

Hyperloop: A high-speed revolution

Sachindra Shankar, Sasmita Singh, Jibitesh Kumar Panda

Department of Mechanical Engineering, Anurag University, Hyderabad 500088, India

Abstract

The hyperloop system is a high-speed revolution in the field of transportation systems, consisting of a pod tube and a propulsion system for the pod's movement in the tube. This system is feasible up to a distance of 1500 Km due to the higher infrastructural cost. The current study discusses the different components of the hyperloop system and their working principle. This paper also discusses safety issues, which are critical issues for this system. The cost of traveling is also a serious concern for the scalability of this transportation system. **Keywords:** Hyperloop, High Speed, Transportation, Pod, Tube

1. INTRODUCTION

The idea of traveling at a very fast speed has been a dream for human beings for centuries. The work on high-speed transportation was started in 1829 when Stephenson's rocket made a world-time record of 58 Km/h in the Rainhill competition. The Japanese carried forward the legacy of high-speed races with the inauguration of the Tokaido Shinkansen train in 1964 with a top speed of 210 km/h. Currently, trains like Spain's AVE, France's TGV, and Germany's ICE can easily maintain an average 300km/h speed. A similar type of system is maglev, which utilizes the magnetic levitation technique to achieve high speed. These trains are operational on short and long-distance routes in different world regions. The concept behind the operation is to use small and light vehicles on less expensive guideways that require less power for propulsion [1]. A maglev train is operational between the city center and Shanghai Airport in China. However, the root of these maglev trains lies in Japan, and the Tokyo-Nagoya maglev will be operational in 2027. Although maglev technology has proven its technical feasibility through various tests, concerns persist regarding its practicality for commercial use, mainly due to the significant upfront investment necessary for building dedicated infrastructure. The air transportation system is one of the fastest, but some challenges are still associated with it. Air transport is notably disadvantaged by its elevated costs relative to alternative modes like sea or land transport. The increased charges for air freight stem from various factors, including fuel expenses, infrastructure investments, and handling fees. Therefore, it is imperative for businesses to meticulously assess the cost-effectiveness of air transport according to their particular requirements and financial constraints. Airplanes possess restricted cargo space compared to ships or trains, presenting difficulties for businesses handling bulky or oversized

shipments. Air transport is the most effective for high-value, time-sensitive goods requiring rapid delivery rather than large-volume shipments.

Hyperloop technology is a method of traveling that can fulfil this dream. The idea of the tube-based transportation system for passengers and goods was first proposed in a USA patent in 1950 [2]. The method discusses the transportation system in which the magnetic force can accelerate and decelerate the car. This method is also helpful in the reduction of air resistance between the moving car and the tube. Instead of wheels akin to trains or cars, the pods are engineered to glide on air skis, employing a concept similar to an air hockey table or magnetic levitation to minimize friction, according to a Tesla document proposed by Elon Musk, The

Table 1. Summary of the work related to the Hyperloop system

Author's Name	Area of Research	Conclusion
Premsagar et al. [3]	Technical, environmental, economic, and human considerations in assessing the applicability of the hyperloop to a particular location	Much research should be done to make the hyperloop system viable for the mass population.
Rajendran et al. [4]	Simulation-based approach to know about the hyperloop networks	The parameters like pod capacity, Number of hyperloop capsules, commuter volume, and willingness to use the

		hyperloop system affect the system's viability.
Goeverdan et al. [5]	A comparative study between the hyperloop system and the other modes of transportation systems	the HL system has relatively positive social/environmental performances, particularly in terms of energy consumption, emissions of GHGs, and noise
Decker et al. [6]	Feasibility of a hyperloop as a new-generation transportation system	Underwater routes will have a significantly lower materials cost due to more favorable loading conditions generated by buoyancy.
Gkoumas et al. [7]	status of Hyperloop development and identified issues and challenges	Expansion of taxonomy to cover other domains of knowledge
Hansen et al. [8]	Hyperloop system technology concepts are analysed	There are multiple issues associated with the hyperloop system like, such as limited seats, the long time required to stop the train, and the necessity of high acceleration and deacceleration rates.
Almujibah et al. [9]	to identify potential physiological and social challenges	High acceleration/deceleration, high speed, and high magnetic field are potential risks or sources

