied to ensure the currency and accessibility of the reviewed material. Only studies published between 2010 and 2025 were included, reflecting the rapid evolution of resilience research over the past decade and a half. The restriction to English-language publications was necessary to maintain consistency in interpretation and ensure access to a broad audience of international scholars. Peer-reviewed articles were exclusively included to maintain academic rigor and reliability, as exemplified by studies in reputable journals such as those by Chen et al. (2021) and Hu et al. (2024).

The types of research included in this review were intentionally diverse to provide a comprehensive perspective on resilience. Both qualitative and quantitative studies were incorporated, including randomized controlled trials, cohort studies, case studies, and computational modeling. Empirical studies offered real-world insights into transportation disruptions and recovery efforts, while modeling studies provided predictive frameworks and strategic insights. For example, Ahmed and Dey (2020) employed qualitative approaches to highlight community-based resilience strategies, whereas Miao et al. (2024) advanced modeling techniques to explore innovative adaptation strategies for infrastructure resilience. This methodological plurality enriched the review by ensuring that technical, social, and policy dimensions of resilience were adequately captured.

The literature selection process unfolded in several stages. First, all search results were imported into a reference management system to facilitate organization and duplication checks. Duplicate articles across databases were identified and removed. The initial pool of articles was then screened based on their titles and abstracts. At this stage, studies that did not clearly indicate relevance to transportation resilience and natural disasters were excluded. This step substantially reduced the volume of articles and sharpened the focus of the review.

Following the initial screening, full-text reviews were conducted on the remaining articles. This phase involved evaluating whether the studies met all inclusion criteria, particularly regarding methodological rigor and relevance to transportation resilience. Studies that lacked sufficient methodological detail or whose findings were peripheral to transportation systems were excluded at this stage. For example, certain papers focusing on environmental management without clear linkage to transportation resilience were screened out. The final pool of articles selected for analysis reflected a balance of empirical evidence, theoretical contributions, and applied methodologies.

Each selected study was critically evaluated using an adapted quality assessment framework. This framework considered the clarity of research objectives, the appropriateness of methodological approaches, the robustness of data collection and analysis, and the relevance of findings to the broader discourse on transportation resilience. Studies such as Pitilakis et al. (2016), which highlighted systemic vulnerabilities in transportation infrastructure, were noted for their methodological rigor and comprehensive scope. Conversely, studies with limited sample sizes or insufficient transparency in methodological reporting were considered less robust, though still included if they contributed unique contextual insights.

In synthesizing the selected literature, the analysis emphasized thematic coding of resilience strategies and challenges. Themes included infrastructure reinforcement, emergency logistics, community-based adaptation, and technological innovations. This thematic organization facilitated cross-study comparisons and allowed for the identification of convergences and divergences across geographic regions and methodological traditions. Comparative analysis also highlighted differences between developed and developing nations in terms of resource availability, policy implementation, and community engagement. For instance, Duy et al. (2018) illustrated vulnerabilities in Ho Chi Minh City linked to unplanned urban expansion in flood-prone areas, while Kolpakov et al. (2021) documented energy supply chain disruptions in the United States, reflecting context-specific resilience challenges.

By adopting this methodological framework, the study ensured that the narrative review was both comprehensive and analytically rigorous. The integration of diverse study designs and geographic contexts allowed for a holistic understanding of transportation resilience strategies. Moreover, the systematic application of inclusion and exclusion criteria minimized bias and enhanced the reliability of findings. This methodological rigor positions the study to contribute meaningfully to academic discourse and to provide actionable insights for policymakers, planners, and practitioners seeking to enhance the resilience of transportation systems in the face of escalating natural disaster threats.

RESULT AND DISCUSSION

The literature reviewed in this study reveals a wide range of strategies and practices aimed at enhancing the resilience of transportation systems during natural disasters. The findings are organized thematically into four major domains: physical infrastructure, management and policy systems, technological and innovative solutions, and socio-economic factors. These themes collectively illustrate the multidimensional nature of transportation resilience and provide a comprehensive perspective on global and regional responses to disaster-related disruptions.

