Deliverable D2.2

Potential benefits to the railway system derived from maglev and maglev-derived systems

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1 Executive Summary

The Deliverable outlines a methodology for identifying, assessing, and integrating potential technologies and subsystems from maglev-derived systems into existing railway infrastructure. Considering the Breakdown Structure element, the main technologies have been selected and examined, such as Vehicle Structure, Propulsion System, and Guidance and Control Systems, identifying different possibilities like Full MDS, Hybrid MDS and Rail Vehicle Upgrades with Maglev-derived subsystems.

The technologies are evaluated based on criteria like cost, compatibility, energy efficiency, safety and related benefit focused on performance enhancement, reduced maintenance, increased capacity, and financial viability, are identified. The primary benefit of MDS systems over conventional rail systems is the decrease in friction, which can lead to faster speeds, greater energy efficiency and less maintenance expenses. In the documents are addressed the advantages of each subsystem as specified in the Work Breakdown Structure (WBS) in MaDe4Rail Deliverable 2.1 and considering the results of the Technology Readiness Assessment (TRA) in MaDe4Rail Deliverable 6.1.

Furthermore, the final part deals with identification of potential benefits to the railway system derived from the importable technologies. The proposed methodology, aligned with the European Commission Guide to Cost-Benefit Analysis of Investment Projects, focuses on five key steps: description of the contexts, definition of objectives, case studies identification, benefit analysis and Risk assessment.

The methodology examines socio-economic trends, political landscapes, existing service conditions, provides a baseline for the project alignment with territorial and technical environments, establishes objectives related to improved travel conditions, environmental quality, population well-being, quantifies objectives, including congestion reduction, enhanced network capacity, safety improvements and compliance with standards, identifies case studies based on coherent functions aligned with investment objectives, distinguishes project typologies and lists physical realizations for a comprehensive analysis. It offers a systematic approach for stakeholders seeking to integrate maglev-derived technologies into railway systems. By following the European Commission guidelines, the methodology ensures a thorough assessment of benefits, including improvements in travel conditions, environmental impact reduction, enhanced safety. This framework empowers decision-makers with valuable insights for strategic and informed transportation infrastructure investments.

2 Abbreviations and acronyms

Abbreviation / Acronym	Description
ABF	Air Bearing Fender
ATO	Automatic Train Operation
ATC	Automatic Train Control
CAPEX	Capital Expenditure
CBA	Costs Benefit Analysis
EDS	Electrodynamic Suspension
EDW	Electrodynamic wheels
EMC	Electromagnetic Compatibility
EMS	Electromagnetic Suspension
ERTMS	European rail traffic management system
ETCS	European Train Control System
EV	Electric Vehicle
FRMCS	Future railway mobile communication system
GDP	Gross Domestic Product
GHG	Greenhouse gas
GNSS	Global navigation satellite system
GoA4	Grade of Automation 4
HMI	Human Machine Interface
HVAC	Heating, Ventilation and Air Conditioning
LIM	Linear Induction Motor
LSM	Linear Synchronous Motor
Maglev	Magnetic Levitation
MCA	Multi-Criteria Analysis
MDS	Maglev Derived System
MVB	Multifunctional Vehicle bus

OPEX	Operational Expenditure
PMP	Permanent Magnet-wheel Propulsion
PWM	Pulse width modulation
TRA	Technology Readiness Assessment
TMCS	Train control and management system
WBS	Work Breakdown Structure
WP	Work Package

3 Background

The present document constitutes the Deliverable D2.2 *Potential benefits to the railway system derived from maglev and maglev-derived systems* in the framework of the Flagship Project HORIZON-ER-JU-2022-FA7-02 – Maglev-Derived Systems for Rail (MaDe4Rail) as described in the EU-RAIL MAWP.

4 Objectives

In this comprehensive deliverable, we embark on a meticulous exploration of maglev and its derivatives within the context of transportation systems. Our primary objective is to conduct a thorough analysis that delves into the potential benefits and discerns the corresponding indicators for assessing the seamless integration of maglev and maglev-derived technologies with conventional railway systems.

Our focus extends beyond simple identification in order to develop a complete approach to the integration of maglev technology. This methodology follows to the rigorous standards specified in the European Guidelines for cost-benefit analyses, and it forms the foundation for all subsequent technical and economic studies. Our approach, which extends the foundation established by Tasks 2.4–2.5, aims to both reveal the intrinsic benefits of maglev systems and open the door to a more sophisticated comprehension of their possible synergies with conventional railway infrastructures.

In the transportation sector, innovation, efficiency, and sustainability intersect as we work our way through the complexities of this examination. The combination of conventional railway networks and maglev technology is a paradigm change, and our delivery is positioned to clarify the subtle aspects of this combination.

5 Identification of potential technologies and subsystems from maglev-derived systems importable into the railway system

5.1 Methodology to identify benefits and indicators

Inputs of this document are from the work developed with Task 2.4 *Identification of potential technologies and subsystems from maglev-derived systems importable into the railway system itself* and the matrix that was produced at the end of Task 2.4, as described below.

Taking into consideration the results of Task 2.3 Breakdown structure of basic technologies and identification of technical enablers for the systems identified and definition of a common architecture and Deliverable D2.1, for each element of the Breakdown Structure, the main technologies have been selected; for example, for the Vehicle Structure the following possibilities have been identified:

- New vehicle structure,
- Structure for Hybrid MDS interoperable with railway infrastructure,
- Structure for Rail vehicle upgraded with MDS subsystems or technology.

The matrix was constructed with as many rows as the technologies identified, then a series of columns included information and evaluations regarding the potential of the different technologies to improve the performance indicators of the railway system.

The columns included in the matrix are as follows.

- **Importable back to the railway system**: it has been indicated if the technology can be imported into the railway system (yes or no).
- **Macro Expected Benefits according with Table 3.3 of EU - Guide to Cost-Benefit Analysis of Investment Projects (edition: December 2014):** one or more benefits referring to the EU - Guide to Cost-Benefit Analysis of Investment Projects (edition: December 2014) have been indicated.
- **More precise expected benefits (one or more) to justify that the technology is importable**: an explanation of why the technology brings the identified benefits was described.
- **Possible indicator(s) to measure the expected benefits**: possible indicators to measure the identified benefits have been reported.
- **Justification/description of selected indicators**: an explanation has been given as to why these indicators are applicable.
- High level engineering and/or designing actions required to adopt the technology in the railway system: it was explained if the technology requires specific actions to be imported, which have been further detailed in WP4 (MaDe4Rail D4.1, 2023).

5.1.1 High level engineering and designing actions required to adopt the technology in the railway system

For each subsystem it has been analysed the associated technology and has been explained the action that are required to adopt the technology in the railway system as follows.

Structure

Structure for Rail vehicle upgraded with MDS subsystems or technology: vehicle design integration, checking railway gauge compatibility with railway standards.

Propulsion

Linear Induction Motor (LIM): integration of the design to the vehicle, checking air gap distance with LIM armature mounted on the track and railway gauge compatibility with railway standards. LIM can be split and powered by separate converters for a high transport system availability:

- analyse railway regulations and find gaps,
  - analyse infrastructure capacity to be integrated with LSM stator, sleepers redesign, design of mountings, EMC,
  - design maintenance processes,
  - redesign command control schemes.

Electrodynamic wheels: Track rebuilding and vehicle design integration.

Lateral wheel-based propulsion/braking: design of infrastructure upgrade with additional guideways, integration in substructure, vehicle design and control system.

Suspension

Electrodynamic suspension based on permanent magnets: design of infrastructure upgrade with additional guideways, integration in substructure; vehicle design integration, control system re-design.

Ferromagnetic passive levitation technology: Design of infrastructure upgrade with additional guideways, integration in substructure, vehicle integration, control system re-design.

Airlev

Track rebuilding: vehicle design integration.

Guidance

Electromagnetic/Electrodynamic suspension: design of infrastructure upgrade with additional guideways, integration in substructure, vehicle integration, control system re-design.

Lateral wheels or traditional bogie guidance: design of infrastructure upgrade with additional guideways, integration in substructure, vehicle integration, control system redesign.

Aircushion based guidance Track rebuilding: vehicle design integration.

Vehicle control system

Train Control Module System: transversal activity applicable to all the rolling stock.

Braking

Linear Motor: relevant adaptation between LIM and PWM converter for hypersynchronous regenerative braking. Control of highly reliable energy storage is necessary for emergency braking by DC injection.

Electrodynamic wheel brakes: track rebuilding, vehicle design integration.

Electrical system

Current contact shoe and power rail: very well mastered technology, usually installed to supply metro lines.

Pantograph and overhead catenary: vehicle to be adapted to use the overhead existing system.

Inductive energy transfer: guideway to be equipped with specific coils to generate a variable electromagnetic field from the inside vehicle. Vehicle propelled by Linear Synchronous Motor (LSM) can use the variable electromagnetic field related to the speed of the vehicle. High frequency converter technology is needed.

Battery onboard: design of new high-storage capacity battery system to install on board in safety conditions.

Guideway

Upgraded conventional railway infrastructure: no actions to be taken.

Monitoring, safety, control

Specific positioning systems based on the maglev technology: fulfilment of vehicles TSI.

Switches and segment switches

Upgraded conventional railway infrastructure: design of infrastructure upgrade with mountings for linear motor, integration in substructure, checking EMC and railway gauge compatibility with railway standards, re-design command control schemes.

Substructure

Structural components: design of infrastructure upgrade for the propulsion technology, integration in substructure, checking EMC and railway gauge compatibility with railway standards, re-design command control schemes.

Ballasted railway track with sleepers: to use it with imported MDS systems it will be necessary:

- integrations and updates with propulsion technology,
- integration in substructure,
- checking EMC and railway gauge compatibility with railway standards,
- redesign command control schemes.

Railway slab track: to use this technology with imported MDS systems it will be necessary:

- integrations and updates with propulsion technology,
- integration in substructure,
- checking EMC and railway gauge compatibility with railway standards,
- redesign command control schemes.

Power supply

Track power supply to Infrastructure for long propulsion track-side stator: design of infrastructure upgrade with mountings for power supply subsystems, integration in substructure, checking EMC and railway gauge compatibility with railway standards, re-design command control schemes.

Vehicle power supply to vehicle for all functions: upgrade vehicle design for power supply subsystems, checking the railway gauge compatibility with railway standards, re-design command control schemes.

Sensing, communication, positioning

Specific positioning systems based on the MDS technologies: it will be necessary to check the compatibility with the future TSI.

5.2 Overview and applications of selected MDS

In this document, the following definitions are considered.

- **Maglev system** refers to magnetic levitation (maglev) systems as transportation systems adopting methods and principles of magnetic levitation to suspend carriages, counteracting gravitational forces by means of magnetic fields.
  Maglev-Derived System (MDS) is defined as innovative, fast track-bound transportation system for rail application that use levitation-based technologies, such as linear motors with magnetic or pneumatic levitation, as their foundation.
- **Air-levitation system** refers to MDS with suspension and/or guidance system based on aerodynamic forces. We refer to systems that utilize a cushion of air to lift the vehicle.
- **Pure maglev system (Full MDS)** refers to maglev systems that use specific and dedicated infrastructure, not compatible with the existing railway infrastructure.
- **Pure air-levitation system** refers to air levitation systems that use specific and dedicated infrastructure, not compatible with the existing railway infrastructure.
- **Hybrid MDS** refers to systems that are compatible with railway infrastructure.

- **Hybrid MDS based on air levitation** refers to air levitation transport systems that are compatible with railway infrastructure.
- **Hybrid MDS based on magnetic levitation** refers to magnetic levitation systems that are compatible with railway infrastructure.
- **Rail vehicle upgraded with MDS Technologies** are conventional rail vehicles upgraded with MDS sub-systems or technologies.

Based on the results of the overview of the traditional maglev systems and innovative maglev-derived systems performed in WP2 (MaDe4Rail D2.1, 2023), the vehicle subsystem definition and system-level interface identification from WP4 (MaDe4Rail D4.1, 2023) and the technological maturity analysis developed in WP6 (MaDe4Rail D6.1, 2023), the systems have been analysed.

5.2.1 Full MDS

A comprehensive Maglev-Derived System (MDS) in Figure 1 represents a transformative transportation paradigm utilising magnetic levitation for both vehicle suspension and propulsion. In contrast to traditional systems with wheels and tracks, MDS technologies harness magnetic forces to lift and propel vehicles. This technological innovation is often linked to high-speed trains and urban transit systems.

This forward-looking system holds significant potential for expanding the existing European Network, fostering connectivity through interoperable passenger stations. Notably, some Maglev-based systems may still align with the broader interoperable European network, promising compatibility.

