Hyperloop Standards Desk Review

Non-Traditional and Emerging Transportation Technology (NETT) Council

January 2021

U.S. Department of Transportation

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List of Abbreviations

Abbreviation	Term
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
DG MOVE	Directorate-General for Mobility and Transport
DG RTD	Directorate-General for Research and Innovation
DOT	Department of Transportation
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EC	European Commission
CENELEC	European Committee for Electrotechnical Standardization
CEN	European Committee for Standardization
EMSA	European Maritime Safety Agency
ESA	European Space Agency
EN	European Standards
ERA	European Union Agency for Railways
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HyperloopTT	Hyperloop Transportation Technologies
MLIT	Japanese Ministry of Land, Infrastructure, Transport and Tourism
JRC	Joint Research Centre
JTC	Joint Technical Committee
NETT	Non-Traditional and Emerging Transportation Technology
OCC	Operation Control Center
PHMSA	Pipeline and Hazardous Materials Safety Administration
RFC	Request for Comment
S2R	Shift2Rail
SDO	Standards Development Organization
U.S. DOT	United States Department of Transportation
VH	Virgin Hyperloop

Introduction

As hyperloop[1] technologies continue to mature and operators move toward more advanced testing and demonstration projects, industry stakeholders have expressed a need for greater regulatory clarity. In July 2020, the U.S. Department of Transportation (U.S. DOT) released *Pathways to the Future of Transportation: A Non-Traditional and Emerging Transportation Technology (NETT) Council Guidance Document (Pathways to the Future of Transportation)* to provide a framework for the Department's approach toward transformative technologies, including hyperloop.[2] During the development of *Pathways to the Future of Transportation*, the NETT Council engaged with stakeholders to better understand how U.S. DOT's regulatory structure can support or hinder transportation innovation. One theme that resulted from this outreach was the need for the Department to consider the applicability of international or private sector standards to hyperloop systems in the United States.

Purpose of Document

This report was developed by the Volpe National Transportation Systems Center on behalf of the NETT Council. The purpose of this document is to 1) assess the status of hyperloop standardization activities; 2) develop a foundation for future hyperloop standardization efforts; and 3) identify stakeholder perspectives on the applicability of existing standards to domestic testing and deployment. This document does not include U.S.-specific standards unless they have been identified as relevant by an external stakeholder group.

Based on this initial analysis, a preliminary framework of hyperloop system components and associated regulations and voluntary technical standards will be developed. U.S. DOT is also soliciting public comments on this document, which will be incorporated into the framework. This report is not intended to be exhaustive or final, but rather is intended to serve as a starting point for policymakers, the industry, and the general public to understand better the areas where relevant standards currently exist, areas where existing regulations or technical standards could be adapted or modified to address hyperloop-specific considerations, and areas where new voluntary technical standards or regulations may be needed. Importantly, this report does not try to include or synthesize standards for hyperloop from established modes of transportation.

Methodology

A literature review was completed to identify domestic and international standardization activities being conducted by government entities, standards development organizations (SDOs), and private industry. In addition, public responses to the following NETT Council requests for comment (RFC) were reviewed to understand stakeholder needs better:

1. November 2019 RFC (Docket No. DOT-OST-2019-0165) on projects, issues, or topics that DOT

[1] For the purposes of this document, hyperloop is considered a pod- and magnetic levitation-based mode of transportation in a vacuum-sealed tube or system of tubes that operates in a low-pressure environment to reduce drag, increasing efficiency to drastically reduce travel times. This is consistent with the definition used in the NETT Council report, "Pathways to the Future of Transportation."

[2] https://www.transportation.gov/sites/dot.gov/files/2020-08/NETT%20Council%20Report%20Digital_Jul2020_508.pdf

should consider through the NETT Council, including regulatory models and other alternative approaches for non-traditional and emerging transportation technologies.[3]

2. July 2020 RFC (Docket No. DOT-OST-2020-0112) on the [Pathways to the Future] document and the next steps for the NETT Council.[4]

U.S. DOT Hyperloop Oversight

In *Pathways to the Future of Transportation,* the Secretary of Transportation explained that hyperloop systems employing electromagnetic guideways (i.e., magnetic levitation technology) are subject to FRA's safety oversight. Accordingly, such a hyperloop system will be subject to FRA jurisdiction.[5] Under the Federal railroad safety laws, FRA has jurisdiction over the safety of railroads, as defined in 49 U.S.C. 20102(2), which includes any form of non-highway ground transportation that runs on rails or electromagnetic guideways, except urban rapid transit operations that are not connected to the general railroad system of transportation (general system). Moreover, FRA considers a standalone intercity railroad to be part of the general system, even if it is not physically connected to the general system (as FRA has previously stated with respect to the Alaska Railroad; 49 CFR part 209, appendix A).

Pursuant to its statutory authority to address "every area of railroad safety" (49 U.S.C. § 20103), FRA currently has regulations addressing: equipment, control systems, track, operating practices, training, human factors, and control of drug and alcohol use. However, these regulations are based on the existing, conventional (steel wheel on steel rail) railroad environment. Significant operational, equipment, and control systems differences may exist between a possible hyperloop system and existing railroad operations in the United States. In many of the railroad safety disciplines, FRA's existing regulations do not address the safety risks and operational peculiarities of a potential hyperloop system. Therefore, for FRA to facilitate hyperloop operations as envisioned, an alternative regulatory regime—such as a rule of particular applicability or a comprehensive set of waivers—appears necessary to provide effective safety oversight.

Where possible, FRA would draft performance-based regulatory requirements addressing the safety risks underlying an operation, rather than the technology itself, mandating a systems approach to safety. This systems approach would include requirements addressing all aspects of the hyperloop system, including: system command and control software and hardware; infrastructure; equipment; operating practices; system qualifications; maintenance; and any other unique aspects of a hyperloop system (e.g., the low-pressure operating environment). No matter the regulatory regime chosen for a possible hyperloop system, FRA will also apply its existing technology-independent regulations (e.g., alcohol and drug regulations, positive train control regulations, system safety/risk reduction regulations, and training and qualification regulations) and consult relevant modal experts across U.S. DOT Operating Administrations through the NETT Council as appropriate to ensure safety.

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[3] https://www.federalregister.gov/documents/2019/11/26/2019-25638/non-traditional-and-emerging-transportation-technology-nett-council

[4] https://beta.regulations.gov/document/DOT-OST-2020-0112-0001

[5] (Please see FRA's Policy Statement regarding "The Extent and Exercise of FRA's Safety Jurisdiction," contained at 49 CFR part 209, appendix A, discussing in greater detail FRA's safety jurisdiction over railroads.)

