# Deliverable D 7.1
# Concept Proposal (System)

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|---|---|
| **Project acronym:** | Pods4Rail |
| **Starting date:** | 2023-09-01 |
| **Duration (in months):** | 30 |
| **Call (part) identifier:** | HORIZON-ER-JU-2022-01 |
| **Grant agreement no:** | 101121853 |
| **Due date of deliverable:** | 30-08-2024 |
| **Actual submission date:** | 13-12-2024 |
| **Code:** | Pods4Rail-WP07-D-SMO-AT-001-13 |
| **Responsible/Author:** | SMO-AT/Walter Struckl |
| **Dissemination level:** | PU |
| **Status:** | D |

Reviewed: Yes
Reviewers: DLR, HACON, SMO, SMO-AT, UPM

*This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101121853.*

| Document history | | |
|---|---|---|
| *Revision* | *Date* | *Description* |
| 1 | 20.09.2024 | First issue task internal |
| 2 | 04.10.2024 | WP 7 Internal review |
| 3 | 25.11.2024 | WP-Lead and SteCo review |
| 4 | 13.12.2024 | Final version |

| Report contributors | | |
|---|---|---|
| Name | Beneficiary Short Name | Details of contribution |
| Walter Struckl | SMO-AT | Chapter 1-8 (Lead Chapter 5) |
| Manuel Osebek | DLR | Chapter 1-8 (Lead Chapter 6), WP-Lead |
| Rolf Goßmann | HACON | Chapter 1-8 (Lead Chapter 7) |
| Maria Traunmüller | MID | Content Chapter 5.2, 5.5 |
| Simon Collart-Dutilleul | Univ Eiffel | Content Chapter 6.2.3 |
| Philippe Bon | Univ Eiffel | Content Chapter 6.2.3 |
| Seddik Reguieg | Univ Eiffel | Content Chapter 6.2.3 |
| Marion Berbineau | Univ Eiffel | Content Chapter 7 |
| Juliette Marais | Univ Eiffel | Content Chapter 7 |
| Arne Lamm | DLR | Content Chapter 7 |
| Linus Brünner | DLR | Content Chapter 5.3.4.1-4 and 5.4 |
| David Krüger | DLR | Content Chapter 6 |
| Nicolai Schmauder | DLR | Content Chapter 6 |
| Jesus Felez | UPM | Content Chapter 6.4.3 |
| Airan Frances | UPM | Content Chapter 5.3.4.3 |
| Jorge Portilla | UPM | Content Chapter 6.4.4 |

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# 1 Executive Summary

In work package 7 (WP 7), the Transport Unit (TU) is developed under technical aspects. Functional and security-relevant requirements and framework conditions are derived and expanded based on previous WPs. For three use cases (UC), these requirements are specified in more detail and transferred into technical concepts of the TU, its interfaces and an operating system. One focus is on secure and efficient movement within the Pod system.

The size of the proposed TU corresponds to standardised 10 ft and 20 ft containers, whereby a smaller unit, the 5 ft container with a length of 1500 mm, is also introduced. The Carrier Unit (CU) for road transport should have a loading area of 10 ft and 25 ft for the CU for rail transport. To define the main TU layout, floor plans were created. For estimating the weight and energy balance, main components were listed and analysed. As the HVAC unit is expected to be the largest consumer in the TU, a simulation model was built up to estimate the battery capacity. The investigations have shown that carrying the entire capacity in the TU is not valid due to the enormous weight, which would make handling the TU more difficult and the system less efficient. Only a part of the capacity should be carried that is sufficient to supply all systems of the TU while it is not coupled to the CU, for example, during the transshipment of the TU.

To define all TU interfaces, possible technical solutions are first collated, evaluated and the most suitable solution is identified by using evaluation matrices. These are then combined with the works in chapter 5 to create an overall CAD model. Because the new Pod system is expected to cover several applications in coexistence with already existing infrastructure, it is suggested to use standardised systems, also to achieve rapid technology readiness. It is therefore suggested that interfaces and dimensions are compatible with existing ISO containers. For the transshipment process and the interfaces towards the CU and storage systems, handling with (autonomous) forklift systems show advantages in compatibility and efficiency. For communication needs, the transmission of signals and data should be done wireless, so that every related unit (CU and TU) are able to interact with the developed operation system.

The paradigm of using existing standards also applies for the software applications ensuring a smooth planning, dispatching and management of the Pods operations including end-customer integration via the suggested mobility management platform. The concept for the future Pods Operations Management System is developed and presented. An assessment of existing and upcoming technologies and their integration has been performed to enable the highest efficiency of the overall system. The work has shown that compatibility with existing systems brings major advantages in terms of market acceptance and the coexistence of different systems. At the same time, however, this also results in restrictions of flexibility and the introduction of new, potentially more efficient technologies. Furthermore, the results are based on some assumptions, which must be elaborated in the following WPs. These are, for example, safety aspects or the dimensioning of the CU, which should comply with the proposed TU concept, for an overall system efficiency.

## 2 Abbreviations and acronyms

| Abbreviation / Acronym | Description |
|---|---|
| 5G | Fifth-generation technology standard for cellular networks |
| 6G | Sixth-generation technology standard for cellular networks |
| AC | Alternating Current |
| ACEA | Association des Constructeurs Européens d’Automobiles, European Automobile Manufacturers’ Association |
| AI | Artificial Intelligence |
| ALICE | Alliance for Logistics Innovation through Collaboration in Europe |
| API | Application Programming Interface |
| APO | Automated Pods Operation |
| ATO | Automatic Train Operation |
| BTMS | Battery Thermal Management System |
| CAPEX | Capital Expenditure (investment costs) |
| CCS | Command and Control System |
| CI/CD | Continuous Integration / Continuous Deployment (pipeline) |
| COM | Coupling of Media |
| COP | Coefficient of Performance |
| CU | Carrier Unit<br>▪ Rail-CU: Carrier Unit for rail transport<br>▪ Road-CU: Carrier Unit for road transport |
| C-V2X | Cellular network(s), in context with vehicle-to-everything |
| DC | Direct Current |
| DevOps | Development / Operations (IT System Administration) |
| DMPS | Digital Maintenance Planning System (FA3) |
| DSRC | Dedicated Short-Range Communication(s) |
| ECM | Electrical Coupling Method(s) |
| ECU | Electronic Control Unit(s) |
| EE | Electric and Electronic |
| EK | Expert Knowledge |
| EMI | Electromagnetic Interference |
| ERA | European Union Agency for Railways |
| ERTMS | European Rail Traffic Management System |
| ETCS | European Train Control System |
| ESA | European Space Agency |
| EU | European Union |
| EUSPA | European Union Agency for the Space Programme |
| EV | Electric Vehicle(s) |
| FAx | Flagship Area x (Europe’s Rail) |
| FAKRA | Facharbeitskreis Automobil |

| | |
|---|---|
| FPx | Flagship Project x (Europe’s Rail) |
| GA | Grant Agreement (of the Pods4Rail project) |
| GNSS | Global Navigation Satellite Systems |
| GoA | Grade of Automation |
| GPS | Global Positioning System |
| HL | Hazard Level |
| HPC | High-Performance Computing |
| HS | Handling System |
| HVAC | Heating, Ventilation and Air Conditioning |
| HVIL | High Voltage Interlocking system |
| HZ | Handling Zone |
| IAMS | Intelligent Asset Management System (FA3) |
| ICE | Internal Combustion Engine |
| ID | Identification number |
| IEEE | Institute of Electrical and Electronics Engineers |
| I/O | Input/output |
| IoT | Internet of Things |
| IP 2 | Innovation Programme 2 (Infrastructure) of Shift2Rail |
| IT | Information Technology |
| IXL | Interlocking (railway system) |
| LFP | Lithium-Iron-Phosphate |
| LTO | Lithium-Titanium-Oxide |
| MaaS | Mobility-as-a-service |
| MAC | Media Access Control |
| MAWP | Multi Annual Work Programme |
| MCM | Mechanical Coupling Method |
| ML | Mainline (railways) |
| MMP | Mobility Management Platform |
| MPG | Main Product Group |
| MSC | Maritime Safety Committee |
| NFR | Non-Functional Requirement(s) |
| OC | Operation Category |
| OCORA | Open Control Command and Signalling Onboard Reference Architecture |
| OP | Operating Point |
| OPEX | Operational Expenditure (operational costs) |
| OPPL | Operations and Planning |
| OTA | Over-the-Air |
| PI | Physical Internet |
| PIS | Passenger Information System(s) or Service(s) |
| POMS | Pods Operations Management System |
| PRM | People with reduced mobility |

| | |
|---|---|
| RAMS | Reliability, Availability, Maintainability, Security |
| RBD | Relative Braking Distance |
| RBPI | Road-Based Physical Internet |
| RC | Receiving Carrier Unit |
| RCA | Reference Control Command and Signalling Architecture |
| RDT | Requirement - Direct Transshipment |
| RF | Radio Frequency |
| RFLS | Requirement - Forklift System |
| RGEN | Requirement - General |
| RILD | Requirement - Integrated Lifting Device |
| RIM | Rail Infrastructure Manager(s) |
| RZ | Receiving Zone |
| S2R | Shift2Rail Programme (Horizon 2020) |
| SA | Storage Area |
| SC | Supply Carrier Unit |
| SCI-OP | Signalling and Control Interface – Operational Plan (RCA) |
| SCM | Signal Coupling Method(s) |
| SDK | software development kit |
| SDV | Software Defined Vehicle |
| SDVoF | Software-Defined Vehicle of the Future |
| SotA | State-of-the-Art |
| SWOT | Strengths, Weaknesses, Opportunities, Threats (analysis) |
| SZ | Supply Zone |
| T2T | Train-to-Train |
| T7.1, T7.2, T7.3 | Task 7.1, Task 7.2, Task 7.3 as part of WP 7 |
| TA | Transshipment Area |
| TCBM | Thermal Car Body Model |
| TCR | Temporary Capacity Restriction(s) (of the rail network) |
| TCS | Train Control System |
| TD2.x | Technical Demonstrator x of the IP 2 in Shift2Rail |
| TS | Transshipment Scenario |
| TSI | Technical Specification for Interoperability |
| TSI OPE | Technical Specification(s) for Interoperability on Operations |
| TSO | Transport Service Operator(s) |
| TT | Requirement - TU to TU Interface |
| TU | Transport Unit (also known as vessel) |
| UC | Use Case |
| UITP | International Association of Public Transport |
| V2I | Vehicle to Infrastructure |
| V2N | Vehicle to Network(s) |
| V2P | Vehicle to Pedestrian |
| V2V | Vehicle to Vehicle |

| | |
|---|---|
| V2X | Vehicle to Everything |
| VC | Virtual Coupling |
| VCTS | Virtually Coupled Train Sets |
| Wi-Fi | Wireless Fidelity |
| WP | Work package |
| WTB | Wire Train Bus |
| XiXo | Check-in Check-out |

**Remark regarding the terms *autonomous* and *automated:***
Within Pods4Rail the aim is to develop a concept for a fully autonomous Pod system. Within this Deliverable, the terms automated (according to GoA 4) and autonomous (according to GoA 5) are both used.

# 3 Background

The present document constitutes the Deliverable D7.1 “Concept proposal Pod system” in the framework of the Flagship Area 7, project Pods4Rail as described in the EU-RAIL MAWP. The work carried out in this task is linked to a knowledge exchange with FP4 WP 5 and WP 18 and the FP6 WP 5 especially to the propulsion architecture and other system elements like for example HVAC.

The Deliverable D7.1 within WP 7 contains the works of three tasks, namely Task 7.1 “Concept proposal for the vessel” (chapter 5 within this Deliverable), Task 7.2 “Concept proposal for interfaces” (chapter 6 within this Deliverable) and Task 7.3 “Concept proposal for operation system” (chapter 7 within this Deliverable). The results of all three tasks are given within this document.

This WP summarizes the fundamental work done in WPs 2, 3 and 4 of the Pods4Rail project to provide the technical framework for the design concept of the TU as well as the communication platform for the operation of specific passenger and freight applications, which will be further detailed in WP 8 and WP 9. For these and the Handling System (HS) design (WP 13) as well as the Rail-CU design (WP 14), this WP 7 provides important boundary conditions.

# 4 Objective/Aim

This document has been prepared to provide a first concept proposal for the Pod system as a **general objective of WP 7**, consisting of the TU, the interfaces towards the CU and towards the surroundings as well as the operation system for the Pods. Due to various focusses of the concept proposal in each chapter, this document shows different detail levels of the given concept developments. Also, meanwhile some chapters are more focussing on railway domains, others are more focussing on road technologies. This is meant to combine promising technologies of both domains and implement them into one overall Pod system. The given concept proposal in this document has to be seen as suggestions based on the research done within this project, therefore, additional concept ideas or technologies solutions can also be chosen on a later project phase.

The main **objective of Task 7.1** (see chapter 5) is the proposal of a technical concept for the TU, which will be supplemented by a 3D-CAD-model (of the TU) for a passenger transport UC. For this purpose, relevant design decisions will be made, including the TU size for different UC, a floor plan for the passenger transport UC as well as the weight and energy balance of the proposed TU-design. Furthermore, possible emergency cases and service and maintenance of the TU are discussed.

The **aim of Task 7.2** (see chapter 6) is to define and design the relevant interfaces. Building on the work of Task 7.1 and the overall layout, the requirements for each interface are first collated and then supplemented with further and more specific requirements as the project progresses. The aim is to translate these requirements into specifications, which are then implemented in the CAD model. The derived CAD model serves as a basic preparatory work for the following WP-. The overall packaging of the TU- and its interfaces (WP 8 and WP 9) can be detailed after the work of Task 7.2. Furthermore, the aim is to have defined the required and most suitable interfaces (mechanical, electrical, communication) to the CU and the Handling System (HS), including their requirements and the possible arrangement configurations, by the end of the task. This is essential preliminary work for the development of the HS (WP 13) and the Rail-CU (WP 14).

