

Operational and Safety Readiness for Hyperloop Adoption in Saudi Arabia: A Narrative Review

¹*Jihad thajudeen

¹Health and Safety Manager, Alstom, Saudi Arabia.

Abstract

Hyperloop is an emerging next generation transportation technology that has the potential to revolutionize intercity transportation with its ultra-high speed capabilities, energy efficiency, and sustainable operations. With Saudi Arabia's Vision 2030 initiatives progressing, there has been growing interest in innovative transportation solutions, especially in the context of smart city and infrastructure development projects. The aim of this review was to investigate the operational and safety readiness of Hyperloop adoption in Saudi Arabia by assessing the maturity of the technology, the infrastructure needed, safety concerns, regulatory aspects, and the national readiness. The methods used was a narrative review of peer reviewed journal articles, conference papers, government reports, industry papers, and international transportation reports from 2020 to 2026 which included 26 studies. Literature was retrieved using electronic search and themed according to the following categories: operational readiness, safety readiness, infrastructure needs, regulatory aspects, and the Saudi Arabian context. The results show that Hyperloop technology has come a long way in terms of automation, propulsion and digital infrastructure. But there are significant issues with infrastructure spending, safety certification, emergency preparedness, cybersecurity and regulatory standardization. Saudi Arabia has a number of strategic strengths such as Vision 2030 projects, smart city projects like NEOM, government support, and the growing digital infrastructure, all of which, when combined, make the Kingdom ready for future adoption. Saudi Arabia has the potential to implement Hyperloop successfully, but there are still challenges related to operational, safety, and environmental considerations that need to be overcome, which will require further technological advancements, pilot testing, and public-private partnerships, as well as international cooperation.

Keywords: Hyperloop, readiness for operation, safety readiness, smart mobility, sustainable mobility, transportation innovation, Vision 2030.

1. Introduction

The transportation industry is experiencing a rapid and unprecedented shift as governments and industry leaders look for innovative solutions that can meet the demands of the increasing urban population, population growth, environmental issues, and rising mobility needs (Mavlutova et al., 2023). While there have been significant advances in conventional modes of transport in recent decades, such as road, rail, and air transport, their travel time, energy use, congestion, and greenhouse gas emissions remain constraints on sustainable mobility targets (Winkler et al., 2023). To meet these challenges, Hyperloop is one of the most promising future transportation technologies to emerge. Hyperloop was originally conceived in 2013 and involves a combination of low-pressure tube infrastructure, magnetic levitation, and electric propulsion systems to

transport passengers and goods at speeds of up to 1,000 km/h (Liu et al., 2022). The idea behind Hyperloop is to reduce the aerodynamic drag and rolling resistance, which makes it possible to travel faster and reduce the energy consumption while the train is moving.

Hyperloop has recently become a topic of significant academic and industrial interest in the last decade. A study by Gkoumas (2021) related to Hyperloop discusses that research on Hyperloop systems has grown significantly since 2014, including in the fields of aerodynamics, operations, safety, energy systems, infrastructure, and communication technologies (Gkoumas, 2021). The study highlighted Hyperloop's potential as a disruptive transportation technology while emphasizing the need for further investigation into operational feasibility and safety assurance frameworks. Similarly, Gkoumas and Christou

Jihad thajudeen

Health and Safety Manager, Alstom, Saudi Arabia.

Email: jihad676@gmail.com

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(2020) observed that Hyperloop has been a subject of international investment and policy interest, especially in Europe and North America, with some pilot projects and testing facilities being developed to test out the technical feasibility and eventual commercialization of Hyperloop (Gkoumas & Christou, 2020).

Research indicates that Hyperloop has the potential to significantly shorten the time taken to travel between major cities, decrease carbon emissions compared to air travel, increase energy efficiency, and facilitate economic growth by connecting cities (Premasagar & Kenworthy, 2022). For instance, Hyperloop systems are expected to reach speeds of up to 1,200 km/h, which could cut down the travel time between distant urban areas by over 70% compared to traditional rail transportation (Premasagar & Kenworthy, 2022). Moreover, simulation studies have indicated that Hyperloop could carry high amounts of passengers with lower operating costs than some of the current high-speed transportation options (Yavuz & Öztürk, 2021). The benefits have sparked interest in these from a global perspective by both policy makers, researchers, and investors who are interested in sustainable mobility solutions for the future transportation network.

Saudi Arabia has a bold transformation agenda in its Vision 2030, aimed at diversifying the national economy, minimizing reliance on oil revenues, and establishing the Kingdom as a world leader in innovation, logistics, and sustainable development (Moshashai et al., 2020). Transportation modernization is a key element of this vision, as mobility systems are key to economic development, tourism growth, urbanization, and regional integration (Al-Roubaie, 2025). As a result, Saudi Arabia has been investing in the development of transportation infrastructure such as highways, airports, railways, logistics centers, and smart city initiatives (Anwar & Oakil, 2023). The most notable ones include the mega-projects linked to Vision 2030, such as NEOM and The Line (Touri, 2024). The goals of these projects are to create technologically advanced urban environments with sustainable and intelligent transportation systems. The vision of The Line, a linear smart city designed around zero-emission mobility, aligns closely with the characteristics and objectives of Hyperloop technology (Khashoggi & Mohammed, 2022). These advancements offer a distinctive chance for Saudi Arabia to assess and consider the adoption of new transportation solutions that can meet the future urban and intercity mobility demands.

Specific studies on the Kingdom of Saudi Arabia have also

pointed to the possibility of applying Hyperloop in the Kingdom (Balabel & Almujiabah, 2022; Khashoggi, 2023). Almujiabah (2021) compared the High-Speed Rail (HSR), Magnetic Levitation (Maglev), and Hyperloop technologies on the Riyadh-Dammam route. The results indicated that Hyperloop would be the most cost-effective in terms of average social cost of the transportation modes considered, estimated at €67.70 per passenger by 2030, which is lower than the estimated average social cost of HSR and Maglev of €103.30 and €100.20, respectively. The study found that Hyperloop has the potential to become a viable option for the next generation of transportation in Saudi Arabia, as it is more efficient and could be economically beneficial (Almujiabah, 2021).

Saudi Arabia's geographic characteristics also contribute to the interest in Hyperloop adoption, aside from the economic factors (Balabel & Almujiabah, 2022). There are many major cities in the Kingdom, which are far from each other, such as Riyadh, Jeddah, Dammam, Makkah, and Madinah. Current travel routes are long-distance roads or rely on domestic aviation (Dahim, 2023). Hyperloop can offer a major intercity transport solution with super high-speed capabilities and can be integrated with the existing transport network, and can help meet the national development goals (Balabel & Almujiabah, 2022). As a result, the readiness of the Kingdom of Saudi Arabia for implementing Hyperloop has become a pertinent topic in academic and policy debates.

