



Review paper

Hyperoperability – main challenge for the future guided transport systems based on hyperloop concept

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Abstract: The hyperloop concept is not new, but for many years it was hard for engineers to believe that it could be economically and technically feasible. Nowadays some technical solutions, which could enable construction and operation of a guided transport system based on hyperloop concept, are much more imaginable. Therefore a number of start-up companies are working on comprehensive proposals and chosen technologies aiming at creating the fifth transport mode thanks to innovative concepts, new technologies, and chosen railway, air transport, and space technologies. As new transport mode is expected to offer transport with high speed nearly equal to the speed of sound its feasibility will strongly depend also on coherency between transport means and transport infrastructure in a scale of a future fifth transport mode continent-wide transport network. To meet this challenge railway and start-up companies work together in two streams – in the formal framework of the European standardisation to prepare future hyperloop related EN standards and in research and development projects. The scale of required wide technical coherency on one side and the diversification of products and existence of different developers/producers/contracting entities providing infrastructure and transport means and creating market on the other side contradict if appropriate rules are not set precisely early enough. Such rules in railway transport are based on interoperability concept supported by agreed stable essential requirements and defined in the Railway Interoperability Directive and Technical Specifications for Interoperability. Paper presents findings regarding poor applicability of the railway interoperability to the hyperloop type transport systems at their early stage of development as well as challenges and

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proposed approaches for the dedicated hyperloop coherency approach – the hyperoperability as it is being discussed in the framework of the Hypernex European project.

Keywords: railway, guided transport systems, hyperloop, interoperability, hyperoperability

1. Introduction

The hyperloop concept is not new. As a concept it has already been defined for decades, but recently developers and scientists explore that concept much more seriously and intensively [1–5]. In the past the hyperloop concept was believed to be at the edge of reality – hard for engineers to believe that it could be economically and technically feasible taking into account technical state of the art of all necessary technologies and expected costs. However as presently some technical solutions associated for instance with magnetic levitation and obtaining and keeping low pressure environment, which could enable hyperloop construction and operation are much more imaginable than few years ago, number of start-up companies are working on comprehensive proposals and chosen technologies aiming at creating the fifth transport mode defining and utilising innovative concepts and developing technologies [2]. Creation of the fifth transport mode may speed up due to economic needs associated with overcoming the energy crisis, as some decision-makers seem to believe that due to low aerodynamic friction it will be significantly cheaper than existing transport modes. Creation of a new mode however requires important development steps, which might take place thanks to adaptation of chosen railway, air transport and space technologies for instance respectively thanks to defining hyperloop internal coherency and consistency rules, transport means being at the same time air tight and vacuum sealed and high speed effective propulsion technologies.

Remembering multiple technical and financial efforts, which were lost at the beginning of the railway system development as well as taking into account the fact that due to expected traveling speeds, reaching nearly speed of sound, hyperloop developers and railway experts undertook common works on coherency between transport means and transport infrastructure being planned to be constructed hundreds and even thousands kilometres away from each other to be later combined in a single transport system. To meet this challenge railway and start-up companies work together in two streams – in the formal framework of the European standardisation to prepare future hyperloop related EN standards [3] and in research and development projects [2, 6]. The scale of required wide technical coherency on one side and the diversification of products and existence of different developers/producers/contracting entities providing infrastructure and transport means and creating market on the other side contradict if appropriate rules are not set precisely early enough. Such rules in railway transport are based on interoperability concept supported by agreed stable essential requirements and defined in the Railway Interoperability Directive and Technical Specifications for Interoperability. Within Hypernex project (EU project 101015145 – Ignition of the European hyperloop ecosystem) rail, air, and space technologies were analysed. Railway Research Institute was responsible for rail ones focusing on railway solutions, and that is discussed in the following sections.

2. Guided transport systems technical and regulatory framework overview

It is important to understand the regulatory framework of the commonly utilised guided transport systems before defining rules aiming at ensuring coherency between transport means and transport infrastructure for the new fifth transport mode based on hyperloop concept. Therefore, following subsections present comprehensive approach to technical solutions and regulatory framework for trams, metro, railways and unconventional guided transport systems (UGTS). The aim of the analyses conducted by authors within Hypernex project was to find aspects, which should be taken into account during creation of a new guided transport mode based on hyperloop concept. The four subchapters dedicated to findings in relations to trams, metro, railways and UGTS are followed by hyperloop obvious technical and legal challenges.

Before presenting individual guided transport systems it is important to subdivide all transport systems into three main parts:

- **transport means** meaning trams, metro trains, trains and unconventional vehicles which transport passengers and goods between different locations (including transport means maintenance procedures),
- **transport infrastructure** meaning routes along which transport means are moving (including transport infrastructure maintenance procedures), and
- operational and emergency **transport procedures**, which are used in normal operation and in degraded circumstances.

2.1. Trams technical solutions and regulatory framework overview

2.1.1. Trams – short technical overview

Trams infrastructure is composed by: tracks, tram stops, traction power supply systems and overhead contact line installations as well as elements of signalling which are usually added to road signalling systems as most of the trams are running within roads or along the roads passing many crossroads.

Trams as transport means are light in comparison to transport means utilised by other guided transport systems e.g. metro trains or railway vehicles. At the same time trams are much heavier than passenger cars, and therefore individual cities in which trams are utilised in most cases decided to introduce tram signalling supporting respecting traffic rules.

2.1.2. TRAMS – short legal overview

Tramways and trams are in most cases under construction regulations dedicated for roads. That seems reasonable as tram movements take place partly on the roads. The amount of requirements and their verifications significantly differ between countries and partly between cities. Such situation is acceptable as long there are no technical connections between tram systems of different cities. And that is the case in most places. Individual construction products are under Regulation (EU) No 305/2011 of the European Parliament

and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products.

2.1.3. TRAMS – short info about current and future trends

1. More and more high speed trams are being introduced. They are usually running along dedicated infrastructure, which fully, or nearly totally separated from roads. That creates legal challenges as roads regulations in such case are no longer easily applicable.
2. Moreover in some places trams started to use railway infrastructure. As a result, it was important to take into account huge differences in crashworthiness between trams and railway vehicles. As a result, a new category of vehicles is emerging – a tram-train.
3. Trams are more and more tailored to the needs of serving cities taking into account persons with reduced mobility. That includes low flooring, small gaps between platforms and door steps, places for wheelchairs, etc.

2.2. Metro technical solutions and regulatory framework overview

2.2.1. Metro – short technical overview

Metro infrastructure is composed by: engineering structures incl. tunnels, slab track structures, underground stops, traction power supply systems and third rail power supply installations, dedicated trackside signalling plus in many cases track-train transmission based control command systems supervising metro train runs against given permissions as well as communication systems ensuring operational communication between metro train drivers and dispatchers.

Metro trains are usually used to ensure homogenous or nearly homogenous traffic. Metro trains homogeneity is important to ensure similarity between speed-up and braking characteristics of the trains which is a prerequisite for control command systems ensuring short headways between metro trains. Passengers do not check, what time there is a train as headway between trains is usually about two minutes.

2.2.2. Metro – short legal overview

Metro systems are in some cases under construction regulations dedicated for metro and in some cases under railway related regulations. Of course individual construction products are under Regulation (EU) No 305/2011.

2.2.3. Metro – short info about current and future trends

More and more metro systems are equipped with automatic systems ensuring safe driverless operation. An *IEC 62267:2009 Railway applications – automated urban guided transport (AUGT) – safety requirements* standard defines grades of automation. The GoA already introduced in metro homogenous systems are at the moment being introduced in railway system – see Figure 1.