Status of Hyperloop Standards Research and Development Activities

This section summarizes the current status of hyperloop standards research and development activities as of October 2020. Activities included in this report range from academic studies, to consultant-led analyses commissioned by governments, to industry-driven initiatives. In many cases, hyperloop technology developers have been actively collaborating with policymakers and SDOs.

The table below briefly summarizes the key activities and reports discussed in this section. Organizations listed in bold are considered to be the primary authors or organizers of the effort; other organizations listed either provided funding or were consulted as key stakeholders.

Table 1. Key Standards-Related Hyperloop Activities and Reports.

Activity/Publication	Associated Organizations
Pathways to the Future of Transportation: A Non-Traditional and Emerging Transportation Technology (NETT) Council Guidance Document	• **U.S. DOT**
European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) Joint Technical Committee (JTC) 20 (CEN/CLC/JTC20—Hyperloop systems)	• **CEN** • **CENELEC** • Transpod • Hardt Hyperloop • Zeleros Hyperloop • Nevomo (formerly Hyper Poland) • Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) • Directorate-General for Mobility and Transport (DG MOVE) • European Commission (EC) Joint Research Centre (JRC) • Directorate-General for Research and Innovation (DG RTD)

Activity/Publication	Associated Organizations
EC Request for Services: Study on a Regulatory Framework for an Innovative Transport Technology such as Hyperloop	• **TRL Limited** • European Union Agency for Railways (ERA) • European Union Aviation Safety Agency (EASA) • European Maritime Safety Agency (EMSA) • European Space Agency (ESA) • Shift2Rail (S2R) • JRC
S2R Call for Proposals on Innovation in Guided Transport	• **Contractor (TBD)**
Preliminary Feasibility of Hyperloop Technology in Canada	• **AECOM** • Transport Canada
“Future of Hyperloop” report	• **Delft Hyperloop** • Dutch Ministry of Infrastructure and Water Management
Generic Guideline for Design, Operation and Certification	• **TÜV SÜD** • Hyperloop Transportation Technologies (HyperloopTT)
Hyperloop Certification Center	• **Virgin Hyperloop (VH)**

The report also references activities or comments from the following organizations:

Table 2. Additional Organizations Associated with Hyperloop Standards Development.

Category	Organization(s)
Entities associated with planned hyperloop deployments	• Consultative Group at the Office of Principal Scientific Adviser on Future Transportation (India) • DP World (Dubai) • Saudi Arabian Ministry of Transport • Government of Guizhou, China • Governments of Estonia and Finland • Emory International Law Review
Entities associated with magnetic levitation (maglev) deployments	• Japanese Ministry of Land, Infrastructure, Transport and Tourism • China Railway • German Federal Railway System
RFC respondents	• VH • HyperloopTT • Texas DOT • Swisspod • Great Lakes Hyperloop Consortium • Hardt Hyperloop • Zeleros Hyperloop • Delft Hyperloop

Governments and Standards Development Organizations

U.S. DOT: Pathways to the Future of Transportation

U.S. DOT provided initial guidance for hyperloop technologies through *Pathways to the Future of Transportation*. This guidance responds to feedback from transportation innovators and notes that "safe integration [of hyperloop] into the transportation system could be accelerated through re-use, modification, and integration of exiting (technical) standards from other transportation modes and (in some cases) non-transportation sectors."[6]

CEN and CENELEC: CEN/CLC/JTC20—Hyperloop systems[7]

In February 2020, CEN and CENELEC created CEN/CLC/JTC 20—Hyperloop systems. The Spanish

[6] https://www.transportation.gov/sites/dot.gov/files/2020-08/NETT%20Council%20Report%20Digital_Jul2020_508.pdf
[7] https://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:2739090&cs=16BC2EE8E576CC19E11AB172CCCC40CC7

Association for Standardization, along with the Royal Netherlands Standardization Institute, both members of CEN and CENELEC, proposed this committee with the goal of creating European Standards (EN) for the interoperability and security for hyperloop systems. The proposal noted that interoperability is critical both in ensuring consistent operations across Europe and in enabling different technologies to be used within one system.

The committee will be structured into working groups featuring hyperloop companies, SDOs, and industry experts. These working groups will focus on topics of vehicle systems, infrastructure pipe components, general infrastructure, and communications protocols. In its initial proposal, the committee identified several priority work areas to be addressed within a three-year timeframe.[8] These were selected based on their importance to interoperability and include:

- **Pressures of operation**: Impacts of low-pressure environments on safety (e.g., characteristics of fire and smoke under different levels of pressure; protocols for re-pressurization during evacuation; standardized "normal mode of operation").
- **Door sealing**: Ability of doors to seal properly and consistently under different conditions.
- **Vehicle-tube interface**: Ability of different vehicles to operate within one system (track specifications, tube diameter, etc.).
- **Communications protocols**: Common communication system between vehicles and the operation control center.
- **Emergency evacuation:** Impacts of infrastructure (e.g., frequency of support pillars, power supply locations, etc.) on unified approach to evacuation.

Other topics to be considered by the committee include:

- Signaling system (vehicle-track)
- Fire and smoke—allowed materials
- Emergency procedures
- Emergency evacuation and tunneling
- Environmental conditions on passenger cabin: temperature, ventilation, lighting, noise, etc.
- Passenger external forces: acceleration limits, jerk, etc.
- Design for environment
- Grounding systems
- On board electronics and electrical equipment
- Electromagnetic interference (EMI)/Electromagnetic compatibility (EMC)
- Infrastructure and materials requirements needed to meet alignment requirements, weather, or geological condition
- Airlocks
- Station requirements and standards
- Maintenance depot and standards

[8] https://www.standard.no/Global/PDF/Standardisering%20-%20nye%20prosjekter/Hyperloop%20systems.pdf

DG MOVE: Study on a Regulatory Framework for an Innovative Transport Technology such as Hyperloop

The EC released a request for services to "make a comparative research on the regulatory needs and safety specific issues of a new innovative technology/transport mode such as Hyperloop on the ground of safety, compare different safety approaches, and provide the founding elements for a potential EU Regulatory framework for such technology."[9] The request included an indicative clustering of standards that could partially or entirely apply to hyperloop systems. Work is expected to take place over a 9-month timeframe and was expected to begin in June 2020.

S2R: Call for Proposals on Innovation in Guided Transport

S2R is a European Union-funded joint undertaking that works to advance the integration of emerging and advanced rail technologies. The organization's 2020 annual work plan and budget included a call for proposals to gather "all relevant stakeholders around a common encompassing activity on innovative concepts for guided transport modes. The outcome of this activity should provide…clarity on operational concepts and standardization possibilities and also enable a structured discussion with policy-makers around safety/security and transport system(s) integration at [the] European level."[10] Work under this agreement is scheduled to begin in January 2021.

