Deliverable D 4.2

Project requirements and technical specifications for MDS bogies/vehicles

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1 Executive Summary

The objective of deliverable 4.2 is the definition of the system requirements of each specific configuration and the development of generic MDS pod technical specifications at vehicle level.

Initially, an understanding of the system's definition and the conditions under which it will operate has been described (Chapter 5). An assessment of hazards and corresponding risks associated with the system's use has been considered to ensure the feasibility and safety of the project. This approach aligns with the Common Safety Method for Risk Analysis (CSM RA), as indicated in EU regulation no. 402/2013.

The system's information and operational context are derived from two key documents: deliverables D6.1 and D7.1 of the MaDe4Rail project. Document D6.1 encompasses the technology components and various potential configurations, while D7.1 outlines the use cases. These details provide a comprehensive understanding of the system, further elaborated in Chapter 6 of the report.

Chapter 6 discusses the functional, economic, business, and operational requirements for each use case. Following this, the hazards identified in Deliverable D3.1 are illustrated, formulating specific system requirements to mitigate these identified risks.

Information from the earlier chapters is utilized in Chapter 7, which focuses on the technical details of the Maglev Derived System (MDS pod) vehicle. This information is crucial for the activities in work package 8 (WP8) and will assist in developing a prototype vehicle for one of the use cases discussed in deliverable D7.1, and technically analysed in detail in Deliverable D7.2.

2 Abbreviations and acronyms

Abbreviation / Acronym	Description
Airlev	Air levitation train
CPU	Central Processing Unit
dB	Decibel
DNSH	Do Not Significant Harm
EDW	Electrodynamic wheels
EMC	Electromagnetic Compatibility
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
FRMCS	Future Railway Mobile Communication System
GoA	Grade of Automation
GSM-R	Global System for Mobile Communications – Railway
IEC	International Electrotechnical Commission
IM	Infrastructure Manager
LIM	Linear Induction Motor
LPG	Liquefied Petroleum Gas
LSM	Linear Synchronous Motors
Maglev	Magnetic Levitation
MDS	Maglev-derived System
TSI	Technical Specification of Interoperability
UIC	International union of railways
U-LIM	Linear Induction Motor U shaped armature
WP	Work Package

3 Background

The present document constitutes the Deliverable D4.2 “Project requirements and technical specifications for MDS bogies/vehicles” in the framework 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 Objective/Aim

The objective of this document is to establish a comprehensive set of requirements and technical specifications for a MDS pod/vehicle. The primary goal of this document is to provide a detailed framework that guides the design, development, and implementation of an MDS vehicle and its interfaces with other subsystems, ensuring safety, efficiency, and reliability.

The document will define a set of MDS vehicle subsystem common requirements and specific use case system requirements, together with MDS vehicle Technical Specifications, to provide the basis of the prototype design for one chosen use case, which will be developed in WP8.

This activity will be possible by exploiting the results of the Work Packages 3, 6 and 7: from WP3, the risk analysis output will be fundamental to formulate specific system requirements to mitigate the identified risks; WP6 identifies the technology components and various potential configurations; and WP7 outlines the specific use cases.

Starting from the definition of the operational context for each use case, the 3 MDS configurations (Hybrid based on magnetic levitation, hybrid based on air levitation and conventional rail vehicle upgraded with MDS technologies) system requirements will be developed, considering the following aspects: operational, economic, safety, and business aspects.

Operational aspects:

- Define the operational parameters and performance criteria for maglev-derived systems. Set benchmarks for speed, acceleration, and deceleration to maximize efficiency. Establish guidelines for energy consumption and operational costs to ensure the economic viability of the system

Economic aspects

- Establish cost-effective design principles to minimize construction, maintenance, and operational expenses.
- Define criteria for assessing the economic viability of MDS projects, considering both initial investment and long-term operational costs.

Safety assurance

- Define safety standards and protocols to ensure the secure operation of MDS, addressing both passenger and operational safety.
- Establish emergency response procedures and fail-safe mechanisms to mitigate potential risks.

Cost – benefit considerations

- Evaluate the upfront costs of implementing MDS against the potential long-term benefits, including reduced travel times, increased capacity, and environmental advantages

In conclusion, this document aims to provide a comprehensive and cohesive framework for the development and implementation of MDS pods/vehicles, emphasizing safety, technical excellence, interoperability and cost-effectiveness. By achieving these objectives, MDS technology can emerge as a transformative force in modern transportation, offering efficient, sustainable, and economically viable solutions for the future.

5 System definitions and operational context

In this chapter three system configurations were analysed and defined, selected based on the results presented in deliverables D6.1 and D7.1. For each use case, the fundamental elements of the system were comprehensively described, including the vehicle's structure, propulsion, suspension and guidance systems, braking systems, and vehicle control and monitoring systems. These aspects served as the basis for defining vehicle requirements. Furthermore, the benefits of implementing each of these systems in comparison to existing Maglev systems were highlighted.

Additionally, this chapter provides specific examples of the applications of these systems. The specific conditions and routes where each proposed solution could find practical application were analysed. These examples help illustrate potential use scenarios, enhancing the understanding of practical implementation aspects and the utilization of these innovative system configurations in real conditions.

5.1 Hybrid MDS based on magnetic levitation

5.1.1 System definition

The interoperability of infrastructure is a key requirement: while classical Full Maglev systems like Transrapid and planned hyperloop routes will require purpose-designed infrastructure, hybrid MDS solutions will allow mixed operations: of conventional railway rolling stock as well as MDS pods/vehicles.

The system concerns the application of a hybrid MDS based on maglev on existing railway lines. In the case, the MDS pods/vehicles will utilise the existing infrastructure and will operate with conventional trains on the same lines. The propulsion, guidance and levitation will be assured by Maglev-derived technologies.

The basic MDS rolling stock unit will be a single pod (vehicle). Its size will be similar to a single wagon and should carry up to 70 passengers. It will also be possible to combine single pods into a “platoon” which is made out of two or more virtually coupled consists, which are not connected mechanically. Depending on the specific demand of capacity the pods can also be designed with physical couplings. The cabin crew in those pods, if present, is solely meant for passenger care.

The pods will consist of main components listed below:

- Structure
- Propulsion
- Suspension
- Guidance
- Braking system
- Vehicle control and monitoring system

The mechanical structure of the vehicle makes it possible to ensure the safe installation of the propulsion systems, suspension, stabilisation, and other necessary subsystems, as well as ensuring the safe transport of passengers with their luggage.

Different technologies can be used for the hybrid MDS based on maglev configuration, that will affect directly the vehicle requirements. For instance, the propulsion could be achieved through a Linear Synchronous Motor (LSM), orthrough a Linear Induction Motor U shaped armature (U-LIM), changing completely the specific technical characteristics of the MDS pod/vehicle.

For the configuration with a LSM, for instance, the vehicle part of propulsion system (called mover) is energetically passive and consists of a set of NdFeB permanent magnets arranged on a steel core. The vehicle begins to move when the electric power of precisely selected parameters is provided to the linear motor stator. Then the electromagnetic force starts to act on the mover and moves the pod. The linear motor must provide both the propulsion force, and the force required to brake the vehicle. The level of automation will be at least GoA 3.

The pods suspension and guidance are magnetic systems and require the use of permanent magnets or electromagnets arrangements onboard the vehicle The interaction between guideways (could be specific beams for maglev or existing rails, depending on the configuration) and levitation skids is required to generate the appropriate levitation and stabilisation forces. The MDS pod/vehicle will be able to also operate on wheels similarly to a conventional train. The wheels are the same as in railways but need specific auxiliary systems (e.g. additional suspension systems for disengagement) or finishes (e.g. specific wheel coverings with composite materials or rubber) that prevent wheel damage during engaging operations. The bogies are also similar to that known from traditional railway vehicles and have to secure the same functionalities, when pods are running without levitation or along not equipped lines. In those cases, running stability and all static and dynamic loads are handled by the wheel-rail contact and the components of the bogie. To reduce the weight of the pods the bogies are made of lightweight materials e.g. aluminium alloys or composites.