Basic functions of train operation		On-sight train operation	Non-automated train operation	ETCS baseline 2.3.0.d 3.4.0/3.6.0	Semi-automated train operation	ETCS system TSI 2022	Driverless train operation	Unattended train operation	ETCS specifications to be ready in 2025
		TOS	NTO		STO		DTO	UTO	
		GoA0	GoA1		GoA2		GoA3	GoA4	
Ensuring safe movement of trains	Ensure safe route	X (points command/control in system)	S	S	S	S	S	S	S
	Ensure safe separation of trains	X	S	S	S	S	S	S	S
	Ensure safe speed	X	X (partly supervised by system)	S	S	S	S	S	S
Driving	Control acceleration and braking	X	X	braking S accelerating X	S	S	S	S	S
Supervising guideway	Prevent collision with obstacles	X	X	X	X	X	S	S	S
	Prevent collision with persons	X	X	X	X	X	S	S	S
Supervising passenger transfer	Control passengers doors	X	X	X	X	X	X or S	S	S
	Prevent injuries to persons between cars or between platform and train	X	X	X	X	X	X or S	S	
	Ensure safe starting conditions	X	X	X	X	X	X or S	S	S
Operating a train	Put in or take out of operation	X	X	X	X	X	X	S	S
	Supervise the status of the train	X	X	X	X	X	X	S	S
Ensuring detection and management of emergency situations	Perform train diagnostic, detect fire/smoke and detect derailment, handle emergency situations (call/evacuation, supervision)	X	X	X	X	X	X	S and/or staff in OCC	S and/or staff in OCC

NOTE

X = responsibility of operations staff (may be realised by technical system).

S = realised by technical system.

Fig. 1. Grades of automation Table taken from IEC 62267:2009 with added columns describing different ETCS (European Train Control System) baselines associated with non-automated train operation NTO, semi-automated train operation STO and unattended train operation UTO, Source IEC 62267:2009

2.3. Railways technical solutions and regulatory framework overview

2.3.1. Railway – short technical overview

Railway infrastructure is composed by: engineering structures & tracks (bridges, viaducts, tunnels) utilising both ballasted and slab tracks, stations composed by sets of interlinked tracks with platforms and dedicated buildings ensuring necessary services for passengers and freight forwarders, traction power supply and overhead contact line installations as well as trackside signalling plus in many cases track-train transmission based control command systems supervising train runs against given permissions as well as communication systems ensuring operational communication between metro train drivers and dispatchers as well as between adjacent dispatchers, plus telematics systems for freight and for passenger services ensuring seamless exchange of information between infrastructure managers, train operators, freight forwarders (e.g. shippers) and individual clients. Telematic applications were introduced by EU regulations to facilitate using railway connections

for logistic networks at the time of split of national railways into infrastructure managers and railway undertakings.

Trains are composed out of railway vehicles, which are frequently significantly heavier than in case of metro. Usual axle load is 22,5 tons per axle. Usually there are four axles under single vehicle, but special vehicles for heavy cargo are also utilised e.g. twenty axle vehicles for transport of transformers. Trains are composed by electric/diesel multiple units or by locomotives and coaches for passengers or by locomotives and wagons for freight.

Both infrastructure and trains, in case of passenger trains, are required to be prepared to serve persons with reduced mobility including different kinds of disabilities as well as persons traveling with infants and/or small children as well as persons having communication challenges.

2.3.2. Railway – short legal overview

Requirements for railways are defined by two dedicated directives:

- railway interoperability directive (presently (UE) 2016/797) with which eleven Technical Specifications for Interoperability (TSIs) are associated – see Chapter 6.1.2 and
- railway safety directive (presently (UE) 2016/798) with which six Common Safety Methods (CSMs) are associated – see Chapter 6.1.3.

The TSIs as well as the CSMs are binding directly, however general rules which are defined in the quoted directives are implemented in each Member State of the EU in a national regulatory framework. Usually in a form of Railway Transport Act.

However, construction works are to be performed under general construction regulations and individual construction products have to respect rules established under Regulation (EU) No 305/2011.

2.3.3. Railway – short info about current and future trends

1. Railways are introducing new propulsion solutions e.g. hydrogen cells.
2. Railways are trying to dedicate lines for high speed passenger traffic and for freight traffic.
3. Railways are speeding up – more and more lines are constructed for 350 km/h. This is a maximum speed for which railways can claim that all the requirements are already defined by the directives, TSIs and CSMs and railway standards.
4. Railway traffic is not homogenous. However automatic train operation is being introduced. Currently utilised ETCS on-board installations (baselines 2.3.0.d, 3.4.0, and 3.6.0) intervene when trains are running in a way that without intervention would lead to exceeding maximum speed limit or running beyond movement authority. Works dedicated to introduction of the semi-automated train operation STO on the basis of the TSIs to be published in 2022 as well as of the unattended train operation UTO on the basis of the TSIs to be published in 2025 are ongoing. They involve Railway Agency of the European Union as well as industrial partners associated within UNIFE as well as European railway companies. Overview of the functionalities which have to be ensured without involving railway on-board staff is shown in Figure 1.

2.4. Unconventional guided transport systems (UGTS) technical solutions and regulatory framework overview

2.4.1. UGTS – short technical overview

Unconventional guided transport systems infrastructure frequently differs from systems to system as usually such systems serve only precisely defined relationships. UGTS infrastructure is composed by engineering structures & tracks (bridges, viaducts, tunnels) utilising both ballasted and slab tracks frequently with steel ropes or sprocket wheels, stations with platforms, escape paths and corridors, trackside mounted propulsion, simplified signalling especially when vehicles going in different directions use the same track which is rather common, emergency communication including equipment available for passengers along escape routes.

UGTS systems frequently have propulsion trackside. Moreover, they are frequently serving significant vertical differences. Therefore, such systems utilise dedicated vehicles which fit only to precisely defined infrastructure. However also such vehicles frequently need to be prepared for persons with reduced mobility. Usually UGTS systems serve relatively short distances. Toilets may be accessible only trackside, but emergency push button certainly should be accessible for short person and/or person on a wheelchair.

2.4.2. UGTS – short legal overview

Legal framework is system type and country dependent. Disregarding requirements and verifications regarding transportation capabilities, construction works are to be performed under general construction regulations and individual construction products have to respect rules established under Regulation (EU) No 305/2011.

2.4.3. UGTS – short info about current and future trends

Some UGTS systems require drivers, however new solutions being constructed are more and more supervised by operator located trackside or autonomous. At the same time social changes more and more show, that security related equipment e.g. for detection of: left luggage, which might be full of explosives, presence of unauthorised persons in restricted areas, which might be associated with terrorist attack or suicide. Such systems have to be analysed also against cyberattacks taking into account that availability of different technologies is changing over time and transport systems which were accepted as properly protected may be in danger after few years as transport systems are frequently constructed for thirty years or longer while electronic programmable solutions are changing every few years.

2.5. Hyperloop obvious challenges

Hyperloop obvious technical challenges can be summarised as follows:

- 1) hyper-tubes (incl. creation and keeping vacuum),
- 2) hyper-guideways (incl. degraded modes),
- 3) hyper-stations (entering/leaving low pressure environment),

- 4) hyper-traction power supply,
- 5) hyper-vehicles,
- 6) safety, security, cybersecurity.