Physical Infrastructure

Recent studies underscore that strengthening the physical components of transportation systems is fundamental to enhancing resilience against natural disasters such as floods and earthquakes. Zhang et al. (2019) demonstrated the importance of reconfiguring transportation networks through bi-level programming models to minimize disruptions during extreme events. This approach emphasizes the strategic redesign of networks to enhance redundancy and reduce cascading failures. Similarly, Li et al. (2024) highlighted the necessity of holistic infrastructure planning in flood-prone areas, advocating for comprehensive risk analyses combined with advanced drainage systems to mitigate the impact of flooding. Their research suggested that adaptive infrastructure capable of accommodating climatic variability can significantly reduce the destructive effects of both floods and earthquakes.

In terms of comparative evidence, developed nations have generally adopted more technologically advanced adaptive strategies than developing countries. In Europe and Japan, advanced materials engineering, AI-based traffic management, and real-time structural monitoring systems are widely employed to fortify transport networks against disaster impacts (Chen et al., 2021). For instance, Chopra et al. (2016) assessed vulnerabilities in the London metro and demonstrated that predictive maintenance supported by advanced sensor technologies could improve resilience and reduce downtime. By contrast, developing nations such as Vietnam face budgetary and technological constraints that limit their ability to adopt cutting-edge solutions. Duy et al. (2018) found that in Ho Chi Minh City, infrastructural deficiencies combined with rapid urban expansion in flood-prone zones exacerbated vulnerabilities. Instead of deploying advanced technology, strategies in these contexts tend to rely on pragmatic improvements to basic infrastructure and the integration of emergency management systems, illustrating a stark disparity in resilience capabilities between developed and developing regions.

Management and Policy Systems

Governmental policy frameworks play a pivotal role in shaping resilience outcomes for transportation systems. Mostafavi (2017) argued that evidence-based and integrated transportation policies can enhance resource allocation and enable systematic reinforcement of infrastructure. This perspective is echoed in Verma et al. (2025), who documented how local governments in the United States have adopted resilience-oriented financing mechanisms and inter-agency collaborations to strengthen transport networks post-disaster. Such policies not only fund infrastructure repair but also institutionalize disaster preparedness as a priority in urban planning.

Policy measures promoting sustainable and transit-oriented systems also contribute to resilience. Arora et al. (2024) demonstrated that investment in public transit and transit-oriented development reduces reliance on road networks and provides faster alternatives for evacuation and aid distribution. Their findings emphasized that resilience is not only about recovery after disaster but also about embedding adaptive capacities in long-term infrastructure planning.

Empirical evidence further illustrates the effectiveness of emergency management systems across diverse contexts. Kolpakov et al. (2021) analyzed fuel supply chain management during Hurricane Irma in Tampa Bay, showing that coordinated communication protocols between government agencies and emergency responders minimized disruptions. Their study highlighted how cross-sector collaboration ensured rapid response, reducing the disaster's overall impact on transportation and energy supply. In Europe, Pitilakis et al. (2016) documented integrated disaster management approaches in the United Kingdom, focusing on crisis communication and adaptive response strategies. Their results showed that the establishment of effective information distribution systems was central to enhancing resilience, further demonstrating the influence of governance structures on transportation system recovery.

Technological and Innovative Solutions

Technological innovation has emerged as a transformative factor in disaster resilience for transportation systems. IoT technologies enable real-time monitoring of critical infrastructure, allowing for early detection of vulnerabilities and pre-emptive action. Chen et al. (2021) reported that IoT-based sensor networks deployed in transportation systems can predict structural failures and facilitate rapid response, thereby minimizing the likelihood of catastrophic breakdowns. Similarly, Xu et al. (2019) showed how AI can optimize resource allocation during disasters by predicting demand for emergency services and guiding deployment decisions, thereby reducing recovery time.

