Deliverable D2.1
Written report of the definition of multi-modal mobility systems

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1 Executive Summary

The intended goal of task 2.1 is to consider the railway-specific system part of an intermodal Pod system. As a first step of the definition the envisaged Pod system was explained.
The Pod system should operate autonomously, be electrically powered and the approved transport units are designed for people and freight separate from a specific transport carrier. Autonomous operation is ensured by a mobility management system for operations and logistics as well as all aspects of a mobility-on-demand offer, represents a completely new form of mobility and could form a transport concept of the future.

However, the technical, geographical, and chronological system boundaries were described and relevant interfaces to affected systems such as energy supply, infrastructure and other modes of transport are identified. Accordingly, the rail-bound Pod system will be operated on passenger- and freight routes in Europe (branch lines) with a lifespan of 30 years.

Finally, task 2.1 leads to a clear description of the Pod system and its main subsystems. According to the state of the art, relevant subsystems were referenced together with a basic assumption of the TRL.

Task 2.1 will be the foundation for all other Work Packages and ongoing assessments within ERJU Flagship Area 7 project Pods4Rail.

2 Abbreviations, Terms and Definition

2.1 Abbreviations and Acronyms

AE	Affiliated Entities
AI	Artificial Intelligence
API	Application Programming Interface
BEN	Beneficiaries
CBTC	Communications Based Train Control
CEN	European Committee of Standard
CO_2	Carbon Dioxide
CT	Cooperation Tool
DMP	Data Management Plan
EN	European Norm
ERJU	Europe’s Rail Joint Undertaking
ETCS	European Train Control System
EU	European Union
GA	Grant Agreement
GDPR	EU General Data Protection Regulation
iCCTV	Intelligent Closed-Circuit Television
IoT	Internet of Things
IPR	Intellectual Property Right
ISO	International Organization for Standardization
MaaS	Mobility as a Service
MAGLEV	Magnetic levitation train
MMP	Mobility Management Platform
MMS	Mobility Management System
MPT	Motorised Private Transport
ORDP	Open Research Data Pilot
PC	Project Coordinator
PCS	Pods Coordination System
PIS	Passenger Information Service
PMMP	Pods Mobility Management Platform
PSC	Project Steering Committee
PT	Public Transport
R&D	Research and Development
SoA	State of the Art
TEN-T	Trans-European Transport Network
TRL	Technology Readiness Level
VTOL	Vertical Take-Off and Landing
WP	Work Package

2.2 Terms and Definitions

In this section the key technical terms that are fundamental to the definitions and the design and implementation of a seamless, intelligent, and interconnected transportation ecosystem will be explained. Understanding these terms is essential for envisioning the potential and capabilities of the Pod system.

Autonomous Vehicles: Vehicles equipped with advanced technologies enabling them to operate and navigate without human intervention, crucial for achieving autonomy and optimization in transportation.

Carrier: The carrier will be part of the Pod. Functionalities of the carrier includes integration of propulsion equipment, energy storage, driving boogie, parts of communication and control equipment, crash elements and coupling system.

Intermodal: Movement of goods (in one and the same transport unit or a vehicle) by successive modes of transport without handling of the goods themselves when changing modes (e.g., container transport). [1]

Multimodal: Multimodal transport is characterised by the transport of goods using two or more different transport modes. To change the means of transport, transshipment of goods is required. [2]

On-demand Transport: On-Demand Transports are those where transportation services are provided when needed, often enabled by digital platforms and real-time scheduling, ensuring flexible, personalized mobility solutions for passengers and freight.

Pod: usually Podcars – a decentralized, fully autonomous transport system. Pod is a vehicle consisting of the carrier and the transport unit, which are connected to each other by a coupling system.

Pod2X communication: Communication framework or system designed to facilitate seamless and efficient information exchange and interaction between Pods and external entities or systems, denoted by 'X.' The 'X' can represent various stakeholders, such as other Pods, traffic management system, logistics platforms, infrastructure, or other elements within a network.

Railway: Railway is a means of transport that transfers passengers and goods on wheeled vehicles running on rails, which are incorporated in tracks. This includes all kind of railway, like main line railways, tram, light rail, metros.

Supermodal: Will be defined as an autonomous operating system for the transport of passengers and goods. The main difference will be that the payload (passengers & goods) will optimise the way and mode of transport fully autonomously to meet constrains like (e.g., time, distance, costs, comfort).

Synchronisation: The coordination and alignment of various elements within the transportation system, such as schedules, routes, and activities, to ensure smooth and efficient movement of freight or passengers.

Transport unit: The transport unit (for passenger and/or freight) will include all the safe carriage of passengers or goods and its comfort and safety functionalities during transport.

Transshipment: The transfer of goods from one transportation mode to another during their journey, often occurring at hubs or terminals. Transshipment allows for the continuation of the journey using different modes of transport.

3 Background

The present document constitutes the Deliverable D2.1 “Written report of the definition of multi-modal mobility systems” in the framework of the Flagship Area 7 project Pods4Rail as described in the EU-RAIL MAWP.

4 Objective of the Document

This document has been prepared to provide a description of the new transport system. The goal is to set a common understanding of the system and the main components which are the basis of the project during its development. This will provide the basis for definition of the system to be developed and description of the necessary requirements on the technical and operational sides. The activities will provide the required input for activities of other Work Packages. The system definition intends to describe the main building blocks and the boundaries of its application areas. Furthermore, the used terms will be explained for relevant readers and stakeholders of other WPs’.