Hyperloop obvious legal challenges can be summarised as follows:

- 1) interoperability approach definition and legal enforcement,
- 2) defining appropriate amount of regulatory and standards framework,
- 3) preparation of standards and regulations and legal enforcement.

3. Railway transport system interoperability

For many years the railway systems in the various Member States of the European Union have developed independently of each other, using different technical solutions. Such risk is also highly probable in the case of a new hyperloop system. Lack of technical solutions' harmonisations entails difficulties for railway undertakings providing services and causes them to incur higher operating costs (e.g. for the purchase and maintenance of different rolling stock). That shows, that necessary harmonisation has to be defined for hyperloop as a new transport mode early enough in its development process as hyperloop is intended to serve long distance connections frequently between different countries.

The implementation of interoperability, and therefore the harmonization of technical requirements at European Union level, is the result of the adoption of Directive 2008/57/EC of the European Parliament and of the Council of 17 June 2008 on the interoperability of the rail system within the Community, which was replaced by Directive 2016/797 of 11 May 2016. According to the provisions of this Directive, interoperability means the ability of the railway system to ensure the safe and uninterrupted passage of trains meeting the required level of performance.

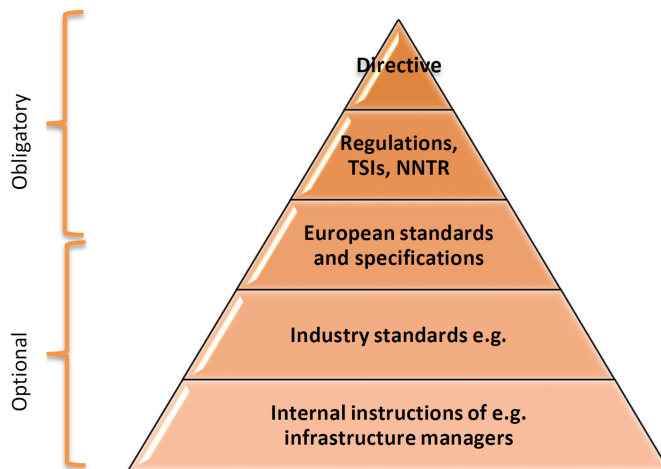


Fig. 2. Relationship between different legal and formal requirements, Source: own elaboration based on European Union Railway Agency TSIs Guidelines

Directive 2016/797 defines the subsystems that contribute to the railway system and defines essential requirements for them. Following structural and functional subsystems are defined:

Structural subsystems

- Infrastructure;
- Energy;
- Track-side control-command and signalling;
- On-board control-command and signalling;
- Rolling stock.

Functional Subsystems

- Railway traffic operation;
- Maintenance;
- Telematics applications for passenger and freight services.

In addition, the structure of the railway system distinguishes:

- interoperability constituents,
- interfaces, which are the links between the subsystems.

The interoperability constituents are also assessed and certified. In addition, the interoperability constituents shall be verified and assessed as part of the assessment of the subsystems concerned.

The detailed requirements for each subsystem are defined in the so-called Technical Specifications for Interoperability (TSIs). These documents define not only the requirements for the subsystem in question, but also the requirements related to the interfaces to the cooperating subsystems and the requirements for interoperability constituents. The first set of TSIs defining the requirements for the trans-European high speed rail system was published in 2002. Since January 2015, specifications defining the requirements for rail subsystems have been in force without distinguishing between the high-speed and conventional networks and without distinguishing between the trans-European network. TSIs apply to the whole railway system and consequently to all rail investments made and all types of rolling stock purchased. The Technical Specifications for Interoperability are characterised by a common structure. Each specification has seven Chapters and annexes. The requirements for subsystems are defined in Chapter 4 and for interoperability constituents in Chapter 5. The TSIs also describe so-called “open points”, areas that should be regulated for the single market but are not yet. Therefore, national requirements apply to open points.

According to the general approach of the European Union, products must meet the essential requirements specified for them. This approach is also applied in the railway sector. The fulfilment of the essential requirements by railway products (including interoperability constituents) and subsystems guarantees their interoperability. The following essential requirements apply to rail transport:

- Security;
- Reliability and availability;
- Health;
- Environmental protection;
- Technical compatibility;
- Availability.

The description of the adopted essential requirements is divided into parts applicable to the railway system as a whole and parts applicable to the individual subsystems. The complete set of all descriptions of the essential requirements is contained in Annex III to Directive 2016/797 of 11 May 2016. A directive is a legal act addressed to the member

states and requires what is called a process of implementation into the domestic legal order of the country. Directives are mostly addressed to all member states. Member States implement directives by either creating or modifying existing pieces of national law as appropriate. As a result, all national laws, such as statutes or regulations, remain subject to EU regulations.

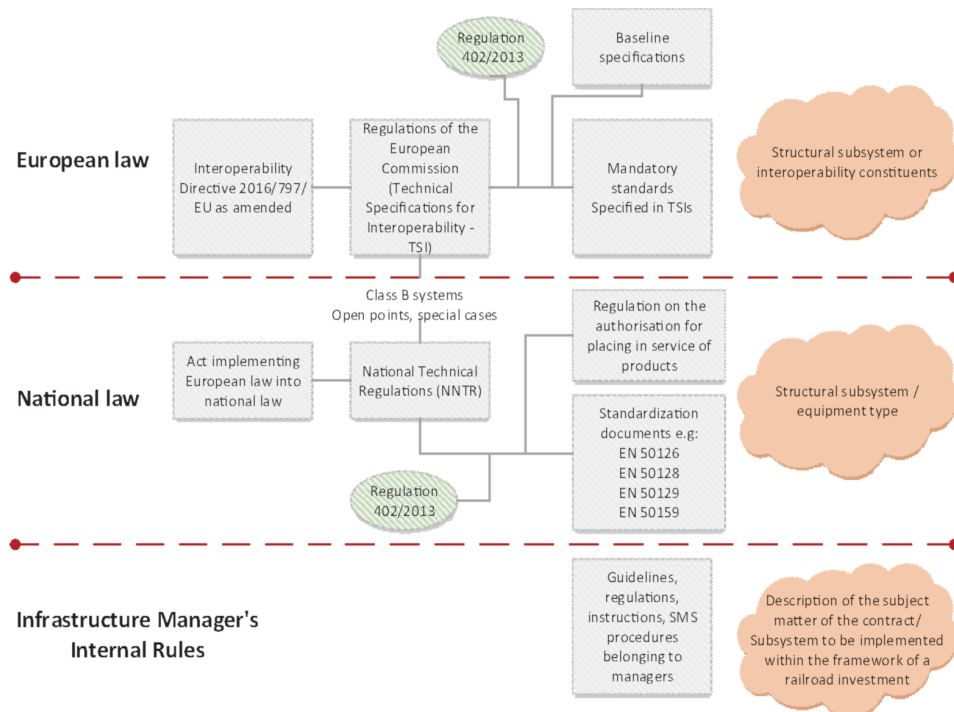


Fig. 3. Legal requirements in the railway transport commissioning processes

Source: own elaboration based on European Union Railway Agency TSIs Guidelines

TSIs organise requirements and therefore also refer to normative documents. The Directive itself states that TSIs may refer to normative documents or parts of normative documents where this is necessary to achieve interoperability. In addition, it states that the use of these documents is compulsory as far as the use of the TSI is compulsory. Standards which are referenced in TSIs therefore become mandatory.