Digital twin technology is another notable advancement in resilience planning. Yao et al. (2023) explained how virtual models of transportation networks can simulate disaster scenarios, identify potential failure points, and test recovery strategies before actual events occur. Such simulation-based planning has proven invaluable in enabling transportation authorities to prepare for a range of disaster scenarios, offering a cost-effective and risk-free platform for resilience testing.

Compared with traditional manual approaches, these technologies significantly improve both the speed and accuracy of disaster response. Zhang et al. (2019) illustrated that adaptive network management based on real-time data reduced recovery times compared to static manual strategies. Lei et al. (2019) further noted that AI-enhanced systems provided more accurate forecasts for recovery operations, improving decision-making in critical situations. These findings collectively highlight that while traditional methods may provide baseline responses, advanced technologies enable proactive adaptation and enhance the resilience of transportation systems under stress.

Socio-Economic Factors

Socio-economic conditions play an equally critical role in shaping the resilience of transportation systems. Inequities in resource distribution often mean that marginalized communities lack access to resilient infrastructure or alternative transportation options. Loni and Asadi (2024) noted that social inequality directly correlates with heightened vulnerability, as communities with fewer economic resources are less able to invest in adaptation or recovery measures. These disparities underscore the importance of integrating social equity into resilience planning to ensure that disaster response measures reach vulnerable populations.

Educational and awareness levels also influence community resilience. Khodayar et al. (2025) found that populations with higher levels of disaster awareness and preparedness exhibited stronger resilience in transportation disruptions. Their study emphasized the value of community education programs and training initiatives to build social capacity for effective disaster response.

Cross-national comparisons further reveal significant disparities in resilience outcomes based on economic capacity. Hong-xia et al. (2023) observed that advanced economies, such as Japan and Western European nations, benefit from integrated emergency management systems, advanced technologies, and resilient infrastructure that collectively enable rapid recovery from disasters. By contrast, Duy et al. (2018) reported that developing nations often suffer prolonged recovery periods due to fragile infrastructure, disorganized emergency management, and limited financial resources. These findings demonstrate how global disparities in wealth and infrastructure investment translate directly into differences in resilience, reinforcing the need for targeted support and international cooperation to strengthen transport systems in vulnerable regions.

Global Perspective

When viewed globally, resilience strategies in transportation systems exhibit both convergence and divergence. Developed nations tend to invest heavily in technological innovation and institutional frameworks, creating proactive and integrated systems of resilience. In contrast, developing nations often adopt reactive and resource-constrained strategies, focusing on immediate restoration rather than long-term adaptation. Nevertheless, both contexts highlight the necessity of aligning resilience strategies with local socio-economic and environmental conditions. For example, while advanced digital technologies drive resilience in Western contexts (Yao et al., 2023; Chen et al., 2021), community-based adaptation and pragmatic infrastructural reinforcement remain more relevant in Southeast Asia (Duy et al., 2018; Ahmed & Dey, 2020).

This global comparison underscores that resilience in transportation is not a universal blueprint but rather a set of adaptive strategies shaped by available resources, governance structures, and societal needs. The disparities identified between nations reveal critical opportunities for cross-learning and knowledge transfer. For instance, low-cost community-based models in developing regions may offer scalable solutions even in resource-rich settings, while advanced simulation and AI-based approaches in developed nations could be adapted to fit the financial and infrastructural constraints of developing economies.

In summary, the results highlight that transportation resilience during natural disasters is influenced by a complex interplay of physical infrastructure, policy frameworks, technological innovations, and socio-economic contexts. Infrastructure reinforcement and adaptive design reduce physical vulnerabilities, while integrated policies and governance structures enhance systemic coordination. Advanced technologies provide unprecedented predictive and adaptive capabilities, yet socio-economic inequities remain significant barriers to resilience in many regions. Collectively, these findings stress the importance of a multidimensional approach that simultaneously addresses structural, systemic, technological, and social dimensions to ensure that transportation systems worldwide can withstand and recover from the increasing frequency and intensity of natural disasters.