Although Hyperloop has great potential, a lot of issues are yet to be addressed in its operational, technical, regulatory, and safety aspects before it can be commercially viable (Hansen, 2020). The implementation of Hyperloop systems involves several cutting-edge technologies, such as vacuum technology, magnetic levitation, autonomous control systems, real-time communication systems, and high-speed propulsion systems (Abhilashi et al., 2023). At commercial scale, the successful coordination of these technologies has yet to be tested.

The Hyperloop system requires a massive network of tubes, stations, energy systems, and advanced monitoring technologies. Kirschen and Burnell (2023) pointed out that the Hyperloop design is a very complex optimization problem, as the performance of the vehicle and the design of the infrastructure must be designed together to ensure the operational efficiency of the Hyperloop (Kirschen & Burnell, 2023). This complexity makes it harder to implement and raises questions about the long-term sustainability of operations. Considering the very high

operating speeds and enclosed vacuum system, any system failure can have serious consequences. A study identified key safety concerns for future Hyperloop systems, including emergency evacuation, system redundancy, passenger protection, and infrastructure resilience (Mitropoulos et al., 2021).

Brighente et al. (2024) stated that Hyperloop infrastructure requires a lot of interconnected digital systems, which are used for navigation, communication, monitoring, and operational control. In their analysis, they found that cyberattacks could be a serious threat that could affect operational safety and lead to catastrophic events if appropriate protection measures are not put in place (Brighente et al., 2024). Further challenges in operation include the development of communication systems that can sustain reliable connections at very high speeds. The Hyperloop industry does not have any internationally accepted standards for design, certification, safety assessment, or operations that are available (Gkoumas & Christou, 2020). Current transportation laws and regulations may not fit well with the specific features of evacuated tube transportation systems, making it difficult for policymakers and regulatory authorities to implement them (Nejad, 2020).

Despite increasing global interest in Hyperloop transportation and its alignment with Saudi Arabia's Vision 2030 objectives, there remains insufficient understanding of the Kingdom's operational and safety readiness for adopting this emerging technology (Balabel & Almujiabah, 2022). Most of the existing research focuses on technical feasibility, theoretical performance, and economic gains, and there is a lack of in-depth analysis of infrastructure needs, safety measures, regulatory readiness, cybersecurity issues, and operational integration (Alanazi & Alenezi, 2024; Almujiabah, 2021). This knowledge gap makes the evidence-based decision-making process difficult when it comes to the future deployment of the Hyperloop in Saudi Arabia, and it is evident that there is a need for a critical review of the existing literature to identify opportunities, challenges, and policy priorities.

Hence, this narrative review was designed to explore the operational readiness factors, analyze safety issues, and analyze the readiness of the Kingdom of Saudi Arabia for the implementation of Hyperloop. It also aimed to highlight the key gaps in policy and research that need to be filled before Hyperloop can be adopted on a large scale.

2. Methodology

2.1. Review Design

The study used a narrative review approach to critically review the operational and safety readiness of Hyperloop transportation systems and assess their applicability in the context of Saudi Arabia. A narrative review was deemed suitable due to the relatively small number of commercial Hyperloop implementations and the multidisciplinary nature of the literature, which includes engineering, transportation planning, infrastructure development, safety management, sustainability, public policy, and smart mobility. This helped to identify, synthesize, and interpret existing knowledge about Hyperloop technology and its relevance to Saudi Arabia's transportation transformation projects in Vision 2030.

2.2. Search Strategy

A structured literature search was conducted to identify relevant publications addressing Hyperloop technology and its associated operational and safety dimensions. Academic publications were retrieved from electronic databases such as Scopus, Web of Science, ScienceDirect, SpringerLink, Google Scholar, IEEE Xplore, and Transportation Research International Documentation (TRID). Further searches were conducted in institutional repositories and government, transportation agency, and industry reports for relevant gray literature. The search process was limited to publications from 2020 to 2026 to ensure that the core review reflected recent developments in Hyperloop research and transportation innovation. Literature was identified using a combination of keywords and search terms. These were "Hyperloop technology", "Hyperloop transportation", "Hyperloop safety", "Hyperloop operations", "Hyperloop infrastructure", "evacuated tube transport", "maglev transportation", "high-speed transportation systems", "Saudi Arabia transportation", "smart mobility", "sustainable transport", "transport innovation", "future mobility" and "Vision 2030". Boolean operators (AND and OR) were used to combine search terms and enhance search precision. The initial search produced a broad set of records. Titles and abstracts were screened for relevance, followed by full-text assessment of potentially eligible publications against the predefined inclusion and exclusion criteria. Records were retained when they directly addressed operational, safety, infrastructure, regulatory, economic, or adoption-related aspects of Hyperloop or closely related emerging transportation technologies and

provided substantive technical, empirical, planning, or policy evidence. Duplicates and publications that did not meet the scope or evidence requirements were excluded. The final synthesis comprised 26 studies.

2.3. Inclusion and Exclusion Criteria

To ensure relevance and consistency, specific inclusion and exclusion criteria were established before the review process. Table 1 shows the inclusion and exclusion criteria of the study.

Table 1- Inclusion and Exclusion Criteria for Literature Selection

Inclusion Criteria	Exclusion Criteria
Publications written in English.	Publications written in languages other than English.
Studies published between 2020 and 2026 capture recent developments in Hyperloop and future mobility research.	Pre-2020 publications were not included in the 26-study core synthesis. If older foundational literature is consulted for background context, it is not counted in the thematic totals.
Peer-reviewed journal articles, conference proceedings, government reports, industry reports, technical reports, and policy documents.	Editorials, opinion pieces, magazine articles, blog posts, news articles, and non-scholarly sources lacking empirical or technical evidence.
Studies addressing Hyperloop technology, evacuated tube transport (ETT), magnetic levitation (Maglev), ultra-high-speed transportation systems, and related emerging mobility technologies.	Studies unrelated to high-speed transportation systems or future mobility technologies.
Research examining operations, maintenance, system integration, transportation planning, digital infrastructure, automation, energy systems, and operational feasibility.	Studies focusing solely on theoretical engineering concepts without operational implications.
Studies investigating safety frameworks, risk assessment, hazard analysis, passenger safety, cybersecurity, emergency response, infrastructure resilience, and system reliability.	Publications that do not address safety, risk, or reliability considerations.

2.4. Data Synthesis

Following the screening and selection process, the included literature was analyzed using a thematic synthesis approach. This approach was chosen because the studies reviewed had different goals, methods, geographic areas, and research designs. The review aimed to find commonalities, patterns, and concepts within the results instead of combining them statistically.