This deliverable of D2.1 will provide results of the qualitative study including implications for the development of the multimodal mobility system, including general overall specification with description of the required technologies.

5 Description of the Pod System

5.1 Initial Situation

5.1.1 Railway as a backbone of future’s transport

The challenges that transport faces under today's circumstances are diverse requiring revolutionary changes. In particular, the demand for sustainable solutions for transporting people and goods force us to rethink the situation and develop new approaches and ideas for the transport of the future.

Above all, global megatrends happening in different areas including environment and climate change, demographic changes, urbanisation, and technological trends such as digitalisation, artificial intelligence (AI), and connectivity are having an impact on shaping the transport of the future. Railway as a means of transport plays a major exposed role in the mass transport of people and goods as well as in local public transport and individual freight transport. Railway is considered a key driver in pursuing Europe's strategic goal of smart, green, and sustainable growth and is expected to serve as the backbone of the entire European transport system, accounting for less than 2% of final energy consumption in the transport sector. With around 200,000 km of rail network in the European Union (EU), rail is one of the most important and environmentally friendly means of transport, whose importance continues to grow and is being developed into a high-performance, flexible, multimodal, and reliable integrated European railway network (TEN-T).

To cope with this mobility transformation, rail has the task of taking over a larger share of transport demand over the next few decades and introducing sustainable and intelligent mobility concepts that focus on today's mobility needs. Digitalisation and automation are becoming central to modernizing the entire system.

5.1.2 Challenges for the transport sector

Transport systems in general, and in this context, rail transport, are heavily dependent on social developments and trends. A trend that has been predicted for decades and has a strong impact on the design of transport is increasing urbanisation, the migration of the population from rural to urban areas. Since the beginning of the 2010s, however, the level of urbanisation has stagnated in some regions of Europe. The reason for this stagnation is the rising costs of living in cities, which means that families are increasingly deciding to leave expensive cities with their often overloaded infrastructure and move to the rural areas. [3] [4] [5] [6] [7] [8] At the same time, a decline in rural areas continues to be observed in large parts of Europe, which is linked to a demographic decline and changes in the population structure, e.g., the migration of people and companies from the rural periphery. This demographic decline in rural areas in turn leads to general problems for rural society. The number of public services and facilities (e.g., health and social services) is decreasing, as is the supply of everyday necessities and the availability of local public transport. [9] This development is reflected not least in the fact that the proportion of older people in rural regions of Europe is much higher than that of younger people. [10] This correlates with the ongoing trend of an ageing population in Europe. [11]

Demographic changes, phenomena such as urbanisation and counter-urbanisation, as well as rising population, are flanked by challenges that arise from the needs of environmental protection. Reducing emissions and energy consumption remain key demands from society and politics with an impact on the transport sector. The European Green Deal includes the commitment to make the EU the first climate-neutral continent by 2050. In the transport sector, the European Green Deal calls for a 90% reduction in greenhouse gas emissions. [12]

At the same time, railway is labelled as a means of transport that, due to its high efficiency, low energy consumption and balanced environmental impact. As the most environmentally friendly mode of transport, railways are responsible for around 0.3% of direct CO_2 emissions from the combustion of fossil fuels and for the same proportion (0.3%) of energy-related particulate matter emissions. [13] New technology for energy-optimised driving, new energy supply and drive technology as well as in operations control technology will help to further improve these values. In addition to reducing emissions and lowering energy consumption, land consumption and the sealing of areas are increasingly becoming the focus of social interests. The EU's Soil Strategy proposes to avoid sealing agricultural and undeveloped areas as much as possible and to primarily build on areas that are already sealed. [14] The same should be achieved for transport. There are also increasing efforts to limit motorised private transport in large cities and to develop new models for life in large cities that follow a “zero-emission” strategy. [15] [16] [17]

Another aspect that influences usage behaviour in passenger transport and here in motorised private transport (MPT) as well as public transport (PT), especially in metropolitan areas, is the economic situation of the population, especially the young generation. The high youth unemployment that has existed in the EU for years, the high number of precarious employment relationships and the resulting limited financial framework of people are reflected in the use of private and public transport, especially among the younger generation. [18] [19] [20] [21] As a result, young people in big cities are no longer focusing on owning a car. [22] [23] On the other hand, there is growing potential for car sharing offers, which are primarily used in metropolitan areas. [24] The market for “shared mobility” offers in Europe, which includes rental vehicles as well as taxis and similar driving services, was estimated at around 70 billion Euros in 2022 and could reach a size of 150 to 200 billion Euro by 2030. [25]

Finally, the limited financial resources in public spaces affect the available public transport, making it more difficult to expand the existing offering. [26] [27] [28] [29] In recent years, drastic increases in energy costs have made matters worse, impacting the transport sector. In contrast, there are increasing measures in Europe to improve the railway offering as the most environmentally friendly means of transport with high capacity, for example through greater comfort, an offer adapted to the secondary lines or a higher frequency of train services. [30]