Transport Canada: Preliminary Feasibility of Hyperloop Technology in Canada

In 2019, Transport Canada released a request for proposals to "review the implications to the regulatory framework that the following [hyperloop] elements will impose upon [TC]: On Board Passenger Emergency/Evacuation; Power Outage - Preserving life support systems in capsules; Capsule Depressurization; Immobilized Capsule in Tube; Structural Integrity of Tubes; Earthquakes; Monitoring and Controlling Capsule Movements within the Tubal Network to Avert Collisions or Incidents; Human Related Incidents including acts of Terrorism."

AECOM, a multinational engineering firm, was awarded the contract and published *Preliminary Feasibility of Hyperloop Technology* in July 2020.[11] The document's regulation section evaluates and identifies potential hazards associated with hyperloop technologies, then classifies these hazards to determine what guidance and governance is needed, and finally discusses how other transportation modes have addressed similar problems.

The basis for this report's regulatory analysis is a hazard/threat/vulnerability assessment that identifies areas where mitigation measures, including the adoption or development of standards, could be needed to address safety concerns. Based on this assessment, the following risk areas were identified for further policy analysis, with the assumption that safety is included as an overarching consideration in each category: Vehicle Design, Infrastructure, System Components, Communications, Security, and Environmental Factors.

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[9] Request for Service N°MOVE/C4/2020-85 in the Context of the Framework Service Contract with Re-Opening of Competition for Technical Assistance in the Field of Mobility and Transport. MOVE/ENER/SRD/2016-498 Lot 6.
[10] https://shift2rail.org/wp-content/uploads/2019/11/Annual-Work-Plan-and-budget-for-2020.pdf
[11] https://buyandsell.gc.ca/cds/public/2019/03/27/ce8f3260f399ab7cec4cf4ab32b8221a/rfp_t8080-180829_en.pdf

Dutch Ministry of Infrastructure and Water Management: Delft Hyperloop "Future of Hyperloop" Report

The Future of Hyperloop was commissioned by the Dutch Ministry of Infrastructure and Water management, and was published in June 2019 by Delft Hyperloop, an academic team from the Delft University of Technology.[12] The document does not go into depth on standardization and regulation but does list standardization as a barrier for development. The document states that standardization will be vital to ensure interoperability across Europe, while cautioning that if regulation comes too early, it could stifle development. Delft Hyperloop suggests that both rail and aviation standards and certification processes may be adaptable to hyperloop.

Industry

HyperloopTT and TÜV SÜD: Generic Guideline for Design, Operation and Certification[13]

HyperloopTT partnered with TÜV SÜD, an international engineering services firm, to develop a set of certification guidelines for hyperloop systems. TÜV SÜD developed the guidelines using a combination of HyperloopTT's Hazard Analysis and Risk Assessment and existing regulations for "rail, metro systems, cable cars, amusement rides, aviation, and the process industry." Rather than suggesting new standards, the document provides best practices for safe operation.

The TÜV SÜD Guidelines have been incorporated into HyperloopTT systems and were presented to the European Commission and to DOT. The guidelines could serve as a regulatory framework foundation for planned hyperloop deployments in both United Arab Emirates (UAE) and Europe.

VH: Hyperloop Certification Center

VH, another American hyperloop company, is currently planning its Hyperloop Certification Center. Seeking to expand from its 500m test track outside of Las Vegas, the company issued a request for proposals from which it received responses from 17 States interested in hosting the country's first full-size hyperloop system, which will be used for the development of "regulatory and safety standards, research frameworks, and testing infrastructure."[14] In October 2020, VH announced that the center would be built in West Virginia.

In addition to the two activities noted above, several hyperloop companies have provided input on proposed standards or potential gaps; these have been noted in the relevant sections throughout the document.

Other

Proposed Hyperloop Deployments and Activity Across the World

Government organizations in locations that have been identified as candidates for early deployments of hyperloop systems have begun to develop institutional frameworks to address regulatory and

[12] https://drive.google.com/file/d/1TdhkxiGgjKXMnKSzqHFz6AObcCfqQLOr/view
[13] https://www.tuvsud.com/en/press-and-media/2020/july/tuev-sued-publishes-safety-guidelines-for-hyperloop-applications
[14] https://www.constructionreporter.com/news/site-for-new-hyperloop-certification-center-under-review

standardization needs.

In India, the Consultative Group at the Office of Principal Scientific Adviser on Future Transportation was created to develop hyperloop standards.[15] This body falls under the jurisdiction of The Office of the Principal Scientific Adviser to the Government of India and was formed in preparation for a potential hyperloop route between Mumbai and Pune. In September 2020, the chairman of VH signed an agreement with the chairman of the board of directors at Kempegowda International Airport, Bengaluru to begin a pre-feasibility study. The study will look at both technical and economic aspects of the proposed route connecting the Bengaluru Airport with the city-center and is expected to take a year to complete.

The UAE is another location with known hyperloop activities. HyperloopTT is working to construct a 10 km segment of what would eventually become a 150 km route between Abu Dhabi and Dubai, with the goal of beginning passenger operations by 2023. VH is working with DP World, a Dubai firm that specializes in cargo logistics (and VH's largest investor), to launch DP World Cargospeed, a hyperloop brand focused on freight. Referring to the NETT Council's plan to establish regulatory framework for hyperloop systems, Sultan Bin Sulayem, Group Chairman and CEO of DP World said, "The decision is a huge vote of confidence that we are all on the right side of history. The move, which brings hyperloop systems one major step closer to reality, validates our decision to take this technology seriously and support this innovation."[16]

The Saudi Arabian Ministry of Transport announced in February 2020 that it would be working with VH to conduct a national pre-feasibility study, with longer-term plans including the potential construction of a 35 km test and certification track, a research and development facility, and a manufacturing plant. The pre-feasibility study focused on the economic impact to the country by exploring potential routes, expected demand, and job creation.[17]

In 2018, HyperloopTT signed a deal with the government of Guizhou, China to build a hyperloop system in the city of Tongren. The project is expected to consist of two parts, a 10 km route connecting the city and airport, and a 50 km route connecting the city to a major tourist destination, Mount Fanjing. However, there has been no recent news on the progress or status of this project.