The studies were initially reviewed in detail to gather data on technological development, operational needs, safety, infrastructure, governance, regional applicability, sustainability, and public acceptance. Findings from each study were recorded and compared across publications. Similar concepts were then clustered into thematic codes. A study was allowed to contribute to more than one theme when its findings addressed multiple dimensions of readiness; therefore, the thematic counts are non-exclusive and their sum can exceed 26. Seven major themes were identified: technology development and innovation;

operational readiness and system integration; safety, risk and security; regulatory, governance and standardization; Saudi Arabia readiness and strategic alignment; sustainability and environmental impact; and socio-economic, public acceptance and policy implications. Figure 1 presents the number of included studies coded to each theme and illustrative, non-exhaustive examples of studies within each category.

For analytical clarity, readiness in this review is distinguished across four related dimensions. Strategic readiness refers to national priorities, institutional support, smart-city programmes, investment direction, and alignment with Vision 2030. Enabling or infrastructure readiness refers to the availability and planned development of tube networks, stations, energy systems, digital infrastructure, maintenance facilities, and multimodal connections. Regulatory readiness concerns standards, certification, governance, safety assurance, and legal

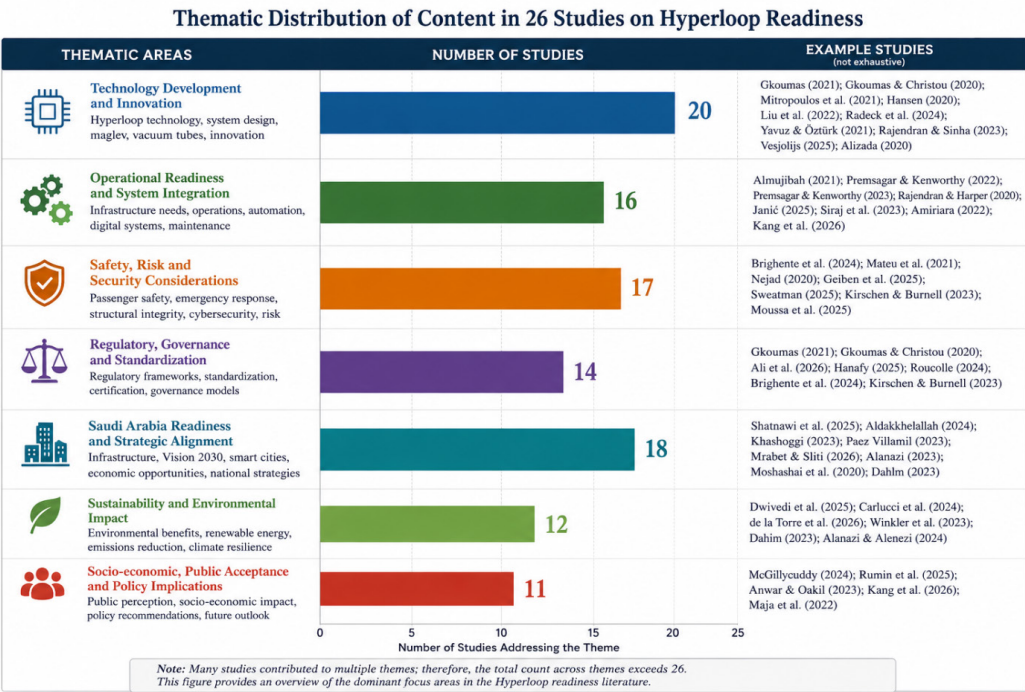


Figure 1. Thematic distribution of content in 26 studies on Hyperloop readiness (author’s thematic coding; studies may contribute to multiple themes).

pathways for an emerging transport mode. Operational and safety readiness concerns system integration, automation, maintenance, emergency response, passenger protection, structural resilience, cybersecurity, and workforce capability. These dimensions are related but should not be treated as equivalent: favorable strategic conditions do not by themselves demonstrate infrastructure, regulatory, operational, or safety readiness.

3. Results

3.1. Evolution and Global Progress of Hyperloop Technology

3.1.1. Technological Foundations of Hyperloop

The Hyperloop system has been proposed to offer many benefits over traditional high-speed rail and aviation, such as reduced travel times, lower energy consumption, and decreased environmental impact. The research on Hyperloop has been rapidly developing in various aspects, such as propulsion systems, infrastructure design, passenger comfort, safety assurance, and economic feasibility, as highlighted by Gkoumas (2021) (Gkoumas, 2021). Kang et al (2026) suggested that Hyperloop is a revolutionary mode of transport that holds the promise of revolutionizing intercity travel with its potential for high speeds and connectivity, but with significant technological

and financial risks (Kang et al., 2026). Additionally, Hansen (2020) highlighted that Hyperloop is an amalgamation of several well-developed technologies such as magnetic levitation, vacuum engineering, and others, but they have not been tested at scale in an operational, commercially viable transportation system. The study identified that operational challenges of maintaining tube pressure, passenger safety, and cost-effective infrastructure deployment are key engineering challenges to overcome for successful operations (Hansen, 2020). The overall findings of these studies suggest that Hyperloop has significant theoretical potential but has yet to be fully developed and tested for commercial use and will still need to undergo further development and testing before it can be widely adopted.

3.1.2. International Demonstration and Pilot Projects

Hyperloop technology has been tested in several countries and organizations through pilot projects to determine the feasibility and performance of the technology in real-world applications (Araghi & Wilmink, 2022). These projects have been essential to test the reliability of the propulsion systems, the design of the tubes, the safety measures for the passengers, and the reliability of the operation. Virgin Hyperloop has been one of the more

prominent projects, having successfully tested passengers in Nevada, USA, proving the feasibility of humans traveling in a vacuum tube (Alizada, 2020). Celestin (2023) noted that the development of the Hyperloop technology has grown considerably in North America, Europe, and the Middle East, and the governments and private investors have begun to see the potential of this technology to help achieve Sustainable Mobility goals (Celestin, 2023). Gkoumas et al. (2020) have discussed that the Hardt Hyperloop project has been active in Europe, working on standardization and interoperability of the systems to enable future cross-border transportation networks (Gkoumas & Christou, 2020).

Additionally, McGillycuddy (2024) found that socio-technical integration, stakeholder involvement, and public acceptance have become key areas that are increasingly being recognized as necessary prerequisites for successful implementation in European pilot projects (McGillycuddy, 2024). Moreover, Paez Villamil (2023) studied the viability of applying superconducting maglev technology to the NEOM development in Saudi Arabia and how the experience of international pilot projects can be applied to future Hyperloop and advanced mobility projects in emerging smart cities (Paez Villamil, 2023). While there is no operational commercial Hyperloop system as of yet, the fact that these pilot projects are running is still useful to have an understanding of the capabilities of the technology, the challenges that can be encountered in operation, and the strategies that can be used to implement a Hyperloop system in the future (Vesjolijs, 2025).