TSIs do not indicate harmonised standards developed in conjunction with the Interoperability Directive. Harmonised standards are European Standards developed by the European standardisation organisations in support of Union harmonisation legislation, adopted on the basis of requests for standardisation from the European Commission after consultation with the Member States. Harmonized standards are part of European Union (EU) law, but their application is voluntary. However, meeting the essential requirements for a specific

product is paramount. Products manufactured in accordance with harmonized standards benefit from a presumption of conformity with the relevant essential requirements of directives, regulations or other EU legislation. The use of harmonized standards facilitates the fulfilment of the essential requirements, but is not mandatory. The exceptions are standards that are referenced in TSIs.

The harmonization of technical requirements of the European Union railway system is carried out in two ways. Firstly, all Member States are obliged to apply the same technical requirements contained in special legal acts of the European Union – the Technical Specifications for Interoperability. Secondly, Member States are obliged to reduce their national technical requirements.

Implementing interoperability is a gradual process planned over many years. Ensuring that rolling stock and infrastructure conform to Technical Specifications for Interoperability is, in principle, only required when they are upgraded or renewed. The period before all railway lines and vehicles are interoperable is regarded as a transition period during which not only European regulations but also, to a certain extent, national regulations have to be applied. All countries have been obliged to identify and make available the national requirements which must be complied with. National requirements are a list of standards assigned to specific systems that must be met in order for a product to be placed in service. These National Notified Technical Rules (NNTR) are defined by the National Safety Authority (NSA), which is also the authority responsible for issuing all authorisations to put on the market (APOM).

The assessment of conformity of products with national regulations is carried out by an authorised Designated Body (DeBo), which is an independent assessment body recognized for its competence. DeBo assesses and verifies the conformity of all phases (design, production, operation and maintenance) in accordance with the applicable national regulations. On the other hand, verification of conformity of products with European requirements in order to confirm interoperability is carried out by Notified Bodies (NoBo – Notified Body), which must first be accredited and then authorised and reported on NANDO (New Approach Notified and Designated Organisations) websites. Thus, full compliance with the essential requirements – as assessed by a NoBo – ensures safe interoperability across the entire trans-European network, i.e. system or product interfaces that are fully compatible to work with other products or systems without any restrictions.

In order to prove compliance with the TSI and ensure that the essential parameters and requirements are met, verification must be demonstrated by means of detailed documentation (design documentation, test results, verification results and any evidence of conformity), which must be verified by a Notified Body (NoBo). NoBo works in all phases of the project: from design to testing and commissioning. Through independent assessment of the conformity of subsystems and constituents with the TSI, the NoBo certifies interoperability by issuing an EC certificate of conformity (for constituents) or an EC certificate of verification (for subsystems).

It is important to undertake appropriate works to reduce technical solutions' acceptance processes' complexity for hyperloop. However also other non-technical aspects of hyperloop

system safety have to be taken into account. Therefore it is important to point out how safety is seen in railway transport.

4. Railway transport system safety ADD-ON

In the Railway Interoperability Directive, which is described in the above section, in the essential requirements for interoperability we can find a reference to the essential requirement “safety”. Safety in EU law is very widely described in the Railway Safety Directive [7] and related documents. Data compiled from website www.eur-lex.europa.eu on November 2, 2021 show following number of legal acts related to the Safety Directive by their type:

No	Nature of the link between the legal act and the Directive	Number of legal acts
1.	Directive is the legal base	13
2.	Implementing acts based on the Directive	8
3.	Delegated acts based on the Directive	5
4.	European documents citing this directive	82
	Σ	108

As can be seen from above, the Railway Safety Directive is the basis for all railway safety legislation and is a collection of more than one hundred regulations aimed at ensuring the development and improvement of the Union’s railway system and improving market access for rail transport services, by:

- a) harmonizing the regulatory structure in the Member States;
- b) defining responsibilities between the actors in the Union rail system;
- c) developing common safety targets (‘CSTs’) and common safety methods (‘CSMs’) with a view to gradually removing the need for national rules;
- d) setting out the principles for issuing, renewing, amending and restricting or revoking safety certificates and authorisations;
- e) requiring the establishment, for each Member State, of a national safety authority and an accident and incident investigating body;
- f) defining common principles for the management, regulation and supervision of railway safety.

Taking into account the content of legal acts related to the Railway Safety Directive for the purpose of this project the following common safety methods (CSMs) will be described.

Currently in European Union legal system we can find 5 CSMs and one valid until 30th October 2025 concerning

- 1) criteria for safety management systems;
- 2) risk evaluation and assessment methods;
- 3) monitoring;
- 4) supervision by national safety authorities;
- 5) assessment of achievement of common safety targets.

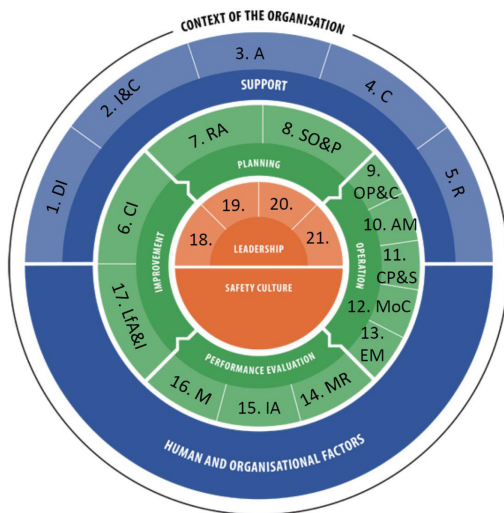
There is no doubt, that for hyperloop solutions possible lack of technical and/or operational rules' harmonisations may result in the necessity to perform complex safety verifications. As safety does not depend only on technical solutions it is important to agree common approach both to technical harmonisation and to other safety aspects early in the hyperloop development process.

4.1. Criteria for safety management systems

For the first time, the criteria for assessing safety management systems for a national safety authority were defined in 2010 in two Commission Regulations 1158/2010 and 1169/2010 dedicated to the assessment of safety management systems of a railway undertaking and an infrastructure manager. According to the current 4th railway package, the purpose of Regulation (EU) No 2018/762 in force in this regard is to define the requirements to be met by infrastructure managers and railway undertakings, compliance with which is supervised by the national safety authority. The applicable requirements for functioning safety management systems can be divided into the following areas:

- 1) organization concerning the activities of the whole organization,
- 2) leadership of the principles on which top management should be involved in the organisation to maintain or improve safety and actions to ensure a high level of safety and definition of the principles for the whole organisation, the roles and responsibilities of individuals in the organisation, the way top management communicates with employees,
- 3) planning activities aimed at minimizing the organization's exposure to risks,
- 4) documentation of the system, system of communication in the organization, management of employees' competencies,
- 5) operational activity of the organization including change management, crisis management, cooperation with contractors and suppliers,
- 6) assessment of the organization's performance including monitoring, internal audits, management reviews,
- 7) improvement consisting of drawing conclusions from the occurring events and continuous learning of the organization.