Maglev Systems

There is likely to be overlap between regulatory frameworks for maglev and hyperloop systems, but there is limited publicly available information about standards or regulations relating to active maglev systems. Currently, operational maglev systems are only found in Japan, South Korea, and China, although numerous other countries have proposed similar systems. The Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) enacted standards for Superconducting Maglev in 2011,[18] and some considerations for operations can be found in MLIT's "Technical Regulatory Standards on Japanese Railways."[19] In January 2020, China's National Railway Administration

[15] https://www.businesstoday.in/sectors/infra/india-closer-to-taking-a-lead-and-leap-with-hyperloop/story/368037.html
[16] https://gulfnews.com/uae/transport/uae-hyperloop-now-a-step-closer-to-reality-after-us-congress-ruling-1.72609186
[17] https://virginhyperloop.com/project/saudi-arabia
[18] https://global.jr-central.co.jp/en/company/_pdf/superconducting_maglev.pdf
[19] https://www.mlit.go.jp/english/2006/h_railway_bureau/Laws_concerning/14.pdf

began using trial standards to unify technical aspects of the trains and railway.[20] China Railway publishes information on technical standards via its website, but English language documentation is not readily available.[21] Similarly, while Germany does not currently have an active maglev system, the German Federal Railway Authority has published a set of project-neutral design principles that may be relevant to hyperloop.[22]

The FRA Maglev Deployment Grants Program has funded preconstruction planning activities and capital costs of viable, existing maglev projects, including projects that involve technologies that employ maglev in conjunction with other complementary technologies. Through this program the Maryland DOT has received multiple grants for the Baltimore-Washington SCMAGLEV Project.[23]

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[20] https://www.globaltimes.cn/content/1165599.shtml
[21] http://www.china-railway.com.cn/english/Innovations/standards/
[22] https://www.eba.bund.de/EN/TechnicalInformation/Maglev/maglev_node.html;jsessionid=54186C5EF30D5FE49A2E78D7514438F1.live11293#doc1544830bodyText4
[23] https://railroads.dot.gov/grants-loans/competitive-discretionary-grant-programs/magnetic-levitation-deployment-grants-0

Assessment of Existing Hyperloop-Related Standards

This section provides an initial assessment of the applicability of existing standards to hyperloop systems. This assessment is based on public comments from technology developers, as well as findings from the initial feasibility studies discussed in the previous section. Additional information regarding individual standards can be found in the following section.

Overall, while there is significant potential to adopt or adapt standards from rail, aviation, and other industries, hyperloop systems are likely to include features that differ from those described in current rules or standards. A selection of comments on regulatory and standardization needs is included below:

Comment from VH on DOT-OST-2019-0165-0001[24]

- "A hyperloop service of relatively short length readily should be considered a fixed guideway transit service subject to regulation by a State Safety Oversight agency (SSO) within the meaning of 49 USC 5329."
    - "…under 49 USC 20102(2), 'rapid transit operations in an urban area that are not connected to the general railroad system of transportation are not railroads subject to regulation under the rail safety regulatory regime."
- "In explaining the scope of its safety jurisdiction in Appendix A to 49 CFR 209, FRA states that 'intercity passenger operations that are not standard gage (such as magnetic levitation systems) are within FRA's jurisdiction even though not part of the general system.' However, the vast majority of FRA's safety rules are drafted for the general system of rail transportation, specifically worded to apply to 'standard gage' rail operations. This includes but is not limited to rules for:
    - track standards (49 CFR 213);
    - freight car safety standards (49 CFR 215);
    - railroad operating rules (49 CFR 218);
    - rear end of train markings (49 CFR 221);
    - safety glazing standards (49 CFR 223);
    - locomotive safety standards (49 CFR 229);
    - safety appliance standards (49 CFR 231);
    - braking systems (49 CFR 232).
- The vast differences between the [VH] hyperloop system and a standard gage railroad leads to the conclusion that [VH] would be exempt from the many FRA rules drafted as applicable to standard gage. We think that inapplicability is appropriate."

[24] https://beta.regulations.gov/comment/DOT-OST-2019-0165-0013

Comment from HyperloopTT on DOT-OST-2020-0112[25]

- "HyperloopTT encourages the development of regulations unique from FRA's current standard gauge rail system regulations, including a Rule of Particular Applicability (RPA) for HyperloopTT projects generally, or specific to any particular project."
- "While HyperloopTT is not considered a 'civil aircraft,' it includes a fuselage designed to accommodate external vacuum conditions while maintaining life safety and support. The FAA is currently authorized to prescribe regulations and standards for aircraft design, production, and maintenance that, on balance, can include several HyperloopTT systems and subsystems."
- "Should a HyperloopTT project consist of bridges and/or tunnels, these features may be subject to FHWA design standards, oversight or inspection."
- "While hyperloop is engaged in interstate commerce, hyperloop cannot operate on any pathway 'open to public travel' as it is not open to the public for use without restriction. Hyperloop operates autonomously on an electromagnetic guideway with no 'driver' present and, therefore, is not subject to commercial driver's license."
- "While hyperloop transports property or passengers interstate for compensation, clarification of potential exemptions as set forth at 49 U.S.C. 33506 may be warranted."
- "While the PHMSA has authorities relating to the transportation of hazardous materials (such as oil pipelines), HyperloopTT is not a transporter of hazardous materials. The PHMSA authorities relating to pipelines do not cover transportation of people."

AECOM/Transport Canada: Preliminary Feasibility of Hyperloop Technology in Canada[26]

- "While a number of the system elements and associated risks are common to multiple modes, several hazards or risks are unique to Hyperloop. As with any emerging technology, regulations and standards play an important role in facilitating the design and development of the components and/or system. This becomes more challenging when the potential risks are unique to the planned system, as any guidance or regulation needs to be formed with a full understanding of how the component is meant to function and consideration of the economic impacts of such measures. As a number of the Hyperloop components are either in need of proof of concept of further refinement, the development of any guidance will be an iterative process."
    - Unique hazards and risks include: G-Force Tolerance, Emissions, Friction, and High-Speed Switching.
- "Independent research also suggests that current code-based design regulations across the globe are insufficient for the design of such [tube] systems. However, this analysis assumes that the tube is made of steel; an alternative is precast fiber-reinforced concrete, which may offer higher stiffness at a lower cost."

[25] https://beta.regulations.gov/comment/DOT-OST-2020-0112-0025
[26] https://tcdocs.ingeniumcanada.org/sites/default/files/2020-08/Hyperloop%20prelim%20study.pdf

Delft Hyperloop: The Future of Hyperloop[27]

- "Standardization is a challenge for hyperloop. As explained in Chapter 2, multiple companies are working on the hyperloop concept, with different ideas. In the end, it is important that a European hyperloop network has a single standard. Therefore, hyperloop companies should eventually converge to a standardized concept. Although it might sound logical, system parameters such as tube diameter must be the same to increase interoperability between countries. For comparison, the width of European train tracks differs between countries, which used to make it complex and expensive to have trains operating internationally. It is important that in the end, companies working on hyperloop converge to a consensus on important design parameters. These parameters lead to standards that have to be determined together with governments. However, standards must not be decided upon too early in the process, as this constrains the development of innovative technologies or ideas. Multiple technologies have to be researched and developed first in order to determine what the best option is to use in the eventual standardized hyperloop system."