The following concept proposal, as main **objective of Task 7.3** (see chapter 7), is intended to provide a concept of a fully automated supermodal (Pods4Rail D2.1, 2024) mobility system for passengers and goods which is sustainable, collaborative, interconnected, digital, on-demand, standardized, scalable and suitable for several transport modes with focus on rail. Such systems allow higher flexibility through supermodality, building on the concept of considering mobility as a service (MaaS) and utilizing the existing infrastructure. Hence, it becomes imperative to consider various aspects of necessary modifications. Such aspects are crucial for ensuring full deployment of the system.

To embed the resulting concept in the research and development landscape, we take a closer look at the operational processes that are influenced by such a Pod solution and derive recommendations for action, specify the operational processes in more detail and define the new subcomponents required for this and those to be modified. The first relevant step here is to focus on the reference architectures that are already implemented in the System Pillar. To this end, we will provide an overview of RCA and OCORA and the processes already defined here and explain how these relate to the Pod concept. As already described in D4.4 (cf. Figure 31), the railway infrastructure will not be examined in more detail in the context of the project, but the focus will be on the onboard system, so we will focus on OCORA in the more detailed analysis and not take a closer look at RCA in this context. As we are pursuing a cross-domain approach, we would at least like to take a look outside the box for the system specification and examine the automotive area and the system-relevant State-of-the-Art (SotA). An important point to mention here is the Software Defined Vehicle (SDV) Architecture in the automotive domain. Finally, we will address the aspect of automation and high automation by considering the findings of existing work and also the ongoing research work from the EURail context (especially R2DATO) and the publications of EULYNX in order to provide requirements for the innovative concept.

# 5 Concept proposal for the Transport Unit

This chapter describes the fundamental work done in WPs 2, 3 and 4 to provide the framework for the technical concepts and operational scenarios for specific passenger and freight applications in WP 8.

There will be no specific methodology covering all technical and operational requirements, but recursive measurements can be applied for some conceptual options.

## 5.1 Definitions and Purpose

The term "purpose" refers to the goal or reason behind something's existence or action. It describes the intent or aim of an activity, object, or organization, indicating what is intended to be achieved or why something was created.

Following four UC will be considered for WP 7 based on the preliminary descriptions in WP 2 and WP 4 (for UC descriptions see WP 4, D4.1):

- UC 1: Basic public passenger transport (<12 (-50) passengers, <30 km, 10-30 minutes, economy class)
- UC 2: Premium Passenger Public Transport (<6 (-20) passengers, <30 km, 10-30 minutes, business class)
- UC 8: PRM application (2-6 passengers, loading devices/equipment, <5 km on road)
- UC 18: Cargo application with 10 ft and 20 ft Container

### 5.1.1 Purpose of Passenger Transport

Pod systems represent a cutting-edge solution in rail transportation, leveraging automation and specialised infrastructure to enhance mobility. Understanding the purpose of these systems requires a closer look at their technical components and functionalities. Passenger transport refers to the movement of individuals from one place to another, typically measured in passenger-kilometres which is calculated by multiplying the distance travelled by the number of passengers in the vehicle. (Schipper, 2003).

Pre-assumptions for the passenger TU to provide services:

**TU & Rail-CU and Infrastructure Technology**

**TU & Rail-CU:** Pods are small, electric vehicles designed to transport a few to several passengers. They are typically constructed from lightweight yet durable materials to maximise energy efficiency and safety. The design of these TU can vary based on capacity and intended use (see WP

4), but they generally focus on providing a smooth, reliable ride.

**Infrastructure Technology**: The infrastructure for Pod systems is tailored to meet the demands of rail vehicles but also connected modes like road or cable cars. There are primarily two types of track systems:

**Branch lines:** A single rail supports the Pod, often installed above ground. No high demand on passenger transport and limited entrance to poor platform infrastructure. There will no charging availability and limited availability of HS.

**Frequent lines** with connection to main networks: Two parallel tracks guide the Pods in both directions. This setup generally offers increased stability and higher capacity for handling more passengers. Stations with decent capacity of HS, electrical charging infrastructure will be available.

**Automation and Control**

**Control Systems**: Pod systems rely on sophisticated computer-based control systems to manage operations and the handling of TU & Rail-CU (see WP 2). This includes:

**Vehicle Control:** Speed and routing of the Pods are regulated by a central control system. Advanced algorithms optimize scheduling and ensure safe distances between Pods, enhancing overall efficiency.

**Communication:** Pods are connected through a communication network that enables real-time data transfer between vehicles and the central control unit. This includes wireless technologies for continuous monitoring and system management.

**Navigation Systems:**
Various navigation technologies guide Pods along their designated routes, including:

**Active Sensors for autonomous driving**: Rail-CU are equipped with Lidar, optical and Radar.

**GPS or air-born transmission of information**: 5G Technology is available at the track with stable transmission. Tunnels are not considered.

**Optical Guidance**: Optical sensors track the Pod's position relative to the track to ensure precise navigation.

**Energy Supply and Efficiency**

**Energy Source:** TU & Rail-CU are typically powered electrically, with several methods for energy supply:

**Conventional Systems:** Energy is transmitted via catenary, third rail or equivalent system to the Rail-CU vehicles.

**Onboard Batteries and Charging Stations:** TU and Rail-CU use onboard batteries, which are recharged at designated stations or via mobile TU charging CU.

**Energy Efficiency:** Due to their smaller size and automated operation, Pods generally consume less energy compared to larger trains. Energy-efficient motors and optimized vehicle design contribute to lower overall energy consumption.

**Safety and Emergency Systems**

**Collision Avoidance:** Automated collision avoidance systems are integral to autonomous Pod operations. These systems utilise sensors and cameras to detect other Pods and potential obstacles, adjusting speeds and routes to prevent collisions.

**Emergency Protocols:** In case of emergencies, such as system malfunctions or power failures, safety protocols are in place (see WP 3). These may include automatic braking, emergency evacuation procedures, and the ability to return to the nearest station. Many systems are designed to ensure continued safe operation even during power outages.

**Onboard observation:** During traveling the TU will be observed by optical system, e.g. CCTV. In terms of emergency automatic instructions will be transmitted to TU passengers.

**Infrastructure and Integration:**

**Stations:** Pod stations are designed to efficiently handle passenger flow, with dedicated boarding and alighting areas. These stations are often integrated with existing transportation hubs to enhance connectivity and streamline passenger transfers. Stations are providing HS to move the TU from mode A to mode B.

**Maintenance and Upkeep:** Maintenance of Pod systems involves regular inspections (automatic detection system) and servicing according to a detailed maintenance schedule. Modular components allow for easy replacement and repair, minimizing downtime and operational costs. Maintenance will be done in depots for TU and Rail-CU.

**Comfort & individuality:**

Comfort in TU encompasses following aspects:

**Seating:** Ergonomically designed, cushioned seats with ample legroom for standard TU. Individually spaces for passengers without disruption by other passengers or services should be provided in a premium class TU or compartment.

**Climate Control:** Efficient heating and cooling systems in operation and also during detached handling of TU to other modes of transport.

**Hygiene:** Regular cleaning and availability must be granted during operation. Automatic observation of hygienic situation via optical sensors should be applied. 5 ft TU will be used as sanitary unit too.

**Amenities:** Free Wi-Fi, power outlets, and onboard working options should be provided for every TU.

**Service onboard:** There will be no personal onboard services for smaller TU.

**Accessibility:** For stops with no availability of HS a 5 ft TU will provide an entrance door system (one or both sides) in order to get passengers onboard. Furthermore, corridor TU (5 ft dimension) should provide access to other TU. (see configuration possibilities)

**Easy access** for passengers with disabilities (PRM) in dedicated areas.

**Quiet Zones:** Areas for relaxation and reduced noise. TU will provide different compartments for specific UC (see WP 4).

These elements work together to ensure a pleasant and enjoyable travel experience, addressing passenger needs and enhancing overall satisfaction.

**Table 1: Dimensions 5 ft containers (Mechanic International, 2024)**

| | |
|---|---|
| Outside dimensions (LxWxH) | 2200 x 1600 x 2260 mm |
| Inside dimensions (LxWxH) | 2049 x 1512 x 2062 mm |
| Door clearance (WxH) | 2106 x 1948 mm |
| Weight | 650 kg |
| Maximum payload | 3350 kg |
| Volume | 6.40 $m^3$ |

**TU capacity and versatile design**

On average, there are about 1 to 1.7 people per car (Bureau of Transportation Statistics, 2024). This number can vary depending on the region, type of vehicle, and specific circumstances:

For railway systems this capacity will also vary considering the geographical location and specific conditions (timetable, transport connections, other alternatives, …)

**Single Occupancy (1-2 passengers):** In many Western countries, particularly in the U.S. and Europe, a significant number of people drive alone, which lowers the average. Therefore, TU will be designed to provide for single transport capsules (5 ft long TU) as well as there are mostly just a few passengers having the same destination and pick up location.

**Group Travel (2-12 passengers):** For group travel trips the TU have to be designed for more passengers, the number can be higher, for specific functions. Configurations of TU considers 5 ft, 10 ft and 20 ft units, depending on the UC (see WP 4).

**Virtual-pooling:** In certain regions or during peak times, the transport demand can be higher due to events like football game, exhibition, weekends…). Following Pods (Rail-CU plus TU; see configuration possibilities) can couple virtually (without using mechanical connection or interfaces) to enhance the capacity of the railway network.

The estimate of occupation rate represents a general average for daily travels, reflecting typical train usage across various scenarios.

**Interoperability design with other modes of transport (supermodality):** In mobility, supermodality reflects how the value or efficiency of a transportation system increases as more elements are added to an already well-connected network. For example, adding a new subway line to a central transit hub provides greater benefits compared to adding it to a less connected area. Similarly, expanding a bike-sharing network in a densely used area yields higher utilization and efficiency compared to a less frequented region. In autonomous vehicle fleets, adding more vehicles enhances coordination and efficiency more in a densely covered area. Essentially, the added value from improvements grows with the strength of existing connections.

The TU sizes (5 ft, 10 ft, 20 ft) must fit to related transport modes (e.g. road, cable car, …) as well as the HS and depot.

### 5.1.2 Purpose of Freight Transport

A freight Pod, or cargo Pod, is a specialised, modular container system designed for efficient cargo transport. The main question will the optimization of capacity vs. standardised containers design.

**Design and Structure**

**Modularity:** Freight TU come in two sizes (10 ft and 20 ft) to accommodate different types and amounts of cargo. Their modular design allows easy adaptation to various transport needs. Freight TU will be defined as conventional container according to ISO 668 can be also used for overseas transport. (ISO668, 2020)

**Materials:** They are usually made from durable, high-alloyed steel, or advanced materials to ensure strength and longevity while keeping the weight low.

Dimension: Most freight Pods are rectangular or cubic, which maximizes space efficiency and allows for easy stacking. The geometry / dimension will be defined as follow: see table below

**Table 2: Dimension of containers**

| Measures | Dimension | 10 ft | 20 ft |
|---|---|---|---|
| External | Length [mm] | 3010 | 6060 |
| | Width [mm] | 2440 | 2440 |
| | Height [mm] | 2590 | 2590 |
| Internal | Length [mm] | 2660 | 5710 |
| | Width [mm] | 2350 | 2350 |
| | Height [mm] | 2380 | 2380 |

**Technological Features**

**Automation:** TU are equipped with automation systems that facilitate transport and handling. This includes sensors for monitoring load volume and security.

**Communication:** TU feature communication systems for real-time tracking and monitoring of the cargo. Technologies like GPS and RFID should commonly be used to track the location and condition of the shipment.

**Climate Control/HVAC:** Some TU should include climate/ HVAC control systems to transport temperature-sensitive goods like food or pharmaceuticals safely.

Access and Security Features

**Access Points**: Freight TU typically have one or more access doors or hatches for easy loading and unloading. These doors are usually secure and lockable to protect the cargo. It is intended to load and unload the TH while mounted on the Rail-CU.

**Security Measures:** The freight TU security features might include locks, surveillance cameras, and alarm systems to safeguard the cargo from theft and damage.

**Integration and Use**

**Rail-CU or other modes of transport:** Freight TU are often used on specialized transport vehicles or systems, such as rail cars, automated delivery vehicles, cable railway or in high-bay warehouses.

**Infrastructure:** Freight TU are designed for use in modern logistics centres, warehouses, and port facilities, where they can be efficiently transferred between different modes of transport.

Overall, freight Pods are engineered to make cargo transport more efficient, secure, and adaptable, enhancing logistics and supply chain operations. The results of this section should determine the relevant know-how for the definition of basic assumptions for the following chapters in WP 8.

## 5.2 Configuration of Transport Units

Here we will set the possible configuration options for the placement on the CU. The methodology will follow on a functional level based on the purpose of application. E.g., for passenger transport a passenger transport unit (equal TU). The purpose of the UC can be fulfilled by the possible variations of the units. There are also a variety of possible configurations that should be evaluated in a later phase (see WP 8). The maximum loading space see chapter 5.3 (i.e. 20 ft). For the Pods4Rail project following dimensions in Table 3 for the different TU variants were defined.

**Table 3: TU variant overview and measurements**

| Measures | Dimension | 5 ft Cargo-TU | 10 ft ISO-Container | 20 ft ISO-Container | 5 ft Passenger-TU | 10 ft Passenger-TU | 20 ft Passenger-TU |
|---|---|---|---|---|---|---|---|
| External | Length [mm] | **1500** | **3010** | **6060** | **1500** | **3010** | **6060** |
| | Width [mm] | 2440 | 2440 | 2440 | 2440 | 2440 | 2440 |
| | Height [mm] | 2590 | 2590 | 2590 | 2590 | 2590 | 2590 |
| Internal | Length [mm] | **1410** | **2660** | **5710** | 1360 | 2870 | 5920 |
| | Width [mm] | 2350 | 2350 | 2350 | 2300 | 2300 | 2300 |
| | Height [mm] | 2380 | 2380 | 2380 | 2200 | 2200 | 2200 |

According to the Table 3, the physical dimensions for each TU variants regarding the outer dimensions and gauging dimensions including wall thicknesses will be shown in Figure 1.