Properly implemented safety management system allows you to combine many aspects of activity to ensure the organization's ability to conduct it in a safe and effective manner. Only properly combined above mentioned elements will allow to properly demonstrate compliance with international and national regulations, standards, sector and business requirements. It also allows for the proper application and results of risk assessment and the application of good practices in all aspects of the business. To ensure that the objectives are met, the safety management system should be integrated into the organization's business processes. Establishing a safety management system requires an organization to understand the risks it must control, the regulatory framework in which it operates, and to have a clear vision of the expected outcomes. Properly functioning safety management system as a coherent whole within an organization is shown in Figure 4.



where:

- | | |
|--|--|
| 1. DI – Documented Information | 11. CP&S – Contractors, Partners & Suppliers |
| 2. I&C – Information & Communication | 12. MoC – Management of Change |
| 3. A – Awareness | 13. EM – Emergency Management |
| 4. C – Competence | 14. MR – Management Review |
| 5. R – Resources | 15. IA – Internal Auditing |
| 6. CI – Continuous Improvement | 16. M – Monitoring |
| 7. RA – Risk Assessment | 17. LfA&I – Learning from Accidents & Incidents |
| 8. SO&P – Safety Objectives & Planning | 18. L&C – Leadership & Commitment |
| 9. OP&C – Operational Planning & Control | 19. SP – Safety Policy |
| 10. AM – Asset Management | 20. RR&A – Roles, Responsibilities & Authorities |
| | 21. CoS&P – Consultation of Staff & Parties |

Fig. 4. Comprehensive visualization of the railway Safety Management System

Source: Guidance for safety certification and supervision [8]

4.2. Risk evaluation and assessment methods

In rail transport, the risk management process is defined in the Commission Regulation (EU) on a common safety method for risk evaluation and assessment [9]. The purpose of this regulation is to standardize the approach to risk management and management of changes by entities operating in EU countries. Using the approach to the risk management process described in the Regulation allows harmonization of the methods used by the entities involved in the development and operation of the railway system to identify and manage risks. In addition it unifies the methods of demonstrating compliance of the railway system with safety requirements and indicates the requirements to be met by the entities supervising the application of the risk management process.

In accordance with regulation CSM RA risk management process for railway transport solutions consists of the hazard management composed by risk assessment and demonstration of the compliance with safety requirements as well as independent safety assessment. Such approach is also adequate for hyperloop.

4.3. Monitoring

Common safety methods for monitoring for infrastructure managers and railway undertakings are defined in a dedicated Commission Regulation [10]. The establishment of a Common Safety Method (CSM) for monitoring serves to effectively manage the safety of the railway system during the organization's operation and maintenance activities.

Implemented by infrastructure managers and railway undertakings, it is linked to the risk management process and consists of the following elements:

- 1) identification of strategy, priorities and monitoring plan(s);
- 2) collection and analysis of information;
- 3) development of an action plan in the event of unacceptable non-compliance with the requirements set out in the management system;
- 4) implementation of the action plan, if such a plan has been developed;
- 5) evaluation of the effectiveness of the measures provided for Monitoring means the arrangements put in place by infrastructure managers or railway undertakings to control the correct application and effectiveness of their safety or maintenance management system. Through the monitoring process the organisation can monitor the achievement of its indicator levels and identify areas for improvement.

4.4. Oversight by national safety authorities

The Common Safety Methods established by dedicated Regulation 2018/761 [11] with regard to supervision by National Safety Authorities describe the principles to be followed by National Safety Authorities in the different European Union countries in the process of granting safety authorisations and safety certificates and their supervision. Particular emphasis is placed on describing the supervision process, the competence of the personnel involved in the supervision process, the criteria to be followed by the national safety authority in taking its decisions and the rules for exchanging information between national safety authorities.

4.5. Assessment of achievement of common safety objectives

The common safety targets defined in the Railway Safety Directive are clearly defined in the dedicated Commission Decision 2009/460 concerning the adoption of a common safety method for assessment of achievement of safety targets [12]. Decision unambiguously indicates to all European Union countries the principles according to which they are to use statistical sources and the methodology of calculating common safety targets and relating them to national reference values for individual members in 6 risk categories: passengers, employees, level crossing users, other, unauthorized persons on railway premises and whole society. Defining uniform risk categories and indicators according to which they are determined allows for objective comparison of safety levels in individual member states. This approach enables the European Commission to raise the required level of safety in individual countries by periodically publishing a safety target value for each risk category.

4.6. Necessity of the safety add-on CSMs

Analysing the safety oversight needs of the ongoing project, we propose limiting the current 5 CSMs to the three that we consider most relevant here:

- 1) on criteria for safety management systems,
- 2) methods of risk evaluation and assessment,
- 3) monitoring.

The reduction of the CSMs in the area of hyperloop technology is due to the need to centralize the oversight of a part of the rail system at the central level of the European Union in the European Union Railway Agency. Supervision of safety in this area should not be handed over to individual Member States. The European Union Railway Agency should have two or three teams of technical experts carrying out its activities in the field of hyperloop infrastructure and rolling stock.

5. Formal standardisation framework for a new transport mode

The inclusion of standardisation issues in the hyperloop vacuum rail project provides an opportunity to enhance coherency and compatibility of the solutions being applied for different purposes through the use of standards and procedures. Standards help to coordinate the flow of processes and work, disseminate knowledge and support innovation. Being prepared in due time standards respond to rapidly evolving markets and their needs, and therefore shall be treated as a tool supporting different stakeholders, especially industrial companies. Standards emerge as a result of demand and the need for legal regulation of the industrial processes. Innovative transport solutions, such as the hyperloop, require establishing international framework for the development of dedicated standards. Stakeholder collaboration on a common roadmap towards standards and regulations shall lead to faster deployment of technology.

5.1. International, European and National Standardisation Organisations

According to the definition, a standard is a document adopted by consensus and approved by a mandated organisational unit, setting out principles, guidelines or characteristics relating to different activities or their results and aiming to achieve an optimum degree of order in a specific area.

The standards development process at international, European and national level is overseen by following organisations:

⇒ on international, global level by:

- ISO International Organization for Standardization – a non-governmental organization based in Geneva, established in 1947, for which Polish Standardisation Committee PKN is one of the founding members;

- IEC International Electrotechnical Commission – a non-governmental organization also based in Geneva, established in 1906.

An international standard is a document establishing, for common and repeated use, certain technical specifications adopted and approved by the international standards organisations ISO – International Organisation for Standardisation and/or IEC – International Electrotechnical Commission.

In international standardisation organisations (ISO, IEC), business and industrial companies can participate in the standards development process by submitting experts to Working Groups (WGs) under Technical Committees (TCs) or Technical Subcommittees (SCs) in which national standardisation bodies are active members (having so called “P-membership”) and actively participate in the work of the TC or S.C. by giving opinions on working documents, vote on draft standardisation documents and attend meetings.

The “O-membership” meaning observers allows access to working documents and the possibility to attend meetings of the technical body concerned but only as an observer.

⇒ on European level, wider than EU, but linked with EU legislative processes by three European Standards Organisations (ESOs), namely by:

- European Committee for Standardization CEN (*fr. Comité Européen de Normalisation*);
- European Committee for Electrotechnical Standardization CENELEC (*fr. Comité Européen de Normalisation Électrotechnique*); and
- European Telecommunications Standards Institute ETSI.

As in the case of the development of international standards, stakeholders create new European standards by participating in the different Technical Committees (TC) and Subcommittees (SC) of CEN, CENELEC and ETSI. Each national entity declares its participation in the work of each TC and SC or announces its lack of interest.

Member States of the European Union are obligated to participate in a number of TCs and SCs, as they are associated with EU legislative processes. As a result, one of the requirements to be fulfilled before entering EU is to become a full member of CEN, CENELEC and ETSI. For instance, Poland became a full member from the 1-st January 2004 to become a full member of the EU from the 1-st May 2004.