Comment from Texas DOT on DOT-OST-2020-0112[28]

- "The [planned] hyperloop is proposed to run adjacent to the Interstate-45 corridor, making cross border connections to Mexico and Canada an important consideration [for standardization]."

Comment from Swisspod on DOT-OST-2020-0112[29]

- "In terms of regulatory alignments with international regulations and standards, we recommend global regulatory alignments and cooperation similar to the recent US DOT 49 CFR alignments with international standards such as the UN Model Regulations, the International Civil Aviation Organization's Technical Instruction for the Safe Transport of Dangerous Goods by Air (ICAO), the International Maritime Dangerous Goods Code (IMDG) and the Canadian Transport of Dangerous Goods (TDG) regulation."
- "In addition, we foresee the following preparations (general overview, to be discussed and agreed upon during the initial discussions) also as part of the development stage:
    - Hyperloop definition
    - Hyperloop elements breakdown
    - Listing applicable regulations/standards from all modes of transport and according to the Operating Administrators
    - Map applicability and feasibility regulations/standards into Hyperloop elements
    - Gap analysis to identify requirements for new Hyperloop-specific regulations/standards
    - Preparation of the regulations/standards
    - Publication process and implementation of regulations/standards"

[27] https://drive.google.com/file/d/1TdhkxiGgjKXMnKSzqHFz6AObcCfqQLOr/view
[28] https://beta.regulations.gov/comment/DOT-OST-2020-0112-0020
[29] https://beta.regulations.gov/comment/DOT-OST-2020-0112-0012

Comment from Great Lakes Hyperloop Consortium on DOT-OST-2020-0112[30]

- "There are three primary commercial entities advancing the hyperloop with different technologies, so how will this 'neutrality' be assured when standards are eventually established for infrastructure, operating equipment, and safety modalities, to encompass the existing variability in approaches taken by the major hyperloop companies?"
- "Will there be standardization around the certification process to permit 'entry into service' for a particular capsule, or will there be unique certification standards specific to a particular company?"
- "Will standards permit interconnectability of systems between the hyperloop companies, or will there be a unique standard for each company addressing the interconnectability of systems across regions and cities?"

Comment from Hardt Hyperloop on DOT-OST-2020-0112[31]

- "Differentiating between standards for cargo and passenger with a view to adopting cargo standards (with lower risk to human life) [should occur] at an earlier date."
- "It is good to note that there are certain aspects of the hyperloop for which there is currently no analogue in other modalities or industries. For example, the air pressure in the pipe is between the pressure in space and the pressure at which commercial aviation operates, hence neither standard may be applicable for hyperloop (i.e. space may be too stringent and is not meant for mass-transit, aviation may not be strict enough). This means that besides the integration of existing standards, new standards also need to be developed."
- "We believe a harmonisation approach on standards between the US and Europe will allow intercontinental interoperability. Ultimately, as we believe the majority of projects to have a [public-private partnership] PPP component, this would be in the interests of taxpayers in the US and Europe as it would allow competition for projects across the Atlantic. We would therefore like to suggest making a connection between JTC20 and the NETT Council to enhance cross-fertilization and work towards interoperability."

[30] https://beta.regulations.gov/comment/DOT-OST-2020-0112-0026
[31] https://beta.regulations.gov/comment/DOT-OST-2020-0112-0017

Preliminary Mapping of Standards and Regulations to Hyperloop Systems Components

This section includes a preliminary categorization of existing standards and regulations to specific hyperloop systems components. The primary system elements in this framework have been lightly adapted from TÜV SÜD's *Generic Guidelines for Design, Operation and Certification*, which includes additional detail about each of the components or processes. **The following standards are not intended to be comprehensive, prescriptive, or definitive.** Exclusion from this section does not imply irrelevance; no items were intentionally excluded, but the broad scope and rapidly advancing nature of hyperloop systems make it challenging to capture all potentially related activities and analyses. Rather, this section is an initial compilation and summary of standards and regulations that have been identified through efforts by industry, researchers, governments, and SDOs. Where possible, standards were categorized in accordance with their source's proposed framework. Some adjustments were made in cases where categories did not align or were inconsistent. With a wide variety of efforts underway to determine the feasibility of hyperloop systems, components of the system have been categorized and defined differently, leading to variation in the way existing standards are being mapped to the hyperloop system.

The standards included below were primarily identified through analyses conducted or commissioned by TÜV SÜD, HyperloopTT, the European Commission, Transport Canada, VH, and Delft Hyperloop. Additional standards were included based on input provided by various entities through public comments.

Overall, the categories for which there was general consensus from multiple organizations regarding the applicability of existing standards included the following: Risk Assessment and Safety Targets, Basis of Structural and Mechanical Design Assumptions and Analysis, Materials, Vehicle/Capsule, Fire Protection and Evacuation, Electromagnetic Compatibility and Exposure, Information Security, and Certification. In some cases, organizations identified the same standard but applied a different categorization, or a single organization included the same standard under multiple categories.

General Safety Requirements

General safety requirements refer to the overarching systems, processes, or materials that contribute to the overall safety of the design and operation of hyperloop systems. These include: Risk Assessment and Safety Targets, Design Principles with Respect to Safety and Reliability, Design Principles with Safety Implications for Availability and Maintainability, Site and Project Specific Conditions, Speed Modes, Basis of Structural and Mechanical Design Assumptions and Analysis, Materials, Aerodynamic Conditions, and Physiological Conditions (air pressure, accelerations, vibrations, etc.).

Standard/Regulation	Organization
IEC/ISO 31000—Risk management	TÜV SÜD
IEC/ISO 31010:2009—Risk management—Risk assessment techniques	TÜV SÜD
ISO 31000:2009—Risk management—Principles and guidelines	EC
IEC/ISO 31010:2009—Risk management—Risk assessment techniques	EC
ISO/IEC Guide 51:2014—Safety aspects—Guidelines for their inclusion in standards	EC
IEC 61511 (all parts) —Functional safety—Safety instrumented systems for the process industry sector	EC
EN 50518—Monitoring and alarm receiving centre	EC
Article 6(3)(a) of the Railway Safety Directive ERA/GUI/01-2008/SAF—Guide for the application of the Commission Regulation on the adoption of a common safety method on risk evaluation and assessment	EC
ECSS-M-ST-/ EN 16601 Section M-80—Risk management	EC
IEC/ISO 31010:2009—Risk management—Risk assessment techniques	VH
DEF STAN 00-56—Safety Management Requirements for Defense Systems	VH
MIL-STD-882E—Standard Practice System Safety	VH

Standard/Regulation	Organization
IEC 62267—Safety assessment and risk mitigation approach	Other