Furthermore, the increasing digitalisation and networking of technical systems and the use of so-called "mobile services" play an important role in the design of mobility offers. Studies show that on-demand transport, where passengers can request transport via an app, can play a key role in making public transport more attractive in the future. [31] Numerous mobile services (Apps) have already become indispensable for public transport users. Further digitalisation in the railway sector offers great potential to improve the efficiency of the system. It is predicted that autonomous vehicles would reduce operating costs in freight transport by around 50%. In general, it is estimated that digitalisation, e.g., through the introduction of driverless locomotives, real-time operation centres or fully automated timetable design, could reduce rail operators' operating costs by at least 15%. [32] This technology driven trends to improve the railway system will also help to alleviate the shortage of skilled workers in the EU, in particular sufficiently qualified personnel to operate the railways. [33] The rail sector is currently facing a shortage of train drivers and a large proportion of the workforce is expected to retire in the next decade. [34]

In addition to some of the above, freight transport faces further challenges. Changing and increasingly growing flows of goods in delivery traffic because of society's changing consumer behaviour will further increase the number of transports with small and very small delivery units in the future. [35] [36] [37] So far, this has only been expressed in road transport. Today's modal split with 75% road freight transport, 18% rail freight transport and 7% inland waterway freight transport must generally change in favour of more environmentally friendly rail freight transport. The aim is already to increase the share of rail freight transport in the EU up to 30% by 2030. [38] A further increase in the share of rail freight transport, especially in the last mile area, can only be achieved with new, innovative concepts. In particular, an improvement in intermodal offerings is necessary here. [39]

5.1.3 Need for a new system

All these aspects pose demanding challenges for transport of passenger and freight transport. Accordingly, it is important to offer new services in transport that respond to the needs of the population and the economy and are designed with ecological aspects in mind. By making optimal use of existing transport systems the need for building new transport infrastructure will be reduced, which leads to the protection of ecosystems for future generations. New approaches can help shape the transport of the future, particularly with a view to creating sustainable transport solutions that conserve resources and minimise emissions.

From a transport economics perspective, it is important that the comparative advantages of the different modes of transport can develop and should be used where they are most appropriate. Rail-based systems are particularly important for sustainable mobility due to their mass performance. For this reason, the idea arose to create a system that, on the one hand, strengthens the existing mode of transport, the railway, and uses other modes of transport, e.g., the road or cable cars, but links them in a further developed and new way. The concept of sustainable and intelligent mobility can build a bridge between modes of transport because it creates a more advantageous overall system and provide socio-economically efficient and long-term sustainable transport for citizens and businesses throughout Europe.

This approach is intended to create a sustainable solution that can help conserve resources by, on the one hand, separating the means of transport from the transport unit and, on the other hand, a Mobility Management System (MMS) helps to transport people or goods demand driven, to ensure at the same time optimised use of means of transport and transport containers. At the same time, the MMS is intended to help make transport more attractive and convenient, for example by eliminating the need for changing means of transport during passenger journeys from origin to destination.

The desired solution focuses on both private transport and public transport in the area of passenger transport, as well as freight transport in its various forms. Creating a fully autonomous transport system can also help to improve the cost position in the railway sector and address the lack of sufficiently trained personnel. The key role of digitalisation and solutions using artificial intelligence to make mobility more efficient, sustainable, and affordable has already been recognised. But security and accessibility can also be significantly improved through the introduction of digital technologies.

5.2 System definition & description

5.2.1 General Aspects of the System

The Pod system can be described as a decentralised, autonomous intermodal transport system that utilises and enhances the advantages of rail transport. The system is intended to help enable continuous door-to-door transport that has the potential to offer on-demand services to people and goods, operation using a Mobility Management Platform (MMP), enabling constant availability of the system's transport components as well as all necessary services for the system and its users.