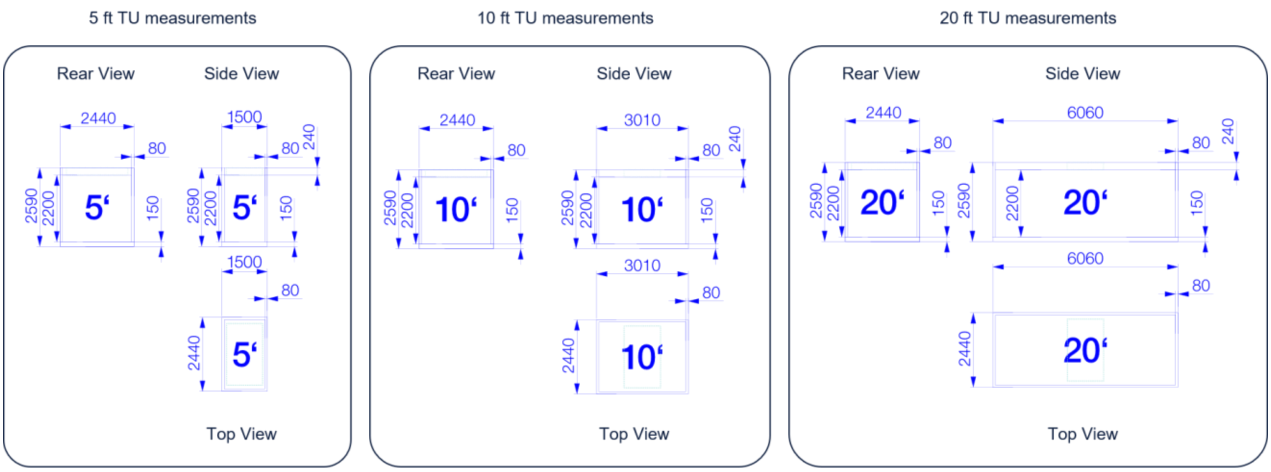



**Figure 1: Measurements of TU variants with Side View, Rear View and Top View**

### 5.2.1 Transport Units for passenger transport

Function: Transport of passengers
**Configuration A)** 1x5 ft Entrance/Exit Unit, 2x10 ft Passenger Unit (long version) with windows
**Configuration B)** 1x5 ft Entrance/Exit Unit, 1x10 ft Passenger Unit (long version) with windows, 1x5 ft sanitary unit, 1x5 ft Passenger Unit (short version)
**Configuration C)** 1x5 ft Entrance/Exit Unit, 3x5 ft Passenger Unit (short version) with windows, 1x5 ft sanitary unit
**Configuration D)** 1x5 ft Entrance/Exit Unit, 3x5 ft Passenger Unit (short version) with windows, 1x5 ft PRM unit

Figure 2 highlights the above-mentioned configurations A-D as possible Rail-CU load cases. As seen in the picture, several combinations are possible. The passengers can walk through the Pod by using gangways between the TU in the direction of travel.

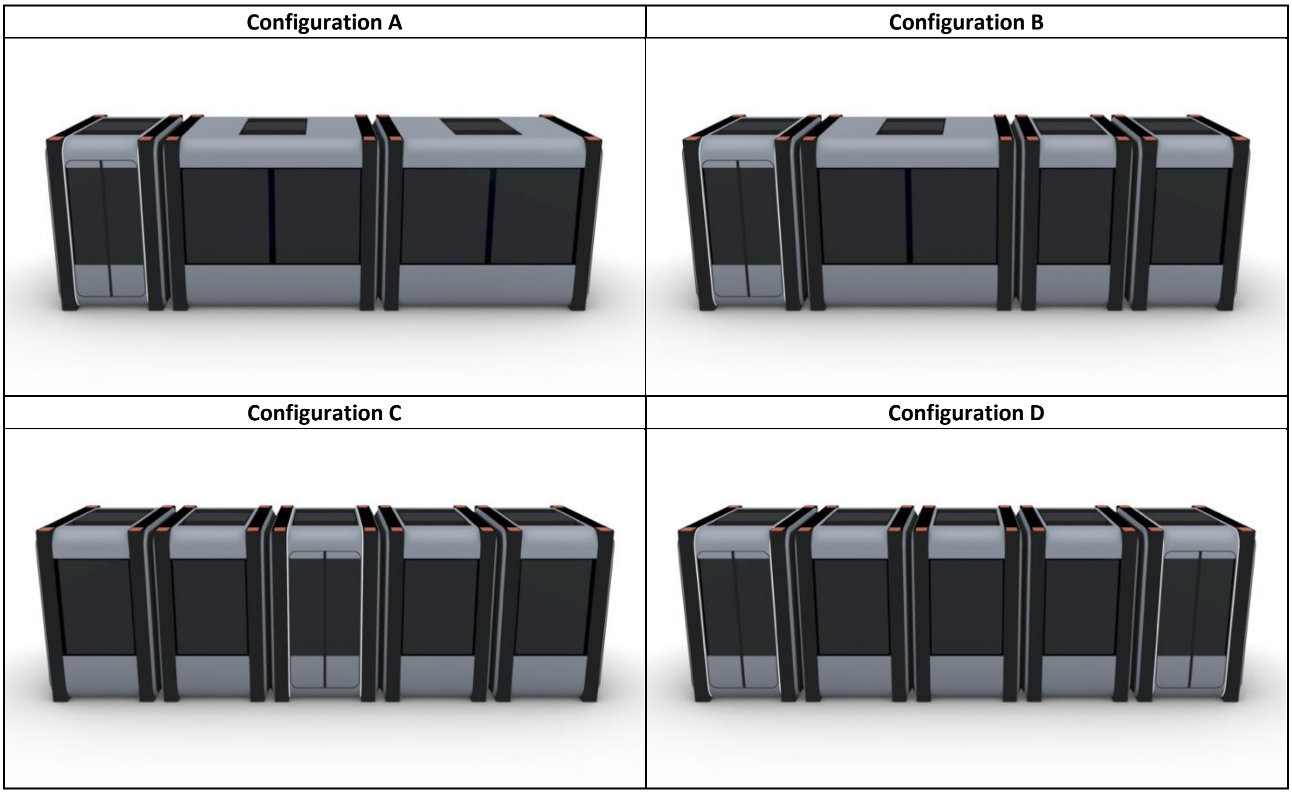



**Figure 2: Exemplary TU configurations on the Rail-CU for passenger transport**

### 5.2.2 Transport Units for freight transport

The main function for freight units are single use freight (such as parcel services) with the dimensions corresponding to ISO 668. Also, multiple use configurations are possible with freight units (such as passenger transport and parcel service on the same CU). Figure 3 shows exemplary

TU configurations on the Rail-CU for freight transport.

| Configuration single use | Configuration multiple use |
|---|---|
|  |  |

**Figure 4: Exemplary TU configurations on the Rail-CU for freight transport**

## 5.3 Architecture

The following chapter aims to configure the variants into a functional Pod architecture. These can be applied by using a variant matrix including configuration units and relevant components.
As a result, each variant has a specific configuration with the necessary components (see EN 15380).

### 5.3.1 Variant matrix for use cases UC 1, UC 2, UC 8, UC 18 and configuration of Main Product Groups

Following structure of Main Product Groups (MPG) will be considered for the TU (10 ft and 20 ft) and basis for further design stages. The requirements for each MPG were defined in WP 4 Task 4.4.

**UC 1, UC 2 and UC 8**
This MPG structure encompasses UC 1 (basic public transport), UC 2 (premium public transport) and UC 8 (PRM transport) in order to determine relevant components for TU. It will also feature MPG which are not located in TU. For better comparability, the system for railway applications (DIN EN 15380-2:2006) was used.

**Table 4: Variant matrix of MPG in TU and Rail-CU oriented towards (DIN EN 15380-2:2006)**

| MPG of TU (Variant 10 ft and 20 ft) – to be considered here | MPG of CU (out of scope in WP 7) |
|---|---|
| B Vehicle body | E Running gear |
| C Vehicle fitting out | F Power system, drive unit |
| D Interior appointments | G Control apparatus for train operations |
| H Auxiliary operating equipment | |
| J Monitoring and safety equipment | |
| K Lighting | |
| L Air conditioning | |
| M Ancillary operating equipment | |
| N Doors, entrances | |
| P Information facilities | |
| | Q Pneumatic/hydraulic equipment |
| | R Brake |
| S Vehicle linkage devices | |
| T Carrier systems, enclosures | |
| U Electrical wiring | |

The 5 ft TU will meet special requirements to allow entry and exit into the Pod system when there is no platform or HS (on the infrastructure). It can also be used as a sanitary unit or additional luggage compartment for tourist applications (see combined load UC 18 WP 4).

**Table 5: Variant matrix of MPG in 5 ft TU (entrance unit, sanitary, others) oriented towards (DIN EN 15380-2:2006)**

| MPG of TU (Variant 5 ft) – to be considered here |
|---|
| B Vehicle body |
| C Vehicle fitting out |
| D Interior appointments |
| H Auxiliary operating equipment |
| J Monitoring and safety equipment |
| K Lighting |
| M Ancillary operating equipment |
| N Doors, entrances |
| P Information facilities |
| S Vehicle linkage devices |
| T Carrier systems, enclosures |
| U Electrical wiring |

The UC 18 (Freight / Cargo Transport) will use two TU sizes (10 ft and 20 ft). Since the TU are not intended to carry passengers, the design will consider different MPG values. For some special cargo cases, there will also be additional equipment on board to ensure constant climate conditions for the cargo (e.g. refrigeration of medicines or food).

**Table 6: Variant matrix of MPG in 5 ft TU (entrance unit, sanitary, others) oriented towards (DIN EN 15380-2:2006)**

<table>
<tr><th>MPG of Cargo TU (Variant 10 ft and 20 ft) – to be considered here</th><th>MPG of CU (out of scope in WP 7)</th></tr>
<tr><td>B Vehicle body</td><td>E Running gear</td></tr>
<tr><td>C Vehicle fitting out</td><td>F Power system, drive unit</td></tr>
<tr><td>L Air conditioning</td><td>G Control apparatus for train operations</td></tr>
<tr><td colspan="2">H Auxiliary operating equipment</td></tr>
<tr><td colspan="2">J Monitoring and safety equipment</td></tr>
<tr><td colspan="2">K Lighting</td></tr>
<tr><td colspan="2">M Ancillary operating equipment</td></tr>
<tr><td>N Doors, entrances</td><td></td></tr>
<tr><td></td><td>Q Pneumatic/hydraulic equipment</td></tr>
<tr><td></td><td>R Brake</td></tr>
<tr><td></td><td>S Vehicle linkage devices</td></tr>
<tr><td colspan="2">T Carrier systems, enclosures</td></tr>
<tr><td colspan="2">U Electrical wiring</td></tr>
</table>

### 5.3.2 Design, Geometry and Clearance configuration

The Pod system will generally adhere to UIC dimensions, although branch lines and private railways have different dimensional profiles. Due to the versatile operational configuration of different TU (length 5 ft, 10 ft, 20 ft) there will also be no separation between passenger and freight transport or between the UC itself. In general, it is noted that Pod CU can accommodate and transport different loads at the same time. (UIC505-1, 10ed).

During the expansion of the routes to Central Europe, it is emphasised that a height of 4830 mm enables the transport of semi-trailers with a height of 4500 mm and recommends an expansion of connecting routes in the EU to 3150 mm wide and 4830 mm high (see Figure 5).

There are special procedures for exceeding the loading gauge. If the loading gauge exceeds the maximum geometry, for example, the adjacent track must be closed, and crossings are not possible without further ado. The Pod-System itself does not have an impact on the infrastructure and will stay within the proposed gauging limits.

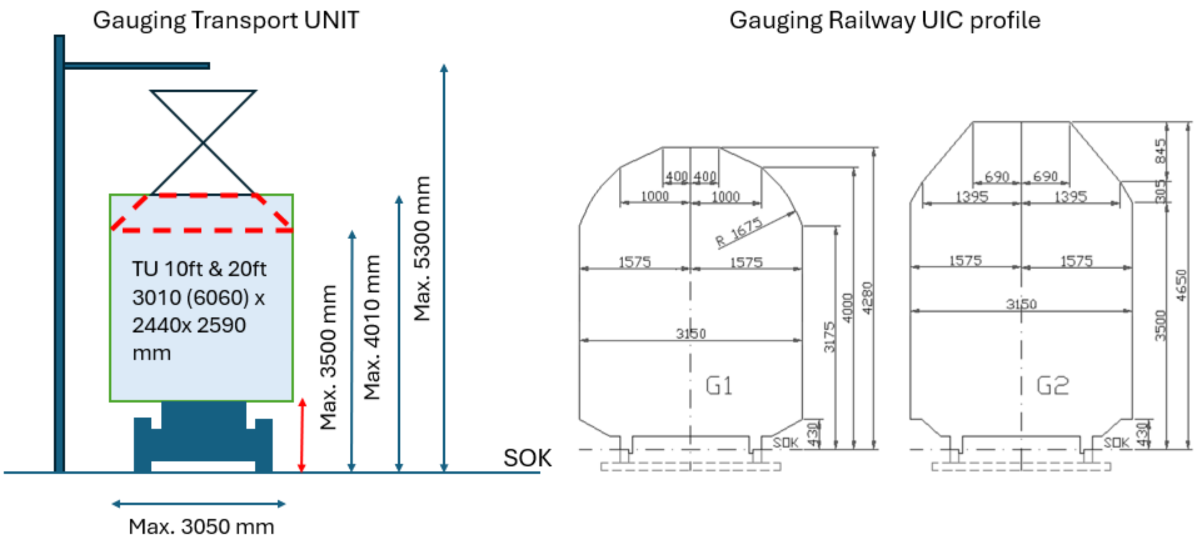



**Figure 5: Main boundary profile of the Pod system compared with the most used UIC profiles G1 and G2 (UIC505-1, 10ed)**

### 5.3.3 Weight balance

The weight balance in railway systems is crucial for ensuring the safety, efficiency, and longevity of both the trains and the tracks. Following key aspects load distribution, fuel efficiency, safety of unbalanced loads, maintenance of rail profiles does have a relevant impact to the Pod system.