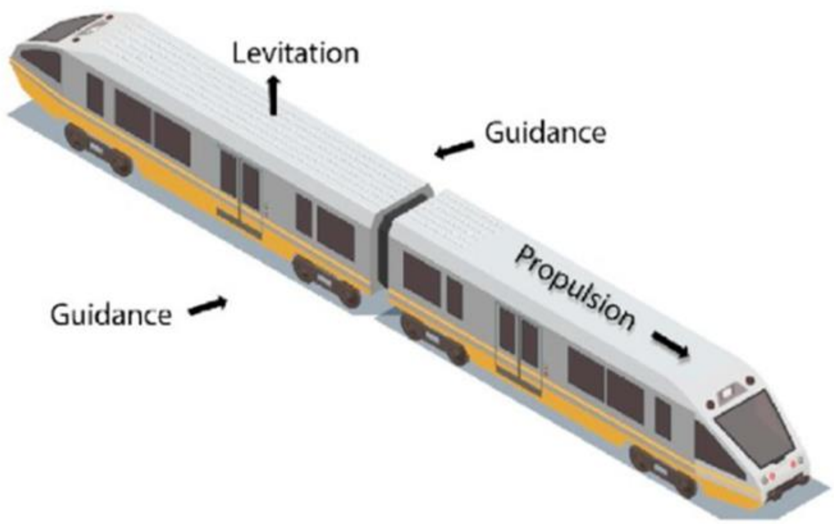

Figure 1. Working principles of a Full MDS

Maglev systems, rooted in magnetic levitation principles, counteract gravitational forces to suspend carriages using magnetic fields. Diverse methods generate essential electromagnetic forces for transportation technology. These include Electro-Magnetic Suspension (EMS) with electromagnets on a magnetically conductive track.

EMS has been utilised, among others, in the Shanghai Maglev system, the Changsha Maglev, and the Linimo. The Shanghai Maglev is a high-speed maglev system, while the Changsha Maglev and Linimo are low-speed maglev systems. The detailed description of the subsystem concepts is provided in the deliverable D4.1.

On the other hand, Electrodynamic Suspension (EDS) creates forces through relative motion between conductive elements and electromagnetic sources. EDS in MDS systems has been employed in the Chuo Shinkansen train, which is a high-speed system in Japan.

Passive Suspension relies on forces from passive elements like permanent magnets, independent of dynamic effects, such as ferromagnetic levitation. This array of methods highlights the adaptability and ingenuity inherent in Maglev transportation systems.

5.2.2 Hybrid MDS

Hybrid MDS include the systems that are compatible with railway infrastructure. Two types of hybrid MDS are analysed in this report, one is based on air levitation and the other is based on magnetic levitation.

5.2.2.1 Hybrid MDS based on air levitation

By combining the right new technologies, a hybrid MDS can enable a transition from conventional track to a future-proof track. Furthermore, it can enable the integration of different rail systems (Figure 2), such as high-speed rail, conventional rail, light rail, heavy rail, within the same network. Developing and applying a new standard technology for guided transport will also bring many new advantages compared to the previously valuable train technology that is now at the end of its life cycle.

The purpose of a hybrid public transport infrastructure is to increase flexibility and efficiency in the transport system, especially in places where different modes of transport converge.

Figure 2. Typologies of systems with promising applications

A combination of technologies like air levitation and propulsion by Electro Dynamic Wheels (EDW) results in such a hybrid transport system. The *Atrain* (European Patent EP 2701960 and

US-patent US 10293803B2) is a concept that holds the combination of air levitation (Air Bearing Fender - ABF) and propulsion by electro dynamic wheels (Permanent Magnet wheel Propulsion - PMP), can transport passenger and goods in an energy efficient way.

This train allows people to move themselves and/or bulk goods freely in any direction on an ultra-thin layer of air. By injecting air in the so-called Air Bearing Fenders, which slide on a flat surface (track/road/floor) an upward force is generated. The ultra-thin layer of air leads to a status with little or no friction between the moving object and the track/road/floor. This technology delivers a great value over traditional transport (wheels) by two facts:

1. The rolling resistance and wear is eliminated,
2. The mass of the vehicle is distributed evenly over a large contact area, compared to the view square centimeters in conventional railway systems, allowing for a much lighter infrastructure.

Propulsion provided by rotating permanent magnetic wheels (i.e., PMP) along aluminum strips (conductors) connected to the track, a non-contact propulsion and braking technique is realized.

This combination makes it possible to:

- Reduce construction and maintenance costs for infrastructure; simple *light* infrastructure, ABF-technology can be applied to a simple plane surface,
- Reduce energy efficient transportation, the (nearly) frictionless principle of carrying, guiding (also by ABF) and propulsion requires little energy,
- Increase comfort and environmental performance,
- Define a new standard technology for all types of guided transport; high-speed, heavy-load transport, light rail, subway, people movers, etc.,
- Increase availability of infrastructure: with the applied EWD is high speed and high acceleration and braking possible,
- Running on the same track when integrating the existing rail system with the proposed system, the traditional train and the proposed train can operate on the same track. This makes a transition to a new standard technology possible without major capital losses.

The benefits of the proposed system provide great opportunities to solve a multitude of problems with the current methods of transport. Specifically, this means a saving on construction, maintenance, energy costs. The related operating costs will be significantly more favorable with respect to current transport. The result is a lower carbon emission through reduced energy consumption. This has a positive effect on energy consumption and the environment and fits into European (EU) and international policy.

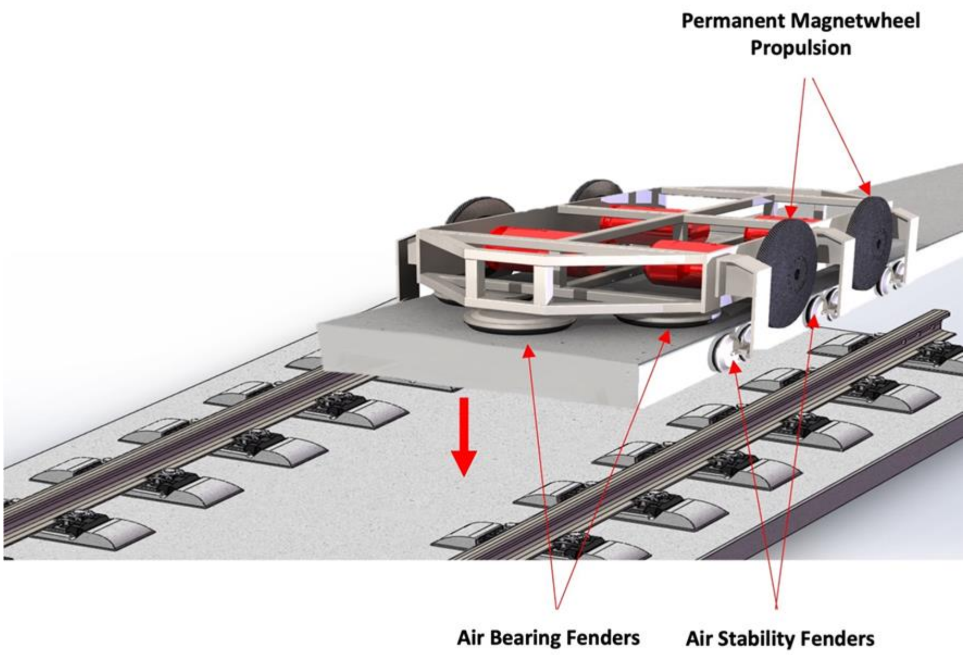

Figure 3. Suspension and propulsion systems

Suspension

By using compressed air in specially developed Air Bearing Fenders, suspension is realized with the proposed system (Figure 3).

Guidance

Likewise, the levitation by air bearing fenders in vertical direction, guidance in lateral (perpendicular to the driving direction) can also be realized by using air bearing fenders.

Propulsion and Braking

Extensive research has been conducted into the possibilities of contactless braking and propulsion. This has led to a principle based on induction. This principle has been further investigated, developed, modelled/calculated.

The above configuration of drive wheel and conducting strip has been calculated using simulation software specially developed for this purpose. A scale model has also been built with which small-scale tests have been carried out. This has demonstrated the working principle and various measurements have also been carried out. The measurements and model calculations agree very well.

The simulations and calculations of the model intended for propulsion of the train have shown that the configuration provides a maximum propulsion force at a difference speed between magnets and conductor of approximately 3-4 m/s. The propulsion force available from one drive wheel is approximately 7.5 kN.

In a train equipped with 8 magnetic wheels, the total traction that can be provided with the magnetic wheels is 60 kN. This allows the train considered to achieve a maximum acceleration up to 1 m/s^2. This also applies to braking. By connecting the magnetic wheel to an electric motor and generator, part of the braking energy can be recovered, which contributes to a more favourable energy efficiency.

In conclusion, the research has led to a useful propulsion and braking concept. The drive is contactless and therefore has major advantages in terms of wear, (no) fine dust released, no wheel-rail contact noise, insensitive to problems such as slippery tracks etc.

5.2.2.2 Hybrid MDS based on magnetic levitation

A hybrid MDS system based on magnetic levitation generally refers to a transportation system that relies both on wheel-based suspension and magnetic levitation suspension in combination or during different operative conditions. As an example, the vehicle can operate on wheels during switch crossing or platform approaching and on magnetic levitation systems on dedicated maglev corridors. The propulsion can be wheel-based during wheeled operation while different technologies can be adopted during maglev operations. A proper choice of the propulsion technology must be done based on a compatibility study and an economic evaluation. The vehicle shall be designed to ensure the compatibility with the existing or upgraded railway infrastructure as well as the interoperability of the transportation system.

Here below are presented two different cases:

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

Series hybrid MDS – traditional rail

As an example (Figure 4), here below a description of a series hybrid based on levitation coupled with a traditional rail. The system is based on the coupling of a standard wheel-based bogie with a series of sliders systems distributed along the length of the wagon. On the infrastructure side, the system is applied in a standard track with traditional switching systems.

Figure 4.Coupling of a standard wheel-based bogie with a series of Ironlev sliders

Ironlev system is designed to be anchored and disconnected to the rail based on the operating phase of the vehicle: during low-speed switch crossing, the Ironlev system is magnetically removed from the rail and the vehicle operates on wheels; instead, during speed cruise phase, the Ironlev system is engaged and bears the load of the wagon, the system operates in a hybrid load configuration.

In addition, the Ironlev slider could be partially engaged to create a magnetic force downward that increase the contact force on bogie wheels (Figure 5). This configuration is adopted for improving wheels grip during acceleration and braking phase.

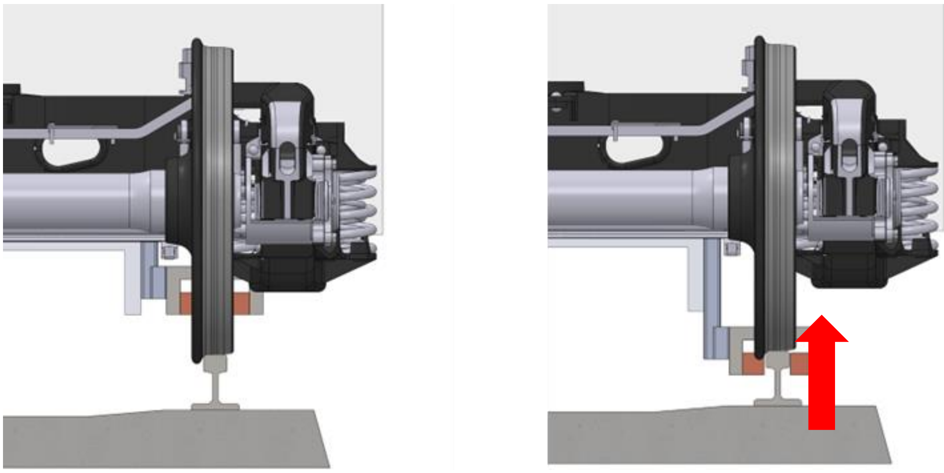

Figure 5.Configuration of boogie-wheels

Parallel hybrid MDS – additional guideways

Another example of hybrid MDS based on magnetic levitation is presented here. The Ironlev system with custom rails can be adopted in combination with traditional wheeled systems to obtain a hybrid system architecture where traditional wheels are used at low speed and over track switches, while there are dedicated maglev corridors in between for high speed and high efficiency ride (Figure 6).