To ensure lateral confinement and centring, lateral stabilization systems are required, in addition to the magnetic levitation systems. The stabilization systems act on the levitation guideway. To make sure the compatibility to the existing conventional lines those elements are only active when the train is running on adapted infrastructure in levitation mode. Anywhere else those components are inactive.

Another crucial point of operating MDS vehicles on existing infrastructure will be the additionally needed cant to reach higher velocities and at the same time to secure the interoperability with traditional trains running on the same tracks. In chapter 4.2.4.2 the TSI 1299/2014 describes the maximum allowed cant which is set to a maximum of 160 mm (or 180 mm for tracks only used by passenger services). If higher cants are needed to reach higher speeds, MDS components can be installed in a way that only effects those vehicles in high speed levitation mode as it is shown in Figure 1. With such a solution, the built in cant stays the same for all vehicles operating on wheels, but vehicles in levitation mode can use the advantages of a higher cant. In any case the solution chosen depends on the specific operational (e.g. mix of trains using the tracks, reachable speeds) and technical (e.g. existing cant, curve radius, gauge) requirements.

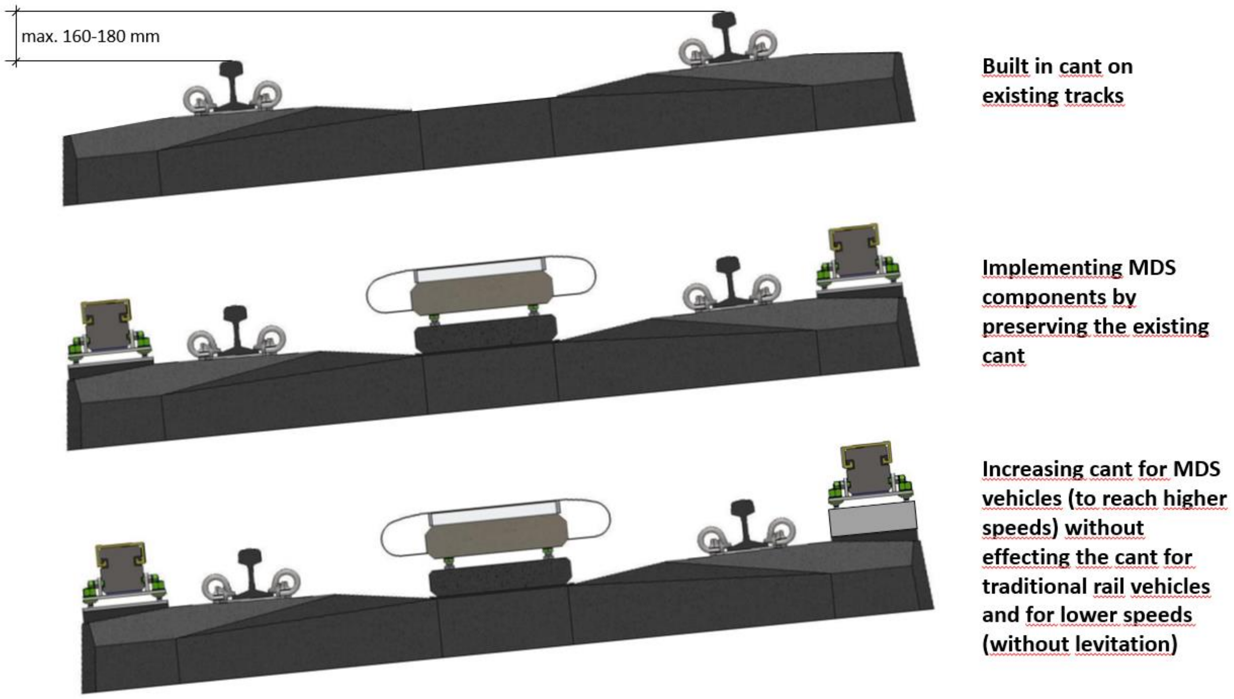

Figure 1 - Implementing additional cant for MDS pods/vehicles

The pods are equipped with an emergency brake to fully stop the vehicle in any place at any given time regardless of the function of the primary brake or propulsion system (in this case combined in one system). The system consists of infrastructure components and rolling stock components, covered by a signalling and vehicle control system layer.

		Vehicles		
		MDS pod/vehicles	MDS upgraded wagon	Conventional wagon
infrastructure	Hybrid MDS infrastructure	Pods will levitate or can run on wheels; Propulsion by linear motor	Wagons can run on wheels automated as single wagon or a group but also in a trainset; Propulsion by linear motor or in combination of linear motor and locomotive	Wagons can roll on wheels in a trainset; Propulsion by locomotive
	MDS upgraded infrastructure	Pods can run on wheels or levitate; Propulsion by linear motor	Wagons can run on wheels automated as single wagon or a group but also in a trainset; Propulsion by linear motor or in combination of linear motor and locomotive	Wagons can roll on wheels in a trainset; Propulsion by locomotive
	Conventional infrastructure	Pods can roll on wheels or levitate; Propulsion by external device (e.g. locomotive)	Wagons can roll on wheels in a trainset; Propulsion by locomotive	Wagons can roll on wheels in a trainset; Propulsion by locomotive

Table 1: Interoperability of different vehicle and infrastructure stages

The infrastructure needs to be adapted in an appropriate way dependent from the specific needs of the use case to bring the positive effects of the new system. Therefore, it is always preferred to modify the infrastructure instead of using infrastructure as is with lessened or no positive effects for the system. Consequently, the infrastructure consists of a conventional (existing) railway line and additional components: a linear motor (placed in between two conventional rails) and additional high-performance magnetic levitation that can be applied directly to existing rails, or through guideways deployed on both outer sides of the rails on Maglev corridors as shown in **Errore. L'origine riferimento non è stata trovata.**. The deployment of this MDS technology will be feasible on existing infrastructure and conventional rolling stock will be still able to operate on it. As a result, infrastructure equipped with such MDS components will be always interoperable with conventional vehicles as it is shown in Table 1 and must not create obstructions in conventional railway operations.

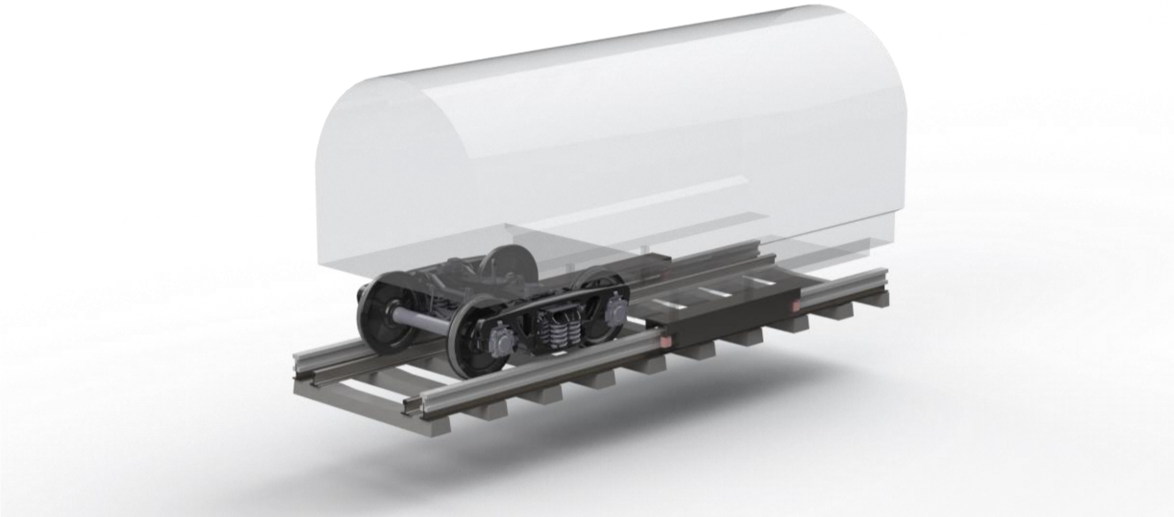

Figure 2 - Example of custom rails adopted in combination with traditional wheeled systems (source: IRONLEV)

Signalling and communication technology shall allow for mixed operation of conventional trains and MDS pods – joint traffic control compliant with conventional train control systems and new ETCS systems communicating with GSM-R and FRMCS in the future. As this is one important aspect to secure compatibility with the existing railways, further studies will need to be conducted to provide evidence of the requirements.