When mentioning these aspects, weight also determines the dimensioning of the drive system (including motors, inverters, battery pack) and the possible transport capacity. A possible discussion related to weight also concerns the materials used or the lightweight structure, which must meet safety and crash worthiness requirements.

As part of this study, the baseline scenario for the weight balance was established in a basic passenger transport UC with 10 ft TU (see UC 1). The values given are estimates for the 1st iteration using basic assumptions on material and design requirements. The weight balance is used to size the car body structure and associated component system.

The following weighting only considers MPG, which is already considered a requirement for public transport. In the final design, various weightings may deviate from the basic design proposal in Task 7.1. In addition, there may be overlap between MPG, as some components provide functions for different systems at the same time. For example, the electrical wiring of MPG U will also be part of the air conditioning system in MPG L.

**Table 7: Weight balance of 10 ft TU for UC 1 (basic passenger transport)**

| MPG of TU (Variant 10 ft and 20 ft) – to be considered here | Weight in kg per MPG | Note |
|---|---|---|
| B Vehicle body | 1260 | Steel vehicle body |
| C Vehicle fitting out | 130 | Only Floor |
| D Interior appointments | 270 | 8 basic seats |
| H Auxiliary operating equipment | 100 | Battery |
| J Monitoring and safety equipment | 50 | CCTV |
| K Lighting | 50 | LED ceiling (part of MPG C) |
| L Air conditioning | 200 | 1 unit |
| M Ancillary operating equipment | 100 | Passenger counting system (additional) |
| N Doors, entrances | 500 | 2 Doors (front and end) |
| P Information facilities | 83 | Screen and communication audio |
| T Carrier systems, enclosures | 340 | |
| U Electrical wiring | 200 | |
| S Vehicle linkage devices | 140 | Gangway between TU |
| **Total weight per TU** | **3423** | **10 ft** |

### 5.3.4 Energy balance

Conventional energy levels in a rolling stock will cover different nominal voltage levels (3KV, 1.5KV, 700V, 400V,230 V, 110V, 24V, 12V, 9V). Here within the estimation of maximal nominal voltages for the most relevant MPG will be analysed.

**Table 8: Energy balance of 10 ft TU (estimated for UC 1 baseline and requirements in WP 4)**

| MPG of TU (Variant 10 ft) | Energy demand (nominal performance) per 10 ft unit [kW] | Note |
|---|---|---|
| H Auxiliary operating equipment | 0.2 | Battery – cooling / heating ventilation |
| J Monitoring and safety equipment | 0.02 | CCTV |
| K Lighting | 0.2 | LED ceiling --> part of MPG C |
| L Air conditioning | 5.64 | One-unit (worst case 4.34 kW) heating |
| M Ancillary operating equipment | | Passenger counting system (additional) |
| N Doors, entrances | 0.33 | 2 Doors (front and end) |
| P Information facilities | 0.05 | Screen and communication audio |
| **Total energy demand per TU** | **6.44** | **10 ft** |

In summary, the most relevant impact of the energy balance is caused by the HVAC system and this part must be examined with the greatest care. Other auxiliary systems play a subordinate role in the energy balance and are therefore to be understood as assumptions in the development phase. The battery is used as an energy buffer for on-board systems (especially the HVAC device), whereby the nominal voltages are only considered for the battery's auxiliary systems (heating and cooling the cells). Further investigations, especially the voltage levels, are described in WP 8.

#### 5.3.4.1 HVAC energy consumption

HVAC is an acronym for "heating, ventilation and air conditioning". Since there are currently no standards for the air conditioning of swap bodies/containers for passenger transport, the normative bases from the railway sector were used for this purpose. In rail applications HVAC systems are used to provide the cabin with heating, ventilation and air conditioning to establish a comfortable surrounding for passengers and personal. (DIN-EN-50591, 2019)

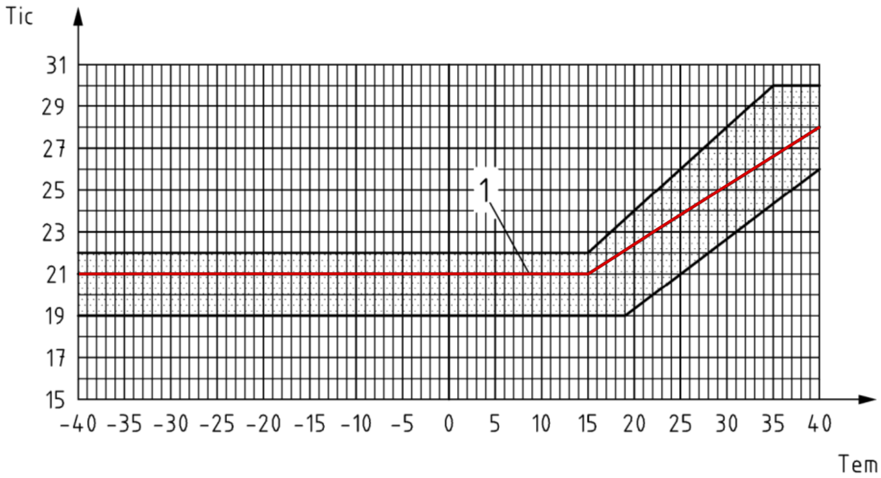
Since the HVAC system is the second largest energy consumer in rail applications, only second to the traction system, with a share in the yearly energy demand of roughly 30 %, it makes sense to calculate the required battery capacity of the Pod system based on the energy consumption of the HVAC unit. (Ebinger, 2022)

For this reason, a thermal car body model (TCBM) was set up in Dymola to calculate the power demand of the HVAC system, considering the specifications from the DIN EN 50591 and DIN EN 14750-1 standards as well as the information provided by previous WP (WP 4).

**Specifications for thermal comfort**

The specifications for thermal comfort can be found in DIN EN 14750-1, which provides information on the room temperature, permissible humidity, fresh air volume and heat dissipation per passenger as well as other specifications to be complied with. (MIT, 2008)

As specified in WP 4 Deliverable 4.4 the Pod system is classified as a category A vehicle using climate zone II for winter and I for summer usage. Such vehicles are characterized by a dwell time of more than 20 minutes and a number of passengers less than 4 persons/m². Therefore, the air temperature inside the TU must be inside the area shown in Figure 6 below. (DIN-EN-14750, 2006) For this project the recommended temperature curve (red line) is used.




1 - Recommended temperature for category A vehicles

**Figure 6: Permissible range for defining the temperature control curve for category A vehicles (DIN-EN-14750, 2006)**

**Calculation of the HVAC energy demand**

Since there are currently no standards for calculating the energy consumption of swap bodies/containers for passenger transport, the normative bases from the railway sector were used for this purpose. To calculate the energy demand of the HVAC system the DIN EN 50591 is used. This standard makes it possible to estimate the annual energy requirement of rail vehicles by means of measurements or calculations. In order to estimate the energy consumption of the air conditioning unit, 16 operating points (OP) are defined in three different operating modes. A distinction is made between:

- commercial operation,
- non-commercial operation and
- parking operation.

The annual energy requirement of the HVAC unit can be estimated by measuring or simulating the power demand at each OP and with the aid of defined or customized operating profiles. The table below Table 9 provides an overview of the OP used for the carried-out simulations.

**Table 9: Operating points for climate zone I for summer and II for winter operation (DIN-EN-50591, 2019)**

| **Operating point** heating/*cooling* | **Ambient temperature** [°C] | **Relative humidity** [%] | **Occupancy** [%] | **Solar radiation** [W/m²] |
|---|---|---|---|---|
| **Commercial operation (12 h/d)** | | | | |
| **OP 1** | -10 | 90 | 0 | 0 |
| **OP 2** | 0 | 90 | 100 | 0 |
| **OP 3** | 10 | 90 | 50 | 0 |
| **OP 4** | 15 | 90 | 50 | 0 |
| *OP 5* | 22 | 80 | 100 | 0 |
| *OP 6* | 28 | 70 (I) | 100 | 600 |
| *OP 7* | 40 (I) | 40 (I) | 100 | 800 (I) |
| **Non-Commercial operation (4 h/d)** | | | | |
| **OP 8** | -20 (II) | 90 | 0 | 0 |
| **OP 9** | -10 | 90 | 0 | 0 |
| **OP 10** | 0 | 90 | 0 | 0 |
| **OP 11** | 15 | 80 | 0 | 0 |
| **OP 12** | 22 | 80 | 0 | 0 |
| *OP 13* | 40 (I) | 40 (I) | 0 | 800 (I) |
| **Parking operation (4 h/d)** | | | | |
| **OP 14** | 0 | 90 | 0 | 0 |
| **OP 15** | 15 | 80 | 0 | 0 |
| *OP 16* | 28 | 50 | 0 | 700 |

The above-mentioned standard also provides information about the operating time in each of the three operating modes. By default, the standard uses an operating time of 20 h/d leaving 4 h/d without energy consumption. Furthermore, it is defined that the vehicle operates 12 h/d in commercial operation, 4 h/d in non-commercial operation and 4 h/d in parking operation.

For this project the default daily operating time is used, which means that the battery can be recharged for 4 h/d. However, for the HVAC energy demand calculation, it was decided to use a worst-case approach. After calculating the power demand in each OP, the result of the most demanding OP is used and multiplied by the daily operation time of 20 h/d. This will lead to a conservative estimate of the required battery capacity.
Due to a lack of information on the driving profile of the Pod system, it is assumed for the simulations that the vehicle is stationary.

### Thermal car body model

The model used for the calculations is shown in the figure below.

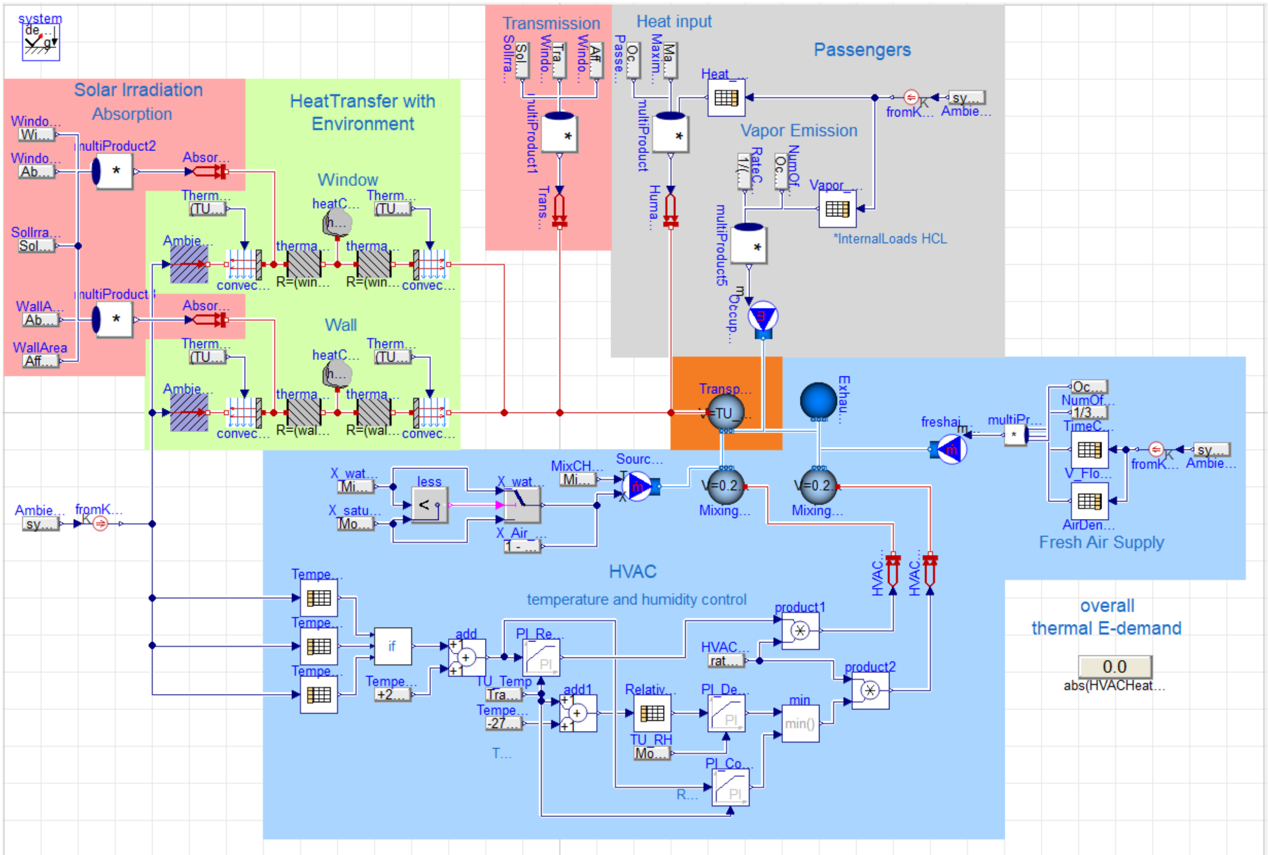



**Figure 7: Simplified Dymola HVAC model to calculate the HVAC energy demand**

The model consists of five parts. The first part is the TU in the middle (highlighted in orange), which is a volume filled with air. For the air the “ReferenceMoistAir” model from the Modelica Standard Library is used. The second part is the HVAC system which is highlighted in blue. The HVAC system was modelled in a simplified way. It has a temperature and humidity control implemented that regulates the humidity and temperature according to the requirements of DIN EN 14750-1 vehicle class A. Furthermore, the air conditioning unit consists of two mixing chambers. In the first mixing chamber the recirculation and the fresh air are mixed and if needed the air is dehumidified (e.g. at high occupancy) by sub-cooling (condensation drying). The second mixing chamber is used to reheat the supply air after dehumidification or to heat the passenger compartment in winter UC. In addition, the amount of fresh air supply is set to 15 m$^3$/passenger. The third and fourth part of the model are the heat transfer with the environment and the influence of solar irradiation highlighted in green and red. The last part of the model is the heat input and vapor emissions from the passengers highlighted in grey.