	related to hyperloop	of discomfort for the passengers.
Chaidez et al. [10]	Discusses about the the second drag/friction source in the Hyperloop system, namely the one related to the locomotion and or levitation of the pod in the tube	Rolling wheel and sliding air bearing-based hyperloop systems require more power to propel and are more controllable, whereas levitation-based hyperloop systems require less power but are less controllable.
Tbaileh et al. [11]	Impact of hyperloop technology in the electricity grid.	The simulation results clearly indicate that hyperloop technologies will require compensation devices to address or preempt the pulsating load both for active and reactive power.
Sung et al. [12]	Aerodynamic Characteristics of Hyperloop System	Tube pressure and drag show a proportional relation

Hyperloop endeavours to establish itself as a novel mode of transportation, positioned as the fifth mode alongside planes, trains, cars, and boats. It aims to offer enhanced safety, speed, cost-effectiveness, convenience, weather immunity, sustainable self-powering capabilities, earthquake resistance, and minimal community disruption along its route. It is envisioned as a viable alternative for statewide mass transit for distances less than 1500 km, offering advantages over flying or driving. Additionally, compared to planned high-speed trains, the Hyperloop is perceived as potentially slower, more costly to operate without subsidies, and significantly less safe. Many studies have already been done on the hyperloop system, which discusses its different aspects. For example,

Premsagar et al. [3] studied the technical, environmental, and human considerations-based approaches in studying hyperloop systems. Rajendran et al. studied the simulation-based approach to learn about the hyperloop networks. They concluded that the pod capacity, number of capsules, and commuter volume affect the viability of the hyperloop system. Goeverdan et al. [5] emphasized the comparative study between the hyperloop system and another mode of high-speed transportation systems. They concluded that the hyperloop system has a relatively positive social and environmental impact. A summarization of all the studies related to the hyperloop system is mentioned in Table 1.

The current study reviews the recent articles published related to the hyperloop system and tries to identify the viability of the system.

2. DIFFERENT COMPONENTS OF A HYPERLOOP SYSTEM

A hyperloop system is a futuristic mode of transportation characterized by its high-speed, low-pressure tube network. At its core, the structure of a hyperloop system consists of a network of elevated or underground tubes through which pods travel at near-supersonic speeds propelled by linear induction motors and magnetic levitation. These tubes are constructed to minimize air resistance, creating a near-vacuum environment to reduce drag and allow for efficient, high-speed travel. The system typically incorporates stations at various points along the route for passenger embarkation and disembarkation. Additionally, advanced control and monitoring systems ensure safe and reliable operation, managing pod movement and maintaining optimal conditions within the tubes. The modular nature of the hyperloop system allows for scalability and adaptability to different geographical and urban landscapes, making it a promising solution for future transportation challenges. A hyperloop system comprises different components, as mentioned below. A representation diagram of the hyperloop system is shown in Fig 1.

Pods/Capsules: In the context of hyperloop technology, a pod refers to a vehicle that travels through a low-pressure tube, propelled by magnetic levitation and linear induction motors. Here's a detailed exploration of the pod's key features and functionalities:

- 1. Aerodynamic Design:** Hyperloop pods are meticulously designed to minimize air resistance, allowing them to glide through the low-pressure environment of the tube with minimal energy consumption. The sleek, bullet-shaped exterior reduces drag, enabling high-speed travel while maintaining stability and efficiency.
- 2. Lightweight Construction:** To optimize speed and energy efficiency, hyperloop pods are constructed using lightweight yet durable materials such as carbon fiber composites. This reduces the overall weight of the pod, allowing for swift acceleration and deceleration without compromising structural integrity.
- 3. Passenger Comfort:** Despite its focus on speed, the pod prioritizes passenger comfort and safety. Interior design features may include comfortable seating arrangements,

ample legroom, climate control systems, and advanced shock absorption mechanisms to minimize discomfort during acceleration and deceleration phases.