Vehicle Control and Monitoring System is a set of measurement and control devices located on each MDS Pod. The system serves as a central vehicle decision system, gathering data from subsystems, communicating with traffic management systems and controlling subsystems if needed. The Vehicle Control and Monitoring System incorporates as well the anticollision system and Juridical Recording Unit. The control centre is part of the infrastructure. CCS will not be used in the existing version and a new development is needed.

The vehicle movement is controlled using the linear motor. An electric power command and control system based on sections and segments of the linear motor stator allows precise vehicle position control on track with an accuracy of up to 5 cm and very fast acceleration and deceleration ensured by high efficiency of the propulsion system. This will allow shorter separation times useful for high-level traffic control and best capacity usage.

In exceptional cases like bigger disturbances or blocked lines, but also for bridging services using conventional railway lines non-equipped with Maglev technology, the rolling stock dedicated for the MDS operations could also operate outside a MDS line. For such movements the vehicle could still compatible and can roll on their wheels under specific conditions, e. g.:

- Different, lessened performance parameters (depending on the locomotive),
- Fitted to existing operational rules and design specifics which allow traffic under those rules (e.g. crash readiness, technical compliant with ETCS, ...),
- External traction from other vehicles, if MDS pod/vehicle might not have an own propulsion system onboard or in case of emergencies,
- other points specific to the conditions.

5.1.2Operational context

The use case of magnetic levitation on existing infrastructure is proposed on an historical regional line based on the implementation of a hybrid MDS pod/vehicle with magnetic levitation and propulsion. The definition of the use case reflects the IM's need to evaluate the performance of a hybrid MDS on secondary regional lines, as an alternative to constructing new HSR lines.

MDS on secondary lines will not allow to reach ultra-high speeds that could be expected on Hybrid MDS introduced on HSR lines. However, a hybrid MDS could bring as well potential benefits related to more flexible and automated operations with lower operational costs and safer services.

The entire route consists of six line-sections and four nodes with an entire length of ca. 580 km. Travel time with the regional trains on this line could take up to 8 hours from one end to the other. The line presents some sections on mountain terrain.

The planned timetable defined for the use case consists of three typologies of services. MDS pods, Regional trains and Intercity trains. Some trains will be entirely associated to the analysed route, while others will use the route only section wise,. In the planned future timetable, daily frequencies of all relations with all intermediate stops will be provided. The distribution of the frequencies over the operating hours of the day will not be fixed in the foreseen timetable and can be worked out in the following studies.

The main characteristics of a hybrid Maglev system are listed as follows:

Infrastructure & Operations

- TSI compliant Infrastructure and vehicles
- Interoperable infrastructure for MDS and conventional trains
- Operations on double-track lines or single-track lines with passings possible
- Track gauge– 1435mm
- Either conventional rail tracks or specifically dedicated tracks in special circumstances
- Adapted conventional rail switches with the ability to reduce the maximum velocity or dedicated switches for MDS pods/vehicles
- Grid connection to the medium voltage network for MDS substations
- Maximum Velocity of track – theoretically up to 220 km/h (depending on infrastructural situation)
- For mixed operation (MDS & conventional rail) specially customized rules are necessary for MDS pods/vehicles and conventional trains
- Dedicated slots for different systems can be a starting point for mixed operations
- Minimum curve radius: for speeds up to 40 km/h, a minimum radius of 200 m is used; for higher speeds, this should increase to 400 m. However, the Technical Specifications for Interoperability (TSI) for European corridors must be complied with (minimum radius is 150m).

Signalling & Communication

- The target traffic model assumes automatic operation of classic vehicles and MDS pods/vehicles

- Signalling and communication technology will allow for mixed operation of conventional trains and MDS pods/vehicles – joint traffic control
- Own signalling system developed with European producent, compatible with or part of former ETCS and ERTMS developments
- Communication via GSM-R and FRMCS in the future including satellites or other wireless solutions.

Vehicle

- Fully automated motion (also for maintenance operation) is possible
- Both for passengers and cargo (two variants) with clear focus on passengers
- Virtually coupled pods are possible, moreover all types of mechanical couplers are possible
- Acceleration from standstill to “minimum levitation speed” – conventional movement on wheels or on magnetic suspension systems using linear motor (without levitation)
- Acceleration from “minimum levitation speed” to “maximum speed” (dependent on track geometry) – magnetic suspension systems levitation, using linear motor
- Deceleration “maximum speed” to “minimum levitation speed” - magnetic suspension systems levitation, using a linear motor
- Deceleration “minimum levitation speed” to standstill - conventional movement on wheels or on magnetic suspension systems– using linear motor (without levitation)
- Emergency operations if MDS traction system is not available

Stations

- Fully compatible with conventional traffic. The existing stations infrastructure (areas for passengers) can be used for both MDS pods/vehicles and conventional trains as the requirements of at least a GoA 3 system are met
- All MDS components in the track segment are only active, when the train is above. Additionally, all devices which could cause danger by electrocution are covered and secured against environmental issues (e.g. flooding) or unauthorised contacts (e.g. passengers at stations)
- There are several scenarios of boarding and alighting passengers to MDS pods/vehicels. The final decision depends on an approved design of a MDS pod/vehicle car body.

5.2 Hybrid MDS based on air levitation

5.2.1System definition

Utilizing innovative technologies, the hybrid MDS pod/vehicle with air levitation enables a shift from traditional to advanced, future-ready railway vehicles operating in existing railway infrastructures. This system facilitates the integration of diverse rail types, including high-speed, conventional, light, and heavy rail, within a single network. The adoption of new, standard technology for guided transportation presents numerous benefits over traditional railway technologies. The key aim of this hybrid public transport framework is to boost both flexibility and efficiency in the transport network, particularly at points where different transportation modes come together. The interoperability between a hybrid MDS based on Airlev and traditional railway involves several key aspects: technological compatibility (e.g., track gauge, signalling system), safety and standards compliance, station and platform integration, scheduling, maintenance and operational training and traffic management.

Figure 3 - Demonstration of five types of Airlev vehicles

The hybrid transport system features a blend of air levitation and electrodynamic wheel (EDW) propulsion and braking. This system utilizes air bearing fenders and permanent magnet wheel propulsion to transport passengers and goods efficiently: this technology is different from “hovercraft” based technologies. It operates on an ultra-thin air layer, significantly reducing friction and wear compared to traditional wheel-based transport. This technology evenly distributes the vehicle's mass over a larger area, potentially allowing for lighter infrastructure. Additionally, propulsion and braking are achieved through non-contact means using rotating permanent magnets along aluminium strips on the track.

- Structure is described on the bogie design. The bogie is adaptable to both conventional railway slab/ballast tracks (comprising rails and sleepers) and new air levitation train designs (ballasted track with track slab inserted in between two rails) (Figure 3 and Figure 4). It includes a propulsion system with four electro-dynamic wheels, two on each side. Fenders serve for levitation and guidance, also enhancing safety. The track incorporates strips for stability fenders (guidance) and as stator, typically made of aluminium.
- The propulsion and braking in the hybrid system are achieved through rotating permanent magnetic wheels (electro-dynamic wheels) along aluminium strips on the tracks, creating a non-contact method for propulsion and braking. The generable traction force of EDW is 5.4 kN each wheel.
- The suspension and guidance are achieved through air bearing fenders. A support surface (track slab in ballastless track or inserted slab upon ballast) is required for the fenders. An inner pressure chamber is situated in or on the support surface. The fender features are: a flexible first rim surrounding the inner pressure chamber; a second rim encircling the first, forming a pressure chamber between adjacent rims. Through calculation, the load-bearing capacity of fenders with a diameter of 600 mm is in order of 36,400 kg.

