Deliverable D3.2: Study of Railway standards potentially applicable to MDS and identification of new standardization needs

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1. Executive Summary

Keywords: Railway safety, European standards, national standards, Technical Specifications for Interoperability, Maglev Derived Systems

The current deliverable aims at identifying the legislative documents that could be impacted by introducing the set of technologies associated to Maglev Derived Systems (MDS). As the input functional specification of MDS categories provided by the D2.1 is rather a high-level one, the proposed methodology is based on Technical Specification of TSI analysis. Considering the functional brake out of MDS, the main entities were identified and used as criterion for a set of TSI selection.

Main entities are infrastructure, communication, rolling stocks, energy, Control Command and Signalling. Some transversal needs, like noise requirements, safety in railway Tunnels (TSI SRT) or people with disabilities or reduced mobility (TSI PRM) specific needs are considered too, so the corresponding TSIs are systematically analysed.

The TSI documents are analysed section by section in order to identify which requirements may need a reformulation to allow the use of MDS Rolling stocks. Moreover, even when the text can remain unchanged, the system specialists point the potential underlying technical challenge that should be addressed.

Technical remarks are stored in an Excel file whose name corresponds to the name of the TSI. The current written document contains a synthesis of issues identified during the TSIs systematic analysis. When needed, some indications related to the necessity for new standardization needs are provided.

After a review of all the documents, the conclusion section summarizes all the issues identified. In this list, a distinction is made between documents that must be modified, updated or created, and technological challenges that seem tractable but still require future in-depth studies.

2. Abbreviations and Acronyms

Abbreviation / Acronym	Description
CCS	Command and Control System
COM	Communication
CSM RA	Common Safety Method
EN	European Normative
ENE	Energy
EU	European Union
IM	Infrastructure Manager
INF	Infrastructure
LOC&PAS	Locomotives and passenger rolling stock
MDS	Maglev Derived System
PRM	Person with Reduced Mobility
RU	Railway Undertaking
TSI	Technical Specifications for Interoperability
WP	Work Package

3. Background

The present document constitutes the Deliverable D3.2 “Study of Railway standards potentially applicable to MDS and identification of new standardization needs” in the framework of the of the MaDe4Rail project from the Innovation Pillar’s Flagship Area 7 – Innovation on new approaches for guided transport modes as described in the EU-RAIL MAWP

4. Aim/Objective

Following safety investigations developed in the deliverable D3.1 entitled "Hazard identification and risk assessment ", the current document target is to identify the legislative documents that could be impacted by the introduction the set of technologies associated to MaglevDerived Systems (MDS).

The proposed methodology considers the list of new specific hazards that are introduced by these technologies and takes into account the proposed necessary mitigation measures allowing to achieve an acceptable level of safety, as specified in the Cenelec 50126 reference table categories (see deliverable D3.1 for more details). The proposed study considers the functional breakdown structure provided in deliverable D2.1.

The main functional domains and the corresponding high level regulatory documents are identified for analysis, such as infrastructure, communication, rolling stocks, energy and Control Command and Signalling regulatory frameworks. TSI documents dealing with transversal needs, like noise requirement or PRM are to be considered too. The starting point of the analysis is the TSIs corresponding to the main functional areas, as the proposed work is a preliminary study that is processed before a detailed specification of technical definitions corresponding to various case studies (as considered in the framework of WP7 of the MaDe4Rail Project).

When the underlying technological background is well known, as for signalling and control TSI, a technical discussion is provided and technical specification documents like subsets are mentioned. In many cases, the high-level functional break-down structure of the D2.1 does not allow for diving into details and the systematic review of TSI rather mentions that further investigations are needed. As it is too early to provide the exact content of new documents, the current work focuses on identifying the needs for new or modification of the existing standardisations and their fundamental reference structures that will have to evolve for the sake of the new MDS applications.

The next section presents the methodology. Then the following sections detail the synthetic analysis of the identified TSIs. The analysis is also documented in corresponding Excel files that are appendices of the current document. The last section concludes the work to be done for building a coherent legislative framework allowing future use of MDS technologies.

5. Methodology

This chapter describes the methodology utilized to analyse the impacts due to the introduction of MDS on the existing railway regulation.

The result of this analysis aims to identify:

1) what are the modifications that should be introduced in the existing regulation for the introduction of the MDS.
2) what are the topics not covered by the existing standards that require a new standardisation for the introduction of the MDS.

This chapter identifies the regulations to be analysed and the methodology to perform the analysis.

5.1. Normative framework hierarchy

Railway systems are regulated by international and national standards.

In Europe, since the early 1990s, the railway sector has been reformed by the European Union through a series of ongoing and evolving regulations. Several railway "packages" were elaborated with the intention of constructing both a more efficient, competitive and sustainable railway system, as well as establishing a Common European Railway Area.

A key outcome of these developments is the technical regulatory framework set out in the Railway Interoperability and Safety Directives and supported by the Technical Specifications for Interoperability (TSIs), Common Safety Methods (CSMs) and European Standards (EN).

The hierarchy of the railway framework in Europe is presented in Figure 1.

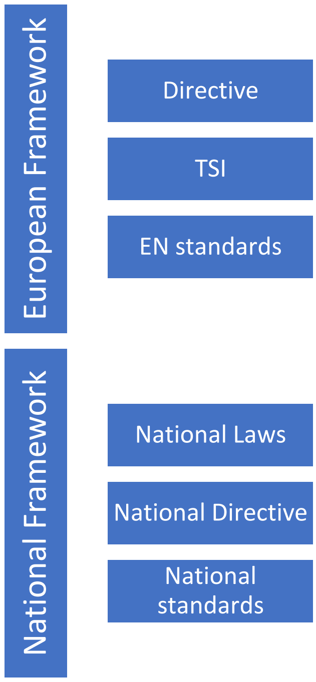

Figure 1 Railway framework hierarchy.

European regulations are mandatory for the member countries. Different Railway Directive Packages have been submitted in the last ten years:

- First railway package of 2001: In July 1998, the Commission presented three new proposals aimed solely at making existing legislation more effective. On February 26th of 2001, the Council adopted the three Directives known as the "rail infrastructure package".
- Second railway package of 2004: On January 23rd of 2002, the European Commission proposed a new set of measures (known as the "second railway package") aimed at revitalising the railways through the rapid construction of an integrated European railway area.
- Third railway package of 2007: On March 3rd of 2004 the Commission adopted its "third rail package" containing measures to revitalise the railways in Europe. This third package should complete the European regulatory framework for the rail sector.
- Fourth railway package of 2016: The 4th Railway Package is a set of 6 legislative texts designed to complete the single market for rail services (Single European Railway Area). Its overarching goal is to revitalise the rail sector and make it more competitive vis-à-vis other modes of transport.

In addition to the railway directive, EU has drafted the Technical Specifications for Interoperability (TSIs) aiming to define the technical solution to guarantee interoperability among the railway network of the different European countries. (*Interoperability Directive.*)

The Technical Specifications for Interoperability (TSIs) are provided by the European Union Agency for Railways and represent the major standard for railways in Europe. They define the technical and operational standards which must be met by each railway subsystem or part of subsystem in order to meet the essential requirements and ensure the interoperability of the railway system of the European Union.

The Directive (EU) 2016/797 defines the subsystems, either structural or functional, that conform the railway system of the European Union.

For each of those subsystems, the essential requirements need to be specified and the technical specifications determined, particularly in respect of constituents and interfaces. The essential requirements can be summarised as safety, reliability and availability, health, environmental protection, technical compatibility and accessibility. The TSI covers the following topics:

- Energy,
- Rolling stock,
- Control Command and Signaling,
- Operation and Traffic management,
- Telematics Applications for Freight and passenger service,
- Infrastructure,
- Noise,
- Safety in railway tunnels,
- Persons with Disabilities and with reduced mobility.

In addition, European Norms (ENs) are developed and maintained by CEN, CENELEC and ETSI to facilitate business and remove trade barriers for industry and consumers within the EU. These organisations (CEN for instance is composed of 30 Member States) work to develop voluntary European standards. These standards have a unique status since they also are national standards in each of its member states.

Engineering standards are the basis for achieving safety and reliability in all sectors. From the automotive industry to electronics and construction, standards ensure that products and services meet prescribed standards and minimize risk.

An important number of EN standards are used all around Europe to define railway systems from infrastructure to rolling stock components. European Standards provide the backbone of railway design, manufacturing and maintenance.

Some standards might be developed under a mandate given by the European Commission. These standards are known as ‘harmonised standards’. However, these standards are still voluntary even if they support regulations or directives, but the essential requirements must be met. If a manufacturer follows the relevant harmonised EN, it benefits from a ‘presumption of conformity’ to the related essential requirement.

An EN can be specified in a Technical Specification for Interoperability (TSI). As the TSIs are mandatory, the specified EN becomes also mandatory.

European Norms defines detailed technical requirements for the construction of different components of the railway systems as track, vehicle, signalling etc. A list of the EN standards is reported in the following sections. This list has been downloaded from the CENELEC website[1].

In addition to the European framework, national regulations are applicable to the railway sector. National standards must comply with EU regulations; however, they can introduce more specific national requirements without to be in contradiction with the EU regulations.

Considering that EU railway regulations are not applicable to independent railway network, as well as metro (Ref. [2]), trams and light rail vehicles network, each defines its own regulations for these networks.

[1] https://standards.cencenelec.eu/dyn/www/f?p=CEN:105::RESET (Setting Committee = Railway application)

5.2. Regulation analysis methodology

The objective of MaDe4Rail project is to evaluate the feasibility to introduce MDS systems on the existing railway infrastructure and more specifically in the interoperability network which must comply with the EU regulations, i.e. TSI and EN standards.

To evaluate the impact of the MDS system on the existing EU railway regulation an impact analysis is performed to evaluate the impact of the MDS systems on the requirements of the existing regulations.

According to the deliverable D2.1 (Ref. [14]), three categories of MDS have been identified:

1. Maglev systems / Full MDS
2. Hybrid MDS
    - Hybrid MDS based on air levitation
    - Hybrid MDS based on magnetic levitation
    - Conventional system upgraded with MDS technologies
3. Hyperloop systems

The common element of the three categories of MDS is the linear motor as the technology used for the propulsion of the vehicles. Considering that the objective of the MaDe4Rail project is the identification and study of MDS systems compatible with existing railway infrastructure, the impact analysis on the existing standard is performed only for hybrid MDS.

To perform the analysis, it's important to know what the characteristics of the hybrid MDS are, to evaluate the impact on the existing requirements of the EU regulation and the needs for standardisation of new elements. A short description of the Hybrid MDS configurations is reported in this chapter0, while more detailed information can be found in the deliverables D2.1 (Ref. [14]) and D4.1 (Ref. [16]).