3.1.3. Current State of Technological Maturity

Despite the massive technological advancements, Hyperloop is still in the development phase, and most experts believe that it is an emerging, not a mature, transportation technology. Recent studies have shown that key technologies like magnetic levitation, propulsion systems, and vacuum systems are technically feasible on their own; the integration of these technologies into a viable, large-scale commercial network is a challenge. Kirschen and Burnell (2023) noted that Hyperloop development is a complex optimization process that involves multiple factors, including vehicle design, infrastructure configuration, operational efficiency, and economic viability (Kirschen & Burnell, 2023). According to the study, there is a balance between engineering limitations and operating requirements to achieve the best performance.

Similarly, Brighente et al. (2022) pointed out that the technological maturity is also limited by cybersecurity risks stemming from the high level of interconnections of digital systems needed to operate Hyperloops. The authors stated that for future commercialization efforts, secure communications, resilient control systems, and complete cyber risk management frameworks are all crucial to safe and reliable operations (Brighente et al., 2024). Furthermore, Radeck et al. (2024) noted that despite the development of Hyperloop beyond the conceptual phase, there are still many challenges to address in terms of infrastructure scalability, regulatory clearance, and safety certification before the system can be commercialized. The study described Hyperloop as a promising but still experimental transportation system that needs a lot of testing and validation in operational conditions (Radeck et al., 2024). So far, the evidence indicates that Hyperloop has great technological potential, but it is not yet ready to be applied at a commercial level.

3.2. Operational Readiness for Hyperloop Deployment

3.2.1. Infrastructure and System Requirements

Advanced infrastructure is key to the successful implementation of Hyperloop systems, as they must be able to handle the high-speed travel conditions and low-pressure environment (Radeck et al., 2024). Hyperloop will need much longer tube networks, special passenger terminals, energy supply systems, communication facilities, and maintenance facilities, compared to the conventional railways (Maja et al., 2022). One of the biggest challenges to commercialization is infrastructure development, as it requires a considerable amount of capital investment for construction and long-term operation. According to Balabel et al. (2022), the cost of infrastructure makes up a significant portion of the overall Hyperloop project expenses, especially in areas with long distances and challenging environmental conditions (Balabel & Almujiabah, 2022). The study also indicated that the investments might be warranted because of significant travel time savings and long-term social benefits.

Similarly, Altorah et al. (2025) found that strategic project management and infrastructure coordination are key success factors in large-scale transportation projects, highlighting the need for phased implementation strategies with new modes of transport (Altorah & Alyakhri, 2025). In addition, Geiben et al. (2025) showed that it is necessary to design very complex solutions to ensure optimal pressure conditions and aerodynamic performance

in Hyperloop tubes, which must be stable and efficient in varying environmental conditions (Geiben et al., 2025). This indicates that infrastructure readiness is one of the key challenges in the deployment of Hyperloop and will need a lot of investments, technical knowledge, and long-term planning. Figure 2 shows that an uninterrupted vacuum

tube, dedicated passenger stations and uninterrupted energy system using tube-integrated energy arrays are required for operational readiness. The diagram emphasizes the importance of directly coupling propulsion systems (like linear induction motors) to the capsule design for safe, high-speed levitation and transport of critical infrastructure.

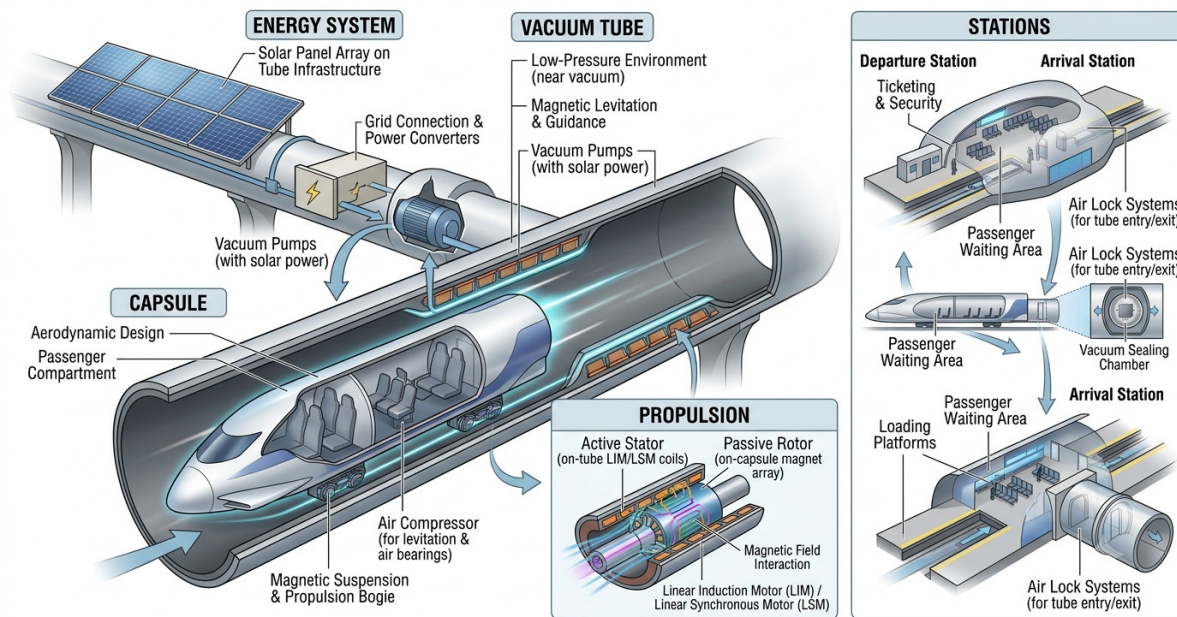


Figure 2. Hyperloop system architecture (conceptual diagram created entirely by the author for this review; not reproduced or adapted from an external source).

3.2.2. Integration with Existing Transport Networks

One of the key components of readiness is the ability of Hyperloop systems to seamlessly connect with the current transportation infrastructure (Abhilashi et al., 2023). To be successful, the Hyperloop needs to be integrated seamlessly with existing transportation infrastructure, such as airports, railways, metro systems, and roads. Integration enhances accessibility, improves passenger convenience, and maximizes transportation efficiency. However, Rajendran et al. (2020) highlighted that network design and operational planning have a significant impact on system performance, and that optimizing network structures can help enhance passenger flow and operational efficiency, reduce congestion, and avoid delays (Rajendran & Harper, 2020). Similarly, Ali et al. (2026) identified smart mobility corridors and integrated transportation systems as important factors to improve regional connectivity, promote tourism development, and achieve sustainable transportation goals in the Gulf Cooperation Council (GCC) countries (Ali et al., 2026). Furthermore, Hanafy

(2025) suggested that the future mobility systems in the Gulf cities will increasingly rely on multimodal integration strategies that can link emerging mobility technologies like Hyperloop, autonomous vehicles, and electric mobility platforms (Hanafy, 2025). This integration can enhance transportation resilience and contribute to overall smart city projects.