Design Principles with Respect to Safety and Reliability

Standard/Regulation	Organization
CENELEC Report R009-004:2001—Railway applications—Systematic allocation of safety integrity requirements	EC
RTCA/DO-254—Design Assurance Guidance for Airborne Electronic Hardware	EC
RTCA/DO-160—Environmental Conditions and Test Procedures for Airborne Equipment	EC
FAA Standards 14 CFR Part 25—Airworthiness Standards: Transport Category Airplanes Subpart C—Structure and Subpart D—Design and Construction	EC
The Canadian Aviation Regulations Part V—Airworthiness	TC
NASA-STD-5017A—Design and development requirements for mechanisms	VH

Basis of Structural and Mechanical Design Assumptions and Analysis

Standard/Regulation	Organization
Eurocode series standards	TÜV SÜD
FAA §25.571—Damage Tolerance and Fatigue Evaluation of Structure	TÜV SÜD

Standard/Regulation	Organization
EN 1990 Eurocode 0: Basis of structural design	EC
EN 1991 (all parts) Eurocode 1—Actions on structures	EC
EN 1992 (all parts) Eurocode 2—Design of concrete structures	EC
EN 1993 (all parts) Eurocode 3—Design of steel structures	EC
EN 1994 (all parts) Eurocode 4—Design of composite steel and concrete structure	EC
EN 1997 (all parts) Eurocode 7—Geotechnical design	EC
EN 1998 (all parts) Eurocode 8—Design of structures for earthquake resistance (pot.)	EC
EN 1999 (all parts) Eurocode 9—Design of aluminum structures (pot.)	EC
CEN/TC250/WG4 report on FRPs (Fibre Reinforced Polymer or Plastic)	EC
Series EN 12XXX—"Aspects from rolling stock may be taken in account for comfort, materials, type of tests, compatibilities under mechanical contact with infrastructure."	EC
Series EN 16xxx – Acceptance criteria of vehicles, devices working under acoustic propagation, auxiliary services (water, etc.), PMR use area, work protection during construction or maintenance	EC
AASHTO LRFDUS—Bridge Design Specifications—Eighth Edition; Incorporating Errata	VH

Standard/Regulation	Organization
APTA-PR-CS-S-034-99— APTA Passenger Rail Equipment Safety Standards (PRESS) (construction and structural)	VH
AS 5100.5—Concrete Design Principles	VH
APTA PR-CS-S-034-99, Rev.2—Standard for Design and Construction of Passenger Railroad Rolling Stock	VH
NASA-HDBK-5005D—Standard for the Design and Fabrication of Ground Support Equipment	VH
NFPA 101—Life Safety Code	VH
NFPA 5000—Building Construction and Safety Code	VH

Materials

Standard/Regulation	Organization
Steel and metallic products including fasteners shall be accompanied with material certificates according to EN 10204 or equivalent attestation.	TÜV SÜD
Concrete, timber, plastic composites shall be chosen prevailingly in accordance to EN-standards or equivalent ones.	TÜV SÜD
Fasteners shall be chosen in compliance with EN ISO 898; EN 14399 (high-strength bolts) and associated standards.	TÜV SÜD

System Design

These categories include the design of the core elements of the hyperloop system, including: Vehicle/Capsule, Causeway, Stations, Energy and Power, Safety Related Control System and Communications, and Electromagnetic Compatibility.

Vehicle/Capsule

Standard/Regulation	Organization
To define the most relevant load categories (e.g., permanent loads, variable loads including dynamic loads and accidental, extraordinary loads) and combinations, pertinent aircraft regulations (e.g., 14 CFR Part 25, CS-25), railway standards (e.g., EN 12663) and structural standards (e.g., EN 1990, EN 1991 to EN 1999) shall be taken into account.	TÜV SÜD
Fire and overheat detection and suppression systems shall be provided as required by EN 45545-6	TÜV SÜD
FAA Standards 14 CFR Part 25.841—Pressurized cabins	TÜV SÜD
Series EN 12XXX—aspects from rolling stock; may be taken in account for comfort, materials, type of tests, compatibilities under mechanical contact with infrastructure	EC
Series EN 16xxx—acceptance criteria of vehicles, devices working under acoustic propagation, auxiliary services (water, etc.), PMR use area, work protection during construction or maintenance	EC
ISO 2631-4:2001—Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration—Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew	EC
EN 50155—Railway applications—Rolling stock—Electronic equipment	EC
Emergency rules from rail: • Series EN 15XXX—drawing, mechanical coupling (emergency), vehicle welding, warning devices on board, braking performance, loading gauge, vehicle designation with functions, aspects of vehicle in rail environment, construction vehicle family • Series EN 13XXX—track aspect. Only to understand request from materials in use or when pod circulates over rails during emergency	EC
EN 50657 Railways Applications—Rolling stock applications—Software on Board Rolling Stock	EC
The Aeronautics Act (R.S.C., 1985, c. A-2)93: Section 4.9—Regulations respecting aeronautics	TC

Standard/Regulation	Organization
Technical Airworthiness Authority (TAA) Advisory	TC
QD 4.650CS—Fuselage Skin Quality (FSQ)	TC
The Canadian Aviation Regulations (SOR/96-433), Part V—Airworthiness	TC
ASHRAE 62.1—Ventilation for Acceptable Indoor Air Quality	VH
ISO 19659—Railway applications—Heating, ventilation and air condition systems for rolling stock	VH
DOT-VNTSC-FAA-05-01—Operational Guidelines for Spaceflight Pressure Vessels	VH
ASME PVHO-1—Safety Standard for Pressure Vessels for Human Occupancy	VH
ISO 2631-1—Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration—Part 1: General requirements	VH

Causeway

Free-Span Tube

Standard/Regulation	Organization
Concrete tube segments: EN 1992: Concrete Structures or equivalent standards	TÜV SÜD
Steel tube segments: EN 1993: Steel Structures	TÜV SÜD

Standard/Regulation	Organization
Fibre Materials: EN ISO 14125 and respective ASTM standards	TÜV SÜD
Fasteners: EN ISO 898; for structural high-strength bolting EN 14399 or equivalent	TÜV SÜD
The Canada Transportation Act (S.C. 1996, c.10)—Environmental Safety Around the Hyperloop Corridor	TC

Pylons

Standard/Regulation	Organization
Design and verification by detailed calculations shall follow the rules of the EN 1990 to EN 1999 standard series	TÜV SÜD

Buried/Submerged Tube*

Standard/Regulation	Organization
United Nations Convention on the Law of the Sea (UNCLOS)	Other
The Helsinki Convention	Other
International Seabed Authority Regulations	Other
European Maritime Special Planning Directive	Other
The Water Convention	Other

Standard/Regulation	Organization
Directive 20004/54/EC of the European Parliament and of the Council on Minimum Safety Requirements for Tunnels in the Trans-European Road Network	Other

*Listed regulations were included in an analysis of a potential international submerged floating tunnel between Estonia and Finland.