The introduction of the hybrid MDS system on the existing railway infrastructure impacts mainly on of the technical requirements related to the construction of the different railway subsystems. For this reason, the analysis on the existing regulations has been focused on the TSI and EN standards[2].

A link has been established between the TSI/EN standards with each fundamental subsystem of MDS breakdown structure defined in the D2.Vehicle, Infrastructure, Energy and Command and Control.

[2] In several case the EN standards detail the principles define in TSI.

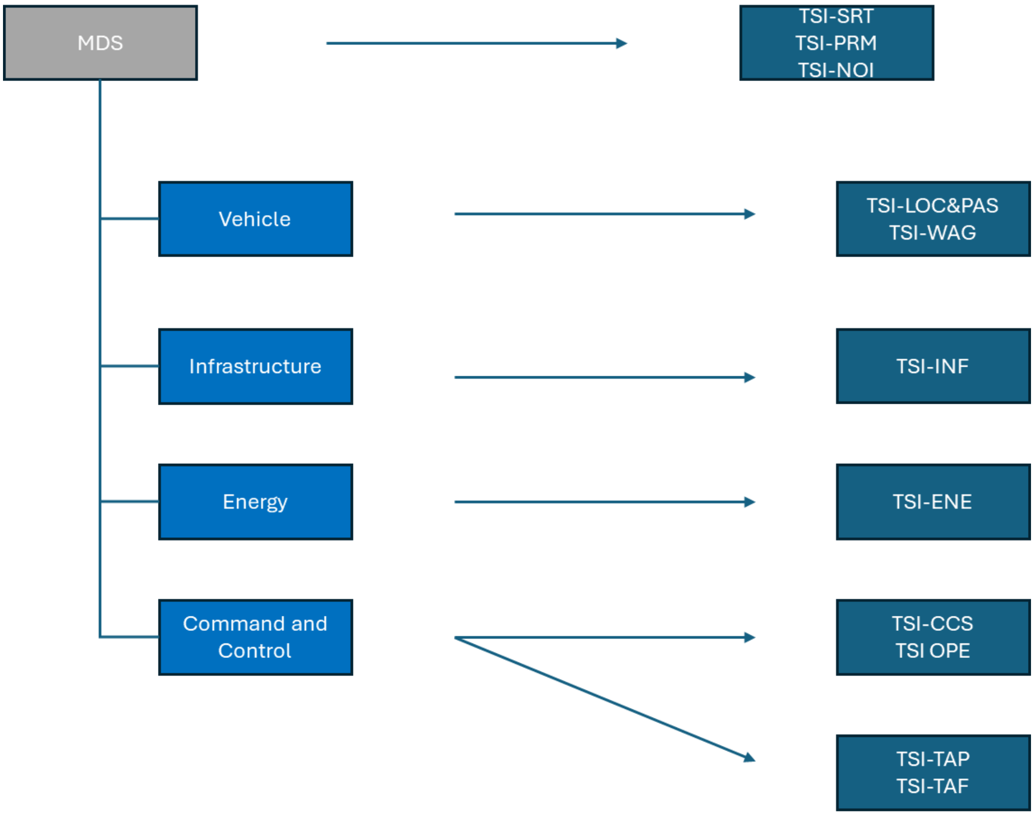

Figure 2 Link between MDS Breakdown Structure and TSI

To perform a systematic analysis, the TSI and EN standard have been allocated to the main five subsystems of an MDS system:

- MDS Overall: this subsystem includes all the generic elements that affect and impact all subjects related to railway. May include, for example, general noise or safety topics.
- Infrastructure: this subsystem includes all components of the railway structure from the platform to the rail and sleeper. Different types of infrastructure can be included as slab, ballasted or embedded track. For MDS systems the magnetic component installed on the ground is included in this subsystem.
- Energy: this subsystem includes all elements related to the energy supply to the vehicle. It includes the linear motor which provide traction power to the MDS system.
- Vehicle: vehicle subsystems include all subjects related to the rolling stock from interior design to the mechanical system.
- Command and control system: it includes signalling and communication systems.

As shown in Figure 2 some TSI are general and applied to the overall MDS system, while others are specific to each MDS subsystem.

The abbreviation of the TSI shown in Figure 2 are listed in the following table.

TSI Abbreviation	**TSI Title**
TSI-SRT	Safety in Railway Tunnels
TSI-PRM	Persons with Disabilities and with Reduced Mobility
TSI-NOI	Noise
TSI-LOC&PAS	Rolling Stock - Locomotives and Passengers Rolling Stock
TSI-WAG	Rolling Stock - Freight Wagons
TSI-INF	Infrastructure
TSI-ENE	Energy
TSI-CCS	Control Command and Signalling
TSI-OPE	Operation and Traffic Management
TSI-TAP	Telematics Applications for Passenger Service
TSI-TAF	Telematics Applications for Freight service

Table 1 TSI Abbreviation

The allocation of the EN standards available on the CENELEC website to the different MDS system is shown in the following sections.

Systematic analysis of the standard has been performed for each subsystem. For practical reason, the analysis of the standards related to the Command-and-Control subsystem have been split into Signalling and Telecommunication subsystem.

A different level of details has been selected for TSI and EN norms because of the level of detail covered by the standards themselves. TSI are a small number of more generic standards that deal with broader topics that can be easily analysed within the project scope.

The EN standards go into more detail on each specific aspects mentioned by the TSI and that form the railway system. The analysis of the EN standards would require specific expertise and the availability of all norms.

At this stage, the objective is to identify the subjects dealt with in the standards that are impacted by the introduction of the MDS and that require a modification of the existent standard or a further evaluation of the impacts on the existing standard.

5.2.1. TSI analysis

The aim of the TSI analysis is to identify the impacts on the existing requirements due to the introduction of Hybrid MDS. An impact analysis has been performed on the subjects dealt on the existing TSI.

For each paragraph of the TSI, the impact analysis has:

1) Assessed the impact due to the introduction of the MDS system on the TSI requirements for each type of Hybrid MDS:
    a. Hybrid MDS based on air levitation
    b. Hybrid MDS based on magnetic levitation
    c. Conventional system upgraded with MDS technologies.

    The impact analysis has been performed for each paragraph of each TSI and the results of the analysis has been classified in the following categories:

Impact Analysis Status	**Definition**
Applicable	TSI requirement must be applicable to hybrid MDS without any change. New technologies have no impact on standard. This category covers two cases: • MDS systems do not have any impact on TSI requirement, • MDS systems must comply with TSI requirements.
Applicable with modifications	TSI requirement is applicable to the hybrid MDS with changes. The intent of the existing TSI requirement remains valid but the requirement must be adapted to be applicable to MDS.
To be investigated	The application of the requirement to Hybrid MDS must be investigated. Considering the level of details of the project it is not possible to define if the requirement can be fulfilled.
Not applicable	TSI requirement is no longer applicable to Hybrid MDS.

Table 2 Category Status of TSI Impact Analysis

2) For the requirements classified as “applicable with modifications” or “to be investigated” the items in the requirements to be changed or investigated have been identified. They have been described in each paragraph of the present document.

5.2.2. EN standards analysis

The analysis of EN standards is performed on a high level, aiming to identify additional issues not covered by the TSI. This means that the analysis has been done only checking the scope of the standard available on the web.

It must be highlighted that most of the EN standards detail the main topics defined in the TSI and define the detailed requirements for the construction of the different railway components for each subsystem.

For these reasons, impact analysis has been performed at high level grouping the different standards related to the same subjects.

5.2.3. Analysis results

The results of the impact analysis on the existing standards applicable to the different MDS systems are reported in the following chapters.

In addition to the results of the impact analysis on the existing standards, the specific needs of standardisation for the new technology have been identified.

6. System definition

This chapters present the description for the three MDS configurations defined within the MaDe4Rail project as the most promising for integration with existing railway infrastructure. The objective of this chapter is to provide a short overview of the systems and their characteristics to evaluate the impact on the existing requirements of the EU regulation.

6.1. Hybrid MDS based on air levitation

A hybrid MDS system based on air levitation is a a transportation system able to operate on an existing railway infrastructure that relies both on wheel-based suspension and air levitation suspension propelled by a linear motor or Electro Dynamic Wheels (EDW). It can enable the integration of different rail systems such as high-speed rail, conventional rail, light rail and heavy rail within the same network.

An example of such hybrid transport system combining technologies like air levitation and propulsion by Electro Dynamic Wheels (EDW) is depicted in Figure 3.

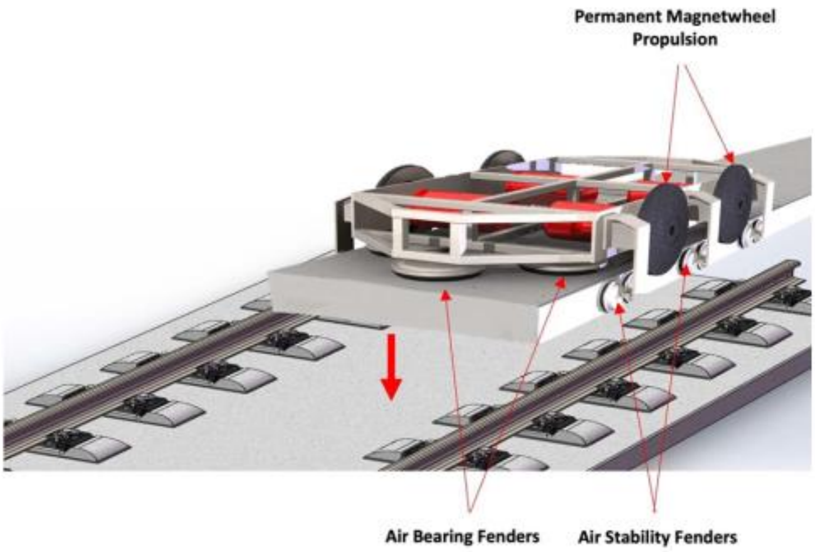

Figure 3 Example hybrid MDS based on air levitation bogie

Such systems facilitate the effortless movement of passengers and bulk goods in any direction by gliding on an ultra-thin layer of air. By channelling air into the specialized Air Bearing Fenders, which move along a flat surface such as a track, road or floor, an upward force is created. This ultra-thin layer of air significantly reduces friction, allowing for smooth and virtually frictionless travel. This technology delivers a great value over traditional transport (wheels) by two facts:

1. The rolling resistance and wear is harshly minimized,

2. The mass of the vehicle is distributed evenly over a large contact area, compared to the view square centimetres in conventional railway systems, allowing for a much lighter infrastructure.