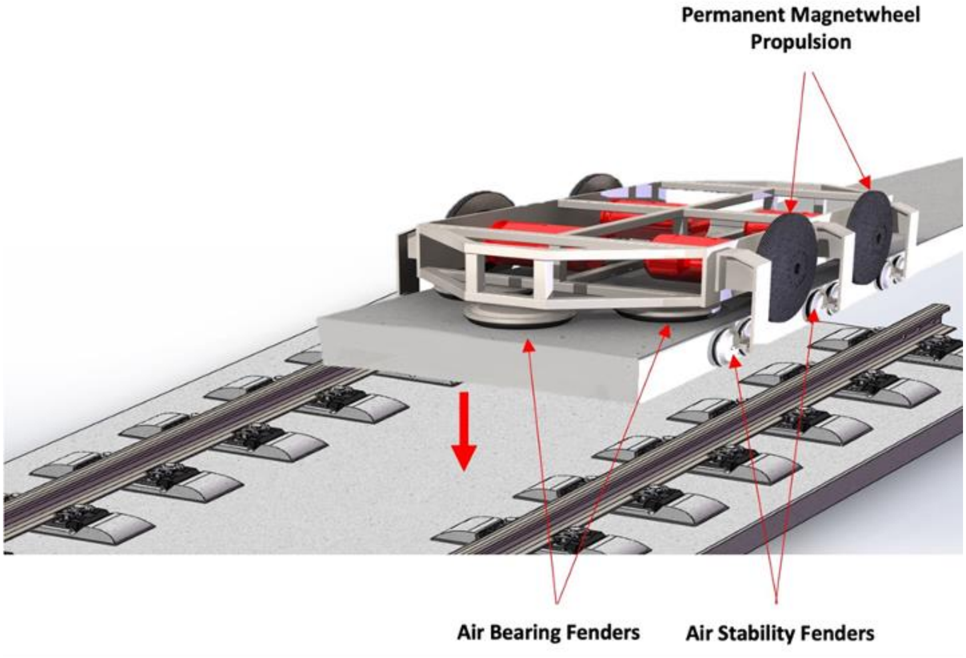

Figure 3 - The slab mounted in between the rails on the existing slab track system

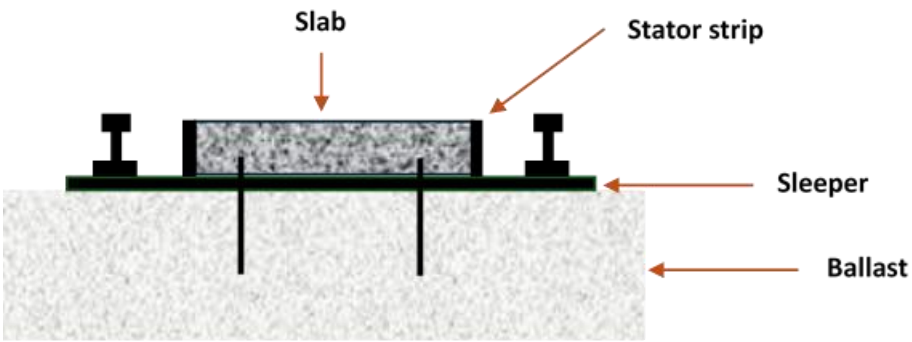

Figure 4 - The slab mounted in between the rails on the existing ballast system

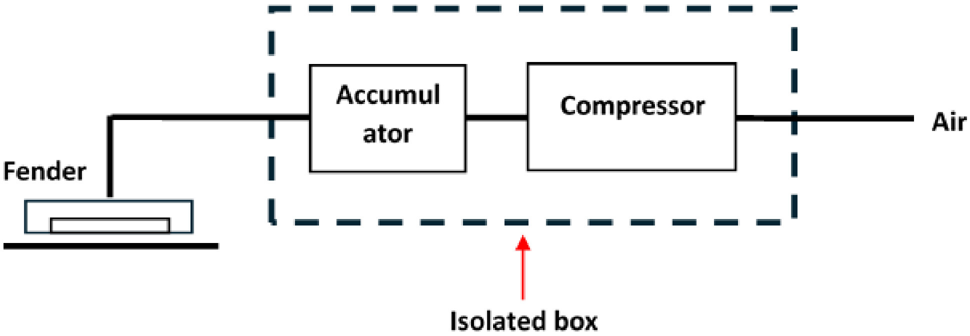

Figure 5 – Air compression system

5.2.2Operational context

The use case of air levitation on existing infrastructure is proposed on an historical regional line, based on the implementation of a hybrid MDS with air levitation and electro-dynamic wheel propulsion. The definition of the use case reflects the need to evaluate the performance of a hybrid MDS with air levitation on main line application.

Hybrid MDS with air levitation will operate at least with speeds of 180 km/h. The hybrid MDS with air levitation could bring as well potential benefits related to lower maintenance, better energy efficiency and a reduction in noise and dust contamination, among others.

The entire route, connecting two main cities which together account for about 36% of the region's total population and attract a significant number of tourists, consists of about 35 km of line including one urban node, divided into two sections.. The entire route is in a flat area, with no steep slopes or tunnels. However, there are bridges and subways along the line to optimize the elevation profile. High-speed trains complete the journey between the two cities in about 25 minutes, while regional services currently take around 45 minutes.

The operational context for air levitation includes environmental conditions, operational conditions, daily operations and example scenarios, vehicle dynamics, passenger and cargo handling, integration with existing infrastructure as well as futureproofing and scalability.

Operational conditions are described as follows:

Speed and efficiency:

- Capable of medium-speed transit, making it ideal for intercity commuting.
- Capacity and flexibility: The technology can be designed to transport both passengers and cargo, the operation on the line can be mixed for both passenger and freight services.
- Safety systems: Equipped with advanced safety features, including automated collision avoidance, emergency braking systems, and robust structural integrity for passenger protection.

Vehicle dynamics:

- Acceleration and deceleration: The trains use electro-dynamic wheels for smooth and rapid acceleration and deceleration, ensuring timely adherence to schedules.
- Airlev mechanism: Employs air bearing fenders to create an ultra-thin layer of air for levitation, drastically reducing friction and wear.
- Energy efficiency: The nearly frictionless movement, combined with efficient propulsion, results in reduced operational costs.

Passenger and cargo handling:

- Boarding and alighting: Streamlined for quick and efficient passenger flow, using existing platforms.
- Integration with existing infrastructure through track compatibility: The trains are able to operate on existing rail tracks, which traditional design shall be subjected to a specific integration assessment also covering maintenance aspects, allowing for a seamless transition from traditional rail systems. For example, putting a slab with

aluminium strips on both sides enables the airlev train to run upon slab and is propelled by electro-dynamic wheels (acting on the aluminium strips).

- Station and Freight Terminal adaptations: existing stations are used. For passenger and freight transport the platforms/loading docks need to be adapted to accommodate the air levitation trains.
- Technology upgrades: built with the capability to integrate future technological advancements, ensuring long-term viability. For example, the designed airlev bogie could be installed in any kind of rail transportation vehicle, such as metro vehicles, freight trains, etc., reducing intensive wheel-rail contact causing noise and increased maintenance needs.
- Scalability: The system is designed to be scalable, both in terms of train length and frequency of service, to meet evolving transportation needs.t

In the following paragraph, the technical specifications and development considerations are presented for an Airlev train system, focusing on areas such as track gauge, loading gauge, vehicle design, and operational parameters.

Track and Gauge Specifications

- Railway track gauge: options include integrating with existing tracks or embedding tracks within a concrete slab. The former is currently preferred.
- Minimum curve radius: for speeds up to 40 km/h, a minimum radius of 200 m is used; for higher speeds, this should increase to 400 m. However, the Technical Specifications for Interoperability (TSI) for European corridors must be complied with (minimum radius is 150m).
- Maximum track inclination: standard inclination is 1/2000, with special designs required for steeper inclines.

Vehicle Design and Performance

- Bogie specifications: designed to carry loads up to 34 tons (for distributed power train architecture) or up to 45 tons (for concentrated power train architecture),
- Maximum operating speed: 180 km/h, extendable to high-speed railway standards.
- Acceleration and Deceleration: 0.6 m/s² per 100 tons mass, with potential for design modifications as per TSI.

Compatibility and Integration

- Loading Gauge: Assumes compatibility with gauge UIC 505-1 (G1).
- Railway Switches and Road-Rail Crossings: Still under development, with aims for cost-effectiveness and robustness.
- Couplers: Compatibility with standard rolling stock.

