**Viability of the Hyperloop**

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# Abstract

This paper explores the viability of the Hyperloop in displacing the traditional transport (road, railway, and flight) system to become the future of transportation. It briefly discusses the application of magnetic levitation propulsion, air-bearing skis suspension systems, and other integrated system engineering processes that aim to bring the Hyperloop from experimental phases to commercialization. The Hyperloop aims to provide a cheaper and faster mode of transportation between major urban centers for increased integration of techno-economical business processes that may cause a paradigm shift in how we live and travel. Proposed theoretical concepts of the Hyperloop suggest pods traveling in excess speed of 700+ mph within a steel tube-controlled pressurized environment. Despite its proposal of providing increased safety, comfortability, cost-effectiveness, and reduced travel times, the complex design of the system evokes a high degree of uncertainty in revolutionizing the transport industry. Further research into the design space of the Hyperloop might help improve design efforts to close the gap between conceptual designs and the realization of the system to provide a feasible and reliable system design that brings the Hyperloop closer to commercial application.

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# Introduction

## The Hyperloop design is not a relatively new concept. The list of predecessors to the Hyperloop date back to the seventeenth-century application of artificial air-pressured vacuum and pneumatic railway for mail and wagon transport systems (Lasky, 2020). These heritages were rather short-lived as they proved to be ineffective, inefficient, or lacked the techno-economical platform to implement such concepts for a large-scale commercial purpose.

## Hyperloop in Transport

## Legacy concepts of the Hyperloop failed to achieve its purpose on the road to realization for reasons such as safety, technological gaps, inadequate funding, or lack of techno-economic platform to support the development of an unproven infrastructure that requires considerable financial backing. So, what makes current proposals for the Hyperloop different and likely to succeed in revolutionizing the autonomous industry? Advances in Systems Engineering (SE) approach to system design may have just paved the way for technology to catch up to what would have otherwise been considered a futuristic concept. Perhaps other factors such as overcrowded airports, increased traffic jams and the need to reduce carbon emissions have made the Hyperloop a more attractive option as society aims to alleviate the burden on current transport infrastructure. Another notable trend in the evolution of the transport industry that has made the Hyperloop a popular innovation concept to explore is the displacement of taxis by ridesharing technologies such as Uber, Lyft, etc. However, to bring an unproven conceptual Hyperloop design to commercial realization, the challenge of funding, geographical complications and engineering complexities must be overcome.

The idea of open-source development of the Hyperloop has encouraged different teams and companies across the globe to engage in feasibility research and experimentation toward the design of the Hyperloop. The realization of Hyperloop transport will set the stage for a paradigm shift in the evolution of the transportation industry. Should the concept evolve to realization, the Hyperloop will revolutionize the way we live, work, and travel by providing shorter travel times, a cost-effective mode of transportation, efficient energy usage, and other beneficial purposes which will be explored in later sections of the paper. At the writing of this paper, a conceptualized Hyperloop system has yet to become a reality for commercial transportation and remains a futuristic proposal despite experimental demonstration of the viability of the design. This paper explores the viability of the Hyperloop given proposed concepts, the reliability of design space, and the need for further research into the techno-economic challenges that must be overcome to bring it to commercial application.

## Viability of the Hyperloop

The new conceptual approach to the Hyperloop design aims to apply magnetic air levitation technology or air-bearing skis suspension systems to propel pods in excess speed of 700 mph between urban centers as a means of replacing traditional road, railway, and air travel. However, to be able to successfully displace our current mode of transportation, the benefits and demand for the proposed concept must justify its need when compared to current transport systems. A comparison of a proposed framework of a Hyperloop infrastructure with current mode of transportation assesses “that, the Hyperloop represents an energy-efficient and high speed solution” (Tudor & Paolone, 2021, p.20) with supporting analysis that were in agreement with existing literature of the Hyperloop concept. Efficient energy utilization coupled with faster travel times supported by the proposed conceptual speed warrants economic demand for the Hyperloop infrastructure.

In his conceptual proposal white paper of an open-source development Hyperloop system, Musk (2013) suggested that the Hyperloop offers “safer, faster, lower cost, more convenient, immune to weather, sustainably self-powering, resistance to Earthquakes and non-disruptive to those along the route” (p.2). The Hyperloop may satisfy customer, business, and societal demands by contributing to economic growth, improving both standard of living and the environment (Hansen, 2020) respectively. The current modes of long-distance travel are high speed trains, maglev trains (select locations) and long-haul aircraft. The Hyperloop aims to provide a better alternative by proposing a convenient mode of travel at near supersonic speeds with less impact to the environment and at a cheaper option.