⇒ on national level by National Standards Organisations (NSOs), e.g. by Polish Committee for Standardization PKN (*pl. Polski Komitet Normalizacyjny*).

At national level, the standardisation process is managed by the National Standards Bodies NSOs, which adopt and publish national standards. National standardisation bodies also introduce all European standards as identical national standards and, at the same time, withdraw any national standards that do not comply with the new ones. Almost every country has its own standards institute.

In the EU, most standards are created directly as EN standards and then reflected as national standards at national level as DINEN in Germany, as British Standards BSEN, as Polish Standards PNEN, as Spanish Standard UNEEN, etc. In case

standards are identical to ones accepted by international Standards Organisations they have enhanced abbreviations in front e.g. PNEN ISO 9001:2015-10. The year and month given after colon differs for different countries as it reflects moment when standard was adopted by specific NSO.

5.2. Harmonised standards

Harmonised standards are a separate category of European standards. These are developed by one of the European standardisation organisations in response to a standardisation mandate from the European Commission or possibly European Free Trade Association EFTA. They account for approximately 20% of all standards. Harmonised standards constitute base for demonstration that products or services comply with technical requirements set out in the relevant EU legislation e.g. in EU Railway Interoperability Directive. The scale of harmonisation strongly depends on industrial branch. For instance, there are nearly 200 EN railway standards harmonised with EU Railway Interoperability Directive, which makes about 80% of all EN railway specific standards. The way how standards have to be developed in order to be acceptable as harmonised standards in the future is shown in Figure 5.

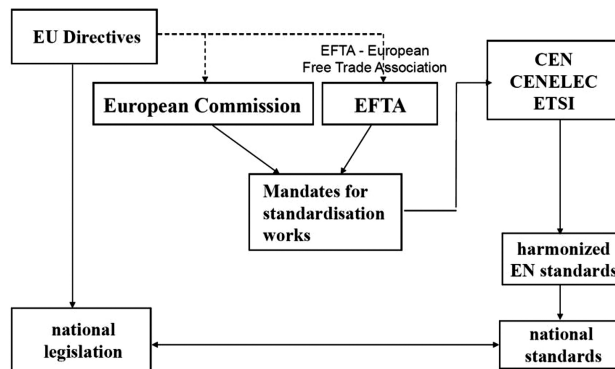


Fig. 5. European harmonised standards development process
Source: CEN/CENELEC standardization guidelines

Compliance with a European harmonised standard guarantees compliance with the applicable requirements set out in EU harmonisation legislation, including safety requirements. As a result, hyperloop-related standards are expected to fall into that category, especially as they do not freeze technical solutions which are expected to change quickly with the first hyperloop implementations. The use of harmonised standards is voluntary and a manufacturer may use any other technical solution to demonstrate that his product meets the essential requirements. European standards are used as instruments to ensure, among other things, the interoperability of networks and systems, the proper functioning of the single market, a high level of consumer and environmental protection and greater innovation.

The European Standardisation Organisations (ESOs) cooperate with each other at many levels. This cooperation results in the CEN-CENELEC Joint Technical Committees (CEN-CLC/JTC). The collaboration ensures that there is no duplication of work when the electrotechnical and non-electrotechnical sectors have common technical topics and that the interests of each party are taken into account. Such approach has been adopted for JTC20 dedicated for hyperloop.

6. Goals and structure of the hyperloop CEN and CENELEC Joint Technical Committee JTC20

A Joint Technical Committee (JTC20) has been established in the year 2020 to provide the basic requirements for the hyperloop system. This is a joint technical committee of the European Committee for Standardisation (CEN) and the European Committee for Electrotechnical Standardisation (CENELEC), which was formed at the request of the start-up hyperloop companies (Hardt, HyperPoland, Transpod and Zeleros) and the national standards organisations of the Netherlands and Spain – NEN and UNE.

The most important objective of the JTC20 technical committee is to define, establish and standardise the methodology and framework governing the hyperloop transport systems and to ensure coherency and consistency of the standards and products taking first of all safety into account. The standardisation of hyperloop technology will require the definition of all its systems and subsystems, as well as the definition of general requirements for passenger and freight transport.

It is believed, that defining such standards will enable seamless travel across Europe as well as on other continents. In contrast the lack of common requirements will result in hyperloop systems with different technical parameters (e.g. tube diameters). This will result in significantly longer travel times (the need to change between different vacuum transport systems) and higher operating costs for transport of passengers and/or freight. In terms of safety, the standards will allow the systems and subsystems of the hyperloop technology to be developed/designed taking into account the occurrence of possible risks. The common solutions will also provide the means and processes to identify, prevent and eliminate these risks during the design, production and testing phase of the hyperloop system.

The introduction of standardised interfaces between systems and subsystems will ensure their trouble less cooperation and the safe operation of hyperloop technology for instance minimising the risks associated with failures.

The JTC20 committee is divided into working groups whose work focuses on various components of the future hyperloop systems, including vehicles, pipe and associated infrastructure and traffic control. JTC20 includes representatives from hyperloop developers, standardisation bodies, development institutes and industrial companies. Due to the importance of coherency and compatibility, the working groups have identified areas on which work has to be started already now.

Key working areas include:

- operating pressure, including the safety implications of a low pressure environment (e.g. need for evacuation, spread of fire and smoke);
- the airtightness and sealedness of the vehicles and infrastructure, including the proper functioning of doors and air locks under various conditions;
- the specification of the pipe infrastructure, including the diameter and the ability of the different vehicles to function within the same system, the resistance to weather and geological conditions;
- traffic control and management, including common communication system ensuring exchange of data between vehicles and control posts;
- emergency evacuation, including emergency procedures, frequency of emergency exits and presence of support columns);
- control command systems supervising vehicle running along infrastructure;
- influence on external environment;
- environmental conditions inside passenger vehicles, including but not limited to: temperature, ventilation, lighting, noise;
- external forces acting on passengers, including, inter alia, maximum accelerations;
- requirements for hyperloop station design and technical facilities.

7. Hyperloop transport systems interoperability and safety

The key working areas does not constitute clear picture what has to be defined. What has to be defined earlier, and what has to be dependent on already taken decisions. There is no clear roadmap to be followed to ensure in case of hyperloop appropriate hyperloop interoperability referring to railway interoperability rules presented in Section 3 and appropriate hyperloop operational safety referring to railway safety rules presented in Section 4.

In order to create a clear roadmap to hyperoperability and hyperloop operational safety it is necessary to start with broad agreement on hyperoperability which will be similar but not equal to railway interoperability. Following “hyperoperability” definition is proposed taking into account results of the above mentioned analyses and the EU Railway Interoperability Directive “interoperability” definition.

Hyperoperability definition proposal:

“Hyperoperability” means the ability of a hyperloop system to allow the safe and uninterrupted movement of hyper-vehicles and hyper-trains which accomplish the required levels of performance for hyper-infrastructure. This ability depends on all the regulatory, technical and operational conditions which must be met in order to satisfy the essential requirements;

Key questions to be answered to fully clarify hyperoperability and then define requirements for hyperloop technical solutions:

1. Do we assume different categories of hyper-lines?

It is rather the case that we can have different categories of hyper-lines.

2. How will we construct stations in relations to low pressure?

There are different possibilities, already presented to ACE readers in another publication [13].

3. Will we create trains out of hyper-vehicles?

The answer is rather positive. That was presented to ACE readers in another publication [14].