3.2.3. Automation, Artificial Intelligence and Digital Technologies

Automation and digital technologies are integral parts of Hyperloop operations, allowing for real-time monitoring, autonomous control, predictive maintenance, and efficient traffic management (Alizada, 2020). Considering the very high operating speeds of Hyperloop systems, human-controlled operation is not likely to offer adequate responsiveness and accuracy. Hence, sophisticated digital systems with artificial intelligence, machine learning, sensor networks, and communication systems are critical to ensure reliability and safety in operation. Amiriara (2022) highlighted that future

Hyperloop systems demand very advanced communication networks with the ability of continuous data transmission, monitoring of the system during operation, and automatic control under difficult operating conditions (Amiriara, 2022).

Additionally, Aldakkhelallah (2024) emphasized the increasing significance of automation readiness in transportation networks, stating that public acceptance and technological readiness are crucial aspects of the adoption of autonomous mobility solutions in emerging markets, such as Saudi Arabia (Aldakkhelallah, 2024). Shatnawi et al. (2025) likewise assessed readiness-related conditions for advanced mobility deployment in the Kingdom, including expert-identified requirements for future automated and connected transport. Yet, cybersecurity, governance, and workforce capability remain significant concerns. Together, these studies indicate that automation and digital technologies can play a central role in enabling safe, efficient, and scalable Hyperloop operations, while also showing that technological and strategic readiness should not be equated with full operational readiness.

3.2.4. Maintenance Strategies and Operational Management

Good maintenance and operational management are essential for the long-term reliability and sustainability of Hyperloop systems (Balabel & Almujiab, 2022). Given the intricate nature of Hyperloop technology, the reliance on vacuum systems, magnetic levitation, and

automated control systems, it is essential to have advanced maintenance protocols that can anticipate and mitigate potential issues, thereby ensuring smooth operations. De la Torre et al. (2026) stated that predictive maintenance, boosted by artificial intelligence and digital monitoring technologies, will be a key focus for future transportation systems in enhancing operational efficiency and minimizing maintenance expenses (de la Torre et al., 2026).

In the same way, Siraj et al. (2023) stated that the transportation management systems should adapt to the challenges of the advanced mobility technologies, such as Hyperloop, autonomous vehicles, and smart transportation systems (Siraj et al., 2023). Implementing effective management frameworks is crucial for maintaining the efficient, safe, and reliable operation of services. Furthermore, Ahmad et al. (2025) emphasized the need for sustainable energy systems and advanced maintenance strategies in the future transportation network to improve environmental performance and operational resilience (Ahmad et al., 2025). This means that maintenance readiness is not just about the technical work of repair but also about training the workforce, the ability to monitor digitally, the governance of operations, and the sustainability aspects. Aligning with the management frameworks proposed by Siraj et al. (2023), Figure 3 details the operational readiness model required to adapt to advanced mobility challenges through synchronized automation and integrated digital systems.

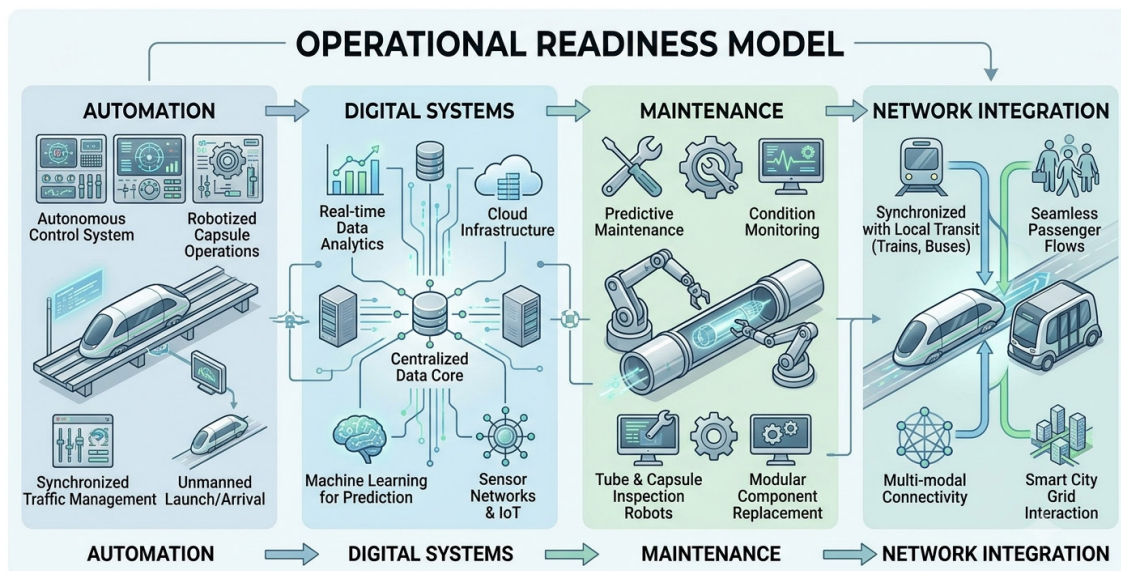


Figure 3. Operational readiness model (conceptual model created entirely by the author from the themes synthesized in this review; not reproduced or adapted from an external source).

3.3. Safety and Risk Preparedness

3.3.1. Passenger Safety Considerations

The most important factor for the acceptance and feasibility of Hyperloop is passenger safety. The Hyperloop capsules run at speeds of up to 1,000 km/h in low-pressure tubes, which presents distinct challenges for safety, including acceleration forces, pressure management, passenger comfort, and emergency protection. In recent years, the importance of passenger safety has been highlighted, and it has been pointed out that redundant braking systems, continuous monitoring technologies and advanced control mechanisms are needed in the design stage. Mateu et al. (2021) proposed to use safety-by-design principles to ensure that passengers are protected in both normal and abnormal operating conditions. In their study, they emphasized the need for system redundancy and fault-tolerant architectures to minimize accident risks (Mateu et al., 2021). Similarly, Rajendran and Sinha (2023) found that passenger safety is one of the main concerns that hinder public confidence in Hyperloop systems, especially due to the lack of commercial-scale passenger operations (Rajendran & Sinha, 2023). Additionally, Rumin et al. (2025) highlighted that ensuring the safety of Hyperloop operations and clear communication about potential risks and mitigation strategies will be critical to gaining public acceptance of the technology (Rumin et al., 2025). The results show that passenger safety is not just a technical challenge, but also a social and psychological aspect that will impact the uptake of future systems.