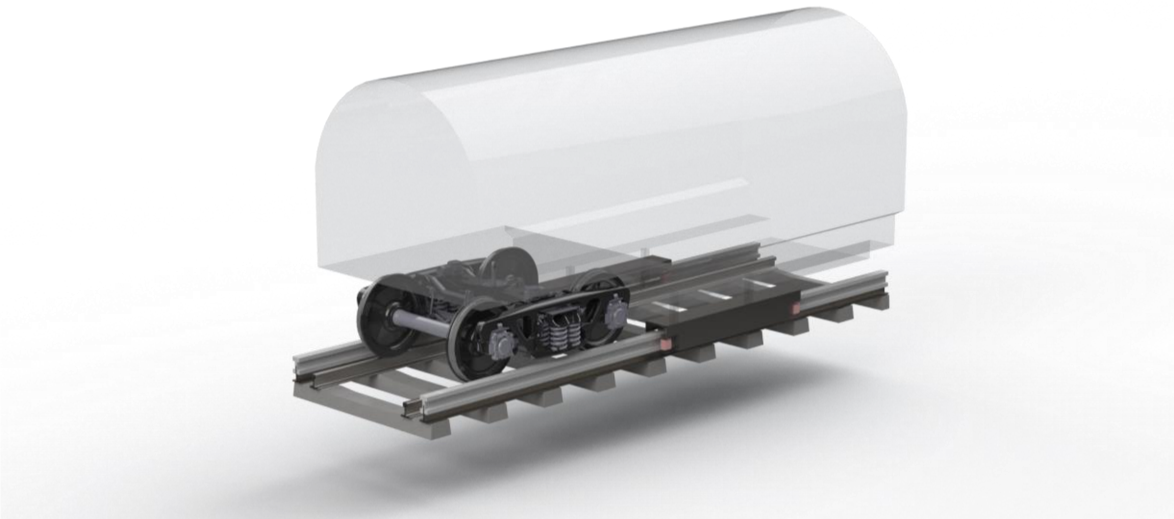

Figure 6.Custom rails adopted in combination with traditional wheeled systems

The system is a complete maglev contactless vehicle that couples levitation support for vertical load (wagon weight) with EMS guidance. EMS guidance is obtained by using electromagnets coil pairs positioned at the end of the slider that interact with the ferromagnetic rail head. EMS system is equipped with a control system that maintains the slider centred around the lateral equilibrium position. By maintaining the equilibrium position, the lateral force is around zero and so coils current is limited. When a lateral load occurs (e.g., turning phases), the EMS system misaligns the magnetic part to counteract the load, minimising EMS lateral force. This architecture is designed to increase the overall efficiency of the system by eliminating the contact friction.

This layout enables complete integration with linear motor propulsion and braking by using LIM or LSM.

5.2.3 Conventional system upgraded with MDS technologies

A conventional system upgraded with MDS technologies refers to a transportation system that relies both on wheel-based suspension and magnetic levitation suspension in combination or during different operative conditions. 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.

A possible application of a conventional system upgraded with MDS technologies is rail platform upgraded with linear propulsion. It serves as a railway transport solution for the movement of goods using traditional rail infrastructure, such as freight yards, sidings and, where possible, open railway networks. This innovative system utilizes adapted freight wagons equipped with a linear motor rotor with permanent magnets and the necessary vehicle electronics.

The modernization of the conventional rail infrastructure involves installing a linear motor stator, power and control systems for the linear motor, and advanced communication systems. This integration allows for the smooth movement of goods, providing a convenient and rapid solution within industrial complexes (closed rail network) or between various facilities via the European rail network. It is worth noting that this maglev-based system eliminates the need for heavy shunting locomotives, emphasizing efficiency and flexibility in the transportation of goods.

An example of such a modernized system is the MagRail Booster. The vehicles are retrofitted freight wagons equipped with a linear synchronous motor drive and other necessary components, such as position sensors, pressure tank, onboard electronics, communication components, etc. Railway wheels and rails serve as the suspension and guidance for the MagRail Booster. On the infrastructure side, there is a linear motor stator. The system structure of the MagRail Booster's retrofitted wagon concept is presented in Figure 7.

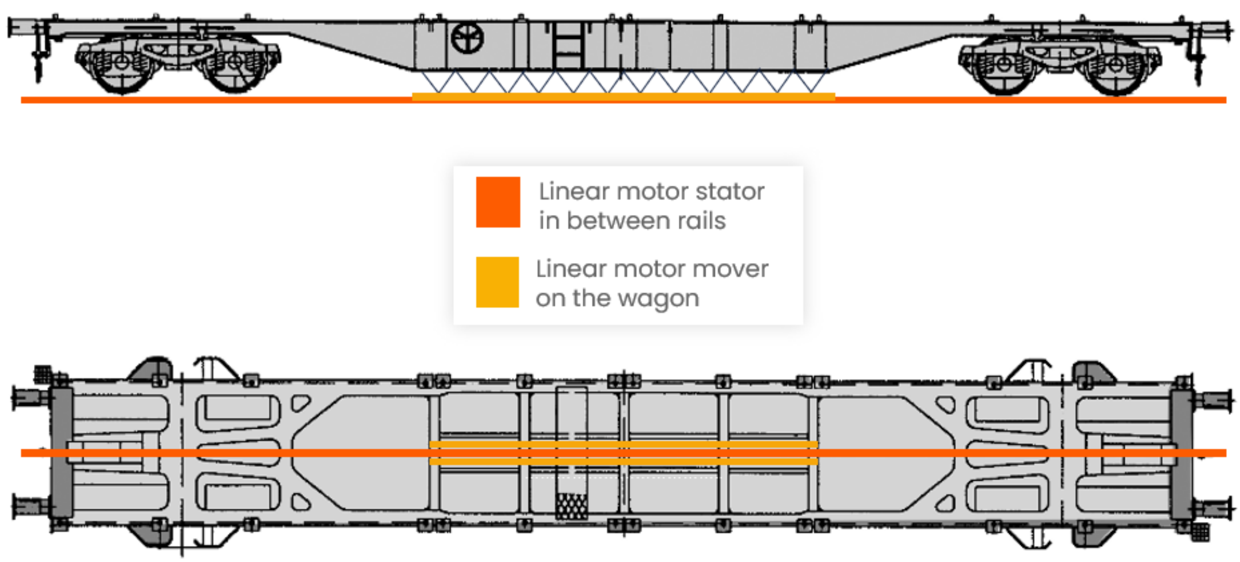

Figure 7.Linear motor-powered retrofitted freight platform – MagRail Booster

Specific use cases for this application were identified in in WP7 (MaDe4Rail D7.1, 2023). Two examples of the most relevant use cases with very high ratings in the Multi Criteria Analysis (MCA) performed in (MaDe4Rail D7.1, 2023) are the incline pusher along the routes with steep inclines and the idea of terminal electrification.

The first best rated use case was the ***Incline Pusher***. Short but steep inclines limit the maximum load of a complete freight O/D connection service. Reduced loading limits due to steep inclines will require additional locomotives for the whole run or on the steep section (with additional operational stops) or reduced loads/ weight of the trains on the whole run. A punctual solution for additional traction is needed instead of constructing an expensive piece of infrastructure (e.g., tunnels and bridges), which could be provided using a linear motor with a defined number of retrofitted wagons where it is needed. Trains can run with more loads and faster on inclines. Capacity and punctuality will increase when overcoming the problem of low adhesion.

The use case of ***terminal electrification*** was the next use case for this application. Terminals of intermodal traffic cannot be electrified because of cranes above the tracks for loading and unloading of wagons and trucks. Electrification in shipping harbours also might interfere with logistic operations. Due to the gauge limitations of a catenary system, different vehicles cannot move around freely. That is why in terminals and harbours rail vehicles usually only can be moved by changing from electrical loco to a diesel-driven shunting locomotive. Ideas of using new battery-driven locomotives or also new locomotives powered by an inductive power system still need drivers, which will be a critical resource; even though such systems are not in place today. Linear propulsion system underneath the trains can be installed to move vehicles from "final station of the train run" to the terminal without catenary and without a locomotive or driver. Tracks can be electrified from below without interrupting the processes within the terminal, harbour or logistic area. Linear motors including a control system can be installed in the needed areas to move trains or train sections / wagon groups from the arrival station to the terminal tracks automatically.

5.3 Benefit identification processes

The expected benefits will be by importing the MDS technologies to the railway system. The main advantage of MDS systems is the reduction in friction, which can result in higher speeds, better energy efficiency, lower maintenance costs compared to traditional rail systems. The benefits of each subsystem, as defined in the Work Breakdown Structure (WBS defined in (MaDe4Rail D2.1, 2023), and considering the Technology Readiness Assessment (TRA) done in (MaDe4Rail D6.1, 2023), are discussed in following paragraphs.

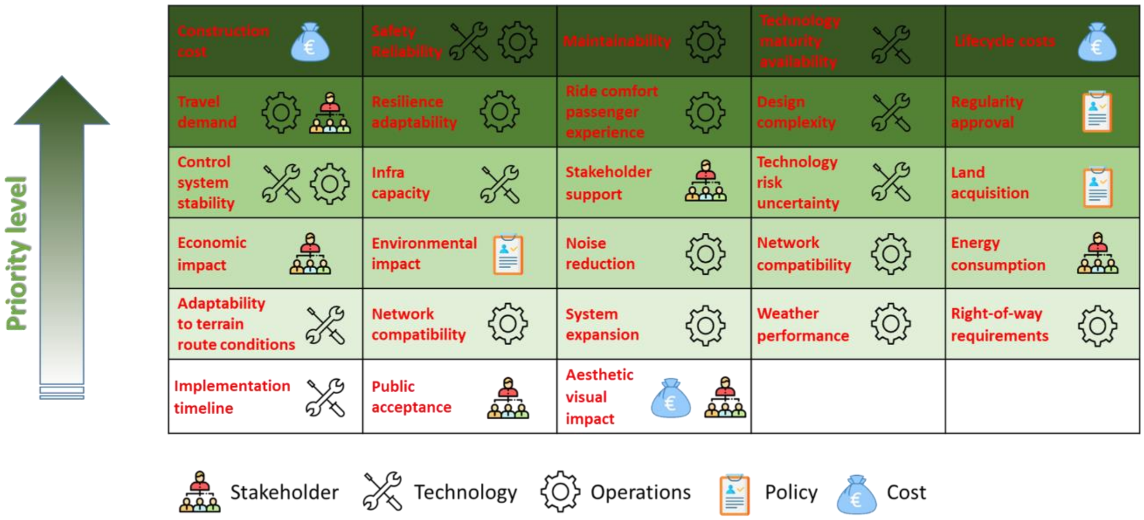

Figure 8.Technology Readiness Assessment

5.3.1 Structure

Using existing rolling stock structure whether it is a freight platform or a passenger rolling stock may be beneficial. The ease of re-homologation for existing platforms represents a significant advantage in the structure of rail vehicles equipped with MDS.

Cost Efficiency: Utilising existing platforms simplifies the re-homologation process, reducing the overall cost associated with obtaining new certifications. This is because much of the original structural and safety-related groundwork has already been established and approved.

Time Savings: Re-homologating an existing platform generally requires less time compared to certifying an entirely new rail vehicle. This results in quicker implementation and deployment of the MDS technology, facilitating a timelier integration into existing rail networks.

Proven Structural Integrity: Existing platforms have typically undergone extensive testing and validation for safety and structural integrity. Reusing these platforms for MDS-equipped vehicles leverages the proven track record of the original design, instilling confidence in the safety and reliability of the upgraded rail vehicle.

Regulatory Familiarity: Regulatory authorities are likely already familiar with the existing platform, making the re-homologation process more straightforward. This familiarity can expedite the approval process as regulators can build upon their existing knowledge of the platform's design and performance.

Enhanced Adaptability: MDS technologies can be more seamlessly integrated into existing platforms, allowing for greater adaptability and compatibility with established rail infrastructure. This adaptability enhances the versatility of the rail vehicle, making it easier to incorporate into diverse rail networks.

Reduced Environmental Impact: Reusing existing platforms aligns with sustainability goals by minimizing the need for manufacturing new rail vehicles. This approach contributes to reducing the environmental footprint associated with the production and disposal of rail vehicles.

5.3.2 Propulsion vehicle-part

Linear Induction Motor (LIM)

The MDS offers a myriad of benefits, encompassing cost efficiency, environmental impact, and technological advancements. The advantages include substantial savings in vehicle operating costs, a significant reduction in noise emissions, and variations in air pollution and Greenhouse Gas (GHG) emissions. The system ensures safe automation, eliminating wear through contactless traction and braking forces transmitted to the ground, facilitating seamless navigation over high slopes.

Additionally, the MDS introduces a low-cost track impact, attributed to the passive armature of the LIM. The integration of LIM design with the vehicle/railcar involves meticulous checks, such as verifying air gap distance with the LIM armature mounted on the track and ensuring railway gauge compatibility with established standards. Notably, the linear induction motors can be divided and powered by separate converters, enhancing system availability, contributing to the overall efficiency of the transportation network.

Direct drive allows contactless traction/braking (independently for the adherence coefficient, reduction of topographical constrains by over passing high slopes). Full automation of the wagon with obstacle detection and communication. On-board electrification allows safe and quick container transhipment (without any additional handling equipment required).

LIM can achieve a structure cost reduction, due the simple mixed armature (steel/aluminium) in-between the rails, with:

- Variation in noise emissions and air pollution (onboard electrical supply of reefer containers).
- Accurate and safe braking mode, essential for the system automation.

Linear Synchronous Motor (LSM)

Benefits associated with the use of LSM in the Maglev-Derived System (MDS) include:

- **Travel Time Savings:** direct drive eliminates slippage, leading to more efficient energy transmission and reducing overall travel time.
- **Variation in Noise Emissions:** the absence of direct contact between the wheel and the track eliminates friction-related noise, resulting in reduced noise emissions for a quieter travel experience.
- **Variation in Air Pollution:** utilizing a separate direct drive allows for more efficient and cleaner energy sources, contributing to a decrease in air pollution emissions.
- **No-Slip on Inclined Tracks:** the slip-free direct drive enables effective operation on inclined tracks, enhancing system flexibility and adaptability to diverse terrain conditions.