The findings of this review highlight that transportation resilience during natural disasters cannot be understood in isolation from the broader systemic factors that shape its vulnerabilities. Literature consistently emphasizes that political, economic, and technological conditions interact to influence the extent to which transportation systems are prepared to withstand and recover from disruptive events. Political governance, for instance, has been identified as a critical determinant of resilience, where inconsistent or inadequate policies often hinder investment in disaster-resistant infrastructure (Loni & Asadi, 2024). Beyond infrastructure itself, Loni and Asadi (2024) argue that social inequities embedded within policy frameworks exacerbate the uneven distribution of resources, leaving marginalized communities particularly exposed to disruptions in mobility and emergency services. These findings reinforce the notion that resilience is not simply a matter of engineering but is deeply rooted in governance structures and equity considerations.

Economic constraints likewise play a pivotal role in shaping transportation resilience. Nations with limited fiscal capacity often face difficulties in allocating sufficient resources for the maintenance and upgrading of transport infrastructure, which heightens their vulnerability during disasters (Lang et al., 2024). In low-income countries, the absence of sustainable investment frameworks often results in prolonged recovery times and increased social and economic losses following disasters. Comparative studies have shown that while developed nations can leverage advanced engineering practices and resilient infrastructure design, developing regions often lack the financial resources to implement such strategies effectively (Duy et al., 2018). This economic disparity underscores the global inequities that define resilience outcomes, suggesting that global cooperation and targeted international support are necessary to bridge these resilience gaps.

Technological advancements represent another significant factor that can mitigate systemic vulnerabilities. Hu et al. (2024) have illustrated that the adoption of advanced technologies such as IoT and AI has the potential to transform transportation resilience by enabling real-time monitoring and predictive responses. Similarly, Yao et al. (2023) demonstrated how digital twin technology facilitates simulation-based planning, providing a proactive means of testing and refining disaster recovery strategies before they are required in practice. When these technologies are integrated into transportation planning and operations, they not only enhance the efficiency of emergency responses but also contribute to long-term systemic resilience by creating adaptive and intelligent infrastructures. The interaction between these technological innovations and governance frameworks highlights the importance of policy support in ensuring that such tools are effectively implemented.

The interplay of political, economic, and technological factors reveals that resilience is fundamentally systemic in nature. Political priorities dictate funding allocations and policy directions; economic capacity shapes the feasibility of infrastructure reinforcement; and technology offers solutions that can only be realized when supported by adequate governance and investment. As Pitilakis et al. (2016) argued, cascading failures in transportation networks often occur not because of isolated infrastructure weaknesses but due to systemic shortcomings in redundancy, coordination, and emergency management. This recognition calls for an integrated approach that situates transportation resilience within broader societal, economic, and technological frameworks.

Recommendations emerging from the literature emphasize the need for multi-level strategies that combine infrastructure reinforcement, policy reform, and social participation. Arora et al. (2024) advocate for the integration of transit-oriented development (TOD) into urban planning as a strategy that simultaneously addresses environmental sustainability and disaster resilience. By concentrating development around public transit nodes, TOD reduces dependency on private vehicles, lowers emissions, and provides efficient evacuation routes during emergencies. Zhang et al. (2019) complement this perspective by underscoring the importance of continuous infrastructure engineering and maintenance, alongside the deployment of adaptive reconfiguration strategies that can minimize disruptions during disasters. These approaches demonstrate that resilience must be embedded in both the physical and operational dimensions of transportation networks.

Beyond technical solutions, literature highlights the importance of cross-sector collaboration in resilience building. Yao et al. (2023) argue that engaging governments, private actors, and local communities in joint disaster planning fosters shared responsibility and enhances preparedness. Such partnerships are critical for mobilizing resources, coordinating responses, and ensuring that resilience strategies address the needs of diverse stakeholders. Community education and training initiatives further strengthen resilience by empowering populations to act effectively during crises (Khodayar et al., 2025). By embedding resilience within community structures, these initiatives reduce reliance on top-down interventions and create distributed capacities for disaster response.