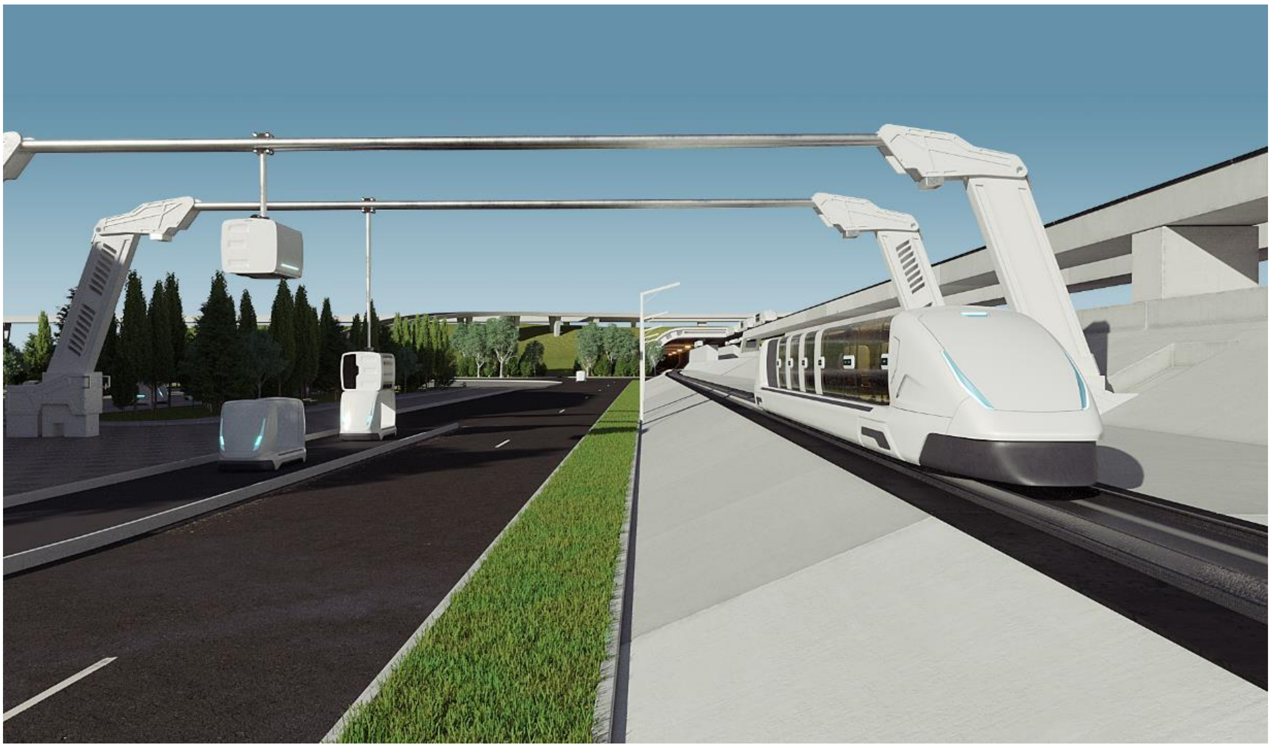

Figure 1: *Design rendering of a transshipment (handling) situation of Pod's. Transport units will be conveyed from Rail mode to Road mode. Source: Siemens Mobility / moodley, 2022*

The new, to be developed system shall be a railway based so-called "Pod System", which means that transport unit and autonomous driven transport vehicle are separated, and both are managed by a Mobility Management System, which is responsible for all aspects of the general operation of the system in its environment.

The specific and innovative design of the Pod separates the autonomous driven transport vehicle (moving infrastructure) and the transport unit (transport unit) for people and/or goods with the possibility of fast switching from one transport system (e.g., railway) to another (e.g., road or cable car/funicular) and thus a continuous transport chain from house to house without changing from one transport system to another (e.g., from a train to a metro, tram, taxi, car or bus) or reloading could be created.

The Pod system for railway will consist of compact transport units for passenger and/or freight transport (transport units) which are compatible with very different transport systems, using standardised autonomous driven transport vehicles, which follow a uniform dimensioning system. Elements based on this grid can be used individually or in combination with each other for a wide variety of purposes. Thus, it is possible to use both individual Pods that travel and move from one means of transport to another, as well as combined units for public transport or simple freight containers.

The Pod system will operate as an intermodal transport system which can be classified as a special type of multimodal transport, whereby two and more modes of transport are used to transport the same loading unit (transport unit). This means that, when changing transport modes, only the loading units (Transport unit) are switched, while the transported things (e.g., people or goods) remain in the same transport receptacles (such as containers). The basic idea is to design the Pod system for the use of different transport modes (e.g., rail, road, cable car/funicular). The Pod system should be sustainable, collaborative, interconnected, digital, on-demand, standardised, scalable, and suitable for several transport modes.

The aim of the development of the Pod system is to reduce energy consumption, noise and pollutant emissions and land consumption, to use raw materials and energy sources as well as existing infrastructure sustainably while at the same time ensuring the greatest possible accessibility and inclusivity for all user groups.

The Pod system will be designed to meet following parameters of an innovative transportation system:

- expected to contribute strengthening the railway transport.
- will contribute to provide socio-economically efficient and long-term sustainable transport for citizens and businesses throughout Europe.
- allow higher flexibility through intermodality, building on the concept of considering mobility as a service (MaaS)
- more convenient, safe, and affordable in-time door-to-door transportation day or night

5.2.2 Scope of the Pod System

5.2.2.1 Technical Scope

The scope of the Pod system is described in the following image, which shows the identified main building blocks, which are in scope of the Pods4Rail project (green), not in scope (orange) or to which the project has interfaces, as well as those elements that are not in the scope of the project and partially considered but are inherent to the system.