4. Is safety enough?

Safety has to be understood in a wide way. We suggest taking into account safety, security and cybersecurity as well as their functional integrity.

5. How widely we should take into account degraded situations?

After an accident it is usually possible to point safety measures and procedures which would prevent occurrence of the accident or minimise its consequences. It is however impossible to prevent occurrence of all imaginable situations. Even applying at the same time ALARP principle (stating that ensuring risk has to be “As Low As Reasonably Practicable”, which is legally required in UK), GAME principle (stating that transport system “should be globally as safe or safer than the existing system accepted as a reference”, which is legally required in France) and MEM principle (accepting the same risk to an individual independently of any technical system calculating it on the basis of the “Minimum Endogenous Mortality” based on the natural death rate of human beings of specified age, which is legally binding in Germany), all together do not ensure one hundred percent protection against accidents.

Detail answers would lead to different possible approaches to hyperoperability. Four possible approaches are shortly described and visualised below.

Possible hyperloop interoperability approaches

1. **Full interoperability even wider than in case of railways**

- Security and cybersecurity has to be taken into account.
- Some decisions will probably block further development of the technology.

2. **Standardised infrastructure and traction vehicles but not hauling vehicles**

- Wide possibilities for constructions of vehicles in relations to different needs for different types of cargo and for regional and long distance passenger traffic.

3. **Only self-propelling hyper-vehicles in normal operation**

- Trains may be created due to capacity challenges

4. **Subdividing vehicles into capsules/containers & traction/guiding frames to enable wide hyperloop flexibility**

- It is possible to define solutions appropriate for different purpose keeping full interoperability between vehicles and infrastructure.
- Such approach widely opens intermodality based on transport containers.

The four possible proposed hyperoperability approaches are shown in Figures 6–9.

Accepting one of the proposed approaches would allow taking decisions regarding required standards defining rules, procedures, technologies and interfaces. Preparation of some standards would require precise defining of the chosen technical solutions, and for that research and development projects are expected to be the best tool. Presently ongoing

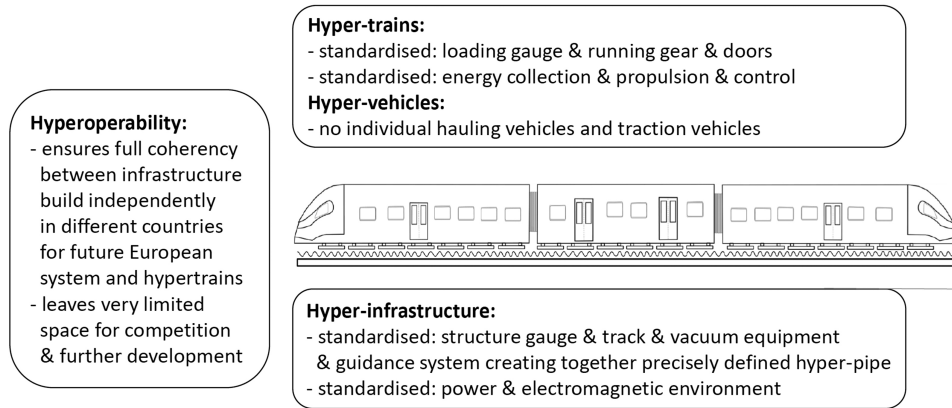


Fig. 6. Visualisation of the full legal enforcement of precise requirements

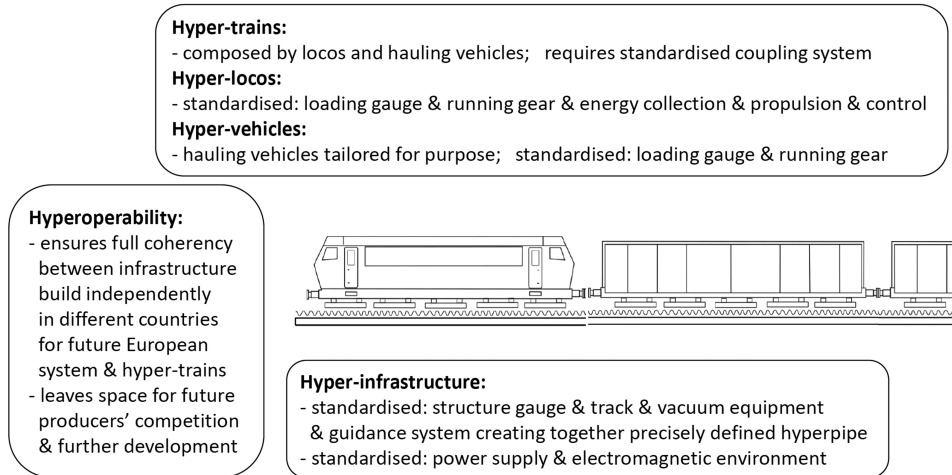


Fig. 7. European harmonised standards development process

research and development works dealing with exact technical solutions risk that they may be legally not acceptable when finally elaborated. Current state of progress of work on hyperloop not only already allows for standardisation but directly requires standardisation. As a result establishment and ongoing activities of JTC20, the joint CEN and CENELEC committee dedicated to hyperloopof solutions have to be seen as a big chance as introduction of some standardisation should already take place in cooperation with research works.

Necessity of the safety add-on CSMs can be summarised as following:

It is important to see the operational safety framework already when working on technical solution on the basis of the essential requirements defined specifically for hyperloop. As existence of different kinds of companies e.g. infrastructure managers and hyperloop un-