Vacuum tube system: The vacuum tube system of a Hyperloop represents the technological backbone of this revolutionary mode of transportation. Employing a network of airtight tubes with near-vacuum conditions, the Hyperloop system eliminates air resistance, enabling pods to travel at unprecedented speeds. Within these tubes, a series of vacuum pumps maintain the low-pressure environment, allowing the pods to glide effortlessly along magnetic levitation tracks. This vacuum tube infrastructure ensures minimal air resistance, reducing energy consumption and enabling the Hyperloop to achieve velocities surpassing those of traditional high-speed trains and airplanes. By harnessing the power of vacuum technology, the Hyperloop system redefines the possibilities of efficient, high-speed travel for the future.

Propulsion system: The propulsion system of a Hyperloop represents a cutting-edge fusion of magnetic levitation (maglev) and linear induction motor (LIM) technologies. Each Hyperloop pod is equipped with powerful electric motors that interact with the magnetic fields generated by the track to propel the pod forward. As the pod accelerates, it glides along the track, suspended in mid-air by the repulsive force between its onboard magnets and those lining the track. This frictionless propulsion mechanism not only ensures a smooth and efficient journey but also minimizes energy consumption. The Hyperloop's propulsion system enables it to achieve remarkable speeds, potentially exceeding 1000 kilometers per hour, while offering passengers a comfortable and environmentally friendly mode of transportation for the future.

Autonomous Control: Hyperloop pods are typically designed to operate autonomously, guided by sophisticated control systems that ensure safe and efficient travel. These systems utilize a combination of sensors, cameras, and artificial intelligence algorithms to monitor the pod's surroundings, adjust speed, and maintain a safe distance from other pods within the network.

Tube support and infrastructure: The tube support and infrastructure of a Hyperloop system are essential components that ensure the safety, stability, and efficiency of the transportation network. The tubes, typically made of durable materials such as steel or reinforced concrete, are supported by a series of pylons or columns strategically positioned along the route to maintain the desired alignment and elevation. These supports not only bear the weight of the tubes but also resist external forces such as wind, seismic activity, and thermal expansion. Moreover, the infrastructure includes stations for passenger boarding and disembarkation, as well as maintenance facilities and power supply systems. Advanced sensors and monitoring technologies are integrated into the infrastructure to detect any anomalies and ensure the optimal functioning of the Hyperloop network. Through meticulous planning and construction, a Hyperloop system's tube support and infrastructure guarantee the reliability and safety of high-speed travel in the 21st century.

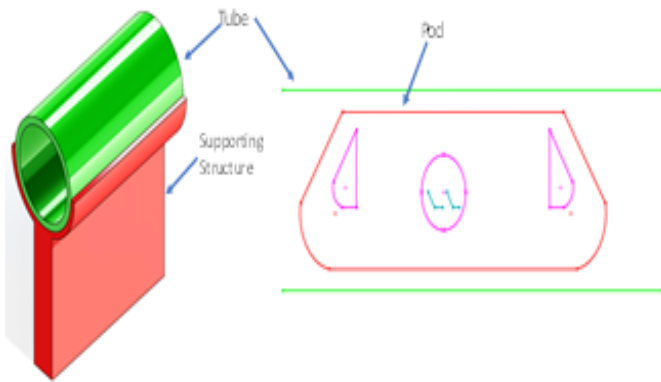


Figure 1. Components of a hyperloop system

3. PASSENGER CAPACITY OF AN HYPERLOOP SYSTEM

The hyperloop, a revolutionary mode of transportation, boasts impressive passenger capacity capabilities. Leveraging its advanced design and cutting-edge technology, the hyperloop system can accommodate many passengers per capsule, with estimates suggesting capacities ranging from around 28 to 40 passengers per pod. This remarkable capacity is made possible by the streamlined, aerodynamic design of the capsules and the efficient use of space within each pod. With high-speed travel and minimal time intervals between departures, the hyperloop promises to efficiently transport large volumes of passengers, making it a promising solution for addressing the growing demand for rapid and sustainable transportation in densely populated regions.