**Assumptions and parametrization**

The carried-out calculations are for the passenger use-cases only. The TU-dimensions and the maximum number of passengers inside each TU have been defined in chapter 5.1 and 5.2. The table below summarizes all the information required for the parametrization of the simulation model.

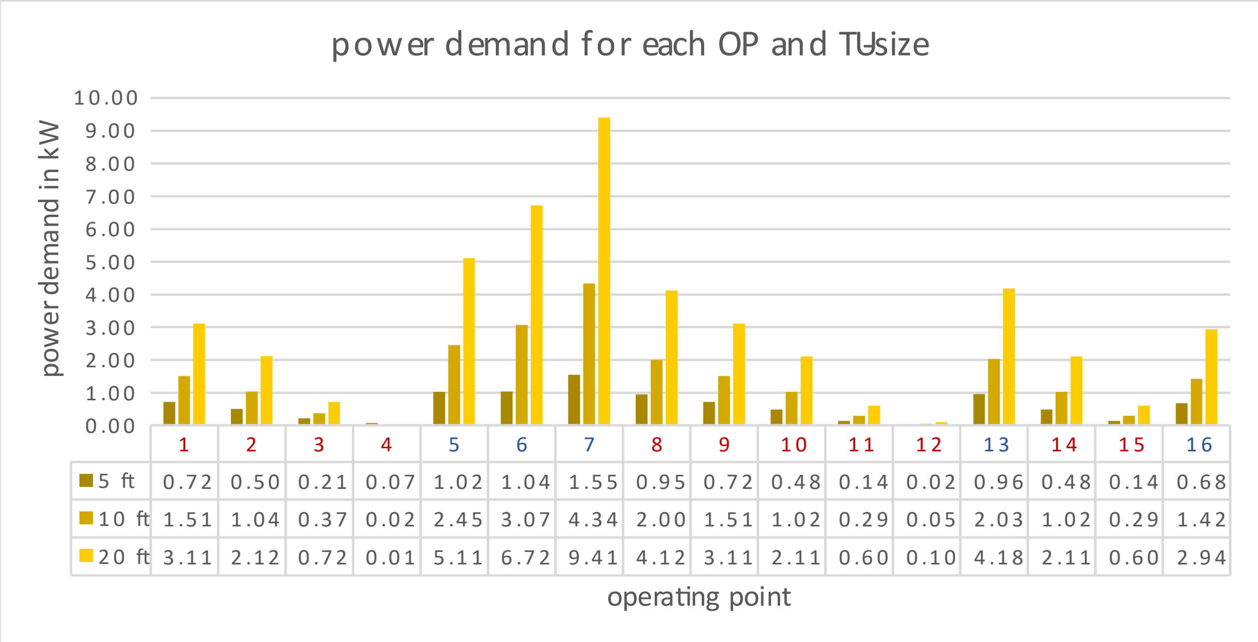
**Table 10: Parameters used for simulation**

| | **5 ft** | **10 ft** | **20 ft** |
|---|---|---|---|
| **Max. number of passengers** | 2 | 8 | 18 |
| **Dimensions** (L x W x H) | 1.36 x 2.3 x 2.2 m | 2.87 x 2.3 x 2.2 m | 5.92 x 2.3 x 2.2 m |
| **Volume** | 6.88 $m^3$ | 14.52 $m^3$ | 29.96 $m^3$ |
| **Area sidewall without windows** | 1.5 $m^2$ | 3.16 $m^2$ | 6.51 $m^2$ |
| **Area sidewall windows** (75 % of sidewall) | 4.49 $m^2$ | 9.47 $m^2$ | 19.54 $m^2$ |
| **Area roof/floor** | 6.26 $m^2$ | 13.2 $m^2$ | 27.23 $m^2$ |
| **Material data** | Walls: Aluminium; t = 0.2 m<br>Windows: Glass; t = 0.025 m | | |
| **K-Values** | Wall: 2.23 W/$m^2$K<br>Window: 2.67 W/$m^2$K | | |
| **Heat transfer coefficient** (stationary vehicle) | Inside: 10 W/ $m^2$K<br>Outside: 10 W/ $m^2$K | | |
| **Solar irradiation** (roof + one sidewall) | Wall: 70 % absorbed, 0 % transmitted, 30 % reflected<br>Window: 0 % absorbed, 30 % transmitted, 70 % reflected | | |

For the simulations, the heat exchange with the environment via the end faces was neglected. This assumption was made because these surfaces are either directly adjacent to a neighbouring TU, which is similarly tempered, or are protected by the CU, so that a low heat flow is expected via these surfaces.

**Simulation results**

Figure 8 provides the simulation results for the three TU-sizes for the passenger use-cases. The power demand for each OP is rising with the TU-size and therefore the number of passengers inside the TU. This is because the air treatment effort is highly dependent on the overall air volume inside the TU as well as the fresh air supply which scales with the number of passengers (15 $m^3$/passenger/h).




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 ft | 0.72 | 0.50 | 0.21 | 0.07 | 1.02 | 1.04 | 1.55 | 0.95 | 0.72 | 0.48 | 0.14 | 0.02 | 0.96 | 0.48 | 0.14 | 0.68 |
| 10 ft | 1.51 | 1.04 | 0.37 | 0.02 | 2.45 | 3.07 | 4.34 | 2.00 | 1.51 | 1.02 | 0.29 | 0.05 | 2.03 | 1.02 | 0.29 | 1.42 |
| 20 ft | 3.11 | 2.12 | 0.72 | 0.01 | 5.11 | 6.72 | 9.41 | 4.12 | 3.11 | 2.11 | 0.60 | 0.10 | 4.18 | 2.11 | 0.60 | 2.94 |

**Figure 8: Simulation results for the three different TU-sizes**

For each TU-Size the most demanding OP turned out to be OP 7 which is an OP for commercial summer use. Using the above-mentioned worst-case approach, the battery energy content needed for air treatment (not accounting for distribution etc.) can be calculated. This is shown in the table below.

Table 11 also provides an estimation of the weight and the volume of a lithium-titanium-oxide (LTO) and a lithium-iron-phosphate (LFP) battery with the estimated battery capacity (energy content) which is needed for air treatment in 20 h self-sufficient operation. This shows that such a heavy and large battery inside the TU makes the concept not feasible. The main part of the battery should therefore be installed in the CU. Only an auxiliary battery should be installed in the TU. The battery inside the CU can then provide the TU with energy and recharge the auxiliary battery inside the TU while both are coupled. The auxiliary battery therefore only has to provide the TU with energy while in self-sufficient operation meaning while not connected to a CU. Such scenarios can happen during transshipment of the TU and is assumed to be no longer than 15 minutes, which reduces the volume and weight of the battery needed inside the TU greatly.

**Table 11: Calculation of the battery energy content using the worst-case approach**

| | 5 ft | 10 ft | 20 ft |
|---|---|---|---|
| **Power demand of most demanding OP** | 1.55 kW | 4.34 kW | 9.41 kW |
| **Battery energy content for air treatment** (assuming 20 h/d in most demanding OP) | 31 kWh | 86.8 kWh | 188.2 kWh |
| **Weight**<br>- 20 h/d; LTO battery at 73 Wh/kg (Nemeth, Schröer, Kuipers, & Sauer, 2020)<br>- 20 h/d; LFP battery at 100 Wh/kg (Rahimzei, Sann, & Vogel, 2015) | 425 kg<br>310 kg | 1189 kg<br>868 kg | 2578 kg<br>1882 kg |
| **Volume**<br>- 20 h/d; LTO battery at 165 Wh/L (Nemeth, Schröer, Kuipers, & Sauer, 2020)<br>- 20 h/d; LFP battery at 210 Wh/L (Rahimzei, Sann, & Vogel, 2015) | 188 L<br>148 L | 526 L<br>413 L | 1141 L<br>896 L |
| **Battery energy content for air treatment** (15 min self-sufficient operation in most demanding OP) | 0.39 kWh | 1.09 kWh | 2.35 kWh |
| **Weight**<br>- 15 min self-sufficient; LTO battery at 73 Wh/kg (Nemeth, Schröer, Kuipers, & Sauer, 2020)<br>- 15 min self-sufficient; LFP battery at 100 Wh/kg (Rahimzei, Sann, & Vogel, 2015) | 5.3 kg<br>3.9 kg | 15 kg<br>11 kg | 32 kg<br>24 kg |
| **Volume**<br>- 15 min self-sufficient; LTO battery at 165 Wh/L (Nemeth, Schröer, Kuipers, & Sauer, 2020)<br>- 15 min self-sufficient; LFP battery at 210 Wh/L (Rahimzei, Sann, & Vogel, 2015) | 2.3 L<br>1.8 L | 6.6 L<br>5.2 L | 14 L<br>11 L |

*assumed specific energy and energy density are current state of the art (mean values) for the battery cells (without thermal management or other parts which might be needed); it can be assumed that these figures will increase significantly in the future

**Further notes**

The power demand in each OP is not accounting for the power which is needed to distribute the air inside the cabin via fans, the controller used to regulate the process nor the intake and evacuation of the air. The calculated power demand is limited to the energy needed for the air treatment. Furthermore, it can be assumed that the HVAC-unit has a coefficient of performance of one (COP = 1) due to unfavourable temperature differences and the assumed heating mechanism (resistant heating).

The calculations are also limited to the normative specifications for rail vehicles. Standards for the air conditioning of other modes of transport can be considered at a later state of the project. The requirements of the strictest standard must be complied with.

Additionally, it should be noted that the battery which is installed in the TU and/or CU should have a larger capacity (energy content) than the above mentioned (see Table 11) so that other consumers of the TU (e.g. lights, passenger infotainment system and more) can also be supplied with energy.

The estimated weights and volumes also do not account for the net and gross capacity of batteries. It was assumed in the calculations that 100 % of the battery capacity is usable. This is not the case. Assuming that the net capacity is 80 % of the gross capacity, the weight and volume of the needed batteries increase by further 20 %, making it even more unfeasible to install the full battery capacity inside the TU.

Furthermore, it has to be noted, that the results do not consider any type of performance management. This could help to reduce the overall energy demand.

#### 5.3.4.2 Auxiliary consumers

In order to estimate the total energy requirement of the TU, a list of all the energy consumers of the TU including some parts of the HVAC system (e.g. fans etc.) must be provided. This list can be found in Table 12.

**Table 12: List of auxiliary energy consumers inside of the TU**

| MPG of TU | Power demand per MPG [kW] | | | Note |
|---|---|---|---|---|
| | 5 ft | 10 ft | 20 ft | |
| H: Auxiliary operating equipment | 0.20 | | | Battery – cooling/heating; ventilation (all TU sizes) |
| J: Monitoring and safety equipment | 0.01 | 0.02 | 0.04 | CCTV |
| K: Lighting | 0.10 | 0.20 | 0.40 | LED ceiling --> part of MPG C |
| L: Air conditioning | 1.30 | | | Air intake/evacuation, distribution and regulation per unit (treatment excluded) |
| M: Ancillary operating equipment | - | | | Passenger counting system (additional) |
| N: Doors, entrances | 0.33 | | | front and back-facing doors (all TU sizes) |
| P: Information facilities | 0.03 | 0.05 | 0.10 | Screen and communication audio |
| **Total power demand:** | **1.97** | **2.1** | **2.37** | |

Combining the content/results of Table 11 and Table 12 the needed battery capacity (energy content) for each TU-size can be estimated. These are presented in Table 13.

**Table 13: Overall energy demand of the TU including HVAC and auxiliary consumers**

| | 5 ft | 10 ft | 20 ft |
|---|---|---|---|
| **Electrical power demand with all consumers** | 3.52 kW | 6.44 kW | 11.78 kW |
| **Total battery energy content**<br>(all consumers; assuming 20 h/d of operation) | 70.4 kWh | 128.8 kWh | 235.6 kWh |
| **TU battery energy content**<br>(assuming 15 min self-sufficient operation) | 0.88 kWh | 1.61 kWh | 2.95 kWh |
| **CU battery energy content** | 69.52 kWh | 127.19 kWh | 232.65 kWh |
| **Weight TU/CU battery**<br>- LTO battery at 73 Wh/kg (Nemeth, Schröer, Kuipers, & Sauer, 2020)<br>- LFP battery at 100 Wh/kg (Rahimzei, Sann, & Vogel, 2015) | 12.1/952 kg<br>8.8/695 kg | 22.1/1742 kg<br>16.1/1272 kg | 40.4/3187 kg<br>29.5/2327 kg |
| **Volume TU/CU battery**<br>- LTO battery at 165 Wh/L (Nemeth, Schröer, Kuipers, & Sauer, 2020)<br>- LFP battery at 210 Wh/L (Rahimzei, Sann, & Vogel, 2015) | 5.3/421 L<br>4.2/331 L | 9.8/771 L<br>7.7/606 L | 17.9/1410 L<br>14/1108 L |

**C-Rates**

The C-Rate of a battery describes how fast it can be charged or discharged and is normalized against the battery capacity in order to make a comparison between batteries easier. A C-rate of one means that the current for charging/discharging is so high, that the battery can be fully charged/discharged in one hour. A C-rate above one means that the battery can be charged/discharged in under one hour (2 C - 30 min to fully charge/discharge) and a C-rate below one means that the charging/discharging process takes longer than one hour (0.1 C - 10 h to fully charge/discharge). (MIT, 2008)

How high the C-rate of the battery needs to be is highly dependent on the driving profile which specifies how much time there is to recharge the batteries of the TU and CU respectively. Assuming the default daily operating time of DIN EN 50591 (20 h/d) a charging time of 4 h/d is available which means a C-rate of at least 0.25 C is needed. If we assume that the parking operation (4 h/d) can also be used for charging, the C-rate can be lowered to 0.125 C.

Furthermore, the C-rate (or the battery capacity) can be lowered even further if measures for energy recovery (i.e. brake energy recovery) are used.