The implementation of LSM technology in the railway system involves a series of high-level engineering and design actions. To begin, a meticulous analysis of existing railway regulations is conducted, identifying gaps, and proposing necessary amendments for seamless integration. The capacity of the current railway infrastructure is then assessed, with considerations for sleepers' redesign and the design of mountings to accommodate LSM stators. Electromagnetic compatibility checks ensure harmonious coexistence with other systems.

A comprehensive maintenance regime is designed, addressing preventive and corrective measures to ensure the reliability of LSM components. This includes routine inspections, testing, strategic replacement of critical parts. Simultaneously, existing command control schemes are re-examined and adapted to the unique characteristics of LSM technology. Advanced control algorithms are considered, ensuring compatibility with the railway network's signalling and communication systems, while cybersecurity measures are implemented for system protection against potential threats. These collective actions form a strategic blueprint for the successful introduction of LSM technology into the railway system, encompassing regulatory compliance, infrastructure readiness, maintenance planning, and optimized command and control mechanisms.

Lateral wheel-based propulsion

- **Travel time savings**: by adjusting contact force that is not dependent on vehicle weight it is possible to improve traction/braking performances and to reduce overall travel time.
- **Variation in noise emissions**: thanks to the fact that systems does not bear the weight of the wagon, alternative material to steel can be adopted, such as rubber and polyurethane that strongly reduce noise and vibrations.

Electro-Dynamic wheels (EDW)

EDW are importable back to the railway system. The macro expected benefits using EDW would be the following points:

- **Vehicle operating cost savings**: reduced Fuel Consumption, EDWs can improve the efficiency of electric vehicles (EVs) by regenerating energy during braking, like regenerative braking systems in current EVs; this means less energy is wasted, reducing the frequency of recharging for electric vehicles and fuel consumption in hybrid vehicles,
- **Variation in noise emissions**: traditional internal combustion engine vehicles generate significant noise due to the engine and exhaust systems; electric vehicles with EDWs, by contrast, operate much more quietly, the EDW system itself, being primarily electric, produces minimal noise compared to conventional engines and mechanical brakes,
- **Variation in air pollution**: EDWs, utilizing regenerative braking, can reduce reliance on mechanical brakes, thereby potentially decreasing the amount of brake dust released into the air, which is a source of airborne particulate matter,
- **Variation in GHG emissions**: by improving efficiency and reducing fuel consumption, EDWs can also help in reducing emissions; this not only benefits the environment but can also lead to savings in terms of taxes and fees related to emissions in some regions.

More precise expected benefits to justify that the technology is importable are given below.

- **Extremely low damages to track**: EDW offers substantial benefits in minimizing track damage. Their design ensures a more uniform weight distribution and reduced stress on tracks, leading to less wear and deformation. This extends track life, lowers maintenance costs, and enhances overall efficiency in rail systems, making EDWs a valuable advancement.
- **Technology in the train not in the track, leading to low rebuilding/construction costs**: EDWs, integrated into trains, distribute weight more evenly and reduce stress on tracks, decreasing wear and tear. EDW shifts the high requirement from track to train, lessening the need for frequent track maintenance and rebuilding. Consequently, it offers a cost-effective approach to railway infrastructure, reducing long-term construction and repair expenses.

The possible indicators to measure the expected benefits are:

- **Maintenance cost**: need for regular inspections, repairs, and upgrades of tracks, signalling systems, and rolling stock; these expenses ensure safe, efficient operations but can be substantial, encompassing labour, materials, technology; EDWs in trains can reduce these costs by minimizing track wear.
- **Track construction cost**: it includes concrete and aluminium, much lower than copper coils; Low maintenance frequency leads to lower cost.
- **Noise intensity measurement**: when measuring the specific noise intensity of normal wheel-rail systems versus EDW, several key methods are used: sound level meter, frequency analysis vibration measurements, microphone arrays.
- **GHG emission measurement**: to measure GHG emissions from wheel-rail and EDW railway vehicles, one assesses the energy consumption and efficiency of each system; EDWs, being more efficient, typically result in lower energy use and, consequently, reduced GHG emissions; this assessment includes analysing fuel or electricity consumption and converting it into equivalent CO_2 emissions.

Track rebuilding and vehicle design integration are needed for high level engineering and/or designing actions required to adopt the technology in the railway system.

- **Track rebuilding**: Aluminium plate with concrete slab is inserted between two rails in normal railway tracks.
- **Vehicle design integration**: Integrating Electro-Dynamic Wheels (EDWs) into vehicle design involves optimizing the wheel assembly for electric propulsion and regenerative braking. This requires redesigning the wheel system for electrical components integration while ensuring structural integrity. The design must also account for efficient energy transfer and maintain compatibility with existing vehicle frameworks.

5.3.3 Suspension

5.3.3.1 Benefits of Airlev technologies adoption

Fender

Fender can be imported back to the railway system. The macro expected benefits using air fender would be the following below.

- **Variation in noise emissions**: Air fenders can effectively dampen vibrations and reduce the noise generated by wheel-track interaction. This leads to quieter operations, benefiting both passengers and communities near railway lines by minimizing noise pollution and enhancing the overall environmental quality.
- **Enhanced Passenger Comfort**: the use of air fenders in air cushion vehicles provides a smoother ride by absorbing vibrations and shocks more effectively than conventional systems. This results in enhanced comfort for passengers, particularly over rough or uneven track sections.
- **Reduced Track Wear**: Air cushion vehicles with air fenders exert significantly less pressure on tracks than traditional rail vehicles, leading to reduced track wear and tear. This translates to lower maintenance costs and extended track lifespan, offering a cost-effective solution for long-term railway infrastructure management.

More precise expected benefits to justify that the technology is importable are given as follows.

- **Increased Speed Potential**: Air cushion vehicles with air fenders can potentially achieve higher speeds due to reduced friction between the vehicle and the track. This can lead to faster travel times and increased efficiency in transport schedules, making rail travel more competitive with other modes of transportation.
- **Lower Energy Consumption**: The reduced friction from using air fenders also means less energy is required to propel the vehicle, leading to improved energy efficiency. This can result in lower fuel costs and reduced greenhouse gas emissions, aligning with environmental sustainability goals.
- **Enhanced Safety Features**: Air fenders provide an additional layer of safety by absorbing impacts more effectively, potentially reducing damage in the event of a collision or derailment. This can enhance the overall safety of rail transport, providing a more secure travel experience for passengers.

Track rebuilding and vehicle design integration are needed for high level engineering and/or designing actions required to adopt the technology in the railway system.

- **Track rebuilding**: Aluminium plate with concrete slab is inserted between two rails in normal railway tracks.
- **Vehicle design integration**: Integrating air fenders into vehicle design requires adapting the vehicle's undercarriage to accommodate inflatable cushioning systems. This involves ensuring structural support for the air cushions while maintaining aerodynamic efficiency and compatibility with existing track infrastructure, all within the constraints of space and weight limitations.

5.3.3.2 Benefits of magnetic levitation suspension adoption

Travel Time Savings: the reduction of friction gives the advantage of increase mean speed during travel, thus reducing overall travel time.

Vehicle operating costs savings: the absence of friction increases the efficiency of the vehicle and reduces operating expenses, such as energy related costs.

Variation in noise and vibration emissions: the absence of direct contact between the wheel and the track during maglev operating conditions eliminates friction-related noise, resulting in reduced noise and vibration emissions for users and for people living nearby.

Infrastructure operating costs savings: the infrastructure cost savings are both in terms of reduction of replacement parts and reduction of maintenance, giving an overall reduction of expenses.

Variation in air pollution and greenhouse gases: the reduction of energy consumption gives the additional benefit of reducing overall air pollution of GHG emissions. In addition, the reduction of maintenance costs, such as replacement guideway or infrastructure parts reduces the overall need and production of steel-based parts, giving additional environmental benefits from a LCA perspective.

Accident savings: some technologies such as passive ferromagnetic systems, are characterised by a bilateral support capability. In particular, the system is magnetic anchored to the rail, preventing derailment and increasing vehicle dynamic stability during curves.

No need for additional infrastructure: in some cases, there is no need for additional guideways, giving huge savings in terms of infrastructure capital expenses.

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- **Increased Speed Potential**: Air cushion vehicles with air fenders can potentially achieve higher speeds due to reduced friction between the vehicle and the track. This can lead to faster travel times and increased efficiency in transport schedules, making rail travel more competitive with other modes of transportation.
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Track rebuilding and vehicle design integration are needed for high level engineering and/or designing actions required to adopt the technology in the railway system.

- **Track rebuilding**: Aluminium plate with concrete slab is inserted between two rails in normal railway tracks.
- **Vehicle design integration**: Integrating air fenders into vehicle design requires adapting the vehicle's undercarriage to accommodate inflatable cushioning systems. This involves ensuring structural support for the air cushions while maintaining aerodynamic efficiency and compatibility with existing track infrastructure, all within the constraints of space and weight limitations.

5.3.4 Guidance

5.3.4.1 Benefits of Airlev technologies adoption

Fender

The specific benefits of using fender for guidance are like that for suspension.

5.3.4.2 Benefits of magnetic levitation guidance adoption

The specific benefits of using magnetic levitation guidance are like that for suspension.

Benefits of the U-shaped armature for LIM: by using LIM, the higher power factor requires a narrow air gap between the embedded LIM inductor and the armature fixed on the track. The extensive experience acquired on the wheel ware showed that the wheel tread is far more impacted than the railway wheel flange, then the advantage of the U-LIM is that the lateral airgap can remain more constant during lifetime than the vertical airgap. The magnetic guidance on the lateral edges of the U-shaped armature is therefore more stable during the material lifecycle.

High level engineering and/or designing actions required to adopt the U-LIM guidance system.

This system has already been tested up to 300 km/h on Grenoble Wheel test bench, but it has not been yet tested and implemented on a conventional railway.

5.3.5 Braking

Electrodynamic wheels (EDW)

The specific benefits of using EDW for braking are like that for propulsion.

Lateral wheel-based braking

The specific benefits of using lateral wheels for braking are like that for propulsion.

Linear Induction Motor (LIM)

The incorporation of LIM in MDS presents notable advantages from the braking perspective. The contactless braking system of LIM technology ensures extremely low track damages, providing a solution that is gentle on the infrastructure. This not only contributes to prolonged track life but also reduces maintenance requirements and associated costs.

The braking mechanism in LIMs operates without physical contact between components, minimizing wear and tear. This contactless nature of braking results in a smoother and more controlled deceleration process for vehicles within the Maglev system. Additionally, the absence of friction-related issues enhances safety, as it eliminates concerns such as overheating and traditional brake wear.

In summary, the braking advantages of Linear Induction Motors in Maglev-Derived Systems encompass reduced track damages, lower maintenance needs, enhanced safety, and a more controlled and efficient deceleration process.

To successfully implement the technology in the railway system, it is essential to undertake high-level engineering and design actions. This includes the need for a relevant adaptation between Linear Induction Motor (LIM) and Pulse Width Modulation (PWM) converter to facilitate hypersynchronous regenerative braking. Additionally, ensuring control over highly reliable energy storage becomes crucial for emergency braking through DC injection.

Lateral wheel-based propulsion and braking

The MDS with lateral wheel-based propulsion/braking offers several advantages. It enhances safety, preventing accidents and ensuring higher overall safety levels. The lateral wheel-based propulsion and braking system is highly controllable, allowing for precise control positioning. Additionally, the system exhibits a high deceleration capability, contributing to efficient braking and control over the vehicle's speed. In summary, the lateral wheel-based propulsion/braking configuration in the MDS ensures a secure and controlled transportation experience with enhanced safety and precise control.

High-level engineering and designing actions necessary for the implementation of lateral wheel-based propulsion and braking technology in the railway system involve the integration of vehicle design. This includes thorough checks for Electro-Magnetic Compatibility (EMC) and compatibility with railway gauge standards. These actions are crucial for ensuring seamless incorporation and alignment of the lateral wheel-based propulsion/braking system within the existing railway infrastructure, meeting safety and operational standards. The comprehensive vehicle design integration process addresses key factors such as EMC considerations and adherence to established railway gauge norms, ensuring the successful adoption of this technology in the railway system.

5.3.6 Vehicle control system

For MDS there are three levels of the command control system to be considered:

1. The on-board vehicle control system which is called for trains the train control and monitoring system (TCMS).
2. The trackside control system which called for conventional systems the train control system or automatic train protection (ATP) and operation (ATO).
3. The traffic management system (TMS) which is typically not safety-critical

The related actions are mentioned below.

Compared to conventional trains currently in use, there are no specific benefits in using a TCMS for MDS. This is a transversal approach applicable to all new generation rolling stocks.