4. COSTS OF A HYPERLOOP SYSTEMS

Implementing a hyperloop system entails considerable costs, reflecting the complexity and scale of the infrastructure required. Factors influencing costs include the construction of vacuum-sealed tubes, specialized propulsion systems, and advanced capsule design. Initial estimates for a hyperloop project suggest expenses ranging from tens to hundreds of millions of dollars per mile, depending on factors such as terrain, environmental considerations, and regulatory requirements. Moreover, ongoing operational expenses encompass maintenance, energy consumption, and staffing, further adding to the financial considerations. However, proponents argue that despite the substantial upfront investment, the hyperloop's potential for high-speed, energy-efficient transportation could yield long-term economic benefits, such as reduced congestion, enhanced connectivity, and increased productivity, ultimately justifying its costs as a transformative investment in future transportation infrastructure.

Ticket pricing

Ticket pricing for a Hyperloop system would likely be determined by a combination of factors to ensure affordability, competitiveness with other modes of transportation, and financial sustainability. Pricing strategies would consider variables such as distance traveled, operating

5. REQUIRED SAFETY FEATURES OF A HYPERLOOP SYSTEM

The safety features of a hyperloop system are paramount to its successful operation and public acceptance. One crucial aspect is using redundant fail-safe systems to ensure passenger safety in the event of any unexpected malfunction or emergency. Automated emergency braking systems equipped with advanced sensors and artificial intelligence algorithms play a vital role in maintaining safe distances between pods and detecting obstacles or hazards on the track. Additionally, the hyperloop infrastructure incorporates comprehensive monitoring systems that continuously assess track integrity, pod performance, and environmental conditions to identify potential risks and mitigate them before they escalate pre-emptively. Emergency evacuation protocols and escape routes are also designed and integrated into the system to provide passengers with safe exit options in case of emergencies. Overall, the Hyperloop prioritizes safety through a combination of cutting-edge technology, rigorous testing, and meticulous planning, aiming to provide passengers with a secure and reliable transportation experience.

Different safety features

1. Emergency Braking Systems: Hyperloop pods are equipped with advanced braking systems capable of rapidly slowing down or stopping the pod in case of emergencies. These systems utilize technologies such as magnetic levitation (maglev) and friction brakes to halt the pod safely.
2. Real-time Monitoring and Control: Hyperloop systems feature sophisticated monitoring and control systems that continuously assess the condition of the infrastructure, pods, and surrounding environment. Real-time data analysis allows for immediate responses to any anomalies or safety concerns.
3. Redundant Power and Control Systems: Critical systems within the Hyperloop, including propulsion, braking, and control systems, are designed with redundancy to ensure reliability and safety. In the

event of a failure in one system, backup systems can take over seamlessly to maintain safe operations.

4. **Structural Integrity and Safety Margins:** Hyperloop tubes and infrastructure are designed with a high margin of safety to withstand various stressors, including pressure differentials, seismic activity, and external impacts. Rigorous testing and adherence to safety standards help ensure the system's structural integrity.
5. **Emergency Exit and Evacuation Procedures:** Hyperloop stations and pods are equipped with emergency exits and evacuation procedures to facilitate safe evacuation in the event of an emergency, such as a pod malfunction or sudden decompression. Staff are trained to assist passengers in evacuating the system safely.
6. **Fire Suppression and Containment Systems:** Hyperloop systems incorporate fire suppression and containment systems to minimize the risk of fires and ensure passenger safety. These systems may include fire-resistant materials, automatic extinguishing systems, and compartmentalization to prevent the spread of fire.
7. **Seismic and Environmental Safety Measures:** Hyperloop infrastructure is designed to withstand seismic events and extreme weather conditions, ensuring the safety and stability of the system even in adverse circumstances. Environmental monitoring and protective measures further enhance safety and resilience.
8. **Regulatory Compliance and Safety Standards:** Hyperloop projects adhere to stringent regulatory requirements and safety standards established by relevant authorities. Compliance with these standards ensures that safety is prioritized at every project stage, from design and construction to operation and maintenance.