Tube Vacuum Technology

Standard/Regulation	Organization
SOR/96-433 Part 6, subpart 5—Division II of The Canadian Aviation Regulations—Requirements for the availability of oxygen supply in the event of pressure fluctuations within the aircraft (see subsections 605.31 (1) and (2) for Oxygen Equipment and Supply	TC

Energy and Power

Standard/Regulation	Organization
EN 50124-2—Railway applications—Insulation coordination—Part 2: Overvoltage and related protection	EC
Series EN 504XX—Energy measurement	EC
Series EN 503XX—Cables and electrical devices including drawing and current capitation, vehicle-infrastructure electrical coordination	EC
Series EN 60XXX—Power electrical components on board and in field elements	EC
EN-IEC 629XX—Batteries, UPS and other	EC
CLC/TR 50488—Railway applications—Safety measures for the personnel working on or near overhead contact lines	EC

Standard/Regulation	Organization
IEC 60076—Power transformers	EC
The Canadian Aviation Regulations Part VI, Subpart 2, Division II	TC

Safety-Related Control System and Communications

Standard/Regulation	Organization
IEC 61508—Safety-related control systems in general	TÜV SÜD
DO-178C—Software Considerations in Airborne Systems and Equipment Certification	TÜV SÜD
DO-254—Design assurance guidance for airborne electronic hardware	TÜV SÜD
IEC 61511—Functional safety—Safety instrumented systems for the process industry sector	TÜV SÜD
EN 50159—Railway applications—Communication, signalling and processing systems—Safety-related communication in transmission systems	EC
EN 50128—Railway applications—Communication, signalling and processing systems—Software for railway control and protection systems	EC
EN 50129—Railway applications—Communication, signalling and processing systems—Safety related electronic systems for signaling	EC
IEC 61508 (all parts)—Functional safety of electrical/electronic/programmable electronic safety related systems	EC
ANSI/STD B11.19—Performance Criteria for Safeguarding	VH

Standard/Regulation	Organization
IEC 62279—Railway applications—Communication, signalling, and processing systems—Software for railway control and protection systems	VH
EN 50128—Railway applications—Communication, signalling and processing systems—Software for railway control and protection systems	VH
IEC 61508-5—Functional safety of electrical/electronic/programmable electronic safety-related systems—Part 5: Examples of methods for the determination of safety integrity levels	VH
TC E-17—The Canadian Rail Operating Rules: Railway Signal & Traffic Control Systems Standards	TC

Electromagnetic Compatibility and Exposure

Standard/Regulation	Organization
Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonization of the laws of the Member States relating to electromagnetic compatibility	TÜV SÜD
1999/519/EC—Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)	TÜV SÜD
EN 50121 and 1999/519/EC—Necessary Hyperloop specific deviations to these requirements or recommendation shall be considered and justified in the EMC management planning	TÜV SÜD
EN 50121-3-1:2017—Chapters 5, 6, 7, 8—Electromagnetic emissions	TÜV SÜD
EN 50121-2:2017—Chapter 5—Emissions measurement; Chapter 4.2—Radio frequency emissions; Chapter 4.2—Radio frequency emissions measurement	TÜV SÜD
EN 50413 – Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)	EC
IEC 61000 (all parts) —Electromagnetic compatibility (EMC)	EC

Standard/Regulation	Organization
IEC 60068—Environmental Testing (hardware qualification of electronic equipment, components and electromagnetic products)	VH
BS CISPR 16-2—Specification for radio disturbance and immunity measuring apparatus and methods—Part 2: Methods of measurement or disturbances and immunity	VH
BS CISPR 16-4—Specification for radio disturbance and immunity measuring apparatus and methods—Part 4: Uncertainty in EMC measurements	VH
SAE ARP 60493—Guide to civil aircraft electromagnetic compatibility (EMC)	VH

Operation and Maintenance

This section includes requirements and recommendations for system governance and staffing, the planning and implementation of safe and reliable operations, and ongoing maintenance.

Operation

System Shutdown

Standard/Regulation	Organization
The Multicrew Aircraft Standard Operating Procedures Checklist and Guidance Material	TC

Automated Systems

Standard/Regulation	Organization
Rail: EN 62290/IEC 62290—Parts 1, 2, 3: Railway applications - Urban guided transport management and command/control systems	EC
Road transport: SAE J3016—Levels of driving automation	EC

Standard/Regulation	Organization
Aviation: General Airworthiness (Safety—as for drones application, autopilot)	EC
Maritime: Inland waterways: Definition of Level of Automation (0 to 5) as defined in the framework of the Rhine convention (CCNR)	EC
ANSI/ASCE/T&DI-21—Automated People Mover (APM) Standards	VH

Maintenance

Standard/Regulation	Organization
Commission Regulation (EU) No 1321/2014	TÜV SÜD
Series EN 17xxx maintenance routines of rolling stock (best practices from rail could be useful for hyperloop)	EC
APTA PR-IM-S-017-02—APTA Rail System Standards (Vehicle Inspection and Maintenance)	VH
The Railway Safety Act (R.S.C., 1985, c. 32) —Part II—Operation and Maintenance of Railway Works and Equipment	TC

Fire Protection and Evacuation

The following categories include requirements for protecting passengers and staff in the event of an onboard fire. These requirements include considerations for prevention, mitigation, and suppression, with the ultimate goal of enabling evacuation from the hyperloop capsule.

Fire Protection

Standard/Regulation	Organization
EN 45545-2:2016—Railway applications—Fire protection on railway vehicles - Part 2: Requirements for fire behavior of materials and components	TÜV SÜD

Standard/Regulation	Organization
EN 45545-3—Railway applications—Fire protection on railway vehicles - Fire resistance requirements for fire barriers	TÜV SÜD
EN 45545-2:2016—Railway applications—Fire protection on railway vehicles—Part 2: Requirements for fire behavior of materials and components	EC
NASA-HDBK-8719.11—Safety Standard for Fire Protection	VH
NFPA 130—Standard for Fixed Guideway Transit and Passenger Rail Systems	VH

Evacuation

Standard/Regulation	Organization
The Aeronautics Act (R.S.C., 1985, c. A-2) – Section 4.76—Emergency Directions	TC
The Canadian Aviation Regulations (SOR/96-433) – Part VI—General Operating and Flight Rules	TC
TP 12296E—Flight Attendant Training Standards	TC
SOR/2016-317—The Prevention and Control of Fires on Line Works Regulations	TC
APTA-PR-E-S-013-99, Rev. 1—Standard for Emergency Lighting System Design for Passenger Cars	VH
NFPA 110—Standard for Emergency and Standby Power Systems	VH

Security

This section includes standards to ensure both physical security (e.g., terrorism, vandalism) and information security (e.g., cybersecurity) during the design and operation of a hyperloop system.