### 5.3.4.3 Energy Harvesting

In the previous section the energy demand from the TU battery has been estimated for the various sizes (see Table 13). For this energy level, solar panels are the most common energy harvesting solution and feasibility studies can be found in the literature (M. Shravanth Vasisht, 2017). In Table 14 it is exposed that, assuming the indicated average solar daily irradiance and unit efficiency values, covering one third of the roof space with panels would be enough to harvest more than the energy demanded in a day. Furthermore, the rated power of the solar panels is estimated to size the power converter associated with it and to estimate its weight.

**Table 14. Solar panel sizing to supply the TU battery**

| | 5 ft | 10 ft | 20 ft |
|---|---|---|---|
| **Estimated TU Battery demand (kWh)** | 0.88 | 1.61 | 2.95 |
| **Occupied surface at roof ($m^2$) (34%)** | 1.26 | 2.53 | 5.05 |
| **Daily energy harvested (kWh)**<br>Average solar daily irradiance 5 kWh/$m^2$<br>Average module efficiency 16% | 1 | 2 | 4 |
| **Panel weight (Kg)**<br>Panel density 10 kg/$m^2$ | 12.6 | 25.3 | 50.5 |
| **Panel peak power (kW)**<br>Panel power density 0.3 kW/$m^2$ | 0.38 | 0.76 | 1.52 |
| **Power converter rated power (kW)** | 0.5 | 1 | 2 |
| **Power converter weight (Kg)**<br>Power converter specific power 0.2 kW/Kg | 2.5 | 5 | 10 |

Other possibilities such as wind energy harvesting can also supply the TU battery with the estimated daily energy demand. For instance, in (V. Nurmanova, 2018) it is proposed a turbine that with a size of about 30 cm of height, 50 cm of width, and 1 m of length, can deliver between 0.5 and 1 kW of power depending on the train speed. Nevertheless, the level of maturity of this technology is considerably lower than the use of solar panels.

Even though the TU battery can supply all the auxiliary consumers within the unit, some of them, such as wireless sensor nodes and communication systems, could benefit from the use of other sources of energy harvesting to avoid extra cabling or to increase their flexibility. In railway applications, the most extended source of energy harvesting is based on vibration. For that, typically piezoelectric or electromagnetic energy harvesters are proposed with a range of power between units and hundreds of mW, Although, these harvesters, together with small batteries and an electronic interface, can supply the devices, this technology also lacks maturity and the proposed designs are still state-of-the-art prototypes as summarized in (Jianyong Zuo, 2023).

#### 5.3.4.4 Energy Transfer Concept

As already mentioned in previous chapters the main part of the TU-supply-battery should be located in the CU, thus making it necessary to come up with a concept to transfer energy from one to another. There are basically two possible variants. TU and CU can be electrically coupled to each other inductively or conductively. The latter can take place during the coupling of the TU and CU or afterwards.

**Inductive energy transfer**

Transferring the energy inductively involves challenges, which have to be addressed. The following aspects need to be discussed (Mayer, 2016):

- Positioning accuracy
- Electromagnetic compatibility
- Detection of metallic and living foreign objects
- Efficiency
- Cooling

The positioning accuracy of inductive charging concepts is a problem if the primary and secondary coil are not positioned automatically for example when a car is parked on a parking spot without the guidance of a suitable system. However, this is not the case in the Pods4Rail project because TU and CU have to be positioned precisely in order to be coupled securely (Mayer, 2016) (WEKA-Fachmedien, 2024). The electromagnetic compatibility has to be checked. The inductive energy transfer must not be allowed to influence other systems inside of the TU/CU as well as the occupants (i.e. with cardiac pacemakers) (Mayer, 2016).

The detection of foreign objects is very important for an inductive energy transfer concept. Metallic and living objects must be prevented from entering the air gap between the primary and secondary coils. The penetration of metallic (especially ferromagnetic) objects must be prevented, as these heat up very strongly in the magnetic field of the coils. The detection of living objects is mandatory for health reasons (air gap > 1 cm) (Baier) (WEKA-Fachmedien, 2024). Both problems can be partially prevented by a very small air gap. For safety reasons, however, detection systems should not be dispensed with.

The efficiency is especially important because the worse the efficiency the bigger the installed batteries have to be. The efficiency of the inductive energy transfer is particularly influenced by the positioning accuracy. A DLR study shows (BIPolplus) that the efficiency of a 22 kW inductive energy transfer, which is meant to recharge cars while parking, has an efficiency over 90 % while optimally positioned and an efficiency over 80 % for all of the tested misalignments. For Pods4Rail an efficiency of 90 % can be assumed because of misalignment not being a problem in this case. This however does not include the efficiency of the DC/AC converter needed to transform the energy supplied by the TU-battery, so that the efficiency is decreased further. (Mayer, 2016)

Lastly, there has to be a cooling system for the coils. This could be done by passive (i.e. thermal mass) or active (i.e. air cooling) measures, adding complexity to the overall system, if combined with HVAC or battery thermal management system, and potentially adding another energy consumer, if an independent system for cooling is added. (Mayer, 2016)

**Conductive energy transfer**

Conductive means to transfer energy means transferring the energy by cable using a plug or other connection method. This is the conventional way to transfer energy. However, using a simple plug connection might make the coupling of TU and CU more difficult by adding another part which has to be positioned precisely. This could be avoided by using an automated wired charging system like the Matrix Charging® system shown in Figure 9.

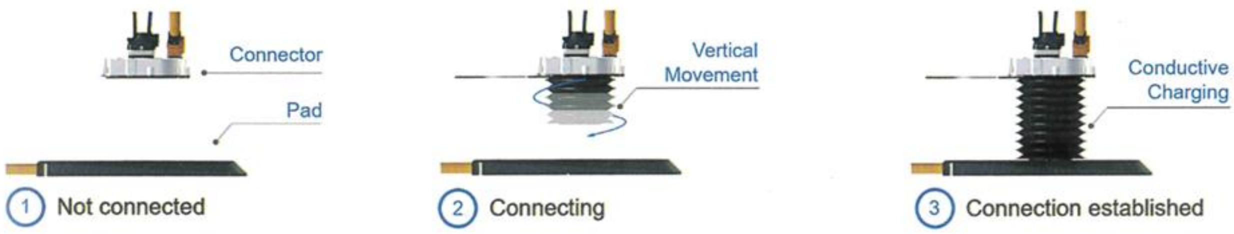



**Figure 9: Connection procedure of the Matrix Charging® system (Buchroithner, 2024)**

This system can be connected after the coupling of TU and CU has been carried out successfully, not adding to the complexity of the coupling procedure.

**Conclusion**

It can be assumed that both described energy transfer concepts are able to transfer the required energy. However, a wired system (conductive) might be the most promising option due to the number of drawbacks that the inductive transfer has. Whether the automated wired system is actually more advantageous than a simple plug-in connection must be decided when designing the interfaces between TU and CU.

### 5.3.5 Description of possible emergency cases for the Transport Unit

In the realm of the TU operation, emergencies can arise unexpectedly and require prompt, coordinated responses. This chapter explores various emergency scenarios related mostly to ail vehicles, including technical failures, accidents, natural disasters, and security incidents. Understanding these situations is crucial for developing effective technical solutions and ensuring the safety of passengers and crew. By analysing railway specific requirements, we can enhance the resilience of the rail transport system and better prepare for future challenges.

#### 5.3.5.1 Rescue team communication

First aiders are doctors (for people suffering from illnesses or injuries), fire-fighters (in the event of fire and other physical dangers such as bees, floods, etc.), police officers in the event of an attack. Emergency cases are based on the assumption that the exact position of the TU is known.

The TU should own its positioning device based on (GNSS/egnos see D3.2 conclusion for example) see Table 15.

**Table 15: Example for requirements taken from D4.4**

| | | | |
|---|---|---|---|
| IM6.1 | Incident Management | There shall be a tracking device inside the Pod, so that rescuers can quickly and easily find the Pod. | PodS4Rail T4.4 |

In the 2021 Report on User Needs and requirements (GSA, 2021) published by the GSA, now EUSPA (EU Agency for the Space Programme), management of emergencies was identified as a potential application for GNSS described as:
*"The management of emergencies can be greatly improved if an accurate, continuous location of the train is available, allowing the emergency teams to optimise their operations, thus GNSS is suitable for this kind of application. In the event of an accident, it is important to know the location of the train in the line, so that rescue teams can reach the place of the accident. For this kind of application, the geographical position of the train shall be provided and it shall be expressed in co-ordinates understandable to railway personnel and the emergency services, which normally use different coordinate systems."*

This document is the outcome of the EUSPA user consultation platform and report requirements discussed during the UCP event with participating stakeholders.

In this issue of the document, positioning requirements for such an application were defined in table 16.

**Table 16: Document and positioning requirements**

| Description | Type |
|---|---|
| The PNT solution shall provide the train position with a horizontal accuracy within a range of 1-10m. | Performance (Accuracy) |
| The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High. | Performance (Availability) |
| The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High. | Performance (Integrity) |
| The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s. | Performance (Time to Alarm) |

The definitions of the different performance criteria are defined in table 17.

**Table 17: Definitions of the different performance criteria**

| Parameter | Description |
|---|---|
| **Accuracy** | Accuracy is a statistical value and is defined as the degree of conformance between the measured position and its true position, at a given level of confidence, at any given instant in time, and at any location in the coverage area. When specifying accuracy, it is essential to specify the statistical context, which is usually assumed to be Gaussian. It is usually expressed as a confidence interval which is associated to probability (normally 95%).<br>Only horizontal accuracy is considered in rail applications. |
| **Availability** | According to EN 50126, availability is the ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided. In the present document the availability is defined as the intrinsic availability of location information fulfilling its performance requirements at the location unit output.<br>In railways, where the relative unavailability of Signal in Space (SiS) owing to limited visibility is a natural condition, lack of SiS is not a cause of non-availability for highly demanding applications (other sensors will compensate for this fact through hybridization). |
| **Integrity** | Integrity relates to the trust that can be placed in the correctness of the information supplied by the Location Unit to the application. Integrity is defined here as the ability of the Location Unit equipment to provide timely warnings to the user when data provided by the system should not be used. |
| **Time to Alert (TTA)** | Maximum allowable time between the occurrence of the failure in the system (e.g. satellite fault) and its presentation to the user. The failure can be due to an excessive inaccuracy being detected (see alert limit) or that a particular satellite is untrustworthy. |

In the last issue of the report (EUSPA, 2023), this application has been removed from the railway needs are they can be shared with some other transport modes and have been considered as not specific to railway uses.

The second service required in the context of emergency management in a TU is the availability of communication means.

At least voice exchange is required and it leads to select corresponding technologies.

#### 5.3.5.2 Fire Safety

Since there are currently no standards for the fire safety of swap bodies/containers for passenger transport, the normative bases from the railway sector were used as a very first orientation. Later interpretations can also be made according to the existing guidelines for buses or cable cars and even other applications might give guidelines for fire safety.

The requirements for fire protection measures for railway vehicles are contained in the standard EN 45545, and is formally divided into 7 parts. The measures in this standard are intended to protect passengers and staff in a railway vehicle. It concerns not only the interior, but also the entire structure of the vehicle, in this case the Pod and its subsystems. This standard generally classifies vehicles into operation (where is the vehicle operated) and design (how is the vehicle designed) categories, whose relationship determines the level of fire danger HL1 to HL4.

The Pod (TU & CU) itself could be classified as in OC 1, where the vehicle is allowed to stop with a minimum delay and where it can always reach a safe place immediately. Based on this, the following requirements can be specified:

- design an interior layout to limit the spread of fire,
- utilize materials and product with a better response to fire properties, i.e. flame-retardant plastics,
- provide means to manage the spread of fire and its emissions, i.e. fire extinguishers,
- design the TU in a way that enables quick and safe evacuation of passengers, e.g. through entrance/exit doors, gangway doors or emergency exits in windows.

Subsequently, the Pod could be categorised as DC A, i.e., a vehicle that is a part of an automatic train having no staff trained for emergency situations. With respect to the previously mentioned, the Pod's fire hazard level could be HL1. This information can then be used to specify requirement levels (R1 to R28) of each product group, i.e., of interior (IN) and exterior (EX) products, and their further evaluation with respect to ignitibility, flame spread and heat release, via specific test methods (T01 to T17). However, assessment of this scope is not yet feasible to the Pod because of and the normative classification of TU in the context of different means of transport, such as railways, buses or cable cars, the early phase of development and thus is not discussed further.

#### 5.3.5.3 Crash Safety

ISO 1496-1:2013 specifies design requirements and testing of freight containers. Since there are currently no standards for the crash safety of swap bodies/containers for passenger transport, the normative bases from the railway sector were used for a very first orientation. Same as remarked in the previous chapter, later interpretations can also be made according to the existing guidelines for buses or cable cars and even other applications might give useful guidelines for crash safety.

Crash resistance or crashworthiness of rail vehicles is included in EN 15227, where various impact scenarios are described. In case of impact, it is generally required to absorb energy in a controlled manner, reduce the risk of overriding, maintain minimal survival space and structural integrity of occupied areas, reduce the risk of derailment etc. The standard defines possible impact scenarios, i.e. collision with the same vehicle or an obstacle, based on the design categories of crashworthiness C-I to C-IV, which reflect the UC of the vehicle.

Due to the complexity of the UC, multiple design categories must be considered (mainly C-I and C-III). However, it would be expedient to apply only parts of the standard that are relevant for the given UC of the Pod and its subsystems. These are:

- a leading end impact between two identical Pods (TU & CU) at a speed of 36 km/h,
- a leading end impact with regional train weighing 129 t at a speed of 10 km/h,
- a leading end impact with small low obstacle.

Other collision scenarios seem to be irrelevant for Pods. However, a vehicle Pod derailment might cause subsequent impacts that are stochastic in nature and thus unpredictable. Therefore, a derailment safety test should be concluded, which can be performed via methods described in EN 14363 (usually method II is used):

- method I – the vehicle passes through an arc with a radius of 150 m with a defined track collapse, where the criterion is wheel lift Δz,
- method II – the vehicle passes through an unsurpassed arc with a radius of 150 m to determine the transverse forces (Y) and is twisted on the test device to determine the maximum wheel force (Q); the criterion is the determination of the Y/Q ratio on the outer wheel,
- method III – the minimum wheel force when twisting the vehicle on the test device and the resistance of the chassis against turning are determined on the vehicle; the criterion is the factor X and the relative unload of the wheel ΔQ/Q.