3.3.2. Emergency Response and Evacuation Systems

Moreover, emergency preparedness should be treated as a core component of operational safety rather than as a secondary response function. Mitropoulos et al. (2021) emphasize integrating emergency response capabilities into infrastructure planning, while Janić (2025) highlights contingency planning and operational simulation for low-probability, high-consequence transport events. Together, these sources provide a more directly relevant basis for assessing emergency preparedness in future Hyperloop operations.

3.3.3. Structural Reliability and Engineering Resilience

Structural integrity is an essential aspect of Hyperloop safety, as the infrastructure must be able to withstand significant mechanical loads, environmental stresses, and pressure differentials over the course of its operation. Hyperloop tubes will stretch hundreds of

kilometers and need to be maintained at near-vacuum which will require durability and structural resilience of the materials. Geiben et al. (2025) showed that the aerodynamic stability and structural performance are highly linked, with even minor changes in the structure having the potential to affect operational safety and efficiency (Geiben et al., 2025). Similarly, Paez Villamil (2023) emphasized the need for the development of advanced materials and engineering solutions in the future, especially in the ambitious project of NEOM, where environmental factors can create extra stresses on the infrastructure (Paez Villamil, 2023). Additionally, Hansen (2020) pointed out that the long-distance structural integrity is one of the most challenging engineering problems for Hyperloop developers, especially in extreme temperature and terrain conditions (Hansen, 2020). The studies indicate that effective engineering design and ongoing monitoring of infrastructure is critical to safe operations.

3.3.4. Cybersecurity and Digital Protection

Cybersecurity is one of the critical safety issues that will be a vital part of Hyperloop systems due to their dependence on automation, artificial intelligence, and digital communication networks. Operational control systems, passenger information platforms, monitoring networks and automated traffic management systems can all be potential targets for cyberattacks. Brighente et al. (2024) have identified cybersecurity as one of the most critical upcoming risks to Hyperloop systems, highlighting the potential for attacks on the operational control infrastructure to threaten passenger safety and disrupt transportation services (Brighente et al., 2024). Similarly, Amiriara (2022) highlighted the importance of implementing secure data transmission methods and robust network designs in future Hyperloop communication systems to mitigate unauthorized access and data breaches (Amiriara, 2022). In the Saudi context, cybersecurity readiness should be considered alongside the wider digital and intelligent-transportation readiness discussed by Shatnawi et al. (2025) and Aldakkhelallah (2024). Hence, cybersecurity should be viewed as an integral part of Hyperloop safety management and not as a peripheral technical problem.

Because Hyperloop operations would depend on tightly interconnected operational technology and information systems, cybersecurity readiness should include secure control-system architectures, strong identity and access controls, network segmentation between safety-critical

and non-critical systems, resilient communications, protection of data and command integrity, continuous monitoring, secure software and firmware management, backup and recovery arrangements, and rehearsed cyber-incident response. These controls should be incorporated into safety assurance and lifecycle risk management rather than treated solely as an information-technology function. For a Saudi deployment, cybersecurity governance would also need to be coordinated with the wider digital infrastructure and critical-infrastructure protection environment. The literature reviewed supports the need for secure communications, resilient control systems, and integrated cyber-risk management as prerequisites for safe Hyperloop operations.

3.3.5. Risk Assessment and Safety Governance

Risk management is the overall approach or process that can be used to identify, assess and reduce risks of safety issues. Technical, operational, environmental, financial, and regulatory issues are all potential

challenges in Hyperloop projects. Kirschen and Burnell (2023) highlighted the importance of incorporating risk management into the design and operation of Hyperloops, as it helps to identify and manage potential risks before they can impact the system (Kirschen & Burnell, 2023). Additionally, Moussa et al. (2025) emphasized the need for proactive risk management and strategic planning for large-scale transportation infrastructure projects, especially in the context of new technologies and uncertainty (Moussa et al., 2025). Moreover, Roucolle (2024) maintained that future mobility systems need to be flexible in terms of risk governance, able to adopt to new technological and environmental challenges (Roucolle, 2024). Overall, these studies suggest that a comprehensive risk management framework is crucial for the safe and sustainable implementation of Hyperloop systems. Figure 4 offers a simplified view of the critical vulnerabilities by dividing hyperloop threats into four basic quadrants: passenger safety, cybersecurity, structural risk, and emergency response.

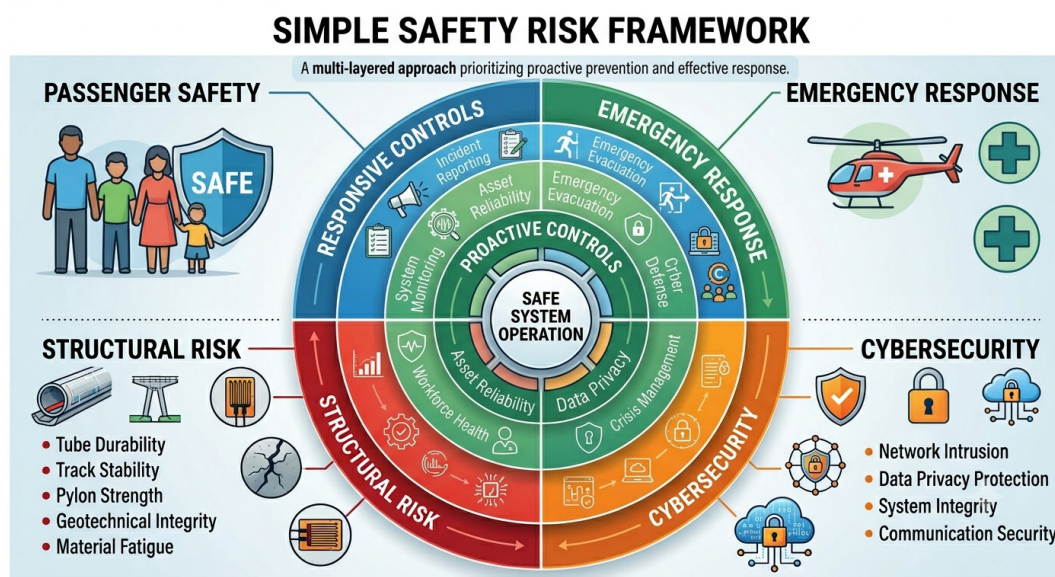


Figure 4. Safety risks associated with Hyperloop systems (conceptual framework created entirely by the author from the reviewed literature; not reproduced or adapted from an external source).