6.2. Hybrid MDS based on magnetic levitation

A hybrid MDS system utilizing magnetic levitation typically describes a transportation system that combines both wheel-based and magnetic levitation suspensions, depending on the operational conditions, and allows for the operation of both traditional trains and MDS vehicles. For instance, the vehicle may use wheels during switch crossings or when approaching platforms, to then switch to magnetic levitation in designated maglev corridors. Propulsion is typically wheel-based during wheeled operations, but it may involve different technologies when operating on magnetic levitation. Selecting the appropriate propulsion technology requires a thorough compatibility study and economic evaluation. The design of the vehicle must ensure it is compatible with both existing and potentially upgraded railway infrastructure, as well as interoperable with the broader transportation system.

In figure 2, two variants of possible Hybrid MDS configurations based on maglev are displayed:

- A hybrid systemwhere wheel-based systems and levitation systems act on the same traditional guideways (**series hybrid case**);
- A hybrid system where levitation systems act on additional parallel separate guideways than the traditional wheel-based systems' one (**parallel hybrid case**).

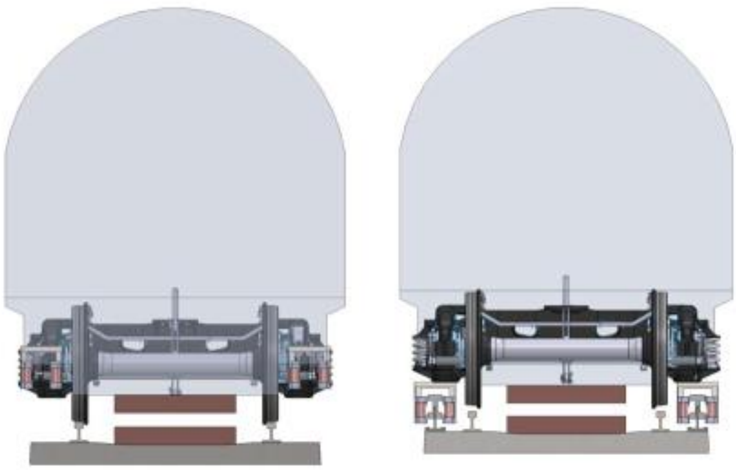

Figure 4 Example of Hybrid MDS based on magnetic levitation: left to right A) vehicle operating on wheels B) Ironlev system engaged on Ironlev guideways, on dedicated maglev corridors (source: Ironbox)

An MDS system can be integrated with conventional wheeled systems to create a hybrid architecture, utilizing traditional wheels for low-speed movements and track switches, and dedicated magnetic suspensions for high-speed, efficient travels. This design aims to enhance system efficiency by reducing contact friction.

On the infrastructure side, the hybrid setup involves augmenting existing railway tracks with auxiliary guideways that work with the MDS suspension subsystem. These could include conductive rails or coils for electromagnetic systems, iron rails for ferromagnetic levitation, or specialized tracks for air levitation. For iron rails, the MDS suspension can be applied directly to traditional guideways without the need for additional rails.

When the system operates on wheels, the guidance is provided by vertical wheels like traditional trains, instead when the system operates on MDS suspension, lateral guidance is required according to the suspension system itself. Generally, guidance subsystem is based on the same technology of the suspension system and integrated in the MDS suspension subsystem (e.g., EDS, EMS or air levitation), so it requires auxiliary guideways for lateral guidance that are generally integrated in the same auxiliary rail used for the suspension. The propulsion and braking can be implemented using different technologies of linear motors or electrodynamic wheels.

6.3. Conventional system upgraded with MDS technologies

A conventional system upgraded with MDS technologies refers to a transportation system that relies on traditional railway architecture, introducing MDS technologies to enhance its performance. Maglev technology has emerged as a breakaway from the conventional wheel-based technology for achieving higher speeds with better performance. On-wheel rail systems use adhesion between wheels and rails to move forward, while maglev systems use propulsion force generated by a linear electro-mechanical system to move forward.

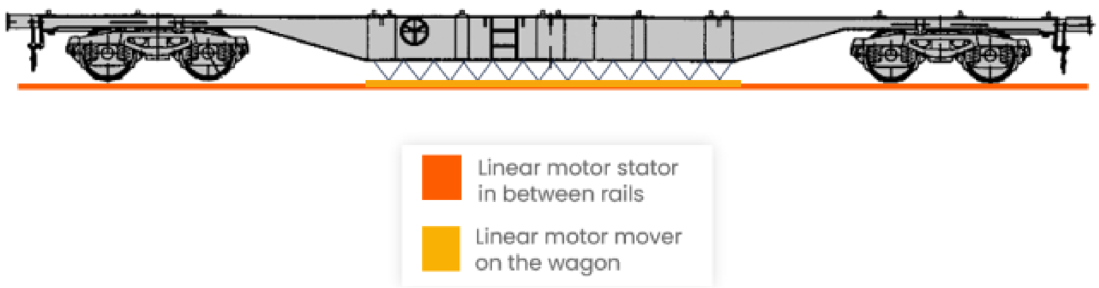

Figure 5 Linear motor-powered retrofitted freight platform

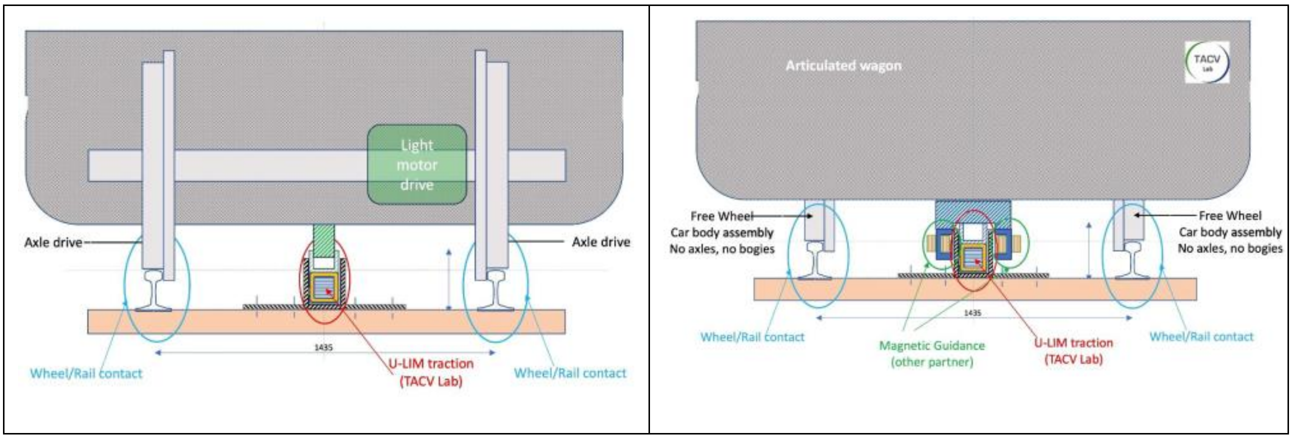

Figure 6 Example of LIM propulsion for MDS system

Alternatively, such a system can be equipped with Linear Induction Motor (Figure 6), with the active part on the vehicle and passive one on the infrastructure.

7. Analysis of standards related to MDS Overall System (GESTE)

7.1. Analysis of TSI

As shown in Figure 2, three different TSIs are applicable to all subsystems of a MDS system:

- Safety in railway tunnel TSI: This TSI concerns all railways subsystems: control command and signalling, infrastructure, energy, operation and traffic management, and rolling stock. It applies to new, renewed and upgraded tunnels which are located on the rail network of the European Union. A tunnel in the context of this TSI is 0.1 km or longer. Where certain requirements apply only to longer tunnels, thresholds are mentioned in the relevant clauses of the TSI.
- Noise TSI: In line with the proportionality principle, this TSI sets out the optimal level of harmonisation related to specifications on the rolling stock subsystem (for both locomotives and passenger rolling stock and, freight wagons) intended to limit the noise emission of the railway system of the European Union.
- Persons with Disabilities and with Reduced Mobility TSI: This TSI applies to the infrastructure, operation and traffic management, telematics applications and rolling stock subsystems. It covers all aspects of these subsystems which are relevant to accessibility for persons with disabilities and persons with reduced mobility.

The results of the impact analysis on each TSI to consider the introduction of MDS technology are described in the following paragraphs.

7.1.1. Impact of MDS on TSI-SRT

The impact analysis on the TSI-SRT has highlighted that the following subjects covered by the current TSI that are impacted by the introduction of the hybrid MDS:

- **Par. 3: *Infrastructure, energy and rolling stock subsystems safety***
  The chapter 3 define the requirements to be implemented to mitigated different hazardous scenarios in tunnels.

Element of the infrastructure sub-system	Ref. Clause	Safety	Reliability Availability	Health	Environmental protection	Technical compatibility	Accessi-bility
Prevent unauthorised access to emergency exits and technical rooms	4.2.1.1.	2.1.1					
Fire resistance of tunnel structures	4.2.1.2.	1.1.4 2.1.1					
Fire reaction of building material	4.2.1.3.	1.1.4 2.1.1		1.3.2	1.4.2		

Table 3 Example of table of TSI-SRT's Chapter 3

MDS systems introduce new elements in the tunnel infrastructure that must be analysed in relation the hazardous scenarios that they can introduce in the tunnel and the mitigation measures to implement to make the hazards acceptable.

- **Par. 4.2: *Functional and technical specifications of the subsystems***
  The chapter 4 is the hearth of the standard that defines functional and technical requirements of the different railway subsystems to ensure safety in the tunnel. The current TSI doesn't consider the installation in the tunnel of the technology for the implementation of the hybrid MDS systems. For this reason, an analysis shall be done to investigate if the existing requirements must be changed or if additional requirements shall be added to ensure the safety in the tunnel in case of MDS operation.

7.1.2.Impact of MDS on TSI-NOI

The impact analysis on the TSI-NOI has highlighted that the following subjects covered by the current TSI are impacted by the introduction of the hybrid MDS:

- **TSI- NOI: *New source of noise and procedure for evaluation***
  Noise limits are well described in the TSI (Ref to Par. 4.2). Limits for stationary, starting and pass-by noise are defined for conventional track and rolling stock. Conventional evaluation procedure and simplified procedure are also defined to measure noise emissions.
  In principle, the noise requirements defined in the current TSI must also be fulfilled by hybrid MDS.
  However, it must also be investigated whether with the new MDS technology there are other elements or situations likely to generate noise that need to be regulated.

Air levitation systems may represent a major source of noise. Technical solutions to be adopted for the air levitation must be studied to comply with the noise requirement of the TSI.
An additional source of noise in hybrid MDS systems may be considered due to the transition phase from traditional bogie to levitation and vice versa. In this case, the landing on the rail or the start of levitation could in fact be a source of noise.

The paragraph 6.2 of the TSI-NOI sets out noise evaluation procedures. They should be extended to consider the specific technology of the hybrid MDS.