A Train Control Management System (TCMS) is the centralised supervision system for all train subsystems, doors, lights, air conditioning, brakes, communication with the outside world, batteries, water tanks and much more. This supervision is not only formed by computing units but also communication systems that interconnect these elements. It includes traditional communication channels such as the MVB (Multifunctional Vehicle Bus) and CAN, but also Ethernet networks with new generation protocols. To this, many input/output devices and gateways, that is, signal routing systems, are added. The TCMS is therefore the train's brain and nervous system and must be carefully designed, simulated and tested. The purpose of the TCMS is to make the train run efficiently, with passenger safety always the highest priority.

The operational advantage in using an MDS with a new generation TCMS is certainly the optimisation of energy consumption and a better distribution of traction to achieve service operating standards. For this reason, a better and more efficient solution for a new generation TCMS is desirable.

A system such as this makes use of numerous human-machine interfaces (HMI) that allow the status of the train's equipment to be communicated to human operators, adding another dimension to the complexity of the TCMS software. The modern TCMS architectures prioritise modularity, that is, the ability to easily add new hardware into the network that adds new features for trains.

These features can be safety and non-safety (HVAC, Lights) and must be managed with different priorities, placing their communication on traditional buses, such as the MVB and CAN or specialised Ethernet networks.

New forms of wireless communication between train equipment and external entities (Train to Wayside Communication System) are also in full development as they allow the implementation of advanced predictive diagnostics or energy efficiency features.

The full impact of the health emergency is yet to be understood and quantified, but it will undoubtedly involve new safety systems and new ways of using coach space. However, one trend is certainly predictable, that of allowing passengers to personalise their seating space, offering them multimedia content and internet connections.

The use of this new generation of TCMS together with the specific optimization for MDS vehicles certainly has the effect of proposing specific solutions characterized for the railway service.

The on-board vehicle control system needs to be developed more or less completely new as it is either non-existing today for freight waggons or not suitable as the today's TCMS in passenger multiple units. As this is closely linked to propulsion, braking and suspension, it has been discussed in the previous paragraphs already.

The adoption of the trackside control system is very different for full MDS on the one hand and hybrid and upgraded conventional system on the other hand:

Full MDS: A completely new, independent development and implementation of the systems for trackside vehicle control and movement supervision. Any existing technology may be used, but architecture, technology and design decisions can be taken completely free. For some MDS the system may be substantially simpler as the long-stator solution ensures the train separation already integrated in the propulsion system as e.g., in the Transrapid in Germany proven.

Hybrid and upgraded conventional MDS: Two actions to be taken for the ATP/ATO Systems:

1. Extending the systems for trackside vehicle control and movement supervision to include the MDS specifics.
2. Protecting the systems against the raised electromagnetic influence, e.g., balises, axle counters and especially (coded) track circuits need made robust against the electro-magnetic fields (which may be impossible in many cases due to different reasons) or need to be removed from critical areas at the rails.

The traffic management system (TMS) needs only a specific train type definition e.g., by adopted braking and accelerating parameters in the software, but no substantial change.

5.3.7 Electrical system

Pantograph and Overhead catenary

Pantograph and overhead catenary are technologies used by some MDS (e.g., Yokohama municipal subway 10000 series, Ironlev hybrid system, SkyTrain rolling stock, Toei Ōedo Line subway, Sendai Subway Tozai Line). In this case, most of these technologies are already present and widely used in the railway system (and this is the greatest benefit).

The advantages are the following:

- using a well-known technology,
- no need to create a new technology,
- no need to maintain two different technologies together,
- in the end, an overhead system instead a grounded one, is easier to protect from theft and vandalism and safer for people.

Since this is technology already present in the railway system, any necessary high-level engineering and/or design actions required to adopt the technology in the railway system are probably to be carried out on the vehicle.

Ground-level power supply system

This electrical system 750V DC, is a well-known technology developed by Alstom, already functional on several tramways for 20 years. This solution seems relevant for local freight MDS, that allows operating on non-electrified conventional railway, by installing the electrical rails in the centre of the track.

This system is fully electrically safe for people and the track environment, as the rail section and the voltage are only switched on when covered by the vehicle.

This solution enables the vertical lifting/transhipment of the freight transported (e.g., Open Top containers).

5.3.8 Systems for Monitoring, Control, and Safety Supervision

The expected and specific benefits for systems for monitoring, control and safety supervision strongly depend on the type of MDS system adopted. For Hybrid MDS and conventional MDS upgraded systems, it can be assumed that the existing systems for monitoring, control and safety supervision have to be continued and more or less extended to support MDS, too. The more disruptive full MDS are opening the space for more innovative solutions without being bound to legacy technologies but consequently not being interoperable, which full MDS are anyway not.

High level engineering and/or designing actions required to adopt the technology in the railway system

Diagnostic and signalling systems on vehicles should be independent of the technology adopted but must provide the driver with the information necessary to safely drive the train. For the diagnostic part shown to the driver, the main information comes from the TCMS, described above, which is the system that controls the train.

The new generation TCMS offer an interface that covers all diagnostic aspects relating to traction, electrical power supply and the status of the braking system. The TCMS does not directly control these modules but receives diagnostic information from them, harmonizes it and makes it available to the driver through a dedicated interface (HMI).

With regards to the signalling system, it is necessary to refer to the ERTMS/ETCS system. The signalling system has been designed to be independent of the vehicle in which it is installed. When the technological choice was made for the creation of the signalling system in the railway sector, MDS vehicles were not considered. For this reason, the technology must adapt to the rules and limitations imposed by the ETCS system to be interoperable and circulate on the same lines that are already equipped with the ETCS system.

Since the signalling aspects are independent of the technology, there are no specific benefits in adopting MDS vehicles.

A positive side effect in the adoption of MDS vehicles is the accuracy of the odometry compared to vehicles with conventional traction. This aspect is very important because one of the foundations on which signalling systems are based concerns the position of the train and therefore the relative distance that the vehicle has travelled with respect to a specific point along the line. In the ETCS system these references are the EUROBALISE installed on the track sleepers. If the odometry is precise, the greater the efficiency of the "railway" system and the risk of having potential delays in the management of the lines is reduced.

To guarantee full interoperability, the MDS system must comply with the Technical

Specification of Interoperability (TSI) and therefore, must not produce interference with the signalling system and in particular, in its own communications which concern the dialogue with the Eurobalises and the radio communication in the GSMR band with control systems installed along the line.

The signalling system, therefore, exports a series of requirements to the vehicles.

This aspect, which initially could be a constraint, instead turns out to be an added value because once the MDS vehicle is certified as interoperable for an ETCS line, it will be able to operate completely on all compatible lines in all countries that implement ERTMS systems. /ETCS and which can operate with MDS vehicles.

The actions can be grouped in two groups depending on the MDS adopted:

Full MDS: Completely new, independent development and implementation of the Systems for monitoring, control and safety supervision. Any existing technology may be used, but architecture, technology and design decisions can be taken completely free.

Hybrid and upgraded conventional MDS: Two actions to be taken are as follows.

1. Extending the Systems for monitoring, control and safety supervision to include the MDS specifics as e.g., for a parallel hybrid MDS not only the derailment of the rail wheels needs to be supervised but the MDS-rail needs to be supervised, too.
2. Protecting the systems against the raised electromagnetic influence, e.g., sensors either need to be removed from critical areas at the rails or made robust against the electro-magnetic fields.

5.3.9 Guideway

The expected and specific benefits for the guideway strongly depend on the type of MDS system adopted for suspension and guidance.

High level engineering and/or designing actions required to adopt the technology in the railway system

The actions are related to the type of MDS adopted.

Full MDS: complete design and re-engineering of the guideways.

Parallel hybrid MDS: this system is based on the use of parallel additional guideways for maglev corridors. The main actions required are the design and integration of additional guideways, sleepers and fastening systems redesign and substructure integration, compatibility analysis.

Series hybrid MDS: This system is based on the adoption of traditional guideways without modifications. For the adoption it is required to modify some auxiliary elements, such as railway pedal, railway junctions and all the other auxiliary elements that interferes with rail head section. In addition, rail head section shall satisfy dimensional tolerances (as an example, welding shall be grinded on both sides, internal and external).

5.3.10 Switches and segment switches

Existing conventional railway infrastructure

The integration of linear motors in switches and segment switches within the existing conventional railway infrastructure results in noteworthy advantages. Firstly, there are notable travel time savings attributed to the efficient performance of linear motors in the switches area. Their design allows for quicker passages through these crucial points in the railway network.

Moreover, the application of linear motors enhances the acoustic environment of the entire system. The contactless transmission of thrust force by the linear motor technology contributes significantly to noise reduction. This innovation not only ensures operational efficiency but also addresses environmental concerns by minimizing noise emissions in railway operations.

The implementation of linear motors in switches and segment switches within the existing conventional railway infrastructure necessitates high-level engineering and design actions. This involves a comprehensive design process for upgrading the infrastructure to accommodate linear motors. Key elements of this process include developing mountings for linear motors, ensuring seamless integration into the substructure, and verifying compatibility with electromagnetic compatibility (EMC) and railway gauge standards.

Additionally, redesigning command control schemes is a crucial aspect of this engineering initiative. This encompasses the adaptation and optimization of control systems to effectively manage the linear motor technology in switches and segment switches. The goal is to enhance the overall performance, safety, and reliability of the railway system through these technological advancements.

Upgraded conventional railway infrastructure

The implementation of linear motors in switches and segment switches within upgraded conventional railway infrastructure brings about several notable benefits. These advantages include significant time savings during travel and a notable reduction in noise emissions. The utilisation of linear motors in the switches area enables faster passages through these crucial points. Furthermore, the overall system benefits from quieter operations as the thrust force is transmitted contactless. This technological enhancement contributes to an improved and more efficient railway system, offering enhanced performance and reduced environmental impact.

To integrate linear motor technology into the railway system, several high-level engineering and design actions are imperative. These include the design of an infrastructure upgrade that incorporates specific mountings for linear motors, ensuring seamless integration into the substructure. Additionally, it is crucial to conduct checks for EMC and verify railway gauge compatibility with established railway standards. Redesigning command control schemes is also a key aspect of adopting this technology, ensuring that the control systems are optimized for the unique features of linear motor applications. These comprehensive actions pave the way for the successful implementation of linear motor technology in the railway system, enhancing its efficiency and performance.

5.3.11 Propulsion- Infrastructure part

Stator with multi-phase winding

Enhancing propulsion in the infrastructure segment through the application of a stator with a multi-phase winding brings numerous benefits in terms of efficiency and the environment. Key aspects include time savings in travel, reduction in noise emissions, mitigation of air pollution, and energy operating cost savings. Direct drive eliminates slip, allowing smooth operation on inclined tracks, and the linear motor makes the entire system more energy-efficient, resulting in lower operating costs. However, the implementation of this technology requires comprehensive engineering actions, such as designing infrastructure upgrades with mountings for the linear motor, integration into the substructure, rigorous testing for EMC, and verification of gauge compatibility with railway standards. Additionally, the redesign of command control schemes is necessary to effectively manage the new technological capabilities. These engineering efforts are crucial for the successful adoption of propulsion technology in the railway system, ensuring optimal benefits and efficient functionality.

Linear Induction Motor Stator

Implementing a LIM Stator in the infrastructure's propulsion system yields substantial advantages in safety, environmental impact, and operational efficiency. These benefits encompass accident prevention, reduction in noise emissions, alleviation of air pollution, reduction in greenhouse gas emissions, and operational cost savings for the carrier. The LIM armature can be strategically dimensioned to ensure compatibility with standard railway gauges and mounted between rail tracks, providing powerful contactless traction and propulsion capabilities. This configuration allows the system to navigate high slopes effectively and manage energy consumption through regenerative braking. Additionally, the low maintenance cost further contributes to the economic viability of this technology. The engineering actions required for successful adoption involve designing integrated fixes for the LIM armature on existing tracks, preferably using concrete sleepers. Ensuring railway gauge compatibility with established standards is crucial, and interruptions in the LIM armature can be strategically implemented at crossing rail/road positions and switches for enhanced operational flexibility and safety. These comprehensive engineering measures are essential for the effective incorporation of Linear Induction Motor technology in the railway system.

5.3.12 Substructure

All maglev systems use elevated track or tunnel track, then the track is installed on pillar using concrete foundation designed according to civil works standards (Eurocode or similar)

The structural components make up the reinforced foundation to support the standardized ground load gauge (EU STI) and satisfy the constraints of the very high speed, including the propulsion and guidance technologies, which are integrated into the track.

Importing MDS Structural components into the railway system is necessary if you want to increase speed or import other propulsion or guidance technologies; so, the measurable benefits provided would be:

- Increase max speed,

- low noise emissions.

because the structural components allow the previously mentioned technologies to be applied.

To import the MDS structural components it will be necessary:

- Design of infrastructure upgrade for the propulsion technology and for increasing loads
- integration with the existing substructure.

Ballasted railway track with sleepers and Railway slab track

Ballasted Railway Track with Sleepers and Railway Slab Track are technologies already used in the railway system. The use of already known technologies intrinsically gives the following benefits:

- using a well-known technology.
- technology used on almost the entire national network and well-known by maintainers (lower maintenance technician training costs),
- no need to create a new technology,
- no need to maintain two different technologies together.