Proposed concepts suggest that the steel tube shall either be tunneled underground or mounted on pylons based on geographical location as seen in figure 1 (right). Safety and reliability are among the major concerns that need to be addressed for the Hyperloop to become a viable transport system. “A completely new transportation mode needs to not only address safety issues that are known from existing modes but also anticipate any safety issues specific to it” (Taylor et al. 2016, p.4). This implies that Hyperloop developing teams need to purposefully engineer the systems and its subsystems with robustness in mind. The Hyperloop concept highlights on robustness by indicating that the system shall be “immune to weather…, resistance to earthquakes and non-disruptive” (Musk, 2013) to environment or parameters subject to it. Robustness of a system is “the degree to which a system or components can function correctly in the presence of invalid inputs or stressful environmental conditions cf. error tolerance, fault tolerance” (IEEE & ISO/IEC, 2010, p.313). Robustness of the Hyperloop and other elements that make up its infrastructure will determine its viability in the presence of any environmental disturbance or external parameters that raises safety concerns.

# Reliability of Proposed Concepts

## The traditional transportation systems are either too slow or not environmentally friendly. This has increased the notion of a need for a new transport system with the capacity to fulfil the needs of faster travel times, environment friendly, inexpensive, and convenient mode of travel. The Hyperloop proposes a viable means of fast transportation between urban centers. Imagine living in New York and commuting to Boston or California to Los Angeles every day for work or other purposes in minutes. The proposed design space of the Hyperloop suggests a propulsion of capsules that will travel through underground or above ground vacuumed steel tubes connecting major cities. Elements of the overall infrastructure of the Hyperloop such as stations, guideway systems, and autonomous software capability system have been omitted from this discussion. However, given the design concepts being experimented by developing teams, the Hyperloop has yet to achieve a satisfactory reliability performance in terms of speed, capacity, and time given the stated conditions proposed in its concept design. Reliability of a system is “the ability of a system or component to perform its required functions under stated conditions for a specified period of time" (IEEE & ISO/IEC, 2010, p. 297). A conceptual pod and tube infrastructure design is illustrated in figure 1.

A white computer mouse

Description automatically generated with low confidence A picture containing graphical user interface

Description automatically generated

Figure 1 (Musk, 2013, p.14): Illustrates a levitated capsule traveling within a controlled tube environment. Right figure illustrates a solar panel attached to tubes supported by pylons.

## Theoretical Concepts

### The theoretical concept presented involves increased engineering technical complexities in designing capsules to travel at near sonic speed whilst suspended within the steel tube. The proposed concepts employ magnetic levitation technology seen in high-speed trains and maglev trains in a pressurized vacuum-controlled environment. Alternative to magnetic levitation technology is the application of air bearing skis suspension systems. Musk (2013) suggests that air bearings offer a better design element for suspending capsules to enhance safety, reliability, and comfortability (p. 19) of passengers whilst maintaining the tube and capsules integrity from its stillness design feature. The design space of the Hyperloop requires complex engineering application which is beyond the scope of this paper and shall not be discussed. However, on the surface, currently developed Hyperloop infrastructure being experimented requires propulsion systems, levitation mechanism with maglev or air bearing technologies, energy management system with solar panels and network of intertwined pods to conserve energy, vacuum tube design and control to prove the feasibility of the proposed concept as demonstrated by SpaceX, Hyperloop Transport Technologies (HTT) and other teams around the world competing to bring the concept to viability in test runs on the road to commercialization.

The development of high-speed trains and the maglev trains implies that the challenge of achieving supersonic speeds with the Hyperloop is a possibility worth exploring. The Concorde plane which was retired in 2003 after operating for nearly 27 years due to funding issues proves that it is possible to overcome engineering hurdles needed to engineer the proposed concepts of the Hyperloop should funding be in place. Engineering complexity can be reduced through the adoption of open-source knowledge integration and standardization of the fundamental system development idea for the Hyperloop to increase interoperability across different systems. The Hyperloop development will benefit from open-source integration of design and development efforts from different engineering team collaboration to help increase its reliability objectives. Designing and developing a system with reliability in mind helps developers adopt robust design methodologies to prevent system failures that raises safety concerns.

### Safety and Reliability

Safety and reliability concerns have generated several technical questions that must be addressed to see a viable Hyperloop infrastructure design for commercial purposes. The following summarizes some of the floating technical questions that have yet to be answered by existing literature concerning the Hyperloop: *(i) what is the optimal pressure inside a Hyperloop tube in order to minimize global energy consumption? (ii) What is the achievable minimal energy consumption of a Hyperloop system? (iii) Is there a strong dependency between the infrastructure operation and the capsules propulsion system design? (iv) Which is the impact of the magnetic levitation on the energy consumption of the capsule?* (Tudor & Paolone, 2021, 1).