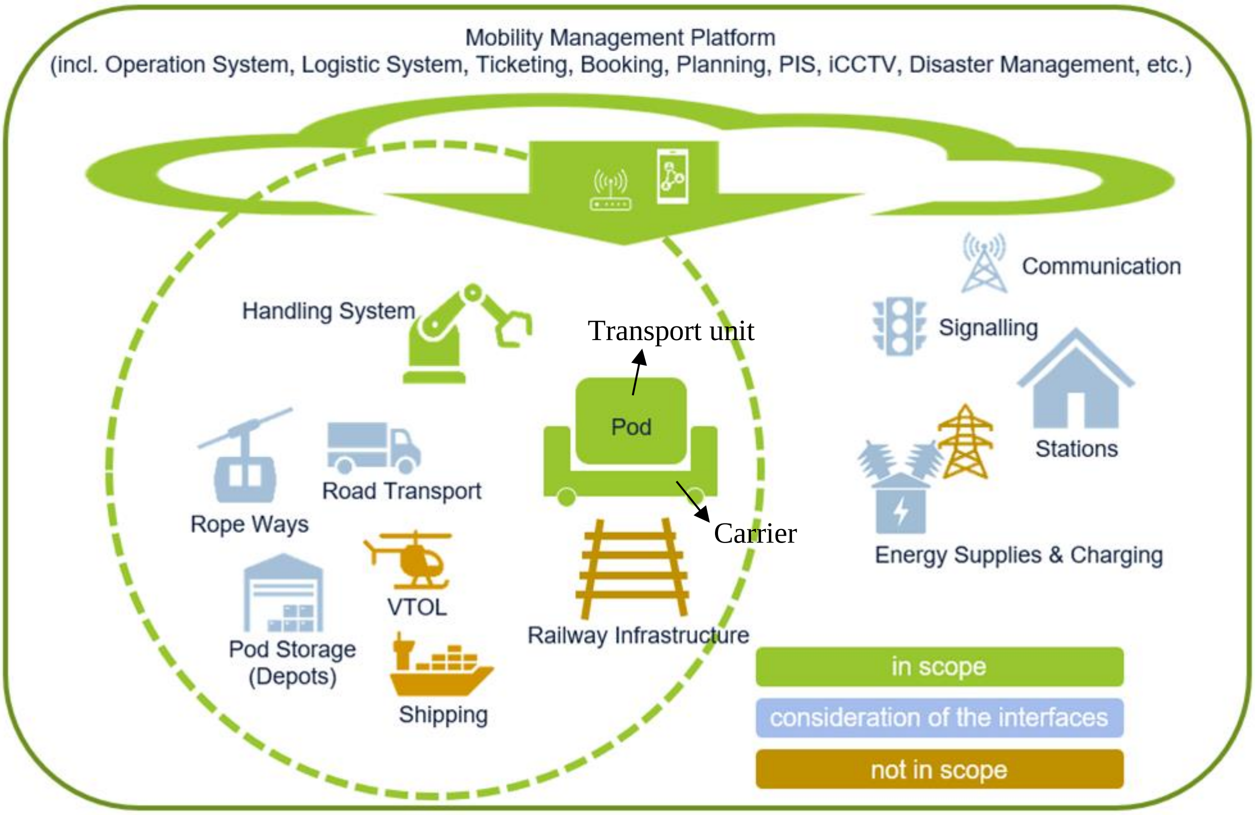

Figure 2: Scope of a Pod system and its core sub-systems

Not in scope of the project are the following transport modes: hyperspeed systems, maglev systems, very high-speed rail applications, overseas shipping, inland waterway transport, air transport, suspended monorails. These modes of transport are an essential part of the transport system and can be considered in a later development phase of a Pod system to achieve, not limit, the possibility of greater transport efficiency.

5.2.2.2 System Network Scope - Operating within European Transport Networks

The Project Pods4Rail holds a primary focus on providing cost-effective and efficient transport services by revolutionising the way railway infrastructure is utilised today. The development of the Pod system is tailored to suit the European geography of transport networks. Initially designed to address the transportation needs of European member countries, the project is also structured to transfer fundamental assumptions and outcomes to the broader global transport market. Within the scope of the current project, it adheres to general system requirements, identified by the key aspects of the European transport landscape.

The following system network requirements of EU Member States must therefore be observed:

Railway Network: The core mode of transportation for the Pods4Rail project is the extensive railway network present within European member states. This includes a comprehensive consideration of various railway configurations such as Branch Lines, Suburban Lines, and Main Lines for Long-distance Transport, all characterized by the standard railway gauge of 1435 mm as per EN 13848-1 and structure gauge compliant with EN 15273.

Tramway Networks: Tramway networks are integral components within urban transport systems, forming a crucial part of the Pods4Rail project's operational scope. Due to the non-uniform rules and standards, the following principles must be observed:

- The design of Pods must follow the maximum allowable contour of the tramway vehicle to ensure maximal safety.
- The cooperation between regular tramways, tramways with Pods and city transport vehicles and infrastructure (such as cars, buses, communication systems (traffic lights)) has to be ensured.
- Special terminals (tram stops) have to be created in order to ensure connection and disconnecting of Pods.

Metro systems: The project accounts for metro systems, essential urban transit systems that complement the overall transportation network.

Furthermore, the Pods4Rail project acknowledges the relevance of other modes of transport when interfacing with the core rail-based system. These include:

Cable Cars/Funiculars: Adhering to Regulation (EU) 2016/424, cable cars and funiculars are integrated into the project, contributing to a holistic and intermodal approach to transportation.

Road Transport network: While rail is a primary focus, the project also considers interfaces with European road transport vehicles to ensure comprehensive integration and seamless connectivity across different modes of transport.

5.2.2.3 Chronological Scope

The considered period of technical development related to a Pod system will be between 2025 to 2050 (time of the first application of the technology in railway systems).

In terms of technologies, the backwards view on technologies will be defined starting in 2018. For economic analyses, a period will be determined with 2050 (long-term forecast due to lifetime expectation for railway infrastructure over 30 to 60 years).

The following forecast perspectives for the Pod system are aimed for:

- 2025 – 2050 Entire development process (simultaneous roll out)
- 2030 – Demonstration (large scale)
- 2040 – Serial Roll out for branch lines or tram
- 2050 – Serial Roll out for entire networks

5.2.2.4 Description of Sub-Systems (Building blocks)

The Pod system comprises several fundamental sub-systems, each crucial in shaping its functionality and operational efficiency. These core sub-systems, or building blocks, comprise Pod, handling system, logistics system, and operational system. **Figure 3** shows how these building blocks come together to enable seamless transportation of passenger and freight.