Furthermore, in the case of Railway Slab Tracks we can add:

- longer life cycle;
- lower environmental impact.

Ballasted railway track with sleepers and Railway slab track are already used in the railway system, to use these technologies with other technologies imported from MDS systems will be necessary:

- integrations and updates with propulsion technology,
- integration in substructure,
- checking EMC and railway gauge compatibility with railway standards,
- redesign CCS schemes.

5.3.13 Power supply

Track power supply to Infrastructure for long track-side stator for propulsion

The integration of track power supply systems for long track-side stators in the infrastructure offers significant advantages, particularly in terms of vehicle operating cost savings. By using an infrastructure-based power supply, there is no necessity to equip each vehicle with an individual power supply system, leading to increased operational efficiency and reduced overall costs. The high-level engineering actions required for the adoption of this technology involve designing an upgraded infrastructure with specific mountings for power supply subsystems, ensuring seamless integration into the substructure. Rigorous checks for electromagnetic compatibility (EMC) and railway gauge compatibility with established standards are essential components of this implementation. Furthermore, a redesign of command control schemes is warranted to optimize the functionality and effectiveness of the power supply subsystems. These concerted engineering efforts are crucial for the successful integration of track power supply systems, promising both economic and operational benefits for the railway system.

Vehicle power supply to vehicle for all functions

The implementation of on-board power supply systems for all functions within the vehicle yields substantial benefits, particularly in terms of infrastructure operating cost savings. This approach eliminates the need for substantial investments in power supply infrastructure mounted along the track, contributing to a more cost-effective and streamlined operational model. To adopt this technology in the railway system, high-level engineering and design actions are necessary. This includes upgrading the vehicle design to accommodate power supply subsystems effectively, ensuring compatibility with established railway gauge standards. Additionally, a redesign of command control schemes is essential to optimize the integration and functioning of on-board power supply systems. These combined efforts are vital for the successful adoption of on-board power supply technology, promising economic advantages and operational efficiency within the railway system.

5.3.14 Sensing, Communication, Positioning Systems

The expected and specific benefits for Sensing, Communication and Positioning Systems depend as well on the type of MDS system adopted. For Hybrid MDS and conventional MDS upgraded systems it can be assumed that the existing systems for sensing, communication and positioning have to be continued and more or less extended to support MDS, too. The more disruptive full MDS are opening the space for more innovative solutions without being bound to legacy technologies but consequently not being interoperable, which full MDS are anyway not.

The new generation of systems that are being developed, mainly in the Europe's Rail R2DATO project, include the introduction of ATO up to GoA4 in the railway environment of train localization also with the use of GNSS receivers and multi-sensors solutions and the introduction of the FRMCS system for ground to train communications. It is important also to include innovations related to Wireless TCMS inside the train. All these innovations are to be taken into consideration as the new MDS vehicles are developed in the railway sector. In addition to the interoperability already required in the current TSIs, compliance with the new systems will obviously be required.

The new sensors for automatic driving in the railway sector which will be high visibility cameras but also radar and lidar sensors which are currently extracted from the automotive world, will require the new MDS vehicles to be compatible with them. Replacing the driver with an autonomous system will allow for greater repeatability of the system's behaviour and greater predictability of the behaviour of the vehicle itself.

The new FRMCS communication system that is being defined in recent years will allow the use of different types of wireless communication means, thus widening the availability of the network but on the other hand increasing the frequency bands to which the vehicle must be compatible. The FRMCS frequency bands for control and command are fixed with 2x4 MHz on the 900 MHz band with coexistence with GSMR during a given period of time and 10 MHz in the 1900 MHz band. This aspect also opens a set of EMC compatibility requirements that will fall on MDS vehicles. However, this represents an opportunity rather than a disadvantage.

The new systems for the absolute localization of the train along the line which are part of R2DATO's activities, have the objective of reducing the uncertainties of the train's position which can occur in degraded conditions or when the system restarts after it has been moved. Together with the mobile block system, the transversal benefit applicable to any type of vehicle is to reduce the system's downtime and increase punctuality and the density of vehicles along the line (i.e., the number of vehicles present along the line at the same time).

The actions can be grouped in two groups depending on the MDS adopted:

Full MDS: Completely new, independent development and implementation of the Systems for monitoring, control and safety supervision. Any existing technology may be used, but architecture, technology and design decisions can be taken completely free.

Hybrid and upgraded conventional MDS: Two actions to be taken are as follows.

1. Extending the Systems for sensing, communication and positioning to include the MDS specifics as e.g., for a parallel hybrid MDS not only the derailment of the rail wheels needs to be sensed but the MDS-rail needs to be supervised, too.
2. Protecting the systems against the raised electromagnetic influence, e.g., sensors, receivers and antennas either need to be removed from critical areas at the rails or made robust against the electro-magnetic fields.

5.4 Indicators for benefit quantification

5.4.1 Structure

OPEX parameters effectively highlight the variations in operating costs among the structures. Examining OPEX, or operational expenditures, provides insights into the ongoing costs associated with maintaining and running each type of maglev infrastructure. This includes expenses related to energy consumption, maintenance, and other operational factors. Therefore, analysing OPEX parameters allows for a comprehensive evaluation of the economic efficiency and sustainability of diverse maglev rail configurations.

5.4.2 Propulsion vehicle-part

Linear Induction Motor

The following parameters are suitable for comparing different Linear Induction Motors (LIM) solutions due to their ability to provide a comprehensive evaluation across various aspects of performance, cost, and environmental impact. OPEX (operational expenditures) and maintenance costs offer insights into the long-term financial implications and sustainability of each LIM system. Construction costs of LIM provide an understanding of the initial investment required for implementing the technology. Noise intensity measurement is crucial for assessing the environmental impact, especially in urban settings. Additionally, the measurement of GHG emissions contributes to the overall environmental evaluation.

Furthermore, factors like high reliability levels and the absence of critical materials and rare earth elements, as seen in specific cases like the U-shaped LIM, emphasize efficiency, sustainability, and reduced environmental footprint, making them significant considerations in the comparison of different Linear Induction Motor solutions.

The latest innovation in power electronics component and converter are economic (due to the mass production for urban rail cars and most recent electrical trucks), suitable and very well adapted to supply and control the LIM traction/braking operation in the most compact and reliable format, at a very high efficiency.

Electrodynamic wheels

The following parameters are well-suited for comparing various Electrodynamic Wheel solutions, offering a comprehensive evaluation across key factors related to performance, cost, and environmental impact. Maintenance cost is crucial for understanding the long-term operational expenses associated with each system, while track construction cost provides insights into the initial investment required. Noise intensity measurement is vital for assessing the environmental impact, particularly in urban environments, and GHG emission measurement contributes to the overall environmental evaluation.

Complete reliance on electrical power leads to zero greenhouse gas emissions, aligning with environmental sustainability goals. Additionally, the emphasis on noise emission reduction, achieved through no mechanical contact and noiseless braking, underscores the system's potential for minimizing environmental noise pollution. Overall, these parameters collectively provide a thorough basis for comparing and evaluating the efficiency, cost-effectiveness, and environmental impact of different Electrodynamic Wheel solutions.

LSM for Full MDS

The following parameters are suitable for comparing different Linear Synchronous Motor (LSM) solutions, offering valuable insights into key aspects of performance and environmental impact. *Delta time*, or the time difference, is a critical metric that indicates how the travel time may vary between different systems. Understanding this variance is crucial for assessing efficiency and overall system performance.

In the context of noise reduction, the emphasis on *noise emission reduction* (dB) is significant, particularly for urban environments where minimizing noise pollution is essential. The statement *no slip = no noise while braking* highlights a key advantage of LSM systems, the absence of slip during braking, leading to a quieter operation. This characteristic contributes to a more favourable environmental profile, making noise reduction an important factor in the comparison of different Linear Synchronous Motor solutions.

LSM for Hybrid MDS

The following parameters are suitable for comparing different Linear Synchronous Motor (LSM) solutions, offering valuable insights into key aspects of performance and environmental impact. "Delta time," or the time difference, is a critical metric that indicates how the travel time may vary between different systems. Understanding this variance is crucial for assessing efficiency and overall system performance.

In the context of noise reduction, the emphasis on *noise emission reduction (dB)* is significant, particularly for urban environments where minimizing noise pollution is essential. The statement *no slip = no noise while braking* highlights a key advantage of LSM systems, the absence of slip during braking, leading to a quieter operation. This characteristic contributes to a more favourable environmental profile, making noise reduction an important factor in the comparison of different Linear Synchronous Motor solutions.

5.4.3 Suspension

The possible indicators to measure the expected benefits are:

- **Track Maintenance Costs**: monitoring the costs associated with track repair and maintenance can provide insight into the extent of reduced track wear due to magnetic or air levitation.
- **Passenger Willingness Surveys**: gauging passenger willing through surveys can help assess improvements in ride smoothness and noise levels.
- **Noise Level Measurements**: using decibel meters to measure noise levels around the tracks can quantify the reduction in noise pollution.
- **Speed and Time Efficiency**: tracking the average speed of journeys and comparing travel times with conventional trains can indicate the speed benefits.
- **Energy Consumption Data**: Monitoring the energy usage per km or mile can reveal improvements in energy efficiency and associated cost savings.
- **Environmental Impact Assessments**: measuring reductions in greenhouse gas emissions and other pollutants can demonstrate environmental benefits.
- **Operational Cost Analysis**: comparing the overall operational costs, including fuel, maintenance, and other running expenses, with those of standard rail vehicles can provide a comprehensive view of cost-effectiveness.

5.4.4 Guidance

Guidance indicators are the same as suspension.

5.4.5 Braking

Linear Motor

The parameters for comparing different Linear Motors include measurements of functional and emergency stopping distances, noise emissions in decibels, and particle emissions identified by a Particle Size Analyzer. These metrics collectively address safety, environmental impact, and operational efficiency. Notably, the incorporation of two independent braking modes, AC regenerative braking and DC injection for emergencies, enhances safety while minimizing the risk of track damage during mechanical emergency braking events. This comprehensive evaluation framework allows for a thorough comparison of Linear Motor solutions, considering safety, environmental considerations, and overall performance efficiency.

Considering the future railway innovations, the linear induction motors also allow repetitive and precise stops, which is a determinant criterion for an integral automation of railway vehicles.

Electrodynamic wheel brakes

The parameters for comparing various Electrodynamic Wheel Brakes solutions encompass maintenance cost, track construction cost, noise intensity measurement, GHG emission measurement, noise emission reduction in decibels (dB), Capital Expenditure (CAPEX), and Operational Expenditure (OPEX). Maintenance and track construction costs provide insights into the long-term financial implications and initial investment required for each EDW Brake system. Noise intensity and GHG emission measurements contribute to assessing the environmental impact of these systems, crucial considerations for sustainable transportation.

The reduction in noise emissions measured in decibels serves as a key performance metric, highlighting the difference between noise levels for EDW brakes and conventional railway systems. Additionally, the CAPEX and OPEX parameters help differentiate between capital and operating costs, providing a comprehensive economic perspective. This multi-faceted evaluation framework allows for a thorough comparison of EDW Brake solutions, considering financial considerations, environmental impact, and noise reduction capabilities.

Lateral wheel-based propulsion and braking

The parameters suitable for comparing various Lateral Wheel-Based Propulsion and Braking solutions include braking distance (meters), maintenance cost, track construction cost, noise intensity measurement. Braking distance is a crucial performance metric that directly reflects the effectiveness of the propulsion and raking system in terms of stopping the vehicle, influencing safety and operational efficiency. Maintenance and track construction costs provide insights into the long-term financial implications and initial investment required for each lateral wheel-based system. Noise intensity measurement is essential for assessing the environmental impact, particularly in urban settings, making it a significant factor in the comparison of different propulsion/braking solutions. This comprehensive set of parameters allows for a thorough evaluation, considering safety, financial aspects, and environmental considerations when comparing lateral wheel-based propulsion/braking systems.

5.4.6 Vehicle control system- TMS

The use of new generation TCMS has an impact on reducing vehicle maintenance costs. This approach does not differ from the same introduction in conventional vehicles, as these are transversal solutions.

The on-board vehicle control system: Indicators are mentioned above in the sections related to propulsion, braking and suspension.

The trackside control system: the indicators are different for full MDS on the one hand and hybrid and upgraded conventional system on the other hand.

Full MDS

The specific indicators are:

- CAPEX and OPEX for the new system

Hybrid and upgraded conventional MDS

The specific indicators are:

- Cost for adoption of the existing system
- OPEX for the adopted system

The traffic management system (TMS) indicators are:

- Improved exactness of operation and
- consequently, indirectly punctuality and capacity
- Reduction in energy consumption
- Reduction in delays and overall OPEX

5.4.7 Electrical system

Pantograph and Overhead catenary

For a technology already used, as indicators we can select some economic benefits derived from savings on design and maintenance costs:

- Delta in the costs of implementation of a brand-new technology compared to use an already existing,
- Delta in the costs of maintenance of the new technology compared to the ones already existing,
- Delta in the operational costs using the new technology compared to the ones already existing.