The proposed concept suggested by Musk (2013) in Hyperloop Alpha white paper addressed energy concerns and safety standards by suggesting the application of solar panels and renewable energy transfer between capsules and tubes. Air bearing skis suspension systems were considered as a cheaper and safer alternative due to their rigidity. However, engineering applications of maglev systems were suggested towards the concept development of the Hyperloop. The design and energy need of the Hyperloop infrastructure will be dependent on the geographical location where the infrastructure will be operated as some zones will be optimal for solar while others will depend on other forms of renewable energy sources due to lack of regular sunlight.

The operational reliability of a Hyperloop will require continuous depressurization of the tube environment to a desired atmospheric pressure and air leaking compensation (Tudor & Paolone, 2021, p.2) to maintain a controlled pressurized environment within the tube. Maintaining a controlled environment within the tube ensures integrity of the tube as well as the operational reliability of capsules in terms of acceleration, constant speed, deceleration, and emergency braking mechanism. This is an engineering complexity that can be accomplished by the modular design of the system. The system engineering process involved in developing the Hyperloop infrastructure should employ robust design principles by integrating very specific structural systems and materials that can accommodate the air permeability concerns. The application of selected materials for building the tube is a robust design feature to resist environmental disturbance such as natural disasters and other occurrences. The question of how the environment interacts with steel tubes and other elements of the Hyperloop Infrastructure lies in its autonomous software design interoperability. Some literature review presents Concrete as a better alternative to steel tube when it comes to air permeability and viscosity (Tudor & Paolone, 2020). However, concrete may easily puncture and may not provide equal resistance to environmental disturbances as a steel tube.

### Standardization and Certification

Lastly, should the challenges of engineering complexity and funding be overcome to produce a viable Hyperloop infrastructure, the issue of standardization and certification of the system has yet to be resolved. The application of open-source system development might help create a uniform standard of systems within the Hyperloop infrastructure. Despite being an element of the automotive industry, it is a relatively new technology that requires its own infrastructure, and hence new standards, guidelines and policies need to be developed to control activities within the infrastructure. Standardization and certification of technologies within the Hyperloop infrastructure can be resolved by building and improving on existing “Common Safety Methods (CSMs) and Common Safety Targets (CSTs) established...to address safety levels, achievement of safety targets, and compliance with other safety requirements” (Gkoumas & Christou, 2020, p.2). The Hyperloop may require a relatively new infrastructure but most of the technologies being employed to develop it are not new. Existing concepts from maglev technologies, air bearings suspension systems, high-speed trains, autonomous software system in vehicles and others are being considered and adopted during the conceptual framework design of the Hyperloop. This does not necessarily imply that standards that govern adopted technologies should be used for the Hyperloop. New risk assessment models should be developed for the whole Hyperloop infrastructure with human safety and system integrity in mind. New testing methodologies must be developed for verifying, validating, and evaluating systems reliability of the Hyperloop and its subsystems.

The conceptual framework of the Hyperloop spans engineering disciplines involving railways (tube and pod construction), road (autonomous software framework), aviation (sonic speed), and civil (infrastructure) engineering technologies. The issue of certification and standardization may be approached by identifying all intricate interdependencies of the Hyperloop system and its subsystems to be able to develop a risk analysis tool that addresses the safety and reliability concern. Decomposition of the Hyperloop infrastructure provides a way forward for identifying other industry standards that may be improved upon and adopted to fit the Hyperloop infrastructure.

# Conclusion

# Hyperloop is a relatively new transport technology that requires a new infrastructure to be able to become a viable mode of transportation in addition to current transport systems if not displaced completely. With the proposed delivery of faster travel times, cost-effective mode of traveling, and utilization of renewable energy sources to promote decarbonization, the Hyperloop addresses economic, social, and environmental benefits. The proposed benefits and feasibility of available concepts warrant it demand to consider exploring viable options and further research needed to bring the design from the conceptual and experimental phase to commercial application. This paper provided a high-level limited scope into the design space of the Hyperloop and briefly touched on the engineering and economical complexities that must be overcome in designing and developing a viable Hyperloop infrastructure beyond the experimental phase. The reliability of proposed concepts was discussed with emphasis on a robust modular design with safety concerns in mind considering that Hyperloop is a new system that integrates existing technologies from different engineering disciplines. Hyperloop technologies may integrate and improve on standards and certification from other industries to address safety and reliability concerns related to the Hyperloop.

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