The considerations above can be extended to the EN standards referred in the Annex B of the TSI-NOI.

7.1.3.Impact of MDS on TSI-PRM

PRM TSI must remain fully applicable as it concerns requirements and solutions not impacted by MDS technology.

7.2. Analysis of other standards related to overall system

Generic and overall EN norms exist and cover various subjects. Considering the classification reported in the Annex B, the standards applicable to the overall infrastructure of MDS systems covers the following subjects:

- Design for PRM: this topic is treated also by the TSI-NOI, however EN norms describe more in detail the technical solutions to be adopted to remove physical barriers for PRM. The solutions defined in the related EN standards are not directly related to maglev technical solution and for this reason EN norms are not impacted by the new MDS technologies.
- Noise emission: this topic is treated also by the TSI, but EN norms are more detailed. Theydescribe in detail noise emissions related to infrastructure androlling stock, but also noise protection aspects and solutions. For this standards, noise sources, limits and procedure for verification must be extended to consider the new technology and solution introduced by MDS.
- Health and safety of maintainers: the EN standards deal with the issue of safety at work, which is not covered by the TSI. Works on and near the track, maintenance works, and construction works are sensitive in railway systems. The EN norms define rules to ensure the safety of workers in this complex system. MDS technology add a new item to the system and the impact on workers safety need to be investigated. For example, the presence of the linear motor in the middle of track introduces new risks for the maintainers that are not present in the existing infrastructure.

- Aerodynamics: some standards (EN 14067. [1-6]) deal with the subject of aerodynamics and the different requirements that have to be met and tested in the case of tunnels or open-air tracks. It should be analysed whether MDS technology and high speeds may have an impact on the requirements of this standards.
- EMC: some standards (EN 50121 series) deal with overall EMC compatibility of a railway infrastructure. The introduction of MDS systems has an impact on the electromagnetic field of the railway infrastructure, because the technical solution for propulsion system (linear motor) and magnetic levitation are new sources of electromagnetic field in the existing railway infrastructure. The compatibility of these new technologies must be studied to define limits of emission and immunity levels to guarantee the safe operation of the overall infrastructure. The test procedures shall be also reviewed to consider the new MDS components.
- Railway safety: the standard EN 50126/8/9 defines the processes and requirements to develop a safe and available railway system or product. The requirements defined in these standards remain applicable with the introduced of MDS system, because they are not related to specific technical solutions. The concepts defined in these standards remain applicable to develop a safe and available MDS systems.

7.3. New standardization needs

The introduction of hybrid MDS systems requires to consider the following aspects:

- Standardization of technical solution at subsystem level. This point is covered more in detailed in paragraphs related to each subsystems;
- Integration of new technologies among them and in the existing infrastructure.

This second point requires to identify more in detail the interfaces between:

- the new subsystems of hybrid MDS system;
- the new subsystems of hybrid MDS and the existing systems.

Most of these interfaces are covered in the standards applicable to each specific subsystem. For example, the interface between catenary and rolling stock is considered in the TSI-ENE and TSI-LOC&PAS as well as in the EN standards referred in these two TSIs.

With the introduction of a MDS system, this interface will change since the propulsion of the rolling stock will be guaranteed by the linear motor.

The identification of the interfaces is a key aspect to ensure that the requirements for the different subsystem are well identified and allocated to guarantee compatibility of different products.

8. Analysis of standards related to infrastructure

8.1. Analysis of TSI

The aim of the TSI Infrastructure is to establish a unified framework for the infrastructure subsystem of the rail system in the European Union. This includes defining technical and functional specifications to ensure interoperability, safety, and efficiency of the rail infrastructure, while promoting modernization and technological advancements. It also provides guidelines for assessing conformity, managing maintenance, and ensuring the integration of innovative solutions, ultimately facilitating a seamless and interoperable rail network across the EU.

It is important to note that the analysis was performed only for normal gauge (1435mm). Paragraphs related to other gauges (1520mm and 1668mm) were omitted by purpose.

8.1.1. Impact of MDS on TSI infrastructure

The analysis based on the consolidated version from 28/09/2023 of the TSI INF (EU 1299/2014) showed several TSI points that need to be taken into account or modified during MDS development:

- Line layout (TSI INF 4.2.3)
- Track parameters (TSI INF 4.2.4)
- Switches and crossings (TSI INF 4.2.5)
- Track resistance to applied loads (TSI INF 4.2.6)
- Interoperability constituents – Rail fastening systems (TSI INF 5.3.2) and track sleepers (TSI INF 5.3.3)

8.1.1.1. Line layout (TSI INF 4.2.3)

The issue related to the line layout includes the following subtopics (Structure gauge – 4.2.3.1 and Distance between tracks – 4.2.3.2).

The TSI INF specifies that the normative document to be considered when analysing the interoperable structure gauge is EN 15273-3:2013+A1:2016 (Railway applications – Gauges – Part 3: structure gauges). The structure gauge is divided into upper and lower part. The upper part can be relatively freely selected according to the standard and local infrastructure manager (IM) requirements. The lower part, however, can be present in two variants: GI2, which is the general variant for the majority of lines, and GI1, which is used in cases where trackside rail brakes are installed.

As MDS components may interfere with the lower part of the structure gauge, it is essential to ensure compliance between the linear motor and levitation system with the GI2 (or GI1 in special cases) from the concept phase. This compliance must then be validated and verified during the V&V process to ensure safety. However, if compliance cannot be achieved, modifications and exceptions in TSI LOC&PAS or in the EN 15273-3 will be necessary. This is particularly relevant for cases involving vertical linear motors and levitation systems that utilize additional trackside and onboard equipment, which may infringe upon the structure gauge.

The distance between tracks is a critical consideration, especially if the line speed will be increased during MDS implementation. This requirement stems from the need to minimize aerodynamic interactions between passing trains; the higher the speed, the greater the required distance. To avoid the significant capital expenditures (CAPEX) associated with modifying infrastructure, it can be demonstrated that a smaller MDS vehicles may result in less significant aerodynamic interactions.

The remaining paragraphs of section 4.2.3 (gradients, vertical and horizontal curves) apply to MDS without modifications. However, it is essential to investigate the performance of MDS propulsion and levitation systems under maximum conditions.

8.1.1.2. Track parameters (TSI INF 4.2.4)

Main open points stated in paragraph 4.2.4 in 1299/2014 that shall be investigated or modified are cant with cant deficiency (subsequently 4.2.4.2 and 4.2.4.3) and rail inclination (4.2.4.7).

One of the objectives of implementing MDS in the TSI network is to achieve shorter travel times on the same or slightly retrofitted infrastructure. One way to accomplish this is by increasing the cants and cant deficiencies, which will allow curves to be negotiated at higher speeds while maintaining the required safety level. Currently, on freight and mixed lines, the maximum cant on the normal gauge is 170 mm, and for passenger lines, it is 180 mm. If MDS is equipped with a levitation system requiring additional levitation infrastructure, the gauge will be wider, necessitating a proportionally larger cant. However, to achieve the desired goal, the actual roll angle must be increased. The concept allows to increase the roll angle only for levitation beams and maintaining the same cant for rails enabling interoperability (Fig. 8).

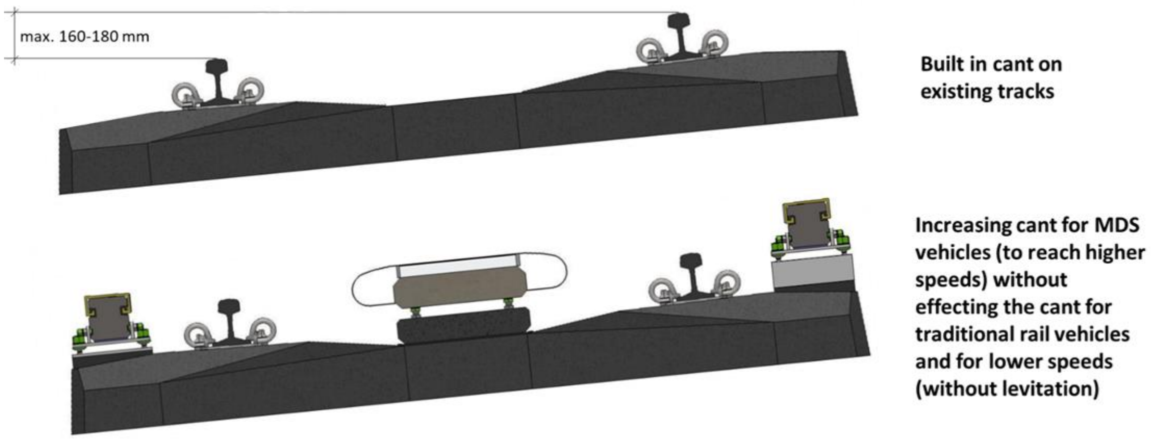

Fig. 8 Track modified with different cants for wheel and for electrodynamic guidance

Regarding cant deficiencies, TSI INF regulations state that:

"It is permissible for trains specifically designed to travel with higher cant deficiency (for example multiple units with axle loads lower than set out in table 2; vehicles with special equipment for the negotiation of curves) to run with higher cant deficiency values, subject to a demonstration that this can be achieved safely." (TSI INF 4.2.4.3(2)).

It clearly gives an opportunity for MDS to increase this deficiency as the vehicles by design will be lighter than regular rolling stock (levitating vehicle mass is one of the design criteria to achieve reasonable energy efficiency, similarly to approach applied in aviation). In particular one of the requirements to fulfil this TSI paragraph is to design a vehicle with lower axle load than stated in Fig. 9. It must be noted that the safety demonstration of the higher cant deficiency is outside the scope of the TSI INF and shall be undertaken by RU, if necessary, with cooperation with IM (described in TSI INF 6.2.4.5).

Traffic code	Structure gauge	Axle load [t]	Line speed [km/h]	Usable length of platform [m]
P1	GC	17 (1) / 21,5 (2)	250-350	400
P2	GB	20 (1)/ 22,5 (2)	200-250	200-400
P3	DE3	22,5 (3)	120-200	200-400
P4	GB	22,5 (3)	120-200	200-400
P5	GA	20 (3)	80-120	50-200
P6	G1	12 (3)	n.a.	n.a.
P1520	S	22,5 (3)	80-160	35-400
P1600	IRL1	22,5 (3)	80-160	75-240

(1) Minimum required values of axle load to be used for checks of bridges using a dynamic appraisal, based on design mass in working order for power heads and locomotives and operational mass under normal payload for vehicles capable of carrying a payload of passengers or luggage (mass definitions in accordance with the specification referenced in Appendix T Index [1] .