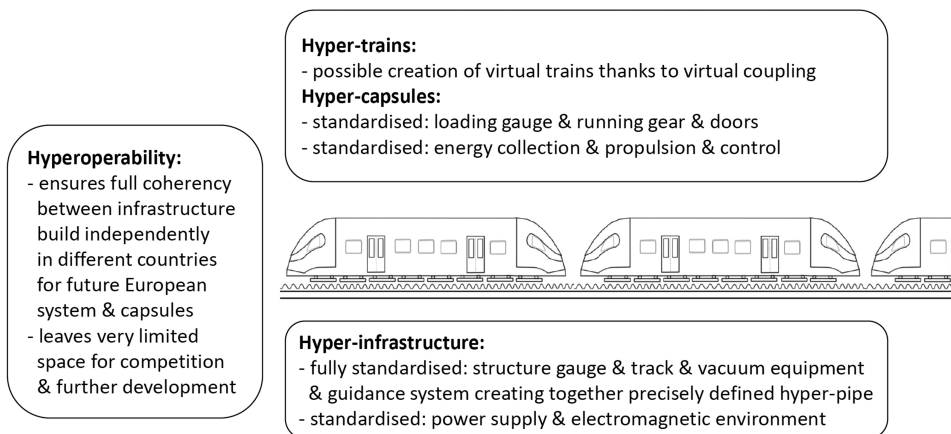


Fig. 8. European harmonised standards development process

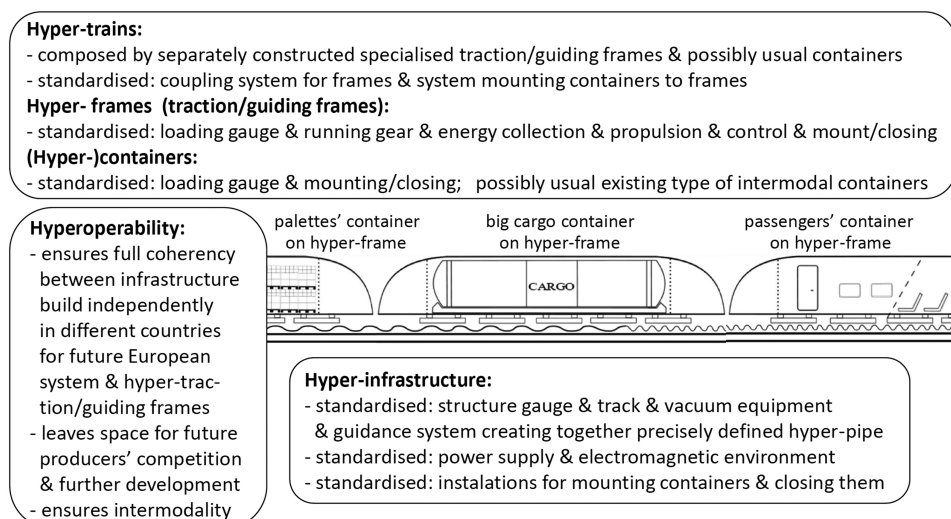


Fig. 9. European harmonised standards development process

undertakings is not foreseen the amount of Common Safety Methods CSMs may be restricted. However, following three CSMs seems to be necessary:

1. Acceptance of hyperloop undertakings and safety supervision by National Safety Authority. Both hyperloop infrastructure and hyperloop transport services shall be taken into account, and both internal safety monitoring and external safety supervision shall be taken into account, and both safety and security shall be taken into account. It is proposed to take into account also cybersecurity and the functional integrity of the safety, security and cybersecurity.

2. There is a need to implement a dedicated CSM on the rules dedicated to verification of the trends in accidents, incidents and events preceding accidents and incidents. A catalogue of types of accidents, incidents and events needs to be elaborated together with precise definitions as well as precise rules how to verify trends in individual and societal risk at least on the yearly basis.
3. The CSM RA for risk acceptance is the only one which may stay as it is at the moment. However even in that case a change of the scope of its applicability as well as hyperloop dedicated guidelines are necessary to be elaborated.

8. Conclusions

Above considerations show, that it is due time to define main legal rules for the future fifth transport mode. Without agreement on hyperoperability there will be different not compatible hyperloop systems. Consequences would be significant and having different nature – technical, operational, economical and organisational. All costly. There are different possibilities, at least four described ones how to define hyperoperability. All of them have advantages and disadvantages. Moreover, some features resulting from the way how hyperoperability would be defined will be treated already now as advantages or as disadvantages depending on the point of view. It is easy to say, that accepted approach shall be the best one, but depending on the stakeholder – early hyperloop implementers, railway industries, aviation industries, aerospace industries, low pressure industries, metal/plastic/composite materials industries, communication and information technology industries, propulsion industries as well as governments, local authorities, etc. – advantages and disadvantages differ not only depending on type of the stakeholder but in case of companies already involved in some works on individual companies as it depends on technologies they are working on at the moment and their readiness and potential. Hyperoperability shall be therefore quickly discussed and decided. Taken decision shall be reflected in a legally binding form as it will influence many already pending works being conducted by different entities working in different countries. Existence of the joint technical committee JTC20 creates a chance for substantive discussion taking into account technical and economic aspects, but it may show that already now agreement is hard to be reached as different stakeholders have too differentiated views. Moreover, even if agreement would be found it is not enough to have it in CEN/CENELEC documents as newcomers, which will certainly come when hyperloop starts to be more and more feasible, will not be obliged to follow. Therefore, just after finding agreement on the JTC20 level in globalised economy at least European legally binding decisions have to follow to secure investments in companies, people, technologies and development projects.

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Hiperoperacyjność – główne wyzwanie dla przyszłych systemów transportu po predefiniowanych torach jazdy opartych na koncepcji hyperloop

Słowa kluczowe: kolej, transport po predefiniowanych torach jazdy, hyperloop, interoperacyjność, hiperoperacyjność.

Streszczenie:

Koncepcja hyperloop jako systemu transportowego istnieje od wielu lat. Niezależnie od tego do niedawna ekspertom zajmującym się systemami transportowymi wydawała się trudnorealizowalna zarówno z powodów ekonomicznych jak i z powodów technicznych. Obecnie niektóre z takich powodów technicznych doczekały się rozwiązań, które mogłyby umożliwić budowę i eksploatację systemu transportu kierowanego opartego na koncepcji hyperloop. Dlatego też wiele firm typu startup pracuje albo nad kompleksowymi propozycjami takiego rodzaju transportu albo nad wybranymi technologiami mającymi na celu stworzenie rozwiązań koniecznych dla piątego rodzaju transportu. Obok nowych technologii i innowacyjnego podejścia analizowane i wykorzystywane są także rozwiązania techniczne, prawne i organizacyjne z sukcesem stosowane, względnie aktualnie wdrażane w transporcie kolejowym, w transporcie lotniczym oraz w przemyśle kosmicznym.

Ponieważ nowy rodzaj transportu ma oferować możliwość przemieszczania pasażerów i ładunków niemal z prędkością dźwięku dla sukcesu koncepcji hyperloop konieczne jest zapewnienie spójności rozwiązań stosowanych w pojazdach i rozwiązań wykorzystywanych w infrastrukturze na skalę przyszłej sieci transportowej, w przyszłości zapewniającej połączenia w skali euro-azjatyckiej. Aby sprostać temu wyzwaniu kolej i firmy startupowe podejmują wspólne działania zarówno formalne w tym w szczególności w ramach europejskich prac normalizacyjnych zmierzające do opracowania przyszłych norm EN dedykowanych dla hyperloop jak i badawcze w tym zarówno związane z rozwojem technologii jak i doбором najlepszych rozwiązań. Wielość aspektów technicznych wymagających uwzględnienia w zakresie spójności technicznej i wymagana dokładność dopasowania pojazdów i infrastruktury z jednej strony oraz zapewnienie różnorodności produktów i funkcjonowania wielu podmiotów oferujących planowanie, projektowanie oraz budowę i utrzymanie zarówno pojazdów jak i infrastruktury hyperloop, a w efekcie współtworzących rynek, z drugiej strony wydają się niemal sprzeczne, jeśli odpowiednie zasady nie zostaną ustalone na odpowiednio wczesnym etapie rozwoju nowego rodzaju transportu. Takie zasady w transporcie kolejowym opierają się na koncepcji interoperacyjności, która bazuje na niezmiennych formalnie zdefiniowanych wymaganiach zasadniczych zdefiniowanych w dyrektywie w sprawie interoperacyjności kolei oraz ograniczeniach dla rozwiązań technicznych zdefiniowanych w technicznych specyfikacjach interoperacyjności TSI.

W artykule przedstawiono argumenty wskazujące na brak zasadności zastosowania koncepcji interoperacyjności kolei dla przyszłych systemów transportowych typu hyperloop na ich obecnym, wczesnym etapie rozwoju. Krótko przedstawiono zasady funkcjonowania systemów tramwajowych, systemów metra, kolei i niekonwencjonalnych systemów transportu po predefiniowanych torach jazdy by następnie wskazać główne wyzwanie dla przyszłego piątego rodzaju transportu i zaproponować cztery możliwe podejścia do zapewnienia w przyszłości spójności systemów transportowych typu hyperloop, czyli cztery możliwe sposoby zdefiniowania hiperoperacyjności zaproponowane przez autorów w ramach europejskiego projektu Hypernex.

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