3.4. Regulatory and Governance Frameworks

3.4.1. Existing International Approaches

There is no specific international regulation that exists for Hyperloop systems at present. Most countries use regulations that were originally created for the railways, aviation or other transport sector. This regulatory void leaves investors, developers, and policy makers uncertain, which can slow the technological advancement

and commercialization process, as mentioned by Gkoumas (2021) (Gkoumas, 2021). Moreover, Gkoumas and Christou (2020) stated that there is a need for collaborative governance by governments, industry and research institutions to create effective regulatory pathways for Hyperloop deployment (Gkoumas & Christou, 2020). In addition, Premsagar and Kenworthy (2023) pointed out the importance of learning from aviation and high-speed rail

governance in developing future Hyperloop regulations (Premsagar & Kenworthy, 2023).

3.4.2. Standardization and Interoperability Requirements

Future Hyperloops require standardization to ensure safety, interoperability, and consistency of operation. If the technical standards are not common, it could be difficult to ensure compatibility between infrastructure and vehicle systems from different organizations. In this context, Ali et al. (2026) emphasized the need to have a standardized mobility framework to support the integration of regional transportation within the GCC region (Ali et al., 2026). Similarly, Hanafy (2025) stated that standardized procedures will be required to connect Hyperloop systems with other smart mobility systems (Hanafy, 2025). Moreover, Zawieska et al. (2025) highlighted that technical standardization will be a key enabler in the implementation of future transportation technologies and operational reliability (ZAWIESKA et al., 2025).

3.4.3. Certification and Compliance Challenges

One of the biggest regulatory challenges for Hyperloop deployment is certification. Current certification systems are not suitable for systems used in vacuum conditions at ultra-high speeds. The certification process should include vehicle design, infrastructure safety, operational reliability, cyber security and passenger protection simultaneously, as discussed in a study (Sweatman, 2025). Moreover, Kirschen and Burnell (2023) observed that the dependency of Hyperloop vehicles and infrastructure makes it difficult to perform a separate certification of each component, as both need to be evaluated together (Kirschen & Burnell, 2023). In addition, Brighente et al. (2024) pointed out that there is a need for cybersecurity certification standards to guarantee that digital systems satisfy a minimum safety and security standard before commercial use (Brighente et al., 2024).

3.5. Assessing Saudi Arabia's Hyperloop Readiness

The evidence for Saudi Arabia is strongest at the strategic-readiness level. Vision 2030, smart-city initiatives, infrastructure investment, digital transformation, and government support provide enabling conditions for considering advanced mobility technologies. This should be distinguished from infrastructure/enabling readiness, regulatory readiness, and operational and safety readiness, where the review identifies unresolved requirements involving large-scale deployment, certification, emergency

response, cybersecurity, workforce capability, and system validation.

Saudi Arabia has a number of strategic benefits that make it a potential country for future Hyperloop adoption. The vast territory, the dispersed urban centres and the technological innovations in the country provide favourable conditions for the development of ultra-high speed transportation systems. Almujiabah (2021) found that Hyperloop could provide significant economic and social benefits along major Saudi transportation corridors, particularly when compared with alternative transport technologies (Almujiabah, 2021). Similarly, Paez Villamil (2023) pointed out the opportunities of advanced transportation technologies for NEOM and other smart cities projects (Paez Villamil, 2023). The Emerald Handbook of Smart Cities in the Gulf Region (2024) also highlighted the importance of future mobility technologies to the development of smart cities in the region (Lytras et al., 2024). The Figure 5 emphasizes the importance of the connection to the NEOM corridor, showing how the proposed route traverses different areas of the region, including administrative and future-tech areas.

In the last ten years, Saudi Arabia has made significant investments in the transportation sector, such as highways, airports, logistics hubs, and high-speed rail networks. These investments offer a solid basis for the use of advanced mobility technology, according to Shatnawi et al. (2025) (Shatnawi et al., 2025). Similarly, Aldakkhelallah (2024) highlighted that improvements in digital infrastructure and intelligent transportation systems have enhanced the country's readiness for future mobility innovations (Aldakkhelallah, 2024). Moreover, Khashoggi (2023) identified that the acceptance of smart mobility solutions is rising in Saudi Arabia, which provided a positive environment for the transformation of transportation in the future (Khashoggi, 2023).

Hyperloop aligns closely with Saudi Arabia's Vision 2030 objectives, particularly those related to sustainability, economic diversification, smart cities, and innovation. Advanced transportation systems contribute to national objectives of increased connectivity and economic competitiveness. Emerging mobility technologies are key to the long-term vision of future Saudi urban developments, as highlighted in NEOM—Lining Up a New Smart City (2026) (Mrabet & Sliti, 2026). Similarly, Transformations in Mobility (2024) emphasized that countries pursuing innovation-driven mobility strategies are more likely to

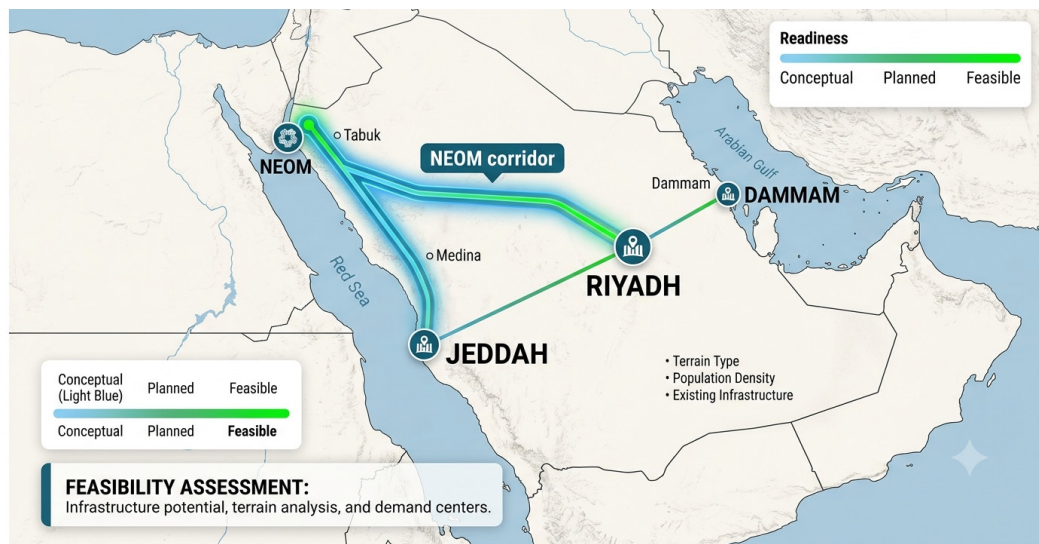


Figure 5. Conceptual Saudi Arabia Hyperloop readiness map (author-created illustrative visualization; not an official Saudi government plan or an existing approved Hyperloop route; route and readiness gradations are conceptual).

successfully adopt disruptive transportation technologies (Madureira, 2026). Moreover, Saudi Arabia was listed as one of the top markets in the region for future transportation innovation, thanks to strong government support and investment (Alanazi, 2023).