Existing conventional railway infrastructure

To date, regarding the electrical infrastructure of existing railway systems, we can distinguish two contact systems delivering the traction power, overhead and ground power supply solutions.

Overhead power supplies are based on the catenary/pantograph system, 2 technologies:

The conventional overhead line can be made by a stretched wire type catenary (107 or 150 mm2), in the case of high-speed trains over 300 km/h powered by alternating current 25kV-50Hz or 15 kV- 16,7 Hz, the catenary section can be doubled using 2 current wires continuous 1500V or 3000V.

The rigid catenary, developed to reduce the electrical gauge in tunnels, has been validated up to 250km/h, with an upper limit of 302 km/h. Two ground power supply systems are possible: The use of the 3rd electrical rail, widely used for metros under voltages of 750V and 1500V DC, validated up to a speed of 150 km/h, Ground power supply initially developed by Alstom for trams at 750V DC, achieved by the contact of a central electric rail on the track, energized by section covered by the tram. Recently, contactless power transfer system, which was developed for automotive, initially in static then dynamic, are tested for tramway and railway car. However, the power remains limited to around 100kW, due on the one hand to the risks linked to electromagnetic radiation emissions at the converter frequencies, and on the other hand to the high investment cost.

Existing maglev infrastructure

Two Electrical systems must be considered for Maglev vehicles following the linear motor used:

Low speed Maglev (100-200 km/h) which can be propelled by means of an embedded Linear Induction Motor, needs to collect traction energy which are usually delivered by means a third rail contact electrical system.

Very high-speed Maglev (400-600km/h) are propelled by linear synchronous motor fixed on the guideway and are supplied trough electrical power station, it doesn't need on board traction energy but only auxiliary power for the vehicle control system and the passenger comfort. The energy transfer is assumed by means of an inductive system.

Future MDS system on railway infrastructure

As with Maglev, it is possible to distinguish between MDS powered by a short linear induction motor (LIM)(integrated into the vehicle) and by a long synchronous linear motor (LSM)(fixed on the track).

Of course, for the LIM-MDS, it will be useful to take into account of the existing electrification of the railway line using catenary, then MDS system might be equipped with the system pantograph/catenary. If the existing railway line is not electrified, then it will be possible to integrate an energy storage system into the vehicle, and to install locally in station stopping areas, an electrical power supply connected by catenary, or by the ground to find the batteries. However, this type of solution is only viable for local services at moderate speed.

Finally, we should consider the fact that people's access to conventional rail lines is not protected in a safe manner. Regarding traffic speed, existing railway lines do not allow high traffic speeds to be achieved due to the radii of curvature of the track, and their impact on the lateral forces applied to the civil engineering infrastructure.

5.4.8 Monitoring, safety, and control

As described in paragraph 5.3.8, these are transversal solutions independent of the technology adopted. The only potential problem is to verify compatibility with the required general rules during the design phase of the vehicle MDS. Once this point is resolved, no further tasks specific to these systems arise. Routine maintenance must verify that all requirements are met as for conventional vehicles.

The possible indicators to measure the expected benefits are:

- Track Maintenance Costs: monitoring the costs of supervision systems monitoring track conditions which can provide insight into the extent of reduced track wear due to magnetic or air levitation.
- Noise Level Measurement Sensing Systems: using decibel meters to measure noise levels around the tracks can quantify the reduction in noise pollution.
- Speed and Time Efficiency: tracking the average speed of journeys and comparing travel times with conventional trains can indicate the speed benefits.
- Energy Consumption Data: Monitoring the energy usage per km or mile can reveal improvements in energy efficiency and associated cost savings.

- Environmental Impact Assessments: measuring reductions in greenhouse gas emissions and other pollutants can demonstrate environmental benefits.
- Operational Cost Analysis: comparing the overall operational costs, including fuel, maintenance, and other running expenses, with those of standard rail vehicles can provide a comprehensive view of cost-effectiveness.
- CAPEX and OPEX of the Systems for Monitoring, Control and Safety Supervision

5.4.9 Guideway

For guideway, it is intended as a track along which automated transit vehicles are guided.

- Track Maintenance Costs: Monitoring the costs associated with track repair and maintenance can provide insight into the extent of reduced track wear due to magnetic or air levitation.
- Environmental Impact Assessments: measuring reductions in greenhouse gas emissions and other pollutants can demonstrate environmental benefits.
- Infrastructure CAPEX costs: evaluating and monitoring infrastructure CAPEX costs can reveal the benefits on guideways.

5.4.10 Switches and segment switches

Existing conventional railway infrastructure

The parameters suitable for comparing various Existing Conventional Railway Infrastructure include *delta time* and *noise emission reduction (dB)*. Delta time, or the time difference, is a critical metric that indicates how the travel time may vary when using different switches. Understanding this variance is essential for assessing efficiency and overall system performance.

In terms of noise reduction, the emphasis on noise emission reduction (dB) is significant, particularly for urban environments where minimizing noise pollution is crucial. The absence of mechanical contact, leading to no noise while passing the switch, contributes to a quieter and more environmentally friendly operation. These parameters collectively provide a comprehensive basis for evaluating the efficiency, safety, and environmental impact of various existing conventional railway infrastructure switches and railway switches.

Upgraded conventional railway infrastructure

The parameters suitable for comparing various Existing Conventional Railway Infrastructure include *delta time* and noise emission reduction (dB). *Delta time*, or the time difference, is a critical metric that indicates how the travel time may vary when using different switches. Understanding this variance is essential for assessing efficiency and overall system performance.

In terms of noise reduction, the emphasis on *noise emission reduction (dB)* is significant, particularly for urban environments where minimizing noise pollution is crucial. The absence of mechanical contact, leading to no noise while passing the switch, contributes to a quieter and more environmentally friendly operation. These parameters collectively provide a comprehensive basis for evaluating the efficiency, safety, and environmental impact of various existing conventional railway infrastructure switches and railway switches.

5.4.11 Propulsion- Infrastructure part

Stator with multi-phase winding

The parameters suitable for comparing different solutions in the infrastructure part of the propulsion, specifically the Stator with multi-phase winding, include *delta time*, noise *emission reduction (dB),* and *OPEX* (operational expenditures). *Delta time*, or the time difference, is a crucial metric indicating potential variations in travel time, offering insights into system efficiency. Noise emission reduction measured in decibels is essential, emphasizing the advantage of no noise during braking due to the absence of slip. This contributes to a quieter operation, especially in urban settings. Additionally, considering OPEX parameters helps highlight the operational cost differences between using switches and not using them, providing valuable information for economic assessments. Together, these parameters form a comprehensive basis for evaluating the efficiency, noise reduction capabilities, and economic considerations of different solutions involving the stator with multi-phase winding in propulsion infrastructure.

Long stator synchronous linear motor

The parameters suitable for comparing different solutions in the infrastructure part of the propulsion, specifically the Long Stator Synchronous Linear Motor, include *delta time*, *noise emission reduction (dB)*, and *OPEX* (operational expenditures). *Delta time*, representing the time difference, is a crucial metric revealing potential variations in travel time, offering insights into system efficiency. Noise emission reduction, measured in decibels, is essential, emphasizing the advantage of no noise during braking due to the absence of slip. This characteristic contributes to a quieter operation, particularly in urban environments. Moreover, considering OPEX parameters helps highlight the operational cost differences between using switches and not using them, providing valuable information for economic assessments. These parameters collectively provide a comprehensive basis for evaluating the efficiency, noise reduction capabilities, and economic considerations of different solutions involving the Long Stator Synchronous Linear Motor in propulsion infrastructure.

LIM stator

The parameters conducive for comparing diverse solutions in the infrastructure part of the propulsion, specifically concerning the Linear Induction Motor (LIM) stator, encompass several crucial aspects. Firstly, evaluating the Adapted track construction cost materials, focusing on the utilization of steel and aluminium for the LIM armature, provides insights into the initial investment required for track construction. This emphasis on adapted materials aids in assessing the cost-effectiveness and feasibility of implementing the propulsion infrastructure.

Secondly, considering the Maintenance frequency is paramount, as it directly influences operational costs. A lower maintenance frequency indicates reduced operational expenses over time, making this parameter a key factor in the economic evaluation of different solutions.

Lastly, highlighting the reliance on Complete electrical power leading to zero Greenhouse Gas (GHG) emissions underscores the environmental sustainability of the propulsion system. This parameter is essential for assessing the ecological impact of various solutions and aligning them with environmental goals.

Together, these parameters offer a comprehensive foundation for comparing and evaluating the economic feasibility, operational efficiency, and environmental sustainability of different Linear Induction Motor stator solutions within the infrastructure part of the propulsion system.

5.4.12 Substructure

Structural Components

The following benefits have been indicated in the previous paragraphs: Increase max speed and low noise emissions. So, the suggested indicators are respectively:

- delta time: the time difference shows how time of the travel may change.
- noise emission reduction (dB): dB difference if compared with traditional railway.

Ballasted railway track with sleepers and Railway slab track

For a technology already used, as indicators we can select some economic benefits derived from savings on design and maintenance costs:

- Delta in the costs of implementation of a brand-new technology compared to use an already existing,
- Delta in the maintenance technician training costs,
- Delta in the costs of maintenance of the new technology compared to the ones already existing,
- Delta in the operational costs using the new technology compared to the ones already existing.

Furthermore, in the case of rail slab track we can also have:

- delta in maintenance costs;
- delta in waste disposal costs.

5.4.13 Power supply

Track power supply to Infrastructure for long track-side stator for propulsion

The parameters relevant for comparing various solutions in the power supply context, specifically Track power supply to Infrastructure for long track-side stator for propulsion in the context of maglev railways, primarily revolve around OPEX (operational expenditures). OPEX parameters are instrumental in revealing the disparities in operating costs among different power supply systems.

The efficiency and cost-effectiveness of power supply systems are critical considerations in the deployment and maintenance of maglev railways. By focusing on OPEX parameters, such as the ongoing expenses associated with various power supply alternatives, one can discern the economic implications of choosing different systems. This includes factors like maintenance, energy consumption, and overall operational efficiency, providing a comprehensive view of the economic viability of each power supply solution.

In essence, the OPEX parameters serve as a key metric for comparing and evaluating the long-term financial implications and efficiency of diverse power supply systems, aiding in the selection of the most cost-effective and sustainable option for maglev railways.

Vehicle power supply to vehicle for all functions

The parameters relevant for comparing various solutions in the power supply context, specifically Vehicle power supply to the vehicle for all functions in the context of maglev railways, primarily centre around OPEX (operational expenditures). OPEX parameters are crucial in highlighting the distinctions in operating costs among different power supply systems.

Efficiency and cost-effectiveness are pivotal considerations in the operation and maintenance of maglev railways. By focusing on OPEX parameters, which encompass ongoing expenses related to various vehicle power supply alternatives, one can discern the economic implications of choosing different systems. This includes factors such as maintenance, energy consumption, and overall operational efficiency, providing a holistic view of the economic viability of each power supply solution.

In summary, OPEX parameters serve as a key metric for comparing and evaluating the long-term financial implications and efficiency of diverse power supply systems, aiding in the selection of the most cost-effective and sustainable option for maglev railways.

5.4.14 Sensing, communication, positioning

Similarly, to monitoring and safety systems, the systems in this category follow the same rules and are in fact transversal. As reported in paragraph 5.3.14, compatibility must be verified and there are no additional costs for the necessary checks compared to other types of vehicles.

The possible indicators to measure the expected benefits are:

- **Vehicle and Track Maintenance Costs**: monitoring the costs of supervision systems monitoring track conditions which can provide insight into the extent of reduced track wear due to magnetic or air levitation.
- **Speed and Time Efficiency**: tracking the average speed of journeys and comparing travel times with conventional trains can indicate the speed benefits.
- **Energy Consumption Data**: Monitoring the energy usage per km or mile can reveal improvements in energy efficiency and associated cost savings.
- **Environmental Impact Assessments**: measuring reductions in greenhouse gas emissions and other pollutants can demonstrate environmental benefits.
- **Operational Cost Analysis**: comparing the overall operational costs, including fuel, maintenance, and other running expenses, with those of standard rail vehicles can provide a comprehensive view of cost-effectiveness.
- **CAPEX and OPEX of the Sensing, Communication and Positioning Systems**

6 Identification of potential benefits to the railway system derived from the importable technologies

6.1 Methodological background

The identification of benefits constitutes a part of the Benefits-Costs analysis, therefore, to carry out this phase the European Commission's ***Guide to Cost-Benefit Analysis of Investment Projects*** is used as a methodological reference.

The objective of the guide reflects a specific requirement for the European Commission to offer practical guidance on major project appraisals, as embodied in the cohesion policy legislation for 2014-2020.

Following the guide, the benefit identification and analysis is structured in five steps, described in the following paragraphs:

- Description of the contest,
- Definition of objectives,
- Case study identification,
- Benefit analysis,
- Risk assessment.