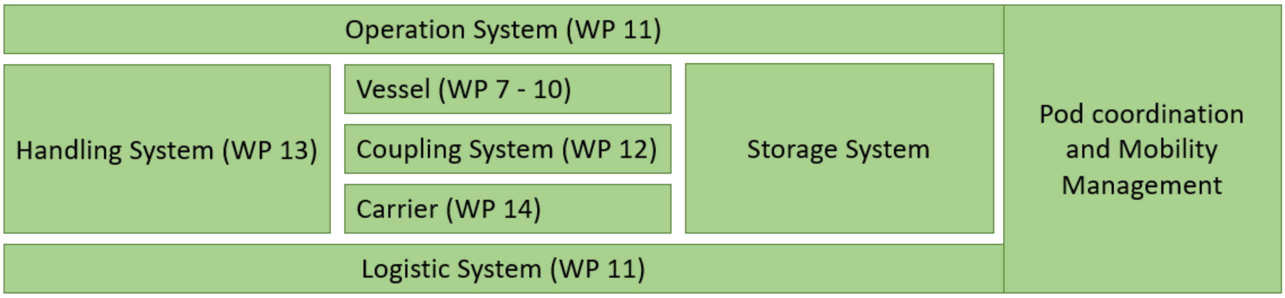

Figure 3: Needed Sub-Systems for a Pod system

The required sub-systems are described below.

Pod:
The foundational design of the system is the Pod (see figure 3) that is composed of two main components, carriers, and transport units (explained below), which can be separated. This innovative design allows for swift transitions between various transport systems, such as railway, road, or funicular, establishing a seamless and continuous transport chain from origin to destination without the need for system changes or intermediate freight handling.

- Carrier (mobile drive unit)

Mobile drive unit for railway without car body for transporting people or goods (called "transport unit"), so that there is only a vehicle underframe construction (also called "carrier" or "moving infrastructure")

- the Carrier should consist of an underframe construction, the energy storage, the propulsion, the auxiliaries and the wheel-axle system, the system for autonomous driving (incl. AI, sensor equipment, etc.), and will be used as a basis for a multi-purpose moving infrastructure, running on existing railway network
- the Carrier should comply with main railway for gauge 1435 mm, structure gauge acc. to EN 15273, or in a different variant for tramway lines
- Carriers shall be coupled virtually to form train sets, eventually mechanically coupled
- due to the system for autonomous driving and virtual coupling, a higher active safety of the vehicles shall be given, so that the design of the vehicles allows a lighter design than conventional rail vehicles, depending on the payload weight

- Transport unit (container, box)

Space for the transport of people or goods with a special design derived for this purpose and provided with the equipment necessary for the application, which can be loaded and coupled with the carrier.

- Coupling system

System that ensures the safe mechanical coupling of transport unit and carrier, as well as, if necessary, the coupling of other systems, such as power supply and communication.

Handling system: The handling system is required for the automated loading and unloading, ensuring, thus, the unhindered transfer of the transport units to the different carrier units, from storages, for loading and unloading of the transport units from one transportation mode (e.g., rail) to another (e.g., road).

Storage system:
The storage system stacks the unused carrier and transport units. The system protects the devices from environmental influences and can also be used for service check-ups. The system is intended to ensure reliable transport of carrier and transport units to their place of use within a certain period without disrupting the operation of Pods.

Pods coordination and Mobility Management:
To manage travel or transport demands and related availability of the vehicles and Pods, a coordinating intelligence is required, knowing at any time the status of vehicles and Pods including their current assignment to booked journeys. An overall Pod management system provides the basis for the required intelligence and includes the following components:

- Pod Coordination System (PCS)

Based on forecasted travel or transport demands, required availability of vehicles and Pods matching the demand are to be ensured. For this purpose, the current vehicle and Pod positions and status as well as the field or network status are communicated to the PCS. The Pods' status includes information about remaining the actual free capacity in terms of free seats or available space for freight containers. The PCS strives for a maximum of operational efficiency allowing a best use of the network capacity against the dynamically changing transport or travel demand. This includes tactical, operational (e.g., on-demand) planning or a mixture. Addressing the on-demand planning, e.g., the PCS makes use of algorithms to continuously decide about best assignment of incoming travel or transport requests to the most suitable Pods and vehicles in operation. Therefore, related control decisions will need to be continuously implemented for the whole system and communicated to the vehicle on-board control units. The Pods coordination process includes management of the impact of incidents. Incidents involve different, temporary availability restrictions of tracks and Pods/vehicles. These non-availabilities need to be considered for re-assignment, re-timing, re-routing or cancellation of transport or travel orders for the Pods and related vehicles. In addition, the PCS is used as a source system for end customer information about network, vehicle/Pod status, coordination decisions taken and their effect on the impacted orders.

- Pods Mobility Management Platform (PMMP)

For supporting end-customer applications, a PMMP is required acting in a similar way as classical MaaS platforms. Specialized mobile-phone apps as well as web applications are used for booking or ticketing for travels or transports using Pods. The end-customer applications also include adequate and updated information about the travels/transports booked or/and used by the customers along with alternative options of travel or transport.