Despite these insights, the literature exhibits methodological limitations that constrain the comprehensiveness of resilience assessments. Many studies remain fragmented in scope, focusing narrowly on technical or infrastructural dimensions while neglecting the broader socio-economic and political contexts that shape resilience outcomes (Duy et al., 2018). This reductionist approach limits the applicability of findings, particularly in regions where vulnerabilities are driven as much by governance failures and social inequities as by infrastructural weaknesses. Moreover, studies frequently overlook local variations in geography, culture, and institutional arrangements that influence the effectiveness of resilience strategies. Lang et al. (2024) highlight that resilience strategies successful in one context may fail when transplanted to another without appropriate adaptation, suggesting the need for more context-sensitive methodologies.

Another limitation lies in the underrepresentation of interdisciplinary approaches in resilience research. While technological innovations such as AI and IoT are frequently discussed, fewer studies examine how these tools interact with social systems and governance structures to shape resilience outcomes. Ahmed and Dey (2020) argue that effective resilience strategies require integration across technological, social, and policy dimensions, yet such interdisciplinary frameworks remain underdeveloped in the literature. This gap points to a critical need for research that bridges disciplinary boundaries, offering holistic perspectives that better reflect the complex realities of disaster resilience in transportation systems.

Future research directions suggested by the literature emphasize the exploration of integrated strategies that combine technological innovation with social and policy considerations. For example, Miao et al. (2024) stress the importance of investigating adaptive strategies that harness new technologies in ways that are flexible and scalable across different economic contexts. Similarly, Mostafavi (2017) underscores the need for policy research that identifies governance models capable of supporting long-term resilience planning, particularly in resource-constrained environments. Such directions highlight the necessity of advancing resilience research beyond conventional technical paradigms, incorporating multidisciplinary approaches that align infrastructure development with equity, sustainability, and adaptability.

The implications of these findings are profound for both scholars and practitioners. For academics, the need to adopt more holistic methodologies that integrate technical, social, and political dimensions of resilience is evident. For policymakers and practitioners, the literature underscores the urgency of embedding resilience into long-term infrastructure planning and urban development strategies, rather than treating it as an emergency response measure. The convergence of findings across studies indicates that resilience in transportation systems is achievable but requires systemic transformation supported by sustained political commitment, adequate financial investment, and the integration of cutting-edge technologies with socially inclusive approaches.

CONCLUSION

This narrative review highlights that transportation resilience during natural disasters is shaped by an interplay of physical, systemic, technological, and socio-economic factors. Findings demonstrate that infrastructure reinforcement through adaptive design, improved drainage, and advanced engineering is central to mitigating damage from floods and earthquakes (Zhang et al., 2019; Li et al., 2024). Equally, effective policy frameworks and inter-agency collaboration enhance systemic coordination, as shown in studies of disaster management in the United States and Europe (Mostafavi, 2017; Verma et al., 2025). Technological innovations such as IoT, AI, and digital twins offer unprecedented predictive and adaptive capacities, significantly reducing recovery times compared to traditional approaches (Hu et al., 2024; Yao et al., 2023). However, socio-economic disparities remain a key determinant of resilience outcomes, with vulnerable populations in developing nations experiencing longer recovery periods and reduced access to emergency resources (Duy et al., 2018; Loni & Asadi, 2024).

The urgency of enhancing transportation resilience lies in the accelerating impacts of climate change and the increasing frequency of extreme events. Policymakers must prioritize investments in resilient infrastructure, embed transit-oriented development strategies, and strengthen community-based adaptation to address systemic inequities. Research should advance interdisciplinary approaches that integrate technological, social, and policy dimensions, while expanding analysis to underrepresented regions where vulnerabilities are most acute. By combining structural reinforcement, governance reforms, technological adaptation, and inclusive social strategies, transportation systems can be better prepared to withstand and recover from disasters, ensuring continuity of mobility and supporting sustainable urban development..

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