Operational Considerations

- Traction Type: utilization of electro-dynamic wheels for traction and braking.
- Weather Adaptability: similar restrictions as Maglev and traditional trains, with improved robustness in low temperatures.

Technical Parameters and Challenges

- Maximum Axle Load: in accordance with TSI Infrastructure.
- Side and Vertical Loads: dependent on train mass, velocity, and track radius; compensated by air fenders. Specific data is not yet available.
- Maximum Track Cant: Determined by air pressure inside fenders, expected to be slightly higher than conventional railways (10% expected).

Energy and Maintenance

- Energy Consumption: Data pending; The power density of Airlev train is mirroring that of electromagnetic maglev. The new Airlev train is expected to consume lower energy, up to 0.1 kWh/ton/km.
- Vehicle Cost and Maintenance: specific figures and data not yet available.

System-Specific Considerations

- Tank and Fender Operating Pressure: Ranges from 5 to 10 bar, similar to Liquefied Petroleum Gas (LPG) tanks in cars.
- Operating Gap and Track Irregularities: In order of 1 mm limit with both rigid and flexible fenders to accommodate track irregularities.
- Fenders Integrity Monitoring: Currently under development.

5.3 Upgraded conventional railway with MDS technologies on wheels

This use case focuses on the application of a rail vehicle upgraded with MDS technologies for freight or passenger applications. Therefore, the trains/wagons will be retrofitted and equipped with MDS technologies to improve their performance. Such solution shows high promise for local freight applications, in particular for terminal electrification and shunting automation.

5.3.1System definition

A MDS with upgraded rail vehicles and linear motors trackside is the preferred retrofit solution for existing rail infrastructure and vehicles that will use electromagnetic, allowing each wagon to move independently without a locomotive. It also brings additional traction power to trainsets with a dedicated number of equipped wagons.

This configuration aims to improve existing rail services for freight, allowing traffic automation and infrastructure electrification with greater flexibility, higher frequency of operations, greater capacity, and enhanced dynamics. This technology can be a solution to add additional traction force to sections with steep inclines to realize higher speed or bigger loads for freight trains or increase speed and hence capacity. The MDS configuration is also suitable for passenger applications,

The vehicle subsystem consists of the main components listed below:

- Structure,
- Propulsion – vehicle part,

- Suspension,
- Guidance,
- Braking,
- Vehicle control system,
- Electrical system,
- Monitoring & safety.

The mechanical structure of a retrofitted vehicle combines a classic wagon with a linear motor. A multitude of different platforms is suitable for MDS retrofit. This component enables transferring internal (from payload) and external (track dynamic responses, wind) forces and distributes them safely to maintain the vehicle's integrity. As the structure serves as the central component of the vehicle, various other components can be attached to it, such as onboard electronics, safety systems, suspension, or monitoring systems.

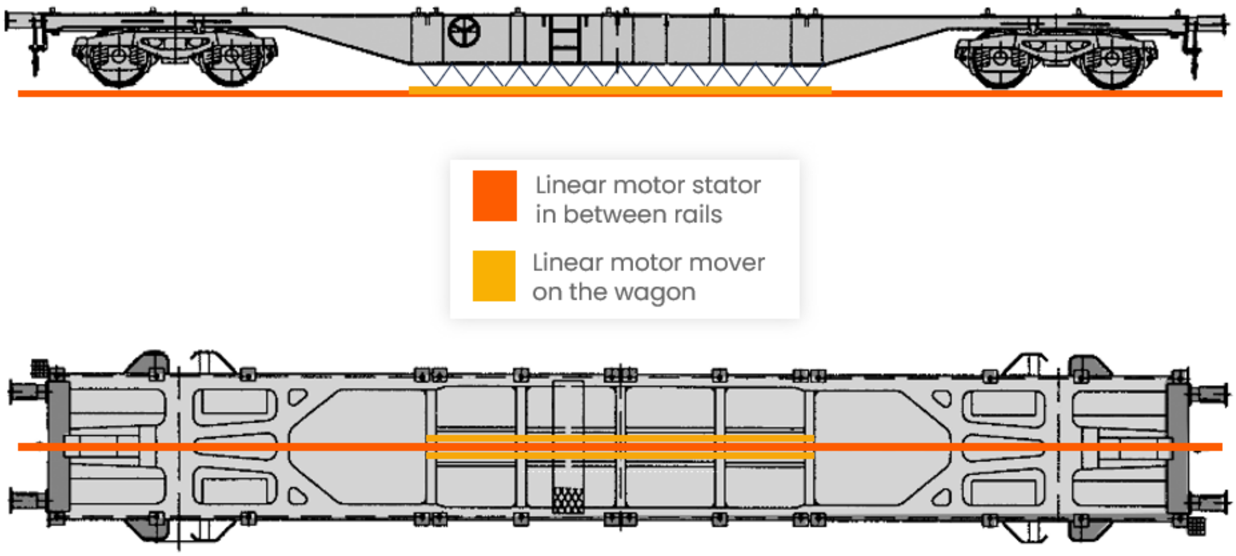

Figure 6 - Principle of updated conventional freight wagon (source: NEVOMO

In the analysed configuration, the linear motor installed in the upgraded conventional vehicle with MDS technologies on wheels is a linear synchronous motor (LSM). This electric machine consists of the mover – a vehicle-mounted set of NdFeB magnets in Halbach array, and the stator (active, powered part) – a 3-phase winding installed in the track. The permanent magnets installed beneath the wagon (as shown in Figure 6) are constituting the mover of the linear motor and are essential for creating the propulsion force for the vehicle.

The position of magnets is adjustable manually or automatically to secure the width of the gap between linear motor and the mover, depending on the use case configuration regarding of specific infrastructure situation. Stability during operation is achieved using a standard suspension system that utilizes existing railway wheels. The wheels provide stability and precise guidance along the track, controlled movement, even weight distribution, and elimination of lateral swaying.

Figure 7 - Example of mounted mover magnet on conventional intermodal rail wagon (source NEVOMO)

Linear motors serve a dual purpose in both propelling the train forward and acting as a braking mechanism. When the train needs to move forward, the linear motor functions in its typical manner to provide traction. Conversely, when braking is required, the linear motor reverses its operation. This reversal transforms the train's kinetic energy into electrical energy, which can then be returned to the electrical grid. Linear motors are versatile and can be utilized for various braking scenarios, including service braking, normal emergency braking, severe emergency braking, and regenerative braking. Furthermore, the system is supported by friction-based braking, utilizing conventional brakes that directly engage with the railway wheels. This holistic braking strategy offers backup and operational safety, facilitating prompt and efficient halting of the vehicle in the event of malfunctions in the electromagnetic braking system.

The vehicle control system in this setup operates in a unique manner, as vehicle movement is primarily controlled from the infrastructure side. A comprehensive command, control, and monitoring system, organized into sections and segments of the linear motor stator, ensures meticulous control of the vehicle's position on the track. The high-performance drive system enables swift acceleration and deceleration, leading to shorter spacing intervals. This feature proves advantageous for advanced traffic control and ensures optimal throughput utilization. Consequently, the vehicle itself is equipped with a minimal set of sensors and devices, specifically tailored for infrastructure safety, control, and guidance systems. These sensors encompass a wide range of functions, including the measurement of position through GPS, IMU, and odometry, as well as monitoring parameters like pressure, voltage, currents, and vibrations.

The electrical system in this setup comprises two main elements. Firstly, there's a dedicated onboard battery, serving as the primary power source for the vehicle's essential electronic devices and communication systems, ensuring continuous operation throughout the journey. Secondly, there's a comprehensive cable wiring network, acting as the backbone of the electrical infrastructure. This network efficiently distributes power to various devices and sensors within the vehicle, enabling proper functioning and effective communication between systems, ultimately contributing to the safe and efficient operation of the entire transportation system.