6.2 Description of the contexts

The objectives of the project, namely the specific functions it must perform, must be consistent with both the territorial context and the technical environment where the project is built. Some baseline elements like socio-economic trends, political, institutional, and regulatory background should be outlined. Typically, they are Socio-economic trend, Political, Institutional and Regulatory issue, and Existing service conditions, like information about the existing transport infrastructure, and recently executed investments that may affect the project performance, technical characteristics of the service currently provided, infrastructure capacity or service quality, frequency, safety.

6.3 Definition of objectives

These are generally related to the improvement in travel conditions for both passengers and goods inside the impact area and to and from the impact area, as well as improvements in the quality of the environment and the wellbeing of the population served.

In more detail, a case study will typically deal with the following objectives:

- reduction of congestion within a network, link, node by resolving capacity constraints,
- improvement of the capacity and performance of a network, link, node by increasing travel speeds and by reducing operating costs and accidents,
- improvement of the reliability and safety of a network, link, node,
- minimisation of GHG emissions, pollution, limitation of the environmental impact,
- adjustment to EU standards and completion of missing links or poorly linked networks: transport networks have often been created on a national or regional basis, which may no

longer meet the transport requirements of the single market (this is mainly the case with railways),
- improvement of accessibility in peripheral areas or regions.

When feasible, they should be quantified and targeted with the use of indicators, logically linked to the project benefits.

6.4 Case studies identification

The first step to identify the case study is to state its functions, which should be coherent with the investment objectives. This should be followed by a description of the project typology, that is whether it is a completely new infrastructure, or a transfer of Maglev technologies to a traditional rail system. Finally, a detailed list of the physical realisations must be included.

The identification of the project as a self-sufficient unit of analysis is usually not so easy issue in the transport sector. This is because most transport projects belong to a wider network and any investment decisions and implementation are not isolated. In case study identification, the basic principle is that its scope must always be a stand-alone socio-economic and technical unit: i.e., it should generally be functional and independently useful from a transport perspective without depending on the construction of other projects (which may however provide synergies). That considered, the following basic rules can be applied:

- when the project consists of realising a given section, sub-portion or phase of a well identified transport investment, the CBA (and the supporting feasibility study) should be focused on the entire investment,
- when the project contributes to implementing a larger investment strategy or plan, encompassing a set of interventions all aimed at achieving the same priority, each intervention should undergo a CBA.

6.5 Forecasting traffic volumes

6.5.1 Factors influencing demand analysis

When developing a demand analysis for transport investments, particular attention should be paid to the sensitivity of traffic to some critical variables such as:

- demographic changes, including, amongst others, the number of people split into age structure, level of education and number of people of productive and non-productive age,
- socio-economic changes, including, amongst others, GDP level in analysed area, incomes, level of unemployment, economic structure of regions being served currently or in the future by the transport infrastructure,
- industrial and logistics structure and developments: location of concentrated industrial activities, natural resources, main transport hubs (ports and airports), logistics structure, and expected developments in supply chain organisation (clustering, unitisation, change in distribution patterns),
- elasticity with respect to quality, time and price: travel demand characteristics, structure and elasticity are particularly important in those projects related to charged

infrastructures, since the expected traffic volumes are determined by fare levels and the transport conditions,

- capacity constraints on competing modes and strategies in place, for example in terms of investments foreseen. This point is particularly relevant for long term investments: in the time span required to complete the intervention, the traffic that may be potentially acquired by the new infrastructure may shift to other modes and, if so, then it may be difficult to move it back,
- spatial changes leading to changes in the distribution of traffic potential,
- change of traffic management policies, e.g. existence of constraints in using the car in determined areas (this is particularly the case of urban public transport) or establishment of taxes or subsidies for competing modes,
- technological changes impacting the cost structure for the project and its alternatives through changes in e.g., fuel efficiency, fleet composition or productivity,

Given the uncertainty of the future trends of these variables, it is generally recommended to develop, as a minimum, three traffic scenarios (high, most likely, low), which should further feed into risk analysis. These should be based on different developments of both exogenous (e.g., GDP growth) and endogenous (e.g., pricing policy) variables. Demand forecasting should be completed for the scenario without the project, and for each project option (§ 6.5.2).

6.5.2 Hypotheses and Outputs of the traffic forecast

To develop traffic forecasting, some justified specific assumptions should be adopted regarding:

- the project's impact area, to limit the traffic study and the related economic impacts. It is important to identify the demand without the project and the impact of the new infrastructure, as well as identify other transport modes potentially involved,
- the degree of complementarity and competition among transport modes. Competing modes and alternative routes, fares and costs for users, pricing and regulation policies, congestion and capacity constraints and expected new investments should be assessed,
- the deviations from past trends, including changes in tax regime, energy prices or toll collection policy,
- the relative sensitivity of demand patterns (such as modal share or volume of traffic) to changes in the transport supply.

Considering the requirements for economic analysis, traffic forecast outputs are developed for passenger and/or cargo traffic. Outputs shall include all information necessary for further technical analyses as well as financial and economic analyses. Although each subsector has its own indicators of traffic forecasts, the following demand parameters are usually collected to feed the CBA model:

- number of vehicles or trains in absolute value, per unit of time (e.g., Annual Average Daily Traffic (AADT), trains per day, etc.) and/or per average trip length (e.g., vehicles/km, trains/km, etc.),
- number of vehicles broken down by category, speed class,
- number of passengers, passenger/-hours, passenger/-km,

- cargo traffic in tons, ton/hours, ton/km,
- travel times and other network performance indicators.

6.5.3 Types of traffic response

Traffic types can be divided according to their behavioural response to a project. This qualification will become relevant when it comes to the assessment of the socio-economic impacts of the project. Depending on the traffic system perspective, and on the actual availability of data on generalised costs from the traffic model, the assessment of socio-economic benefits for each of these categories can be performed differently.

Also, for the purpose of the economic assessment, the traffic surveys should also provide information on the share of trips by travel purpose, for instance business, commuting and leisure trips. An additional distinction by short and long-distance trips can be relevant for road and railways trips.

6.6 Option analysis

The case study should be identified after the assessment of all promising strategic and technical alternatives based on physical circumstances and available technologies. The main potential for distorting the evaluation is the risk of neglecting relevant alternatives, in particular low-cost solutions, such as managing and pricing solutions, infrastructure interventions that are considered as not 'decisive' by designers and promoters, etc.

Possible design options in transport include location/route, alignment, technical solutions, etc. Different options may have different demand, costs, impacts.

Options might include synergies in co-deployment of transport and infrastructure, in view of smartening the transport systems, improving efficiency in the use of public funds, and significantly increasing the socioeconomic impact of projects.

6.7 Benefit analysis

The primary immediate benefits of transportation developments can be measured by the following measurable change.

The consumer surplus, defined as the excess of users' willingness to pay over the prevailing generalised cost of transport for a specific trip. The generalised cost of transport expresses the overall inconvenience to the user of travelling between a particular origin (i) and destination (j) using a specific mode of transport. In practice, it is usually computed as the sum of monetary costs borne (e.g., tariff, toll, fuel, etc.) plus the value of the travel time (and/or travel time equivalents, such as the inconvenience of long intervals) calculated in equivalent monetary units. Any reduction of the generalised cost of transport for the movement of goods and people determines an increase in the consumer surplus. The main items to be considered for the estimation of the consumer surplus are:

- fares paid by users,
- travel time,
- Vehicle Operating Costs,

- operating costs carriers.

The producer surplus, defined as the revenues accrued by the producer (i.e., owner and operators together) minus the costs borne. The change in the producer surplus is calculated as the difference between the change in the producer revenue (e.g., rail ticket income increase) less the change in the producer costs (e.g., train operating costs increase). This might be particularly relevant for public transport projects, especially if the project is expected to feature significant traffic (generated or induced) or a substantial change in fares.

In addition, any transport project may generate relevant non-market impacts on safety and the environment that always need to be evaluated, like:

- Accidents savings,
- Variation in noise emissions,
- Variation in air pollution,
- Variation in GHG emissions.

In what follows, the main information needed and the practical instructions to evaluate the benefits illustrated above are presented.

Travel time

Travel time saving is one of the most significant benefits that can arise from the construction of new, or improvement of, existing transport infrastructure.

Passengers traffic time savings

In carrying out CBA, different methods are possible to value time for passengers, whilst a distinction is usually made between the estimation of work and non-work travel time (including commuting).

The first method is to carry out specific empirical research and/or surveys in that country to estimate both work and non-work travel time. The approach consists of interviewing individuals using the stated preference method or conducting multi-purpose household/business surveys using the revealed preference method and then to estimate a discrete choice model on these data.

As a second option, value of time can be estimated adopting the cost saving approach. The logic is that time spent for work-related trips is a cost to the employer, who could have used the employee in an alternative productive way.

The cost saving method is a simple approach to estimate a single value of work-time in a given country or region. This can, however, be enriched with further considerations and analysis, if necessary and feasible, as illustrated in the box below.

Freight traffic time savings

Reduction in travel times will benefit freight traffic in the following ways:

- reduced driver (and any other persons necessarily travelling with the load,) wage costs per trip,
- reduced vehicle operating costs per trip,
- improved reliability, i.e. timely delivery of transported goods.

The valuation of the first benefit follows the same logic of passenger's traffic so that time savings for truck drivers (or rail carriers' crew members) is evaluated with the cost savings approach. The last benefit item may arise through several mechanisms.

Evaluation of GHG emissions

Climate change impacts occupy a special position in the externalities assessment because: climate change is a global issue, so the impact of emissions is not dependent on the location of the emissions; GHGs, especially carbon dioxide (CO_2), but also nitrous oxide (N_2O) and methane (CH_4) have a long lifetime in the atmosphere so that present emissions contribute to impacts in the distant future; the long-term impacts of continued emissions of greenhouse gases are difficult to predict but potentially catastrophic; scientific evidence on the causes and future paths of climate change is becoming increasingly consolidated. Scientists are now able to attach probabilities to the temperature outcomes and impacts on the natural environment associated with different levels of stabilisation of GHGs in the atmosphere.

The proposed approach to integrate climate change externalities into the economic appraisal is based, in part, on the EIB Carbon Footprint Methodology 67 and is consistent with the EU Decarbonisation Roadmap 2050.

It consists of the following steps:

- quantification of the volume of emissions additionally emitted, or saved, in the atmosphere because of the project. Emissions are quantified based on project specific emission factors (e.g., tCO_2 per unit of fuel burnt, $kgCO_2$ per kilometre travelled, etc.) and are expressed in tonnes per year. In the absence of project specific data, default emission factors from the economic literature can be used,
- calculation of total CO_2-equivalent (CO_2e) emissions using Global Warming Potentials (GWP). GHGs other than CO_2 are converted into CO_2e by multiplying the number of emissions of the specific GHG with a factor equivalent to its GWP,
- evaluation of externality using a unit cost of CO_2-equivalent. Total tonnes of CO_2 emissions are multiplied by a unit cost expressed in EUR/ton.

6.8 Risk assessment

From the point of view of benefits, due to their criticality, it should be carried out a sensitivity analysis of the money values assigned to the goods without any market, especially values of time saving and accidents. In fact, in transport projects very often the value of time savings can represent more than 70 % of all benefits. It is therefore a parameter that must always be analysed and tested carefully.

Other tests may be performed on the expected demand, particularly the generated traffic, on the value of the time, on the accident costs, on the assumptions on economic trends, on the rate of traffic increase over time, as well as on the fare/tariff.

7 Conclusion

The Deliverable included the identification of the potential benefits and the respective indicators for the assessment of the application of maglev and maglev-derived systems in synergy and integration with traditional railway systems, as well as the methodology to integrate them for the technical and economical assessment according to the European Guidelines for cost-benefit analyses, resulting from Tasks 2.4-2.5.

The benefits of each subsystem (structure, propulsion vehicle, suspension, guidance, braking, vehicle control system, electrical system, etc.) are reported in the document. The macro expected benefits would be Vehicle operating cost savings, Variation in noise emissions, Variation in air pollution, Variation in GHG emissions, travel time savings, Infrastructure operating costs savings, Accident savings.

The possible indicators to measure the expected benefits are Track Maintenance Costs, Passenger Willingness Surveys, Noise Level Measurements, Speed and Time Efficiency, Operational Cost Analysis.

The objective of task 2.5 was to systematically identify potential synergies and related benefits for railway systems from the perspectives of economics, the environment, customer attractiveness, and performance that may arise from the potential adoption of importable technologies. This is in accordance with the output from Task 2.4 and with reference to the identified common architecture. The cost evaluation for integrating maglev-derived systems or subsystems into railways will be carried out. This also include a non-financial benefits analysis of these systems, which consider factors like energy consumption, capacity considerations, operations, maintenance, etc. as inputs to the cost benefit analysis.

The process of benefit identification is a component of the Benefits-Costs analysis. As such, the European Commission's *Guide to Cost-Benefit Analysis of Investment Projects* is a key methodological reference throughout this phase.

8 References

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