#### 5.3.5.4 Malfunctions of doors, batteries or the HVAC-system

Since there are currently no standards for malfunctions of certain components of swap bodies/containers for passenger transport, the normative principles from the railway sector were used as a guide. Corresponding standards from the area of buses or cable cars have not yet been considered, but can be used later for a normative comparison.

The standard EN 14752 applies to bodyside entrance systems for rail vehicles. The requirements can be specified as follows:

- maximum force in the first and final phase of closing the door ≤ 300 N,
- average force during further door closing phases ≤ 200 N,
- maximum force to stop the door in motion ≤ 147 N.

Additionally, it is required that:

- the sensitivity of the door system is tested by inserting a 30x60 mm aluminium prism into the lower, middle and upper parts of the door – while doing so, the door cannot be indicated as closed,
- the reliability of the door system is tested by 1 million closing and opening cycles,
- in case of emergency, the door system must be equipped with emergency manual opening.

The requirements for HVAC are a part of the standard EN ISO 19659. The occurrence of malfunction can be prevented by routine checking of the cooling medium. In case of emergency, some windows need to be manually openable. When it comes to batteries, the use of maintenance-free battery almost eliminates the possibility of failure.

Relevant standards:

- EN 14752 - Railway applications - Bodyside entrance systems for rolling stock
- EN 15227 - Railway applications - Crashworthiness requirements for rail vehicles
- EN 45545 - Railway applications - Fire protection on railway vehicles - Part 1-7
- TSI LOC& PAS

### 5.3.6 Strength analysis

Since there are currently no standards for strength calculations of swap bodies/containers for passenger transport, the normative principles from the railway sector were used as a basis. Corresponding standards from the area of buses or cable cars have not yet been considered, but can be used later for a normative comparison.

The design of the TU (and whole Pod also) could be compared with structural requirements of railway vehicle bodies specified by EN 12663 for passenger and freight transport. This standard defines structural design categories (P-I to P-V) and covers various load cases, e.g. lifting and jacking, along with the definition of longitudinal and compressive forces in the coupling area etc. In case of passenger transport, it is necessary to consider the load cases for equipment attachments, such as handrails, seats and other parts of passive safety systems.

Depending on the UC, the Pod (TU & CU) could be considered a passenger vehicle and thus categorised either as a coach (P-I) or a part of a fixed unit (P-II). In case of P-I classification, the unit would be very robust, because it would be designed to withstand a longitudinal compressive load of 2000 kN applied at the level of buffers and/or coupler attachment. On the other hand, inclusion in category P-II would bring the longitudinal force down to 1500 kN, which is more favourable for the Pod while still meeting the requirements of the standard. The standard also specifies:

- tensile force of 1000 kN at coupler attachment,
- compressive force of 400 kN above the top of the structural floor at head stock,
- compressive force of 300 kN at the height of the waist rail (windowsill),
- compressive force of 300 kN at the height of the cant rail.

These loads shall be considered in combination with vertical load of g·m1, resulting from gravitational acceleration of design mass of the TU. Subsequently, the standard defines additional vertical loads, which are based on the design mass of the TU $m_1$ and CU $m_2$ and the exceptional payload $m_4$:

- maximum operating load of $1.3 \cdot g \cdot (m_1+m_4)$,
- vertical load of $1.1 \cdot g \cdot (m_1+m_2)$, resulting from lifting and jacking at one end of the Pod at the specified positions,
- vertical load of $1.1 \cdot g \cdot (m_1+2 \cdot m_2)$, resulting from lifting and jacking the whole Pod at the specified positions.

To satisfy the overall static structural requirements, a superposition of both compressive and tensile force at coupling level with a vertical load of $g \cdot (m_1+m_4)$ should be considered. In case of using the Pod for freight transport, the structural requirements described above prevail, because the loads specified for passenger transport are generally higher.

Requirements for Pod's crash resistance could be defined according to EN 15227 in the previous chapter (Description of possible emergency cases for the TU). On the other hand, these specifications for a detailed design must be compared with the corresponding normative specifications for buses and cable cars. If necessary, new, standardized normative specifications must be developed, due to the switching of the TU. To summarise, the Pod could be classified either as a design category C-I or C-III and thus the relevant crash scenarios include:

- a leading end impact between two identical Pods at a speed of 36 km/h,
- a leading end impact with regional train weighing 129 t at a speed of 10 km/h,
- a leading end impact with small low obstacle.

Additionally, a derailment test of the carrier could be conducted.

The following railway-specific standards will be evaluated in the coming work packages to also meet further regulations and standards of other modes of transport (road, ship, cablecar, air). In this work, current standards from rail vehicle technology were shown as examples, although no guarantee can be given regarding their completeness and further investigations must be carried out specifically for cable car technologies.

Relevant standards (rail specific; needs to be evaluated with other transport modes - road, ship, air)

- EN 12663 - Railway Applications - Structural requirements of railway vehicle bodies

Assessment of strength analysis:

- DVS 1608 - Design and strength assessment of welded structures from aluminium alloys in railway applications
- DVS 1612 - Design and endurance strength analysis of steel welded joints in rail-vehicle construction
- VDI 2230 - Systematic calculation of highly stressed bolted joints - Joints with one cylindrical bolt

## 5.4 Service and maintenance concept

The Pod system appears to be relatively maintenance-free. Nevertheless, service intervals have to be specified for each design group. The following design groups will be looked at in this chapter:

- HVAC-unit
- Door systems
- Couplers
- Transition Bellows
- Lighting
- Battery Thermal Management System (BTMS)
- Battery

However, the main focus is on the maintenance of the air conditioning units.

### 5.4.1 Maintenance of the HVAC-system

In general, all components of the HVAC-unit must be maintained. The following is a selection of things that have to be checked:

- tightness of the cooling circuit (1 per year, before summer season) if necessary, leaked coolant shall be filled in
- air filters need to be cleaned or changed (1 per quarter)
- heating functionality checked before winter season
- operation of compressor and fans (1 per 2 years)

**HVAC maintenance plan**

Maintenance intervals for air conditioning units depend on the components installed and the applicable standards as well as legal regulations. The following is a selection of standards and regulations that must be complied with when maintaining vapor-compression refrigeration systems (state of the art in rail vehicles) (EuroSpec, 2024) (Manufacturer, 2024):

The following railway-specific standards will be evaluated in the coming work packages to also meet further regulations and standards of other modes of transport (road, ship, cablecar, air). In this work, current standards from rail vehicle technology were shown as examples, although no guarantee can be given regarding their completeness and further investigations must be carried out specifically for cable car technologies.

- EN 378: Refrigerating systems and heat pumps - Safety and environmental requirements
- EN 45545: Railway applications - Fire protection on railway vehicles
- EN 50155: Railway applications - Electronic equipment used on rolling stock
- Directive 2014/68/EU („pressure equipment directive“)

- Regulation (EU) 2024/573 („F-gas regulation”)

Furthermore, the manufacturer's maintenance instructions for the subcomponents of the air conditioning unit must be followed.

The HVAC manufacturer is currently setting up a maintenance schedule for the air conditioning units, which lists the maintenance cycles of all components. These are based on a time interval, as the air conditioning unit is also operated when the vehicle is stationary so that the wear of the HVAC components is not directly linked to the mileage of the vehicle. The shortest maintenance interval applies to the air filters, which must be changed every 3 months according to the schedule. Furthermore, the maintenance schedule specifies a mid-life maintenance after half of the service life (after 16 years if designed for 30 years), during which components of the air conditioning unit are replaced in order to ensure functionality for the rest of the intended service life. With regular maintenance and adherence to the specified maintenance cycles, a service life exceeding the design period is possible (based on experience (Manufacturer, 2024)). In addition to the preventive maintenance using the maintenance schedule, a visual inspection and a function test are carried out during maintenance to ensure functionality. If components are found out to be defective, these are also replaced.

However, the statements made in this section are limited to the use of vapor-compression refrigeration systems. When using other air conditioning systems (e.g. magneto-caloric systems), different maintenance cycles may apply due to the use of completely different components. However, such systems are not yet suitable for use in rail vehicles. In the future, it can be assumed that such systems will reach a sufficient level of maturity and thus become relevant for use.

**Maintenance of HVAC-systems in novel Pod-systems**

For the maintenance of air conditioning units in the supermodal Pod concept, it does not matter whether the air conditioning unit is installed in the CU or in the TU, as identical components are used in both variants. If the air conditioning unit is installed in the TU itself, maintenance is possible independently of the CU, which has the advantage that the CU does not have to be present during maintenance and is therefore still available in the transport network. If, on the other hand, the air conditioning unit is installed in the CU, the number of components required is reduced compared to installation in each TU, which can also be an advantage for maintenance. Both variants are technically conceivable.

However, unlike today's rail vehicles, maintenance of the vehicle fleet does not bring the line to a standstill. Due to the different production times of TU and CU, individual TU/CU can be maintained separately, similar to cars, without significantly affecting the transport network.

Furthermore, the current state of the art is preventive maintenance following a fixed maintenance schedule. This means that some components are replaced even though there is no defect, or no defect is expected in the near future. As a result, the service life of the components is not fully utilized, which means higher maintenance costs. As an alternative to the preventive maintenance that is currently established, corrective maintenance of components will probably be favoured in the future. Corrective means that the components are only replaced as soon as a defect is detected, or it is recognized by data evaluation that a defect is imminent. However, since this concept is problematic for maintenance planning, as the rail vehicle has to be taken out of service when a defect occurs, it has not yet become established for rail vehicles. A failure of the entire vehicle fleet due to components failing in all vehicles at the same time is too risky. However, this is less of a problem for the supermodal Pod system. It can be assumed that the TU/CU were not all put into operation at the same time and that the operating times of the TU/CU vary, so that a failure of the entire fleet seems unlikely.

**Maintenance of other relevant Parts of TU and Carrier**

Table 18 lists the needed service and maintenance for the door system, the couplers, the transition bellows as well as for the lighting.

**Table 18: Service and maintenance plan for different design groups**

| Design group | Service and maintenance plan |
|---|---|
| Door System | – depends on type of door drive used<br>– pneumatic:<br>▪ minimal requirements with self-lubricating guide rails<br>▪ function check once every 2 months<br>▪ cuffs in the air cylinder replaced 1/4 years<br>– electric:<br>▪ function check once every 2 months<br>▪ electric motor has to be replaced when damaged |
| Couplers | – need to be checked and cleaned regularly<br>– mechanism shall be lubricated once every 3 months |
| Transition bellows | – checked once every 6 months<br>– if damaged caused by tearing or bursting repair needed:<br>▪ local damage: area has to be fixed<br>▪ local repair not feasible: exchange whole bellows |
| Lightning | – no maintenance intervention needed<br>– can be exchanged if identified as damaged during maintenance |
| BTMS | – depends on type of BTMS used<br>▪ passive cooling and self-heating of the battery are maintenance free<br>▪ active means of cooling/heating require maintenance depending on components used<br>➢ i.e. air cooling or cooling circuit: similar maintenance to HVAC-unit required |

| | |
|---|---|
| Battery | – lithium-ion batteries are low maintenance (i.e. LFP, LTO) (Cadex Electronics, 2024):<br>▪ low self-discharge<br>▪ no cycling required to prolong battery life (no memory-effect)<br>▪ battery aging must be considered<br>▪ condition monitoring required |

As the HVAC-Unit seems to be the most frequent to maintain, the maintenance of the design groups listed in Table 18 should be integrated in the HVAC maintenance plan.

## 5.5 Design proposal / model of the Transport Unit concept

**Flexible and adaptable for maximum variability**

The small, lightweight TU consists of standardised units. The modular system serves to achieve a high level of standardisation with as few components as possible, as well as providing a basis for rapid customisation options with relatively little effort during production. The standardised unit families result in a flexible platform that streamlines production complexity and allows larger quantities of TU to be produced cost-effectively.

### 5.5.1 Visualization of possible Transport Unit configurations and proposal of Transport Unit architecture

**Transport Unit configuration**

All length derivatives are the same in terms of width, height and front design. They differ in terms of their length, door systems, window segments and the covered units on the roof or external attachments. Visually, they have a uniform appearance. The transition between different TU is barrier-free. These are sealed with lips.

**Entrance/exit unit (5 ft)**

As shown in Figure 10, the TU could be accessed and exited via inward-swinging double doors on both sides, as commonly found in buses and trams. These can be opened quickly and both wings can also be opened separately. The mechanism above the door opening can be electrically operated. LED lights can be mounted on the outside of the TU to signal the operating status.

**Figure 10: Opened Entrance Unit**

**Passenger unit (5 ft, 10 ft)**

The internal space of the TU can be very similar to a minibus or cable car cabin. At the same time, the transfer is like a flying experience, so we have prioritised the view of landscapes by maximising the size of the windows surrounding the seating as shown in Figure 11. Flexible interior configurations should make it possible to react quickly to changes in mobility needs.

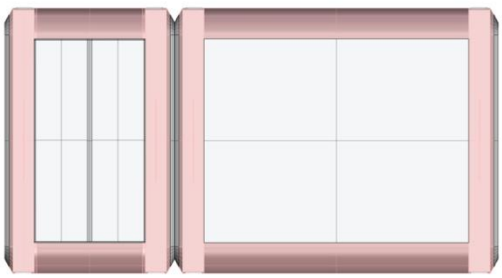
| Entrance unit (5 ft) in combination with Passenger Unit (10 ft) | Front design TU |
|---|---|
|  |  |

**Figure 11: Overview of standardised units**

**Front design Transport Unit**

As a result of the automated operation, no permanent driver's stands are required and the front sides of the TU can be used for access and transfer doors to the next TU (Figure 10). Pocket sliding doors driven by electric motors could be used at these access and transfer points for each TU. These can be constructed as a full glass door or in a sandwich construction for lightweight body design.