6. DIFFERENT SAFETY CONCERNS AND THEIR SOLUTIONS ONBOARD PASSENGER EMERGENCY AND PASSENGER EVACUATION

In the event of a serious incident resulting in oxygen loss for passengers, Hyperloop capsules would deploy oxygen masks similar to those found on airplanes. Once safely reaching the destination, affected capsules would be taken out of service. The safety protocol for onboard air supply in Hyperloop closely resembles that of aircraft. All capsules maintain direct radio contact with station operators for emergencies, enabling passengers to report incidents, request assistance, and receive aid promptly. Furthermore, each capsule is equipped with first aid supplies. Although existing literature lacks thorough discussion of en route passenger illnesses or emergencies, SpaceX asserts that due to the short travel times of Hyperloop (e.g., San Francisco to Los Angeles in 30 minutes), the preferred response to an emergency is for the capsule to notify station operators and complete the journey within a few minutes. Emergency services would be awaiting arrival at the destination. Musk concludes that managing an emergency within a Hyperloop capsule entails completing the planned

journey and meeting emergency personnel upon arrival at the destination.

Power Outage

In the event of unforeseen circumstances such as power outages or system glitches within the Hyperloop infrastructure, ensuring the safety and continuity of travel becomes paramount. While safety measures, including oxygen masks and emergency brakes, are integral components of the Hyperloop system, they are not immune to occasional failures. To minimize disruption and inconvenience to passengers, it is imperative to devise robust contingency plans.

Hyperloop Transportation Technologies advocates for the completion of ongoing journeys even amidst power outages, intending to facilitate passengers reaching their destinations. SpaceX, on the other hand, emphasizes the energy-efficient nature of Hyperloop travel, asserting that the capsules can coast for a significant portion of the journey without continuous power. Their approach to mitigating the risk of power outages involves incorporating redundant lithium-ion battery packs to sustain essential life support systems.

7. HYPERLOOP SYSTEM FOR GOODS

TRANSPORTATION

Implementing a Hyperloop system for goods transportation presents several challenges that must be addressed to integrate successfully into existing logistics networks. One significant challenge involves adapting the Hyperloop infrastructure to efficiently accommodate various types of cargo while ensuring loading and unloading processes are streamlined to minimize downtime. Additionally, the safety and integrity of goods during transit must be ensured, requiring careful packaging and protection measures to withstand the forces experienced during high-speed travel. Regulatory compliance and the development of intermodal infrastructure further complicate the implementation, requiring coordination between stakeholders to navigate legal and logistical hurdles. Balancing the initial investment with long-term cost-effectiveness also poses a challenge, as stakeholders must assess the return on investment regarding reduced transit times, fuel savings, and overall supply chain efficiency. Overcoming these challenges will require collaborative efforts and innovative solutions to realize the potential benefits of Hyperloop for goods transportation.

8. FUTURE OF HYPERLOOP IN INDIA

The future of the Hyperloop system in India holds tremendous promise as the country seeks innovative solutions to address its growing transportation needs. With its potential to revolutionize long-distance travel by offering unprecedented speed and efficiency, the Hyperloop system could significantly reduce travel times between major Indian cities, unlocking economic opportunities and enhancing connectivity. India's ambitious infrastructure development

plans align well with the Hyperloop's goals, presenting opportunities for collaboration between government agencies, private enterprises, and technology developers. However, successfully implementing the Hyperloop in India will require overcoming various challenges, including regulatory approvals, land acquisition, and funding constraints. Nevertheless, with India's commitment to embracing transformative technologies and its burgeoning market for sustainable transportation solutions, the Hyperloop system has the potential to play a pivotal role in shaping the future of transportation in the country, ushering in an era of faster, greener, and more accessible mobility for all.