(2) Minimum required values of axle load to be used for checks of infrastructure using a static loading, based on design mass under exceptional payload for vehicles capable of carrying a payload of passengers or luggage (mass definitions in accordance with the specification referenced in Appendix T Index [1] with regard of the specification referenced in Appendix T Index [2]). This axle load may be linked to limited speed.

(3) To be used for checks of infrastructure used for static loading, based on design mass in working order for power heads and locomotives and design mass under exceptional payload for other vehicles (mass definitions in accordance with the specification referenced in Appendix T Index [1] with regard of the specification referenced in Appendix T Index [2]). This axle load may be linked to limited speed.

Fig. 9 Infrastructure performance parameters for passenger traffic

Rail inclination (TSI INF 4.2.4.7) is a parameter that is set for a specific line segment; however, it may differ between 1/20 to 1/40. This is particularly significant to eddy-current rail levitation systems (e.g. proposed by Ironlev). Therefore, depending on the inclination the levitation performance and applicability shall be checked.

8.1.1.3. Switches and crossings (TSI INF 4.2.5)

Next infrastructure topics are switches ad crossings. The main points are related to design geometry of switches and crossings (TSI INF 4.2.5.1) and the use of swing nose crossing (RSI INF 4.2.5.2).

Design geometry of switches and crossings is defined in TSI INF 4.2.5.1. After conceptual works in WP8, it is possible to design switches that will work with the MDS linear propulsion system to maintain traction continuity (design inspired by cogwheel rail switch). The challenge is still to maintain levitation over the switches; however, swing nose crossing may bring a solution.

Swing nose crossing is required only for lines designed to reach speeds over 250 km/h. However, it turns out that such solution may also be very useful when track continuity is demanded, e.g. by levitation systems. The TSI point itself is applicable without modifications, but it can be extended to solve the MDS switches topic.

8.1.1.4. Track resistance to applied loads (TSI INF 4.2.6)

The TSI paragraph that impact MDS solutions is a track resistance to vertical (4.2.6.1), longitudinal (4.2.6.2) and lateral forces (4.2.6.3) exerted during rolling stock operations.

Maximum vertical and lateral loads shall be compliant with the EN 14363:2016+A2:2022 standard. This shall be possible, especially that the MDS vehicle should have lower axle loads (see 8.1.1.2), however due to the different load distribution and potential excessive vertical loads from MDS components, this topic shall be investigated. Longitudinal loads also shall be checked for the sake of different load distribution – the forces are mainly attached to the middle of the track (linear motor stator). This open point is depicted in Figure 10.

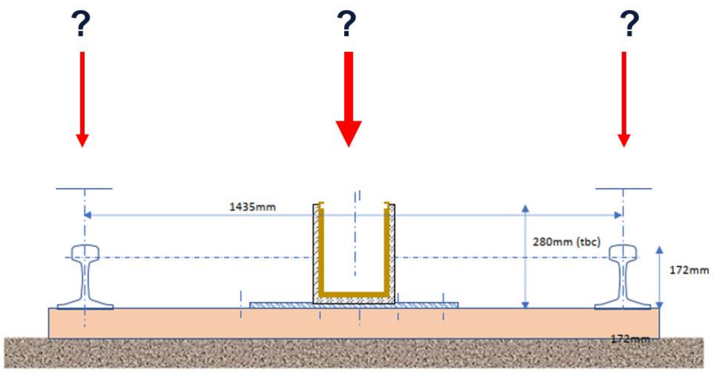

Figure 10 Unknown forces distribution on the MDS vehicles on railway track

Other important topic from system performance point of view is the maximum allowable acceleration and deceleration from the track resistance perspective. As stated in TSI 4.2.6.2.1:

"The track, including switches and crossings, shall be designed to withstand longitudinal forces equivalent to the force arising from braking of 2,5 m/s2 for the performance parameters chosen in accordance with point 4.2.1"

It is known that direct drives allow for significantly higher and repeatable accelerations and decelerations, higher values for sake of line capacity are worth investigating.

8.1.1.5. Interoperability constituents – Rail fastening systems (TSI INF 5.3.2) and track sleepers (TSI INF 5.3.3)

If the loads calculated according to guidelines in TSI INF 4.2.6differ from the state of the art, the standard rail fastenings and sleepers applicability shall be verified and proven. Moreover, additional forces resulting from electromagnetic interaction between linear motor and levitation system on steel rail fastening shall be investigated (vehicle dynamics, EMC, additional eddy currents).

8.2. New standardization needs

The main new standards need is related to the absence of existing European railway standards concerning EMC, gauging and switches. More generally, all technical requirements related to linear motor and levitation should be specified in a normalized way for allowing interoperability testing. From an architectural point of view, the level of interoperability expected from the various specific MDS components with regard to the global functioning of the railway system is a critical question.

It is important to recall that three different MDS systems are considered. As a consequence, interoperability should be studied at the component level considering potential other kind of MDS and with classical railway components. A similar problematic stand at sub-system level, and then at the system operation levels. Performing technical choices will decrease the complexity of analyses to be performed, but clearly new regulatory documents are needed.

9. Analysis of standards related to energy

9.1. Analysis of TSI

The ENE TSI is a European standard designed to ensure the interoperability, safety, and efficiency of the rail system's energy subsystems across the EU. It's made up of a broader set of TSIs created by the European Union Agency for Railways to facilitate a seamless and efficient European rail network.

This specification covers different aspects of the rail energy system, including infrastructure requirements for overhead contact lines, substations, and other electrical supply components. It also outlines requirements for rolling stock to ensure compatibility with the energy infrastructure, addressing aspects such as pantograph design and onboard energy management systems. Operational requirements are provided to guide the proper functioning of the energy subsystem, including procedures for connecting and disconnecting from the power supply, energy metering, and protection requirements. Additionally, the ENE TSI sets environmental and performance standards to promote sustainability and high performance within the rail network.

The implementation of the ENE TSI involves certification and authorization processes for rail operators and manufacturers, who must demonstrate compliance through rigorous testing and validation. Member States are responsible for integrating these requirements into their national regulations and ensuring that both existing and new infrastructure adhere to the standards.

The ENE TSI offers numerous benefits, including enhanced rail network efficiency through seamless interoperability, reduced costs due to harmonized standards, improved safety and reliability from uniform safety standards, and environmental benefits from energy efficiency and the integration of renewable energy sources. Overall, the ENE TSI is vital in achieving a unified, efficient, and sustainable European rail network.

9.1.1. Impact of MDS on TSI energy

Two main issues can be addressed in the ENE TSI analysis:

- *Issue 1* – MDS technologies introduce new components (linear motors in particular) on the railway infrastructure, which could be included as subsystems within the ENE TSI. These components would, in practice, feed energy to trains, and their inclusion would necessitate an update of the ENE TSI.
- *Issue 2* – The introduction of MDS technologies has the potential to impact basic parameters that characterize the energy subsystem. This includes alterations in

electrical, mechanical, and dynamical properties, which must be carefully evaluated and adjusted within the ENE TSI to maintain system performance and safety.

9.1.1.1. Issue 1: necessity to add sections to include new MDS components directly related to the energy subsystem

The ENE TSI specifies all the requirements for all fixed installations necessary to achieve interoperability that are required to supply traction energy to a train.
The linear motor used for the Hybrid Maglev and the conventional railway upgraded may use a short linear induction motor (LIM) integrated into the vehicle and a long synchronous linear motor (LSM) fixed on the track, which could be considered as fixed installation required to supply traction energy to a train. In this case the ENE TSI is impacted and would need to include requirements and regulation for the new components placed on the infrastructure.

For the Hybrid Maglev and for the upgraded conventional railway, the ENE TSI would need to be modified to include specifications that allow the introduction of the linear motor on the infrastructure as an energy provider for the system. Specifically, it is necessary to add proper definitions, electrical requirements, and safety provisions.

9.1.1.2. Issue 2: possible modification to the basic parameters characterising the energy subsystem

The ENE TSI specifies all the electrical, mechanical, and dynamical requirements of the energy subsystem.

The implementation of the linear motor on the infrastructure for hybrid maglev and the upgraded conventional railway requires a proper analysis of the parameters described in the ENE TSI §4.2.2. For both airlev and maglev, the electrical, mechanical, and dynamical values could be impacted by the introduction of the new technologies and components related to suspension and guidance.

Due to the application of the three possible solutions, the electrical, mechanical, and dynamical values need to be re-evaluated to account for levitation (Hybrid irlev and aglev) and the implementation of the linear motor (hybrid maglev and upgraded conventional railway). Specific adjustments would include revising the definitions and performance metrics in the TSI to ensure they accurately reflect the capabilities and requirements of the new technologies.

10. Analysis of standards related to vehicle

In the context of ensuring compliance for MDS vehicles with TSI, a thorough analysis was conducted considering both the TSI LOC&PAS (1302/2014) and TSI WAG (321/2013). However, as defined in TSI WAG 2.1: "This TSI is applicable to 'freight wagons including vehicles designed to carry lorries' as referred to in Annex I Section 2 to Directive (EU) 2016/797", it was determined that no MDS vehicles fall under this category. Consequently, the provisions of TSI WAG were not considered in subsequent research. Moreover, it is important to note that the analysis was performed only for normal gauge (1435mm). Paragraphs related to other gauges (1520mm and 1668mm) were omitted by purpose.

10.1. Analysis of TSI

The aim of the Technical Specifications for Interoperability (TSI) for Locomotives and Passenger Rolling Stock (LOC&PAS) is to ensure the interoperability of the EU rail system while maintaining a high level of safety, reliability, and efficiency. This includes standardizing the essential requirements related to safety, health, environmental protection, accessibility and technical compatibility of the rolling stock across the European Union.

The analysis based in the consolidated version from 28/09/2023 of the TSI LOC&PAS (EU 1302/2014) showed several TSI paragraphs that need to be taken into account or modified during MDS development:

- Track interaction and gauging (TSI LOC&PAS 4.2.3)
- Environmental conditions and aerodynamic effects (TSI LOC&PAS 4.2.6)
- Traction and electrical equipment (TSI LOC&PAS 4.2.8)
- Functional and technical specification of the interfaces (TSI LOC&PAS 4.3)
- Interoperability constituent specification – Main circuit breaker (TSI LOC&PAS 5.3.12)

10.1.1.1. Track interaction and gauging

The corresponding section addresses the calculation and verification rules linked in particular to the risks of interference. Focusing on pantographs, mechanical kinematic gauge calculation shall be justified by calculations or measurements as set out in the specified in the annex of the current TSI. Considering the goal of the TSI, not only technical compatibility, but also health and environmental protection should be targeted.

Use of linear motor impacts magnetics fields creating potential interferences. Considering pantographs, the existing values should be proved to be still coherent with MDS technologies. From a general point of view, the system safety analysis should be reconsidered, with regards to the new technologies. Levitating MDS will own specific range of values in the case of running dynamic behaviour test reports. Instability detection is probably specific to levitating MDS too.