This system incorporates critical safety elements for both the vehicle and its surroundings. Firstly, an Anti-collision System with a front-mounted radar detects obstacles up to several hundred meters away. It serves a dual purpose: facilitating safe braking at lower speeds and minimizing damage at higher speeds in case of a collision. This radar-based system is crucial for accident prevention and mitigation. Secondly, a Self-diagnostic System within the vehicle, comprising an onboard Central Processing Unit (CPU) and various sensors, monitors the vehicle's overall health by tracking parameters like vibration, current, voltage, pressure, and temperature. In emergencies or anomaly detection, the self-diagnostic system swiftly relays critical information to the central control system and engages emergency braking. This proactive monitoring and real-time reporting enhance safety measures and enable prompt responses to potential issues, thereby bolstering the overall safety and reliability of the entire transportation system.

5.3.2Operational context

An upgraded conventional vehicle with MDS technologies on wheels will be used to carry out transportation tasks in specific facilities and areas with existing rail infrastructure. In particular, the largest group of target applications are facilities that rely on transportation within that facility, for which high throughput and flexibility of operations are desired. In principle, the basis of operations is moving loads between reloading points in a shuttle traffic arrangement.

The specific use case analysed in the MaDe4Rail project, is based on the fact that often, short but steep inclines affect the maximum load of a complete railway line. Additional challenges may arise from difficult environmental conditions like ice, snow, and hail that can reduce conventional propulsion effectiveness as well as braking capacity. This can result in reduced loads/weight of the trains or will require additional locomotives, which causes additional operational costs. Often, additional locomotives are running from origin to destination, even when they are only needed in specific areas. MDS can be a punctual solution for additional traction. Even when the benefits in terms of capacity are not so big as that of a constructive and much more expensive solution like tunnels or bridges, an MDS based on upgraded traditional railway vehicles could potentially solve the problem with much lower costs using the existing infrastructure.

The considered existing line, connecting two cities, is a single-track, curvy and has limitations in capacity, speed and travel time. The route is part of a large commuting area and the existing railway is not a competitive alternative to road traffic. Commuting on that connection is currently made mainly by car or bus. The same applies to trips to and from the local Airport, which currently has no railway connection.

A new railway line between the two cities is being designed to provide faster train journeys, smoother work commuting and increased accessibility to and from the Airport. The current route is also part of new network of trunk lines. The purpose of the redesign of the line is to:

- Add significant capacity to the national railway system, enhancing punctual and robust journeys and transport for people and businesses,
- Provide significantly shorter travel times by train within the Country and from It to other countries in Europe,

- Through increased accessibility and new travel origins and destinations, such solution would boost conditions for strong labor market regions and regional development,
- Promote sustainable transportation modes.

The new planned line comprises approximately 60 kilometers of new double-track railway for high-speed trains and fast regional trains. Along the proposed railway corridor, there are also several locations where it is necessary to build tunnels to overcome the conditions in the landscape. The proposed line has gradients up to around 25‰.

Freight service and also slower regional trains will still use the existing railway line (as shown in **Errore. L'origine riferimento non è stata trovata.**). To increase the capacity and efficiency with focus on freight services on this infrastructure, using a MDS with upgraded rail vehicles and linear motors trackside could provide a solution with low costs to the steep incline of the line providing the required operational parameters specifically where they are needed.

The main need to which an upgraded conventional vehicle with MDS technologies on wheels responds is to increase transportation efficiency – below are the assumptions for main characteristics of this system:

- For this use case, upgraded wagons will always operate within trainsets controlled by locomotives and their drivers
- MDS components will provide additional traction force in sections where the power of the traction unit in front of the train (one or more locomotives) is not sufficient
- Track gauge – 1435 mm,
- Freight wagon dimensions do not change (upgrade of existing wagons without changes of wagon structure)
- Technology dedicated for passengers and cargo (two variants),
- Interoperable infrastructure for upgraded and conventional trains,
- Grid connection to the medium voltage network for MDS substations,
- Operating speed – up to 160 km/h (depending on infrastructural situation),
- Traction type: Linear Synchronous Motor with thrust force of up to 14 kN per equipped wagon
- Dedicated onboard battery with voltage rating of 72 V,
- All MDS components in the track segment are only active, when the train is above. Additionally, all devices which could cause danger by electrocution are covered and secured against environmental issues (e.g. flooding) or unauthorised contacts (e.g. passengers at stations).

6 MDS pod/vehicle subsystem requirements

In this chapter a compilation of specific requirements tailored to the three different use cases is collected. Within these pages the set of requirements is described This collection of requirements serves as a comprehensive guide for the upcoming activities in WP7 and WP8.

6.1 MDS pod/vehicle common subsystem requirements

Operational Aspects

- Ensure smooth integration with urban infrastructure, including existing stations, terminals, and transit hubs, to facilitate efficient passenger boarding and disembarking.
- Ensure compatibility with existing rail infrastructure, including track gauges, static and dynamic clearance, signalling systems, switches, and electrification methods, to allow seamless integration with conventional trains.
- The vehicle shall guarantee to meet or exceed the minimum performance requirements for acceleration and deceleration as defined in the Technical Specifications for Interoperability (TSI).
- All system controls shall be compatible with the Radio-based ERTMS system, in line with the requirements imposed by the European Regulation 2024/1679 on "Union guidelines for the development of the trans-European transport network", amending Regulations (EU) 2021/1153 and (EU) No 913/2010 and repealing Regulation (EU) No 1315/2013.Implement advanced vehicle-to-infrastructure (V2I) communication systems for real-time data exchange between the maglev pods and track infrastructure, enhancing safety and operational efficiency
- The vehicle shall be compliant with the loading gauge UIC 505-1.
- The vehicle shall be adapted to platform heights in range 55-76 cm.
- The vehicle shall be compatible with the standard track gauge.
- The vehicle on wheels shall have a maximum axle load not higher than the allowable limits (usually 22,5 tonnes per axle in Europe) on the particular sections of the line.
- The vehicle on wheels shall have a maximum linear or track load not higher than the allowable limits (usually between 8-12 tonnes per meter in Europe) on the particular sections of the line.
- The vehicle shall be maintainable using typical maintenance strategies.
- The system's heat generation must not adversely affect the railway environment.
- All components shall be designed for longevity, with high durability under operational stresses, and ease of maintenance.
- The system must incorporate energy-efficient technologies and materials and prioritize the use of renewable energy sources where possible. The system should also include regenerative braking and energy recovery systems.
- The system must ensure magnetic fields generated do not interfere with existing railway infrastructure and that track materials are compatible with the magnetic fields generated.

- The system must ensure that critical subsystems (e.g., power supply, control systems) have redundancy measures in place to maintain operations in case of failures and design the system to be resilient against natural disasters (e.g., earthquakes, flooding).
- Minimum curve radius – on wheels shall not be less than 150 m.
- Noise levels at speeds shall not exceed 85 dB.

Economic Aspects

With references to the identification and quantification of the benefits identified in deliverable D2.2 a common methodological framework will be applied in the upcoming work of deliverable D7.3. Nevertheless, some first and general economical and socio-economical requirement are mentioned here already:

Cost - benefit Analysis:

- Understanding the level of investment in railway vehicles and infrastructure is key. This involves assessing the condition of tracks, stations, and other facilities, as well as any planned or ongoing infrastructure and vehicle projects.
- At least two scenarios shall be considered: a minimum investment scenario and an optimum investment scenario.
- Conducting a cost-benefit analysis helps in evaluating the economic viability of the railway system. This involves comparing the economic benefits against the investments and operational costs.
    - Cost-benefit analysis / investment case has to be positive based on the "Guide to Cost-Benefit Analysis of Investment Projects" of European Commission
    - Break-even point shall be at least within a proper time horizon between 10-30 years, considering operational savings, investment funding and revenue potential.
    - Reduction of operational costs compared to traditional rail systems (e.g. higher grade of automatization, higher operational and energy efficiency, lower maintenance needs, …) shall be achieved
    - Higher revenues for the IM by increased capacity or better quality usage, resulting in higher demands frequency & flexibility, must be achieved
    - The results of the transport analysis must be positive and present non-marginal benefits to the lines.
    - Higher quality usage that leads to more passengers and freight on the rail (ticket sales and cargo transport fees) must be achieved

Socio-economic analysis

- The result of a conducted examination of current and projected ridership, including demographic details and travel purposes, must prove to be positive.
- The assessment of direct and indirect employment generated by the railway system, along with its contribution to economic growth in related industries and local economies, must prove to be positive.
- The evaluation of the role of the railway in enhancing regional connectivity, facilitating trade, and reducing transportation barriers, must prove to be positive.