Physical Security

Standard/Regulation	Organization
Canadian Air Transport Security Authority Act (S.C. 2002, c. 9, s. 2)—Section 27—Safety of the Public; Section 34—Regulations	TC
The Secure Air Travel Act (S.C. 2015, c. 20, s. 11)	TC
The Air Passenger Protection Regulations (SOR/2019-150)	TC
The Aeronautics Act (R.S.C., 1985, c. A-2)—Section 4.72—Security Measures	TC
Canadian Air Transport Security Authority Act (S.C. 2002, c. 9, s. 2)—Section 27—Safety of the Public; Section 34—Regulations	TC

Information Security

Standard/Regulation	Organization
ISO/IEC 27000—Information technology—Security techniques—information security management systems—Overview and vocabulary	TÜV SÜD
ISO/IEC 27005—Information technology—Security techniques—Information security risk management	TÜV SÜD
ISO IEC 27001—Information technology—Security techniques—Information security management systems—Requirements	TÜV SÜD
IEC 62443 standard series	TÜV SÜD
ISO IEC 27001—Information technology—Security techniques—Information security management systems—Requirements	EC

Standard/Regulation	Organization
ISO/IEC 27005—Information technology—Security techniques—Information security risk management	EC
IEC/TS 62443—Industrial communication networks—Network and system security	EC
ISO IEC 27001—Information technology—Security techniques—Information security management systems—Requirements	VH
ISO/IEC 27002—Information technology—Security techniques—Code of practice for information security controls	VH

Certification

Hyperloop systems are anticipated to require assessment and certification by an independent third-party. These processes are expected to follow an established life cycle process, as defined by the standards listed below.

Qualification

Standard/Regulation	Organization
ISO/IEC 17020—Conformity assessment—Requirements for the operation of various types of bodies performing inspection	TÜV SÜD
ISO/IEC 17065—Conformity assessment—Requirements for bodies certifying products, processes and services	TÜV SÜD

Implementation

Standard/Regulation	Organization
ISO 9001 or equivalent—Quality management	TÜV SÜD
IEC 62278/EN 50126—Railway applications—Specification and demonstration of reliability, availability, maintainability and safety (RAMS)	TÜV SÜD

Standard/Regulation	Organization
DO-178C—Software Considerations in Airborne Systems and Equipment Certification	EC
EASA European Aviation Safety Agency—CS-25 Certification Specifications for Large Aeroplanes Subpart C—Structure Subpart D—Design and Construction	EC
ISO 9001—Quality management systems	VH
ISO/IEC TR 90005—Systems engineering—Guidelines for the application of ISO 9001 to system life cycle processes	VH
ISO/IEC/IEEE 90003—Software engineering—Guidelines to the application of ISO 9001:2008 to computer software	VH
IEC 62278/EN 50126—Railway applications—Specification and demonstration of reliability, availability, maintainability and safety (RAMS)	VH
IEC 62278/EN 50126—Railway applications—Specification and demonstration of reliability, availability, maintainability and safety (RAMS)	Delft
Technical Specifications for Interoperability (TSIs)—Safety in Railway Tunnels, Control Command and Signalling, Persons with Disabilities and with Reduced Mobility	Delft
Life cycle model for the RAMS—(Reliability, Availability, Maintainability and Safety)	Delft
ISO/IEC 17025—Testing and calibration laboratories	Other
ISO/IEC 17011—Conformity assessment—Requirements for accreditation bodies accrediting conformity assessment bodies	Other
ISO/IEC 17024—Conformity assessment—General requirements for bodies operating certification of persons	Other

Other

This section includes standards that were identified as relevant but did not clearly fit into any of the categories identified above.

Standard/Regulation	Organization
ISO 14064-2:2019—Greenhouse gases—Part 2: Specification with guidance at the project level	EC
Guidance: ENCORD Construction CO2 Measurement Protocol level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements	EC
Series EN 506XX—Standards of assumptions under Interoperability domain	EC
Series EN 502XX—Rolling stock components and performances, e.g. radiocontrol in shunting (relevant for deposits), cables	EC
ISO 11201:2010—Acoustics—Noise emitted by machinery and equipment (complemented with EN-ISO 3XXXX on noise)	EC
CEN/TS 16XXX—Conditions for acoustic signals-perception (convergence for users, emergency, maintenance)	EC
ECSS-U-ST / EN 16604 sections n: U-10—Space debris; U-30—Space situation awareness	EC
ECSS-E-ST / EN 16603 sections n: E-10—Systems engineering; E-20—Electrical & optical engineering; E-30—Mechanical engineering; E-40—Software engineering; E-50—Communications; E-60—Control engineering; E-70—Ground systems & operations	EC
ECSS-Q-ST / EN 16602- sections n: Q-10—Product assurance management; Q-20—Quality assurance; Q-30—Dependability; Q-40—Safety; Q-60—EEE components; Q-70—Materials, mechanical parts & processes; Q-80—Software product assurance	EC
NASA Standards NASA Technical Standards (e.g. NASA-STD-6016A, NASA-STD5017)	EC

Standard/Regulation	Organization
Emissions—The Canadian Environmental Protection Act (1999, c. 33)	TC
High-Speed Switching: Rules Respecting Track Safety TC-E-54; Rules Respecting Railway Clearances TC E-05; The Canada Transportation Act—Section 127	TC
DIN 820-2—Standardization—Part 2: Presentation of documents (ISOIEC Directives – Part 2 2016, modified)	VH
NPS 7123.1B—NASA System Engineering Processes and Requirements	VH

Conclusion and Recommendations

As industry, governments, and regulating bodies review existing standards and regulations, they have identified frameworks within industries such as railroad and aviation that may be applicable to hyperloop systems. The similarities between these industries, such as track-based operation and pressurized cabins, have the potential to enable the standards to be repurposed for the new technology. The TÜV SÜD document *Hyperloop Application – Generic Guideline for Design, Operation and Certification* provides an extensive outline of hyperloop systems. In addition to identifying standards, the document also outlines a process for identifying and assessing risks and suggests requirements for items such as emergency communication and power systems, providing a relatively comprehensive foundation for the industry to build on.

While the analysis presented in this document identified several areas where existing standards may be relevant, additional work is needed to detect gaps where appropriate standards have not been identified or developed. This work could include the creation of use cases and associated concepts of operations, an identification of areas where new standards are needed, an assessment of areas which could necessitate a government role, and finally, a collaborative and comprehensive standards development process resulting in appropriate government regulations and industry standards. Some of these efforts have been initiated through organizations such as CEN/CLC/JTC20, which has begun working on standards development and is focusing its efforts on promoting interoperability across the network as a way to save time, resources, and money. Additional engagement with this committee and other ongoing standardization efforts may be beneficial.

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