More generally, active systems based on programmable controller or software should be evaluated in case of functional failure scenarios to prevent potential fatalities. This is related to the limit values that can be specific to MDS systems. All requirements related to wheels should be reconsidered with regards to the specific use in case of MDS technologies. Clearly, when MDS are using wheels, the technical context is not the same.

Depending on the result of the compatibility studies, table values could be updated but more efficiently new raw corresponding to new MDS categories may be introduced (containing specific values). It is too early to decide if new specific technical subsets describing new validation procedure and specifying new test infrastructures are needed.

10.1.1.2. Environmental conditions and aerodynamic effects

Environmental conditions are physical, chemical or biological conditions external to a product and to which it is subjected to. This section of the TSI specify the way they are managed for keeping a safe operational context.

The corresponding section identifies environmental conditions to which rolling stock is subjected to influence the design of rolling stock, as well as this of its constituents. Relevant parameters are defined, and corresponding ranges are proposed with appropriates corresponding requirements.

At the level of components, let us take the temperature as an example:" The temperature to consider for design purpose of rolling stock constituents shall take into account their integration in the rolling stock". For MDS systems, the design of specific components has to be considered. The influence of parameters is specific to the considered technologies.

Considering rolling stocks, they shall meet the requirements of this TSI when subject to snow, ice and hail conditions. Water ice and snow has an evident impact on the braking distance and more generally on the efficiency of friction forces providing the traction function. As a consequence, appendix values should be checked for update, and new rows and columns may be introduced in the corresponding tables.

Talking about aerodynamic effects, levitating MDS will be affected by the combined effect of train speed and air speed causes in a specific manner. It seems that further investigations are needed in order to be able to define a validation framework.

Appendix values should be checked for update, and new rows and columns may be introduced in the corresponding tables. Considering new technological appliance, new validation frameworks described in new subsets documents may be necessary. Further studies are needed before clamming that a specific validation framework, including new regulatory documents is mandatory.

10.1.1.3. Traction and electrical equipment

The traction function should allow trains operation up to the level of their maximal allowed speed.

The traction function provided by linear motors is not using the same physical law as classical rolling stocks that use friction forces. The global objectives presented in the TSI remains unchanged, but new underlying technical documents should be provided.

The global objectives presented in the TSI remains unchanged. However classical computation methods for braking curve will not apply in the case of MDS.

Moreover, the impact of the acceleration on the passenger comfort may be affected by the levitating technologies that may lead to higher maximal commercial speed. If this last characteristic seems to be interesting, it still has to be demonstrated from a technological point of view.

10.1.1.4. Interoperability constituent specification – Main circuit breaker

The main circuit breaker to interrupt current during fault conditions or overload situations preventing extensive damage.

Depending on the type of levitating MDS, current shortage may lead to a particularly dangerous MDS specific hazard called "collision with the infrastructure". A specific design ensuing from different high-level requirement seems to be necessary.

It seems too early to provide a clear answer to the question. However, further studies are needed on this subject.

10.1.1.5. Functional and technical specification of the interfaces

The current section of the TSI provides an inventory of functional interfaces of rolling stocks with other subsystems. Technical argumentation is more relevant in the section devoted to ENE TSI, but it the content of table 6 is affected by the introduction of MDS technologies. A similar situation occurs with interface with infrastructure where content of table 7 may be modified.

Once again, interface with subsystems is obviously impacted. Braking performance is an evident example, but train composition should be considered too (table 8 of the TSI locomotive and Passengers).

Table 9 dealing with interface with CCS is a subject too. Many technical explanations may be found in the section dedicated to the TSI CCS study.

10.2. New standardization needs

For MDS technologies, some new components are introduced as additional functionalities make part of the systems operations (e.g. linear motors, levitation components)

Interoperability should be studied at the component level considering potential other kind of MDS and with classical railway. A similar problematic stand at the level of sub-system, and then at the system and operations level. Performing technical choices will decrease the complexity of analyses to be performed, but clearly new regulatory documents are needed.

11. Analysis of standards related to signalling

11.1. Analysis of TSI

There are two TSIs relating to signalling aspects. First, Commission Implementing Regulation (EU) 2023/1695 of 10 August 2023 on the technical specification for interoperability relating to the control-command and signalling subsystems of the rail system in the European Union and repealing Regulation (EU) 2016/919. Secondly, Commission Implementing Regulation (EU) 2019/773 of 16 May 2019 on the technical specification for interoperability relating to the operation and traffic management subsystem of the rail system within the European Union and repealing Decision 2012/757/EU

11.1.1. Control-command and signalling subsystems TSI

The Control-command and signalling TSI 2023/1695 shall apply to new trackside CCS and on-board CCS subsystems of the rail system as defined in points 2.3 (Trackside control-command and signalling) and 2.4 (On-board control-command and signalling) of Annex II to Directive (EU) 2016/797, covering all the trackside equipment and all the on-board equipment required to ensure safety and to command and control movements of trains authorised to travel on the network.

11.1.2. Operation and traffic management subsystem TSI

The Operation and traffic management subsystem TSI 2019/773 lays down the technical specification for interoperability (TSI) relating to the operation and traffic management subsystem of Union rail system. This TSI set out in the Annex shall apply to the operation and traffic management subsystem set out in point 2.5 (Operation and traffic management) of Annex II to Directive (EU) 2016/797, covering the procedures and related equipment permitting coherent operation of the various structural subsystems, during both normal and degraded operation, including in particular train composition and train driving, traffic planning and management, and also the professional qualifications which may be required for carrying out any type of railway service.

11.1.3. Impact of MDS on Control-command and signalling subsystems TSI

Three main issues can be addressed in the CCS and signalling TSI analysis:

- Issue 1 – *Use of balise BTM-BALISE*
- Issue 2 – *On-board Train Interface*
- Issue 3 – *Train Detection System*

Related to Control-command and signalling subsystems TSI, point 7.2.2 of Annex I (Changes to an existing On-Board subsystem) to this Regulation (2023/1695) shall apply to any modification of an existing on-board CCS subsystem.

The TSI shall apply to existing trackside and on-board CCS subsystems that have one of the following characteristics:

(a) the subsystem is subject to renewal or upgrading in accordance with Chapter 7 of Annex I to this Regulation;
(b) the area of use of a vehicle is extended in accordance with Article 54(3) of Directive (EU) 2016/797, in which case point 7.4.2.3 of the Annex I to this Regulation shall apply, unless no installation of ETCS is indicated in RINF for the subsequent five years in the new area of use and the area of use is limited to two Member States;
(c) the subsystem is subject to the specification maintenance requirements set out in point 7.2.10 of Annex I to this Regulation.

11.1.3.1. Technical Compatibility

- There shall be electromagnetic compatibility between rolling stock and trackside control-command and signalling equipment.
- Equipment shall not interfere or be interfered with by other control-command and signalling equipment or other subsystems.

11.1.3.2. Functional and technical specifications of the Subsystems

Specific considerations for MDS must be taken into account in the following aspects:

- Control-Command and Signalling reliability, availability and safety characteristics relevant to interoperability,
- On-Board ETCS functionality,
- RMR, ETCS and ATO air gap interfaces,
- Trackside Train Detection Systems,
- Electromagnetic Compatibility between Rolling Stock and Control-Command and Signalling trackside equipment,
- ETCS DMI (Driver-Machine Interface),
- RMR DMI (Driver-Machine Interface),
- Construction of equipment used in CCS subsystems,
- ETCS and Radio System Compatibility,
- Technical documentation for Maintenance.

Calculation/supervision of dynamic speed based on train characteristics (for MDS) and trackside information shall be considered, as well as environmental conditions shall be taken into account and requirements for materials referred to in Commission Regulation (EU) shall be respected.

Interface requirements for electromagnetic compatibility between rolling stock and trackside control-command and signalling train detection equipment shall be considered. There shall be electromagnetic compatibility between rolling stock and trackside control-command and signalling equipment.

Information provided to the driver by ETCS and ATO and entered into the on-board one by the driver himself shall be considered, taking into account specificities for MDS. The same goes for the information provided by RMR to the driver, which have to be entered by the driver into the on-board RMR, taking into account specificities for MDS.

Technical compatibility between on-board and trackside CCS subsystems shall be considered, taking into account specificities for MDS.

Technical documentation for maintenance shall be fulfilled by the manufacturers of equipment and the applicant for subsystem verification.

Trackside train detection systems and rolling stock related to vehicle design and operation shall be considered, taking into account specificities for MDS.

Train Detection System (TDS) may or may not exist both depending on the ETCS level adopted and any backup actions chosen by the Infrastructure Manager. If the signalling system provided on the specific line uses TDS, then it is necessary to evaluate the coexistence of the MDS vehicles with the TDS systems adopted. It must be ensured that the present TDS system is able to safely recognize the presence of the MDS vehicle, otherwise there will be serious impacts on the safety of the line.

There are two main families of TDS adopted: track circuits and axle counters. Both systems can in principle have non-detections and/or false detections in the presence of MDS vehicles operating in their full functionality and may not be operational when the system is levitating. This fact certainly has an impact on the extact determination of the presence of the rolling stock on the rail. This means that levitation cannot be implemented if this type of TDS the only one present on the line travelled.

In the particular case of the balises, it is necessary to verify that the new vehicle does not introduce spurious frequencies around the 27 MHz frequency for the balise energization functions and around the 4.2 MHz frequency for the data transfer functions, as indicated in the UNISIG 036 subset contained in the TSI. Moreover, the UNISIG 085 subset reports the types of tests that must be carried out to guarantee operation. Subset 036 and consequently sunset 085 include the verification of potential cross talk aspects between adjacent binaries.

All these types of tests for interoperability verification should be included in the activities carried out for MDS vehicles. If the signalling is ETCS for each type of line on which the MDS vehicle runs in all its operating conditions, it means that the tests must be performed to cover all cases of vehicle operation. If the vehicle is perfectly compliant with the use of Eurobalises, then there are no additional requirements to take into account. If this is not the case, i.e. the MDS vehicle is not able to read the Eurobalises or introduces disturbances that could cause malfunctions on nearby trains, it may cause side effects on other trains. Therefore, the MDS vehicle must comply with the Eurobalises.

If there is not a correct coupling between the wheels and the tracks, the systems currently in use could fail to recognize the vehicle; further investigations must be made in this direction to guarantee interoperability between the TDS systems used and the MDS vehicles. It is also necessary to carry out cross tests between the different technologies adopted to develop the MDS vehicles and the TDS systems in use.

This series of checks is essential to allow the circulation of MDS vehicles in operational service on the lines also travelled by traditional vehicles.