- The analysis of the environmental sustainability of the railway, encompassing its carbon footprint, impact on local ecosystems, and measures for mitigation, as indicated in the Do Not Significant Harm (DNSH) principle, must prove to be positive.
- The assessment of the role of the railway system in promoting social inclusion by analysing its accessibility to diverse populations, including rural and marginalized communities, as indicated in the DNSH principle, must prove to be positive.

Business Perspective

- Evaluate the potential for offering value-added services, such as refrigerated cargo compartments or high-speed parcel delivery, to attract additional market segments.
- Develop a sustainable revenue model, considering factors such as ticket pricing, partnerships, and potential ancillary services.

Partnerships and Stakeholder Engagement:

- Explore potential partnerships with government agencies, private investors, and international organizations to secure funding and support for the project.

Standards and Regulations

- All the safety applicable regulations and standards shall be employed.
- Provide requirements for safely operating MDS trains alongside conventional trains on shared tracks.
- All mitigation measures as result of a future comprehensive system level risk analysis shall be employed.
- All systems must be fail-safe, and they must foresee specific mechanisms to handle failures. Also, detailed evacuation procedures for MDS trains in case of system failure or emergency should be provided.
- The vehicle shall be equipped with advanced collision avoidance systems to prevent accidents and ensure passenger safety. Ensure emergency braking systems that are specific to MDS technology
- Ensure the compatibility with the safety requirements as defined in TSI.
- Ensure compatibility with existing power supply systems and establish protocols for power transitions.
- All devices which could cause danger by electrocution shall be covered and secured against environmental issues (e.g. flooding) or unauthorised contacts (e.g. passengers at stations).
- Implement advanced cybersecurity protocols to protect the system against potential cyber-attacks, ensuring data integrity and operational security.
- Ensure high levels of passenger comfort, including smooth ride quality, noise reduction inside vehicles, and accessibility features for people with disabilities (e.g., ramps, tactile guides, visual and auditory signals).

6.2 Hybrid MDS based on magnetic levitation

Operational Aspects

- All MDS components in the track segment are only active, when the pod/vehicle is positioned above;
- The pod/vehicle shall be designed to operate with speeds up to 220 kph, aerodynamically optimized to reduce drag at high speeds, contributing to energy efficiency and stability.
- Ensure compatibility with high-speed track switches, allowing for smooth and safe transitions between different track segments at high speeds
- The pod/vehicle must achieve an acceleration of at least 1.5 m/s^2, an operational deceleration of 1.5 m/s^2, and have no limit on emergency deceleration capabilities.
- The pod/vehicle should be evaluated for compatibility with high-speed railway requirements, with a particular focus on axle load limitations. Specific load limits per axle will be determined in accordance with relevant standards and operational conditions.
- The vehicle shall ensure levitation stability across various speeds and track conditions,
- The single pod/vehicle shall have –at least 70 passenger seats.
- The pod/vehicle should be developed with advanced materials or coatings for levitation modules to increase their durability and lifespan, particularly against environmental wear.
- The pod/vehicle in levitation state shall not put loads on levitation modules, which would compromise their integrity
- Single vehicle operations shall be possible, but also as (virtually) coupled sets, based on the operational and timetable concept. Physical coupling should also be feasible.
- Preferably predictive maintenance systems will be employed to ensure high reliability and minimal downtime
- The vehicle should integrate an active suspension system to enhance ride quality by automatically adjusting to track conditions and speed variations
- Minimum curve radius – in levitation mode: 400 m
- Maximum track cant: railway standard (150 mm) plus possible additional cant in levitation mode, yielding ca. 190 mm of railway cant equivalent
- Several MDS pods can stand and be boarded and unboarded on a single platform at the same time. If platforms will be used by both systems (MDS and conventional trains) it must be ensured, that additional equipment for MDS pods/vehicles (e.g. additional ramps to reduce the vertical gap between platform and vehicle floor or the horizontal gap between the vehicle and the platform edge) will not interfere with standard requirements for platform approaching
- Develop a modular interior design for the MDS pods/vehicles, allowing easy reconfiguration for different purposes (e.g., passenger, freight, or mixed use) depending on demand.

- Develop advanced cooling systems for the maglev's superconducting magnets, ensuring efficient and safe operation across varying environmental conditions

Market Potential and Growth Projections:

- Target Markets: intercity travellers; short distance flight passengers
- Conduct market studies to assess the demand for high-speed transportation and the feasibility of the MDS system between origin and destination, or intermediate stops.

Regulations and Standards

- Establish specific emergency evacuation protocols for MDS pods/vehicles, considering both elevated and ground-level tracks, ensuring safe and rapid evacuation in case of emergencies.

6.3 Hybrid MDS based on air levitation

Operational Aspects

- Specialized tracks with aluminium strips shall be essential for magnetic propulsion functionality.
- The vehicle shall have a passenger capacity of up to 800 individuals (with multiple cars coupled to trainsets) and a cargo capacity of around 20,000 kg.
- The system should be designed to allow rapid reconfiguration between passenger and cargo modes, enabling flexible use of the vehicles depending on demand
- The vehicle shall be able to operate on existing rail tracks, with a specific design integration assessment covering maintenance aspects.
- The vehicle shall be more energy-efficient than conventional trains.
- The vehicle should implement sophisticated propulsion control algorithms that optimize energy usage based on real-time operational conditions, such as train load, speed, and track conditions
- The vehicle shall achieve a significant reduction in CO_2 emissions, lower than traditional rail systems.
- The vehicle should be designed with modular architecture so that it can be easily upgraded or modified with new technologies (e.g., improved levitation or propulsion systems) without requiring a complete overhaul.

Market Potential and Growth Projections:

- Expansion Potential: Plans for extending services to other major cities and logistic hubs.
- The Airlev system shall target urban commuters for efficient and rapid transportation within metropolitan areas.
- The Airlev system shall target intercity travellers, providing a fast and convenient alternative for travel between cities.
- The Airlev system shall offer reliable and efficient cargo transport solutions for businesses.

6.4 Upgraded conventional vehicle with MDS technologies on wheels

Operational Aspects

- The vehicle shall be designed to operate at 120 km/h.
- Vehicles shall have the possibility of being propelled & controlled individually in specific areas (e.g. shunting yards), based on the operational concept
- Capacity for passengers shall be at least 50 passengers per wagon
- The maximum allowable axle load is 22.5 tonnes per axle.
- The maximum payload for freight vehicles shall be at least 40 tonnes.
- Maximum deceleration shall be 5 m/s2
- Maximum acceleration shall be 1.5 m/s2
- Maximum track inclination shall be 30 ‰
- Maximum track cant: 150 mm
- The vehicle shall withstand loads coming from lateral and vertical accelerations no higher than 1.5 m/s2
- The vehicles shall be suitable for any coupler type
- Vehicles shall be equipped with additional devices for snow removal and ice melting from the surface of the motor due to expected weather conditions.
- Freight vehicles shall be equipped with smart cargo management systems that monitor and optimize load distribution, ensuring stability and safety during transport.
- Ensure that vehicles can operate efficiently in other extreme weather conditions, including high temperatures or heavy rainfall, with features like adaptive traction control and weather-resistant materials.
- Design vehicles to withstand operational stresses in challenging environments, including high-altitude railways or regions with significant seismic activity.

Market Potential and Growth Projections:

- Target Markets: freight services in focus but also effects on passenger service
- Conduct market studies to assess the demand for higher weights of freight trains and additional capacity on sections with steep inclines.

7 Vehicle technical specifications

This chapter presents general technical vehicle specifications concerning aspects such as interoperability, interfaces with other subsystems, safety, sustainability, and various other considerations.