- Disaster Management

Disaster is a serious disruption of the functioning of a system, community, or society, which involve widespread human, material, economic or environmental impacts that exceed the ability of the affected community or society to cope using its own resources. [40]. Disaster management is how to deal with the human, material, economic or environmental impacts of said disaster, it is the process of how to prepare for, respond to and learn from the effects of major failures. [41]. According to the International Federation of Red Cross & Red Crescent Societies a disaster also occurs when a hazard impacts on vulnerable people. The combination of hazards, vulnerability, and inability to reduce the potential negative consequences of risk results in disaster. Specifically, disaster management is about organising and directing resources to cope with a disaster and coordinating the roles and responsibilities of responders, organisations, or a IT system. The goal of the disaster-management leader is to minimise the event's impact, something that involves preparedness, response, recovery, and mitigation. For the Pod systems the disaster management system focuses on the transported people (health problems, fire, information problems, etc.), technical system (e.g., drive system failure,

failure in air condition), the MMS and the surrounding environment (e.g., Obstacle on the route, route interrupted). It should solve problems e.g., for passengers, the freight forwarder, the system provider, the vehicle rental companies.

- CCTV System

Intelligent video surveillance is used to determine information on occupancy rates, passenger flow and safety-related incidents. It complements traditional monitoring with active evaluation of videos on board and analyses them in real time using powerful algorithms.

- Communication systems*:*

As transport of passengers and freight represents a multi-layer market with various actors involved, communication plays an important role in supporting Pods to find their proper market share. Employing advanced technologies like Internet of Things (IoT), telematics and cloud-based platforms, facilitates real-time tracking, and secured data sharing. Availability of data, over time, will enable advanced AI approaches for demand forecasting and optimizing the system. In addition, interconnected ecosystems such as data sharing platforms, and API integration are necessary elements for stakeholders of the transportation market to efficiently communicate, enhance market analysis, ordering and planning, monitoring and strategic decision-making.

6. Description of needed technologies, concepts, and their development status

The following chapter describes the state of the art of essential subsystems that are necessary for the development of the planned pod system and does not claim to be complete (see 5.3.2.4). The needed Sub-Systems (Building blocks) for Pods4Rail follows the illustration in Figure 3. In addition to the TRL, the current development status of the technology is also described as a basis for application to Pod systems. In the case of infrastructure technologies, railway-specific applications are considered.

Table 1: Description of needed technologies, concepts, and their development status

Sub-Systems	Sub-System or Technology required	State of the Art incl. location, installed base, system control, connectivity,… (SoA)	Description of technology demand for Pods
General	*Pod system for transport of passengers and freight*	*SoA of system studies e.g.,* *- for street traffic by Citroën (TRL 2-6), by DLR (TRL 6-7)* *- for funicular/street systems by Doppelmayr with TRL 2, by Leitner (TRL 2-6)* *- for street/air transport by Schaeffler-Paravan (TRL 2)* *- for rail:* *Aachen Rail Shuttle by RWTH Aachen (TRL 4), Automated Nano Transport System (ANTS) by Siemens (TRL 2), autonomous running gear platforms by Parallel Systems (TRL 2-3)* *SoA for automated transport systems for standardised ISO-container is TRL 9, e.g., in large harbours*	*Pod system for passenger transport shall support the philosophy of autonomous rapid transport systems, capable to switch from mode A (railway) to mode B (cable car) without any interference by humans. The Pod system should operate with a minimum of human perception but able to apply mobility on demand services in specific use cases.* *Pod system for freight transport must provide a robust and autonomous handling of freight containers in dedicated areas and driverless transport from location A to location B. The loading and clearing of freight shall operate with SOA technologies (e.g. cranes). The system shall be able to connect with a command centre in order to dispatch the logistical process / handling / handover to clients.*
Operation system / Carrier / Transport unit	Autonomous driven rail vehicle for v_{max}: 60 – 80 km/h	Experimental autonomous rail vehicles for low speed (v_{max}: 30 km/h) with TRL 4-6, e.g., in Korea, Germany, USA	Autonomous driven rail vehicle for Pod transportation. Areas without signalling and GoA4-5 ready environment have to be equipped with sensors and reliable communication system in order to meet a regulation of reliable operation in public transport systems.
Operation system / Carrier / Transport unit	Autonomous driven street cars	Experimental autonomous street cars	Autonomous driven street cars for Pod transportation. Street cars are able to operate in dedicated areas with low speeds and permanent observation (including onboard personal for interfering situation)
Operation system	Railway operation systems with signalling technology	State-of-the-art: e.g., mechanical signalling, electronic signal boxes, ETCS systems, CBTC systems	Railway operation and logistics system without signalling for branch lines. The operation system must provide a safe and reliable operation during coasting and service intervals in different areas (with ETCS and without ETCS) and support the autonomous driving rail vehicle.
Operation system / Pod Coordination and Mobility Managem	Railway operation system for autonomous driving without classic signalling technology	several developments by KRRI or European railway industry for low speed (v_{max}: 30 km/h) with TRL 3-8	Autonomous driven rail vehicle for Pod transportation (use of available technology). The railway operation must observe and monitor the system network and detect incidents on the infrastructure or unexpected interruptions in network. Casual errors and incidents must report, and actions have to be