A possible mitigation at the adoption of TDS is the use of localization systems that implement the safe localization of the train using other sensors, like for example on-board sensors that detects digitally encoded location flags on the guideway. The Train Localization is addressed in the following paragraph. This type of approach, however, requires that there is a signalling system that safely identifies the presence of the train without the use of TDS. In this case we are talking about ETCS moving blocks without TDS.

One area of intervention that, especially in the past, has produced secondary effects on on-board systems is the introduction and interconnection of the on-board signalling system. For the ETCS world, this type of system includes the OBU (On-Board Unit) for train protection functions and ATO (Automatic Train Operation) for automation functions. Both systems interface with the vehicle and can be affected by side effects produced by the vehicle, or even produce unexpected effects. In accordance with railway regulations, it is necessary to carry out all checks of the operating conditions and therefore of the applicable standards referred to in EN 50155. This involves a series of checks of the site where the systems are hosted and of the use of the MDS vehicle in all possible ways operational so that the checks are exhaustive.

The new electronic systems used for on-board equipment are developed according to European regulations, these are designed to be unaffected by a wide band of disturbances. In the railway sector, the disturbance mask was designed for the technologies adopted up to that point. With the introduction of the new MDS systems it is necessary to check whether the masks are still valid. If it is found that the MDS vehicles introduce signals of an amplitude not permitted in the masks currently in force, it is necessary to evaluate how to mitigate this fact.

Therefore, as mentioned for the radio communication part, it is necessary to have a clear image of the signals emitted by the MDS vehicles to evaluate any areas of intervention. Carrying out these investigations is however a step required by regulations, therefore a nominal path for vehicle certification. For now, no additional operations have been highlighted, but only exploratory ones.

11.1.3.3. Functional and technical specifications of the interfaces to other Subsystems

Specific considerations for MDS must be takenc into account in the following aspects:

- Interface to the Operation and Traffic Management Subsystem, considering specificities for the MDS,
- Interface to the Rolling Stock Subsystem. Rolling stock characteristics must be considered to be compatible with train detection systems. Adaptation of this point is needed for new alternative train detection systems necessary when train is levitating,
- Interfaces to Infrastructure Subsystem. Loading gauge (for installation of objects) must be considered.

11.1.3.4. Maintenance rules and Professional competences

Maintenance rules must be considered for the new MDS.

The manufacturers shall provide information sufficient to define the professional competences required for the installation, final inspection and maintenance. Manufacturers shall also indicate the risks for health and safety that arise from using and maintaining their equipment and subsystems.

11.1.3.5. Assessing the conformity and/or suitability for use of the constituents and verifying the subsystems

Specific considerations for MDS must be taken into account in the following aspects:

- Constituents' performance and specifications,
- Principles for testing ETCS, ATO and RMR,
- Modules for Control-Command and Signalling Interoperability Constituents,
- Assessment procedures for Control-Command and Signalling Subsystems,
- Modules for Control-Command and Signalling Subsystems,
- Assessment requirements for an On-board Subsystem,
- Assessment requirements for a Trackside Subsystem,
- Assessment requirements.

Interfaces with ETCS and CCS applications to be considered. ETCS On-board, Odometry, STM Standardised Interface, Eurobalise track Circuits and Axle Counter are considered in ERTMS L2, but new alternative systems shall be considered when the train is levitated. Rules for the design and installation of control-command and signalling onboard and trackside subsystems and test specifications shall be defined.

The manufacturer of the equipment shall inform a notified body of all changes affecting the conformity of the interoperability constituent due to the requirements of the applicable TSI release. Particular attention shall be paid to the assessment of conformity of the on-board ETCS interoperability constituent.

11.1.3.6. Implementing the TSI Control-Command and Signalling

Specific considerations for MDS must be taken into account in the following aspects:

- Upgrading or renewing the Control-Command Subsystems or parts of them,
- Changes to an existing On-Board subsystem,
- Upgrade or renewal of existing trackside subsystem,
- EC type or design examination certificates,
- Legacy systems,
- Conditions for mandatory and optional functions,
- ETCS and radio system compatibility checks implementation rules,
- Train detection systems specific implementation rules.

CCS On-board / Track-side subsystem, EC type-examination or design examination shall be defined. ETCS, ATO and GSM-R and/or FRMCS shall be implemented according to the implementation requirements, taking into account the specificities for MDS.

Existing vehicles and their corresponding vehicle type equipped with ETCS and RMR shall be considered compatible. Modification of the vehicle, its corresponding vehicle type or the infrastructure in terms of technical or line compatibility shall be managed according to the requirements specified for the compatibility of the ETCS and the radio system.

Requirements for the interface with rolling stock shall only be applied to ensure compatibility between TSI's compliant rolling stock and the trackside control-command and signalling system.

11.1.4. Impact of MDS on Operation and traffic management subsystem TSI

Regarding Operation and traffic management subsystem TSI, there are several issues that must be considered in different chapters related to different aspects.

11.1.4.1. *Specifications relating to staff*

- Training, fitness and certification requirements for train drivers for the new MDS,
- Their staff executing safety-critical tasks shall be trained, and train drivers certified, based on the information provided in the Rule Book and the Route Book in accordance with their SMS,
- The RU and the IM shall be responsible for the compilation of their respective Rule Book as integral part of their SMS to instruct staff executing safety-critical tasks, on operational rules applicable to their role for the new MDSs,
- The IM shall establish the infrastructure information covering its network for its own use and for the use of the RUs operating on this network considering the new MDS,
- The infrastructure manager shall inform and instruct drivers in real time about last minute changes to operations regarding the line or relevant lineside equipment.

11.1.4.2. *Specifications relating to trains*

- The Railway Undertaking is responsible for ensuring that all vehicles composing its train are compatible with the intended route(s). The Infrastructure Manager shall provide the information for route compatibility considering the new MDS,
- The RU shall set up and implement braking requirements and shall manage them within its safety management system,
- All vehicles in a train shall be connected to the continuous automatic braking system as defined in the LOC&PAS and WAG TSIs. The first and last vehicles (including any traction units) in any train shall have the automatic brake operative. In the case of a train becoming accidentally divided into two parts, both sets of detached vehicles shall come automatically to a stand as a result of a maximum application of the brake.

11.1.4.3. *Specifications relating to train operations, including ERTMS based operation.*

- Moving block systems should be considered,
- The infrastructure manager shall record the failure of lineside specific equipment associated to MDS,
- The railway undertaking shall record detection by on-board alarm systems related to MDS,
- Characteristics of the MDS must be considered in the contingency arrangements.

11.1.4.4. *Functional and technical specifications of the interfaces*

Specific considerations for MDS in the following aspects:

- Interfaces with the infrastructure TSI (INF TSI),
- Interfaces with the control-command and signalling TSI (CCS TSI),
- Interfaces with the locomotives and passenger rolling stock TSI (LOC&PAS TSI),

- Interfaces with the freight wagons TSI (WAG TSI),
- Interfaces with the Energy TSI (ENE TSI),
- Interfaces with the Safety in Railway Tunnels TSI (SRT TSI),
- Interfaces with the Noise TSI (NOI TSI).

11.1.4.5. Professional competence

- Staff of the railway undertaking and of the infrastructure manager shall have attained appropriate professional competence to undertake all necessary safety-critical tasks in normal, degraded and emergency situations. Specific considerations are needed for MDS.

11.1.4.6. Appendix A to J

Specific considerations for MDS for levitating trains shall be investigated in the following annexes:

- Appendix A ERTMS operational principles and rules – version 6 A130:A144,
- Appendix B Fundamental operational principles and common operational rules,
- Appendix C Safety related communications methodology,
- Appendix D1 Parameters for the vehicle and train compatibility over the route intended for operation,
- Appendix D2 Elements the infrastructure manager has to provide to the railway undertaking for the Route Book,
- Appendix D3 ERTMS trackside engineering information relevant to operation that the infrastructure manager shall provide to the railway undertaking,
- Appendix F Elements relevant to professional qualification for the tasks associated with 'accompanying trains',
- Appendix G Elements relevant to professional qualification for the task of preparing trains,
- Appendix I List of areas for which national rules may continue to apply according to Article 8 of Directive (EU) 2016/798,
- Appendix J Glossary.

11.1.5. Analysis of other standards related to signalling.

What has been reported in the previous sections covers all the elements related to signalling by adopting ERTMS/ETCS systems. If compatibility with a type B national system is also required, then an in-depth analysis of the specific standard must be carried out. Class B systems are usually more sensitive to interference and often use train recognition systems along the line which could be disturbed by the signals produced by MDS vehicles.

11.2. New standardization needs

The evolution of signalling leads to the introduction of new principles which tend to reduce CAPEX and OPEX costs. So, in the future there will be a drastic simplification in the configuration of the lines with a reduction in the systems installed, especially along the line.

This approach is favourable to the introduction of MDS vehicles along the lines because Train Detection Systems will not be present. One part that still remains valid is the presence of the Eurobalises. This could be a sore point in defining standards that satisfy all the technologies of the vehicles in circulation.

Until now the compatibility of Eurobalise has been studied for conventional trains. What could be decided is that which allows mixed circulation, i.e. conventional trains equipped with Eurobalise (BTM) readers while MDS vehicles equipped with a Virtual Balises virtual reader.

Since the MDS vehicle identification along the line is more precise because it is based on the interaction of the linear motors that are installed along the tracks, this, together with other odometric sensors and GNSS receivers,would allow for a very accurate localization system, allowing the virtual balises to be positioned in correspondence with the physical ones.

This type of approach, however, has a strong impact on future TSIs as it is necessary to specify in detail the interactions and technical solutions and the changes also on the RBC side for mixed management (with Eurobalise and Virtual Balise).

12. Analysis of standards related to communication

12.1. Objective of TSI communication

This TSI concerns the telematics applications subsystem and applies to applications for passenger services, including systems providing passengers with information before and during the journey, reservation and payment systems, luggage management and management of connections between trains and with other modes of transport. The TSI aims at ensuring that the interconnection of information and communication systems of different infrastructure managers and railway undertakings is efficient. The provision of up-to-date information and for ticketing services for passengers is considered.

From a pragmatic point of view, for both passengers and freight train, two distinct TSIs provide information needed for the management of travels by railway undertaker. It includes the reservation of part of the railway infrastructure for a given range of time.

Specific formats in reference files are used to check the compatibility between rolling stocks and potential infrastructure they want to use, before assigning a time window of the considered track for a given travel using the considered rolling stocks. The compatibility of the rolling stocks with the infrastructure characteristics is performed. The protocol describing useful message exchanges for managing the assignment of a time slot of a given section of the infrastructure is presented in TSIs.

12.1.1. Impact of MDS on TSI TAP and TAF

Three different issues can be considered.