9. CONCLUSION

The Hyperloop system is a futuristic mode of transportation envisioned as a high-speed, low-friction system that propels passenger or cargo capsules through a network of vacuum-sealed tubes. First proposed by Elon Musk in 2013, the Hyperloop concept aims to revolutionize transportation by achieving speeds of up to 700 mph (1,100 km/h), significantly reducing travel times between distant cities. The system relies on magnetic levitation and linear induction motors to propel the capsules, eliminating air resistance and allowing for efficient, frictionless travel. Companies like Virgin Hyperloop and Hyperloop Transportation Technologies have been actively developing and testing prototype systems worldwide. While the Hyperloop system promises to offer numerous benefits, including reduced carbon emissions, increased transportation efficiency, and enhanced connectivity, it also faces challenges such as regulatory hurdles, safety concerns, and the need for substantial infrastructure investment. Despite these challenges, the Hyperloop system represents a promising glimpse into the future of transportation, potentially reshaping how people and goods move across vast distances.

REFERENCES

- [1] R.D. Thornton, Efficient and affordable maglev opportunities in the united states, *Proceedings of the IEEE* 97 (2009) 1901–1921. <https://doi.org/10.1109/JPROC.2009.2030251>.
- [2] Goddard R. H., *Vacuum Tube Transportation System*, USA Paten, 251199, 1950.
- [3] S. Premsagar, J. Kenworthy, A Critical Review of Hyperloop (Ultra-High Speed Rail) Technology: Urban and Transport Planning, Technical, Environmental, Economic, and Human Considerations, *Frontiers in Sustainable Cities* 4 (2022). <https://doi.org/10.3389/frsc.2022.842245>.
- [4] A simulation-based approach to provide insights on Hyperloop network operations, (n.d.).
- [5] K.; Van Goeverden, D.; Milakis, M.; Janic, R. Konings, *Performances of the HL (Hyperloop) transport system*, 2017.
- [6] K. Decker, J. Chin, A. Peng, C. Summers, G. Nguyen, A. Oberlander, G. Sakib, N. Sharifrazi, C. Heath, J. Gray, R. Falck, *Conceptual Feasibility Study of the Hyperloop Vehicle for Next-Generation Transport*, n.d.
- [7] K. Gkoumas, *Hyperloop academic research: A systematic review and a taxonomy of issues*, *Applied Sciences (Switzerland)* 11 (2021). <https://doi.org/10.3390/app11135951>.
- [8] I.A. Hansen, *Hyperloop transport technology assessment and system analysis*, *Transportation Planning and Technology* 43 (2020) 803–820. <https://doi.org/10.1080/03081060.2020.1828935>.
- [9] H. Almujiabah, S.I. Kaduk, J. Preston, *Hyperloop – prediction of social and physiological costs*, *Transportation Systems and Technology* 6 (2020) 43–59. <https://doi.org/10.17816/transsyst20206343-59>.
- [10] E. Chaidez, S.P. Bhattacharyya, A.N. Karpets, *Levitation methods for use in the hyperloop high-speed transportation system*, *Energies (Basel)* 12 (2019). <https://doi.org/10.3390/en12214190>.
- [11] A. Tbaileh, M. Elizondo, M. Kintner-Meyer, B. Vyakaranam, U. Agrawal, M. Dwyer, N. Samaan, *Modeling and impact of hyperloop technology on the electricity grid*, *IEEE Transactions on Power Systems* 36 (2021) 3938–3947. <https://doi.org/10.1109/TPWRS.2021.3056298>.
- [12] J.S. Oh, T. Kang, S. Ham, K.S. Lee, Y.J. Jang, H.S. Ryou, J. Ryu, *Numerical analysis of aerodynamic characteristics of Hyperloop system*, *Energies (Basel)* 12 (2019). <https://doi.org/10.3390/en12030518>.