The implementation of Hyperloop in Saudi Arabia comes along with both opportunities and challenges. The country's large deserts can enable long-distance transportation corridors to be built with relatively low land acquisition issues. But extreme weather, sandstorms and dust can impact infrastructure performance and maintenance needs. Geiben et al. (2025) pointed out the importance of designing for environmental resilience to guarantee the long-term operation of Hyperloops in extreme weather conditions (Geiben et al., 2025). Similarly, Carlucci et al. (2024) highlighted the importance of climate-responsive infrastructure planning across the Middle East to address environmental stressors and sustainability challenges (Carlucci et al., 2024). Moreover, sustainable engineering solutions that can ensure the efficiency of future transportation systems in the face of climate change were highlighted by Dwivedi et al. (2025). This indicates that environmental adaptability will play a significant role in the success of Hyperloop deployment in Saudi Arabia in the long run (Dwivedi et al., 2025).

4. Discussion

Hyperloop technology has sparked a lot of interest in the field of transport planning, policy, and research, and is seen as a potential solution to the challenges of

the future. Hyperloop is a next generation transportation system that has the potential to revolutionize intercity travel with ultra-high speed transportation, shorter travel times and improved sustainability. This review focused on the operational readiness, safety preparedness, regulatory requirements and strategic suitability of Hyperloop adoption, specifically in Saudi Arabia. The results show that although significant technological advancements have been made, there are still significant obstacles to be overcome before this technology can be a viable option for commercial use.

The reviewed studies indicate that the operational readiness is progressing with the progress of magnetic levitation technologies, automation systems, digital infrastructure and transportation planning. According to Gkoumas (2021) and Premasagar and Kenworthy (2023), a number of the essential technological aspects for Hyperloop operation have been proven to be technically feasible. But infrastructure needs are still a big hurdle. Almujiab (2021) emphasized that a significant amount of financial investment and long-term planning is needed to develop vacuum tube networks, stations, energy systems and maintenance facilities. Similarly, Geiben et al. (2025) highlighted the need for infrastructure resilience and structural stability to guarantee safe and efficient operations. In terms of safety readiness, it was found that passenger safety, emergency preparedness, cyber security and risk management are still very important. The study conducted by Brighente et al. (2022) highlighted the importance of having a wide-ranging safety framework, but no universally accepted

standards or certification procedures are available. The results show that technological progress is not enough without an improvement in the governance and regulation of safety.

Saudi Arabia presents several strategic conditions that are relevant to future Hyperloop exploration. Vision 2030 prioritizes innovation, infrastructure modernization and sustainable development, while investments in digital infrastructure, intelligent transportation, smart-city initiatives, and renewable energy provide an enabling national context. However, these strategic conditions should not be equated with present operational or safety readiness. The reviewed evidence does not demonstrate commercial-scale validation, a complete certification pathway, an established Hyperloop-specific regulatory framework, validated emergency-response arrangements, or full infrastructure deployment. NEOM and other smart-city projects may provide contexts in which advanced mobility concepts could be studied or piloted, but the literature does not establish an approved commercial Hyperloop implementation in Saudi Arabia.

Important readiness gaps remain. The main barriers identified throughout the literature include high capital requirements, infrastructure complexity, regulatory uncertainty, safety certification, emergency preparedness, cybersecurity, environmental resilience, public acceptance, and specialized workforce capability. The absence of internationally harmonized Hyperloop regulations and certification frameworks remains a significant constraint, while extreme temperatures and dust may increase infrastructure and maintenance demands in Saudi Arabia. Public confidence will also depend on demonstrable safety, transparent risk communication, and evidence from pilot or demonstration projects. These findings indicate that Saudi Arabia's strategic readiness is more advanced than its demonstrated operational, regulatory, and safety readiness. The findings of the study indicate a number of policy implications. Saudi Arabia should focus on creating specific regulations for Hyperloop systems, promote public-private partnerships for investments, and implement test projects to assess the feasibility of operation in the local environment. Moreover, international cooperation can help in transferring knowledge, building capacities and harmonizing regulations. The measures would enhance the Kingdom's readiness for future use of the Hyperloop technology, and contribute to the overall national goals of sustainable mobility, economic diversification and technological innovation.

5. Limitations and Future Research

One strength of this review is that it brings together recent multidisciplinary evidence on Hyperloop technology in an integrated way, covering operational, safety, infrastructure, regulatory, cybersecurity, sustainability, and strategic aspects in the context of Saudi Arabia. The review includes literature from transportation, engineering, policy, and smart-mobility studies to provide a broad view of readiness. However, several limitations should be recognized. Commercial Hyperloop systems are not fully operational, so real-world operational evidence remains limited. The narrative-review design and thematic coding also involve researcher judgment, and the 26-study corpus should not be interpreted as an exhaustive quantitative estimate of the entire literature. In addition, thematic categories were non-exclusive, meaning that individual studies could contribute to multiple themes. The Saudi-specific evidence is also more developed for strategic and enabling conditions than for validated commercial operations, certification, emergency response, and large-scale infrastructure. Further studies are needed on pilot-project evaluation, public acceptance, cost-benefit analysis, cybersecurity assurance, emergency-response simulation, and climate-specific feasibility in Saudi Arabia and the wider Gulf region.

6. Conclusion

This review analyzed Hyperloop readiness in Saudi Arabia across technological development, infrastructure and enabling conditions, operational requirements, safety preparedness, cybersecurity, regulatory issues, and national strategic alignment. The evidence indicates substantial technological progress and favorable strategic conditions associated with Vision 2030, smart-city development, digital transformation, infrastructure investment, and government support for innovation. However, these conditions should not be interpreted as evidence of present commercial or operational readiness. Significant gaps remain in commercial-scale validation, infrastructure deployment, safety certification, emergency preparedness, cybersecurity assurance, regulatory standardization, environmental adaptation, and workforce capability. Accordingly, the current evidence supports continued feasibility assessment, structured pilot testing, standards and certification development, and coordinated public-private and international collaboration rather than a conclusion that Hyperloop is already deployment-ready in Saudi Arabia.

Conflict of interest

The author declares no conflict of interest.

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