- *Issue 1 – MDS technologies introduce new homogeneity constraints between rolling stocks and track. It should be possible, from the available information, to identify safely the technologies that are used,*
- *Issue 2 – the maintenance activities are impacted by the nature of the applied technologies: relevant information should be available,*
- *Issue 3 – while computing the compatibility test between rolling stocks and rail sections, an error may lead to critical scenario. Sending an electricity powered train on a non-electrified line will not destroy anything or injury anybody. Things may be completely different when sending a MDS train in an infrastructure where its levitation function will not operate anymore. It seems that the criticality level of the compatibility checking function as increased.*

12.1.1.1. Issue 1 - Compatibility checking between the rolling stock and part of the infrastructure

Various message exchanges for the management of a route reservation, which should be compatible with the type of rolling stocks (electrification or not, various kind of electrifications, etc.).

There are many potential MDS technologies introducing various kind of levitation technologies and/or various kind of linear motors. All these technologies are not compatible between each other.

For example: A linear motor may use a passive magnet on the rolling stocks and an electric field generated by a coil put on the track. Other solutions put the passive magnet on the track, and the active component on the rolling stocks. It is evidence that the linear motor cannot run with a passive component on the track and o the rolling stock. Moreover, the levitation force should achieve a given value, in order to be able handle a given weight of a rolling stock. The couple (technical device for levitation on board, technical device for levitation on the track) should verify some technical properties.

These properties should be identified and then the characterization should be documented in order to be able to classify both the onboard MDS appliance and the trackside MDS Appliance. On the basis of the classification, a new structured file would be proposed for allowing checking efficiently route/rolling stock compatibility.

As a consequence, the TSI text does not really need to be changed, but the reference data structure of the file used for compatibility checking should be adapted. A systematic classification of the various MDS technology should be published, in order to allow a reliable and real time compatibility checking by the mean of an enriched taxonomy.

12.1.1.2. Issue 2 - The maintenance activities are impacted by the nature of the applied technologies

The TSI does not explicitly mention a link between the technologies on track the specific maintenance tasks.

The MDS technologies will have an impact on some maintenance tasks (like ballast regeneration). The potential presence of an active electrified component on the middle of the track will introduce the need of specific maintenance procedures and /or specifically adapted equipment. Consequently, there may be a need to adapt the TSI.

12.1.1.3. Issue 3 - The route allocation may become a safety case.

Non-compatibility between on board MDS appliance and on Track MDS appliance may lead to a collision of rolling stocks with infrastructure ensuing from failure of the levitation function. As a consequence, in the case where no complementary barrier or defence were found, the criticality of the informatic checking process increase.

This may impact the technical specification of the hardware and the software used to perform this task. Another impacted parameter will be the need of maintenance of the considered computers.

12.2. Analysis of other standards related to communication

In a first analysis, the classical technologies used by telematic applications are not affected by the introduction of MDS technologies.

12.3. New standardization needs

The standardization need is mostly related to the need of a reliable and efficient compatibility checking between rolling stocks and routes.

13. Conclusion

Following the global functional analysis of MDS (see D2.1 [15]) and the corresponding list of hazards with their associated mitigation strategies (see D3.1) a methodology aiming to identify the need of legislative evolution on the basis of high-level documents is presented.

From this section, 3 transversal TSIs (namely Noise, PRM and SRT) were identified. Then, 6 TSIs corresponding to the main entities of the functional break-out were provided too: TSI Energy, Infrastructure, Loc and Pass, Control and signalling, TAF and TAP.

Concerning the TSI SRT, MDS technologies introduce new elements whose impact should be investigated before saying whether the corresponding TSI should be modified or not.

Focusing on noise TSI, the new MDS will have to follow the same requirements which are well documented. Meeting these objectives may be more challenging in the particular case of airlev systems.

Globally with transversal TSIs, the introduction of hybrid MDS systems requires considering the following aspects:

- Standardization of technical solution at subsystem level. This point is covered in more detail in paragraphs related to each subsystem,
- Integration of new technologies among them and in the existing infrastructure.

This second point requires identifying in more detail the interfaces between:

- The new subsystems of hybrid MDS system,
- The new subsystems of hybrid MDS and the existing systems.

Considering the main elements of a railway system, one of the most challenging parts seems to be the infrastructure. Analysing the TSI INF, experts report possible modification needs for line layout (TSI INF 4.2.3), Track parameters (TSI INF 4.2.4), Switches and crossings (TSI INF 4.2.5), Track resistance to applied loads (TSI INF 4.2.6), Interoperability constituents – Rail fastening systems (TSI INF 5.3.2) and track sleepers (TSI INF 5.3.3).

If compliance cannot be achieved, modifications and exceptions in TSI LOC&PAS and or in the EN 15273-3 will be necessary too.

However, the main new standards' need is related to the absence of existing European railway standard concerning EMC, gauging and switches. More generally all technical requirements related to linear motor and levitation should be specified in a normalized way for allowing interoperability testing. From an architectural point of view, the level of interoperability expected from the various specific MDS components with regard to the global functioning of the railway system is a critical question.

Regarding ENE TSI, the implementation of the linear motor on the infrastructure for hybrid maglev and the upgraded conventional railway requires a proper analysis of the parameters described in the paragraph 4.2.2. For both airlev and maglev, the electrical, mechanical, and dynamical values could be impacted.

Due to the application of the three possible solutions (Hybrid airlev and maglev and upgraded rolling stocks running on wheels) Specific adjustments would include revising the definitions and performance metrics in the TSI to ensure they accurately reflect the capabilities and requirements of the new technologies.

- The TSI CCS analysis points to several challenging issues. Specific considerations for MDS must be taken into account in the following aspects: Control-Command and Signalling reliability, availability and safety characteristics relevant to interoperability,
- On-Board ETCS functionality,
- RMR, ETCS and ATO air gap interfaces,
- Trackside Train Detection Systems,
- Electromagnetic Compatibility between Rolling Stock and Control-Command and Signalling trackside equipment,
- ETCS DMI (Driver-Machine Interface),
- RMR DMI (Driver-Machine Interface),
- Construction of equipment used in CCS subsystems,
- ETCS and Radio System Compatibility,
- Technical documentation for Maintenance.

Specific considerations for MDS must be considered in the following aspects:

- Interface to the Operation and Traffic Management Subsystem, considering specificities for the MDS,
- Interface to the Rolling Stock Subsystem. Rolling stock characteristics must be considered to be compatible with train detection systems. Adaptation of this point is needed for new alternative train detection systems necessary when train is levitating,
- Interfaces to Infrastructure Subsystem. Loading gauge (for installation of objects) must be considered,
- Specific maintenance rules should be considered.

Conformity assessing will be a subject for new specification too.

Until now the compatibility of Eurobalise has been studied for conventional trains. What could be decided is that conventional trains are equipped with Eurobalise (BTM) readers while MDS vehicles equipped with a Virtual Balises virtual reader. In this case changes at the RBC are necessary.

Concerning TSI TAP and TAF, the core documents are not directly impacted, but there is a clear need of new requirements for reliable and efficient compatibility checking between rolling stocks and routes. Several TSI topic need to be studied or modified during MDS development, like Track interaction and gauging, Environmental conditions and aerodynamic effects, Traction and electrical equipment, Functional and technical specification of the interfaces and Interoperability constituent specification.

Some of the needed upgrades are not challenging, like the ones related top TSITAP and TAF: some new engineering rules have to be created and introduced but there are no technological obstacles.

Concerning TSI Loc and Pas and infrastructure the job becomes more difficult as an accurate system analysis is needed regarding a system which until now not fully technically specified.

The ultimate task is related to TSI CCS, because some innovative solution has to be implemented in order to preserve the functional interoperability with the existing system. On this particular topic the needed contribution seems to be mainly technological. When the efficiency of the industrial solution will be demonstrated, the remaining regulatory works will not be so hard to perform with regard to the previous step.

14. References

Technical Specifications for Interoperability

Directives

[1] Directive (EU) 2016/797 of the European Parliament and of the Council of 11 May 2016 on the interoperability of the rail system within the European Union (interoperability directive)

[2] Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 DIRECTIVE (EU) 2016/798 on railway safety

General TSI

[3] Commission Regulation (EU) No 1303/2014 of 18 November 2014 concerning the technical specification for interoperability relating to safety in railway tunnels of the rail system of the European Union

[4] Commission Regulation (EU) No 1300/2014 of 18 November 2014 on the technical specifications for interoperability relating to accessibility of the Union's rail system for persons with disabilities and persons with reduced mobility

[5] Commission Regulation (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem rolling stock — noise amending Decision 2008/232/EC and repealing Decision 2011/229/EU

Infrastructure

[6] Commission Regulation (EU) No 1299/2014 of 18 November 2014 on the technical specifications for interoperability relating to the infrastructure subsystem of the rail system in the European Union

Energy

[7] Commission Regulation (EU) No 1301/2014 of 18 November 2014 on the technical specifications for interoperability relating to the energy subsystem of the rail system in the Union

Vehicle

[8] Commission Regulation (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the rolling stock — locomotives and passenger rolling stock subsystem of the rail system in the European Union

[9] Commission Regulation (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem rolling stock — freight wagons of the rail system in the European Union and repealing Decision 2006/861/EC

Signaling

[10] Commission Implementing Regulation (EU) 2023/1695 of 10 August 2023 on the technical specification for interoperability relating to the control-command and

signalling subsystems of the rail system in the European Union and repealing Regulation (EU) 2016/919

[11] Commission Implementing Regulation (EU) 2019/773 of 16 May 2019 on the technical specification for interoperability relating to the operation and traffic management subsystem of the rail system within the European Union and repealing Decision 2012/757/EU

Communication

[12] Commission Regulation (EU) No 454/2011 of 5 May 2011 on the technical specification for interoperability relating to the subsystem telematics applications for passenger services of the trans-European rail system

[13] Commission Regulation (EU) No 1305/2014 of 11 December 2014 on the technical specification for interoperability relating to the telematics applications for freight subsystem of the rail system in the European Union and repealing the Regulation (EC) No 62/2006

Project references

[14] 2023-10-31_MaDe4Rail_D2.1_Nevomo_V1.0_PR

[15] 2023-12-20_MaDe4Rail_Deliverable 2.2_DITS_V2.0

[16] 2023-12-05_MaDe4Rail_D4.1_ITF_V1.0

[17] 2024-01-31_MaDe4Rail_D4.2_IFT_V1.0

[18] 2023-11-30_MaDe4Rail_D6.1_UPM_V1.0

[19] 2023-11-30_MaDe4Rail_D7.1_RFI_V1.0

15. Annex 1– TSI Analysis Tables and EN standards

Annex 1 is presented in an Excel file attached to this document.