Sub-Systems	Sub-System or Technology required	State of the Art incl. location, installed base, system control, connectivity,… (SoA)	Description of technology demand for Pods
ent			taken in a defined reaction process.
Operation system / Pod Coordination and Mobility Management	Vehicle control systems for autonomous driven railway vehicles	several developments by KRRI or European railway industry	Autonomous driven rail vehicle for Pod transportation (use of available technology) are currently under development but not approved for regular operation. The autonomous onboard control system must be able to handle use cases in rail networks without interfering action by personal or other influences. Several sensor systems will be used (e.g., Radar, Lidar). The frequent communication network has to handle active and passive information about vehicle, network and status of both.
Pod coordination and mobility management system	Mobility management system	Exiting solutions for road transport available (i.e Uber-Taxi)	To manage travel or transport demands and related availability of the vehicles and Pods, a coordinating intelligence is required, knowing at any time the status of vehicles and Pods including their current assignment to booked journeys.
Operation system / Pod Coordination and Mobility Management / Transport unit	Passenger Information System (PIS)	standard PIS systems in railway sector	PIS for autonomous driven Pod systems must include Emergency and Disaster Management for unmanned vehicle and different transport modes. The PIS must manage and classify independently a critical incident onboard and ensure the communication level between passengers and the communication control centre during operation.
Coupling System	Virtual coupling of rail vehicles	several developments by European railway industry	Virtual coupling in railways is a technology that allows trains to operate in close proximity to each other with a greatly reduced risk of collision, It utilizes advanced communication systems and sensors to synchronize the speed and braking of trains, allowing them to travel as if they were physically connected, even though they are not, which enhances the flexibility and fluidity of train operations.
Coupling system	Emergency coupling of rail vehicles	several developments by European Railway Industry	Pod systems do need a emergency coupling system based on hook coupling
Carrier system	Drive system for small railway vehicles	several developments by European railway industry	Drive system for vehicles shall be operated emission free and energy efficient.
Carrier system	Brake system for small railway vehicles	several developments by European railway industry	Brake systems for vehicles shall be fully electric and for emergency use mechanical brakes (2nd braking system)
Carrier system / Pod / handling system	Power supply systems for small railway vehicles	several developments by European railway industry	Electric power supply system for small railway vehicles must be independently maintain the operation between to stopping points. A recharging of the rail vehicle is possible in dedicated areas around this stopping point. It is also allowed to use other charging-infrastructures (if available from

Sub-Systems	Sub-System or Technology required	State of the Art incl. location, installed base, system control, connectivity,… (SoA)	Description of technology demand for Pods
			existing catenary, third rail or automotive applications). Also mobile charging applications are take into account.
handling system/ logistics system / transport unit	Transportation containers (transport unit)	Standard ISO-Container in 10’, 20’, 40’ dimensions (TRL 9)	Transportation containers (for Pods) for passengers and for freight to be developed.
Handling system / logistics system	Handling system for reloading of the transport containers (transport unit) from one mode of transport to another	for regular freight containers TRL 9	Handling system for fast reloading of the specific different transport containers (Pods) from one mode of transport to another
Carrier system/ Pod/ handling system	Locking system (coupling system) for transportation containers for freight	Automated locking of containers in Shift2Rail project FR8RAIL IV	Locking system (coupling system) for transportation containers (Pods) for passengers and for freight has to be adapted.
Carrier system/ Pod/ handling system	Coupling system for transportation containers for passenger and freight with different moving infrastructures	Mechanical coupling system for standard ISO-Container is TRL 9 - for street traffic by DLR (TRL 6) - for funicular/street system by Leitner (TRL 2-6)	Coupling system for transportation containers (Pods) for passengers and for freight for Pod system with different moving infrastructures. The transport container for passengers must consider electrical, data and mechanical interfaces in order to handle the payload without a loss of comfort and disadvantages for passengers.
logistics system	Dispatching and storage of transport units and carrier units	Existing solutions for industrial storage applications available TRL 9	The logistics system shall coordinate handling and storage for passenger and freight transport units, carrier units and optimize the utilisation of available infrastructure.

7 Conclusion

In the context of re-imagining transportation, Pods4Rail project addresses the challenges and potentials of a groundbreaking intermodal rail-based transport system. It envisions a flexible, decentralized transport system that offers on-demand services across diverse transportation modes for passengers and freight.

T2.1 aims to provide fundamental definitions related to the Pod system including its core elements and scope. It details its technical and geographical scope, key components, and coordination mechanisms.

The focus of the deliverable is on providing the description for fundamental elements of the system, i.e. Pods, handling systems, logistics systems, and operational systems including relevance to freight, passenger as well as disaster management. This will provide input for the follow-up work package for detailed specification and provides the basis of developments.
The definitions underscore the Pod system's transformative potential. By detaching carriers and transport units, it can create a seamless transport chain without interruptions or intermediate handling, offering safe, convenient, and cost-effective door-to-door mobility.

It should be noted that, since this system is a revolutionary system, the consortium regards the deliverable as an open document for future references and modifications. The goal is to set the stage for further development in the upcoming work packages.

While the Pod system has the potential to offer advantages such as increased efficiency, reduced energy consumption, and sustainability, its success highly depends on meticulous planning and adaptation to different transport modes and existing infrastructure, as well as to different legal requirements and issues with user acceptance.

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