Interoperability

- The vehicle shall be compliant with the structure gauge G1, to keep the running stability. In such a case, the vehicle must not exceed the kinematic gauge and the comfort parameters when the train is operating in levitation.
- The vehicle should comply with the applicable EMC standards according to EN 50155 or equivalent standards. It should be ensured that the vehicle does not generate excessive electromagnetic disturbances that could negatively affect the operation of other electronic devices or communication systems. Additionally, the vehicle should be resistant to external electromagnetic disturbances that may occur in its operational environment, including disturbances generated by the rail infrastructure and the influence of eddy currents on board the vehicle.
- All vehicle components must be fire resistant in accordance with EN 45545 standards.
- The vehicle shall be suitable for at least Grade of Automation 3 (GoA3) as defined by IEC 62290. This entails the vehicle's capability to operate autonomously without an onboard driver even on lines with mixed traffic of conventional and GoA3 (or higher) vehicles. Therefore, the compatibility with European Train Control System (ETCS) must be assured to potentially use ATO over ETCS functionalities.
- The vehicle must be designed and constructed to be compliant with the standard platform height specifications as defined in the Technical Specifications for Interoperability (TSI). This requirement ensures that the vehicle aligns with established platform height standards for seamless integration and interoperability within the rail system.
- The vehicle shall be designed and constructed to be resistant to vibrations in accordance with the EN 12663-1 standard. This requirement ensures that the vehicle maintains structural integrity and operational functionality under conditions of vibration encountered during normal operation.
- The vehicle shall be capable of being virtually and physically coupled with and operating in conjunction with standard vehicles, ensuring compatibility and interoperability.
- The vehicle must comply with the maximum load per axle and load distribution requirements as outlined in Article 4.2.3.2 of TSI LOC&PAS and EN 15663. The vehicle shall have a maximum load per axle that is in accordance with these specifications, ensuring safe and efficient operation.
- Levitating vehicles must be capable of running on a maximum cant equivalent to of 190 mm and through switches. The guidance system of the vehicle shall operate without any safety risk, even in the case of degradation of one or more components.
- The vehicle must have a system in place to manage wheel-rail adhesion effectively. This includes mitigating the risk of slippage or derailment when non-rotating wheels lower back onto the track. An assessment of levitation parameters and potential solutions,

such as pre-rotating the wheels during the lowering phase, shall be conducted to ensure optimal wheel-rail interaction.

- For all vehicles with the ability to use a levitation mode the earthing is crucial because there is no contact between vehicle and rail. Therefore, the design for these vehicles must be based on a similar structural architecture for planes ("Faraday Cage") to fit this safety related aspect. Updated vehicles without the ability to levitate will always keep the wheel-rail contact and meet the requirement of earthing at all times.
- The vehicle shall meet the requirements for ride comfort for passengers as per EN 12299, ensuring a comfortable travel experience.
- The vehicle must fulfil the requirements of COMMISSION REGULATION (EU) No 1302/2014 concerning the rolling stock subsystem, including structure and mechanical parts, track interaction and gauging, braking, passenger-related items, environmental conditions and aerodynamic effects, external lights & visible and audible warning devices, traction and electrical equipment, driver's cab and driver-machine interface, and fire safety and evacuation.
- The vehicle shall be compliant with the TSI baseline 4 (EU) 2023/1695 as of 10 August 2023, ensuring up-to-date adherence to standards and regulations.

Safety Considerations

- The vehicle shall be equipped with an independent, redundant braking system, ensuring the capability to stop at any point on the track under various conditions specified in TSI LOC&PAS chapter 4.2.4.2 Main functional and safety requirements.
- The vehicle must have the ability to perform a safe stop at any location on the track, effectively preventing any unintended movement or rolling away.
- The vehicle shall possess the capability to release the pneumatic brake of a wagon independently, without the need for a locomotive.
- The vehicle shall be capable of making independent decisions and autonomously initiating braking in response to operational conditions.
- The vehicle shall be capable of safely moving over switches, ensuring operational integrity in various track configurations.
- The vehicle shall adhere to the crashworthiness standards as specified in TSI LOC&PAS - 4.2.2.5 and EN 15227. This requirement ensures the vehicle's structural integrity and safety in the event of a collision.
- The vehicle must have the running capability to operate safely over power-neutral sections.
- The vehicle's levitation system shall function without any safety risks, even in the event of degradation of one or more components. Detailed safety protocols and contingencies must be in place to address specific points of potential component failure.
- When the levitation system is engaged and lifts the bogie, the vehicle shall maintain proper alignment of the bogie to the track. This includes ensuring the wheels maintain the correct conicity diameter, especially in main curves with a radius of 150 meters. The system must prevent misalignment of mechanical traction links (such as pivots and traction rods) and the primary/secondary bogie suspensions, mitigating the risk of

derailment when wheels return to contact with the track.

- In the event of a sudden malfunction of the levitation system, the vehicle shall have mechanisms in place to safely and promptly bring the wheels back into contact with the track, minimizing impact and ensuring passenger and operational safety.
- The vehicle shall have a mechanism to maintain an effective earthing circuit at all times, including when the vehicle is levitating. This is essential to ensure electrical safety and proper functioning of onboard systems.
- The power system installed on the ground must be designed to deactivate in track sections not covered by the train. This ensures safety by reducing the risk of electrocution when trains are not present.
- The powered sections of the track must be designed to minimize the risk of electrocution, even in scenarios like flooding surrounding the track, including station platforms without Platform Screen Doors or level crossings with or without barriers. Effective insulation and safety measures should be implemented.
- The braking curve of the vehicle shall be compatible with those applicable in the European Train Control System (ETCS) version 4.

Weather Conditions

- The vehicle components should be resistant to various weather conditions in accordance with EN 50125-1. The vehicle should be able to operate even in the presence of snow, ice, or hail, as per TSI LOC&PAS - 4.2.6.1.2 requirements. Additionally, the vehicle should maintain its performance even under such conditions. The presence of ice, snow, or rain should not have a negative impact on the traction booster system's operation.
- In compliance with TSI LOC&PAS - 4.2.6.2.4, the vehicle must be designed to withstand and operate effectively under crosswind conditions, ensuring stability and safety.
- The vehicle must be designed to prevent overheating in all operational modes, including under degraded conditions. This includes the implementation of effective cooling systems and safeguards.

Sustainability

- The design of the vehicle cab shall accommodate the potential future integration of perception sensors necessary for at least GoA3 applications. This requirement aims to ensure compliance with future Technical Specifications for Interoperability (TSI) related to new functions.
- The vehicle shall be compatible with and able to host new features developed as part of the R2DATO project. This includes the integration of additional sensors and functionalities, which may impact the vehicle's design and operation.
- The vehicle shall comply with standards related to acoustics, environmental management, and the principles of recyclability and recoverability, demonstrating commitment to environmental sustainability.

8 Conclusions

This document is the second deliverable of Work Package 4, which focuses on the MDS pod/vehicle subsystem.

This document, encompassing both requirements and technical specifications, lays the foundation for a transformative era in mobility. As the research of innovative transportation solutions needs to stand at the intersection of innovation and practicality, the potential benefits of MDS technologies emerge as a beacon for sustainable, efficient, and high-speed transportation solutions.

MDS pod/vehicle system requirements and technical specifications herein developed will serve as a roadmap for the activities of WP8, where a prototype design of one of the 3 use cases selected in WP7 will be carried out.

The analysis of requirements has underscored the multifaceted considerations essential for the successful integration of MDS pods/vehicles into the European existing infrastructure. From safety standards to regulatory frameworks, the necessity for meticulous planning and collaboration across various stakeholders is evident. It is imperative to address not only the technical intricacies but also the broader socio-economic and environmental implications in the next steps of the project.

The work started with the understanding of the system's definition and the operating conditions and took in consideration the hazards and risks identified for each one of the use cases. The safety analyses shall be progressively developed and upgraded in parallel with the achievements reached in WP3 as the project continues to progress.

Moreover, this document serves as a catalyst for further research and development. As technology evolves, so too will the specifications and requirements for MDS pods/vehicles. Continuous innovation, informed by real-world testing and feedback, will be essential to refine and optimize these transportation systems.

In essence, Maglev-derived technologies hold the promise of revolutionizing the way transportation is perceived and experienced. From reducing travel times to mitigating environmental impacts, the benefits are vast. However, as with any transformative technology, the journey from concept to reality requires careful consideration, collaboration, and a commitment to addressing challenges.

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