## 5.5.2 Conceptional assembly drawing of a defined Pod configuration and assembly of components

**Overview of design variants**

During the first iteration of the design and form-finding process several preliminary concepts were developed and visualized schematically. The design proposal offers a puristic, future-oriented and production-related design. The design focuses on efficiency, modularity and sustainability in order to meet the requirements of modern transport. The edgy 3D geometries are due to compatibility with existing ISO containers (rectangular or cubic design) and the defined grid for the interfaces (Figure 12).

**TU concept 1-4**

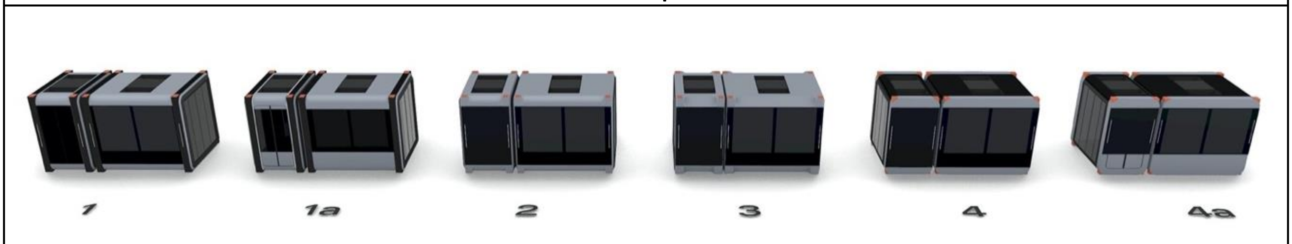



**Figure 12: Overview design variants**

In design concept 1, the main frame is more visible. In concept 2 and 3, the main frame and the interfaces has been designed as a homogenous unit. Variant 4 differs formally through rounded elements on the outer edges of the units (all variants from Figure 12).

Variants 1 and 1a were used for the assembly drawing (Figure 13). However, this does not yet correspond to a selection regarding the final design.

Further engineering and form-finding process is examined in WP 8.

**Concept Transport Unit**

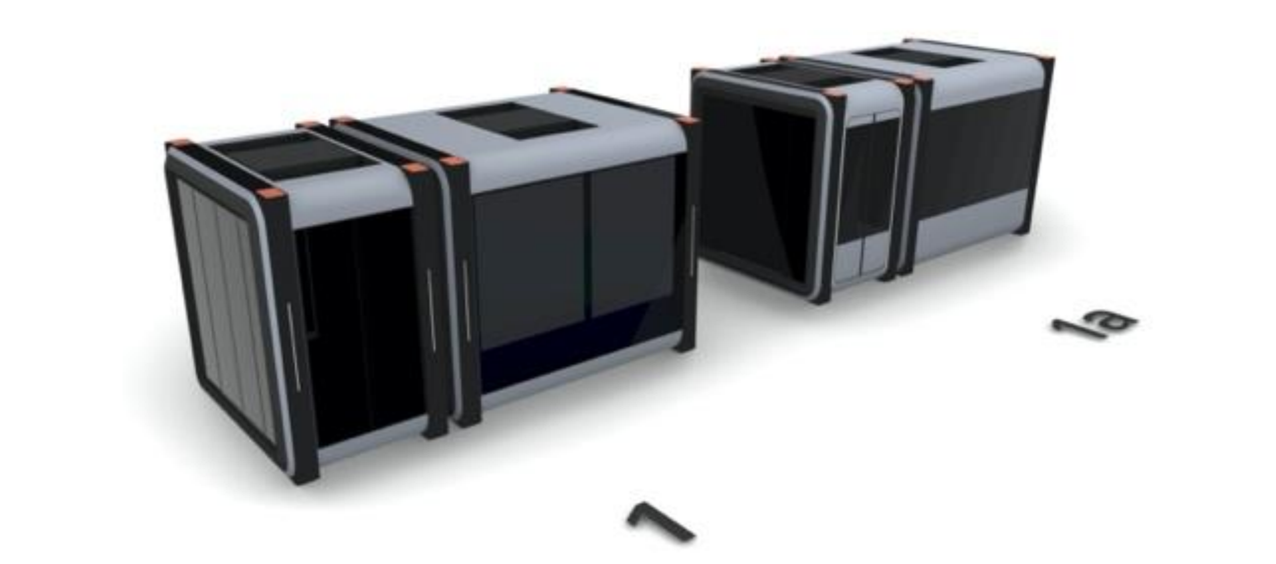



**Figure 13: Conceptional assembly drawing TRL 2**

The main structure of the car bodies must also be considered to be stable in accordance with the requirements for stackability as shown in Figure 14. How the stacking of TU can be made possible in detail and whether this also makes sense from a logistics process point of view (HS, storage system) is examined in more detail in WP 8.

**Stacking of Transport Units**


**Figure 14: Example of stacked Transport Units**

## 5.5.3 Conceptional description of technical parameters

The following main components were positioned on the units as follows: Door systems and cabin windows, HVAC-unit, Battery, Interfaces.

**Table 19: Transport Unit key data**

| | Entrance unit 5 ft | Passenger unit 5 ft | Passenger unit 10 ft |
|---|---|---|---|
| Length (m) | 1500 | 1500 | 3010 |
| Seats (-) | -- | 2-6 | 12 |
| Standing (normal) | 2 | 6 | 50 |
| Front doors<br>Usable passage width (mm) | 1000 | 1000 | 1000 |
| Side doors<br>Usable passage width (mm) | 1000 | -- | -- |
| Ceiling (mm) | 240 | 240 | 240 |
| Floor (mm) | 230 | 230 | 230 |

Figure 15 explains the integration of inswinging door systems at the side and pocket sliding doors at both ends of the transport unit. The pocket sliding doors serve also as connections between the transport units. The inwards opening doors moves away from the flow of passengers and enables free movement into the vehicle. In the open position, the inswinging door system requires minimal space outside the vehicle. The respective clearance of at least 1,100 mm also allows people with reduced mobility (PRM) access to the transport unit. If needed, bigger cleared doors could be foreseen also in combination with electric ramps or similar aiding devices.

| Door systems and cabin windows – front view | Door systems and cabin windows – side view |
|---|---|

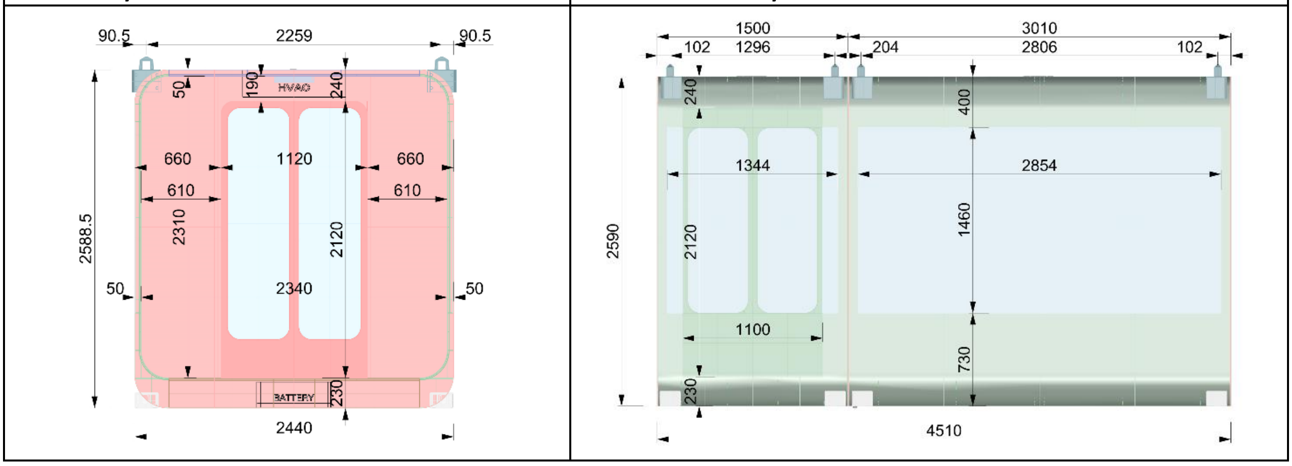



**Figure 15: Door systems and cabin windows**

Figure 16 shows one possible idea to integrate a compact HVAC unit (Heating, Ventilation and Air Conditioning) in the ceiling of the TU. The unit is designed to fit efficiently into the ceiling while maintaining an interior height of 2100 mm, ensuring sufficient headroom and a spacious feel for passengers. It can be installed in pre-designed mounting slots within a recessed ceiling structure, allowing for easy installation and maintenance.

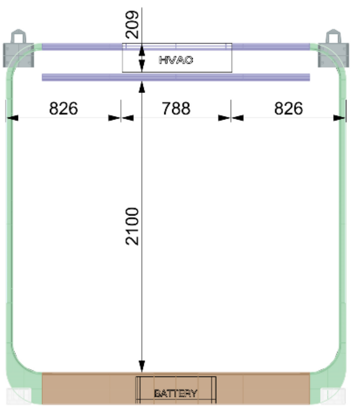
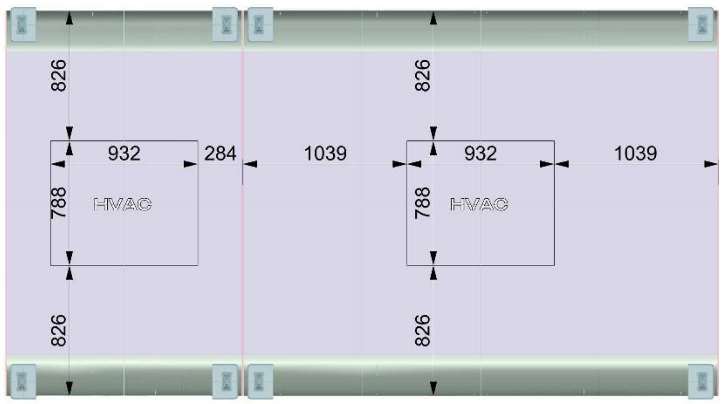
| HVAC-unit – front view | HVAC-unit – bird view |
|---|---|
|   |   |

**Figure 16: HVAC-unit integration**

Figure 17 shows where the battery modules could be placed in the vehicle floor. Each module could be installed in specially designed trays in the underfloor, integrated into the main frame. This ensures stability, safety and reduces vibrations. The modular structure allows easy battery upgrades. Maintenance processes could be simplified through access hatches or quick-release mechanisms.

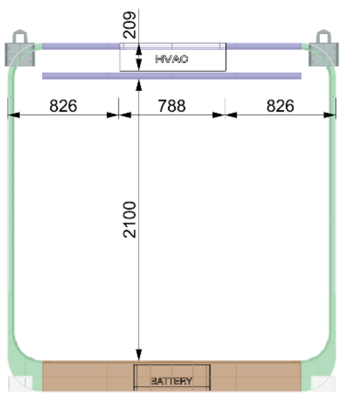
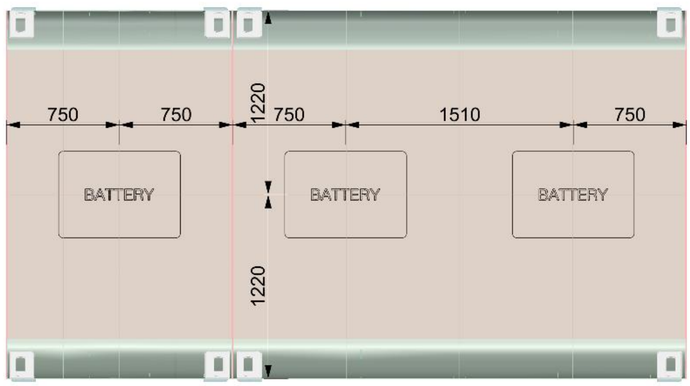
| Battery – front view | Battery – floor plan |
|---|---|
|   |   |

**Figure 17: Battery integration**

## 5.6 Outlook

Nowadays, the global initiative is dealing with the reduction of $CO_2$ emissions and overall improvement in terms of efficiency, reusability, and manufacturability. For this reason, modern vehicles are often designed to be as lightweight as possible. Because of that, aluminium alloys, high strength steels, or various composite materials may be used in design of the TU.

Manufacturing recommendations generally should be arranged with respect to strength and safety requirements. Additionally, there are several legislative documents regarding the requirements for specific type of joints, i.e., EN 15085 for welded joints, DIN 6701 for bonded joints, and DIN 25201 for bolted joints. The evaluation of rail vehicles is then performed based on EN 50126, which involves risk assessment, safety validation and continuous evaluation. This, however, is not yet feasible for the Pod and thus general recommendations will be provided.

There are various options for production of Pods. In practice, one can primarily consider the use of a welded steel frame, which will ensure sufficient structural strength. It is necessary to minimize deformations and stresses in the material both during operation and during handling and storage. The risk scenarios (such as crash, overloading, extremely high and low temperatures) has to be considered and the structure must have sufficient safety factor. The basic welded frame can be covered with both sheet-metal parts and composite or polymer sheets.
Another production option is the use of extruded aluminium profiles or glued plastic parts.

### 5.6.1 Industrialisation (Production)

The TU can be manufactured in several ways using different materials and different technologies. These include:

- Differential welded steel structure made of normal grade steel. This structure design is easy to manufacture and requires simple fixtures. However, the disadvantage is a higher weight and the difficulty to create an attractive, modern-looking design.
- Differential welded steel structure made of steel with high yield strength of up to 700 MPa. This structure possesses same properties as the previous one while simultaneously achieving lower weight, almost to the point of aluminium structure.
- Integral welded aluminium structure made of large-area aluminium profiles produced by extrusion. A lower weight and more attractive shape can be achieved. However, massive welding fixtures are required and the difficulty of repair increases, lowering its potential of reusability.

The following picture shows the basic welded frame structure with following parameters:

- Outer side panel is made from steel with thickness 2.5 mm
- Outer roof panel is made from steel with thickness 1.5 mm
- Outer floor panel is made from steel with thickness 5.0 mm
- Roof structure is made from beams with thickness 3.0 mm

- Side wall structure is made from beams with thickness 3.0 mm
- Floor is made from beams with thickness 3.0 mm

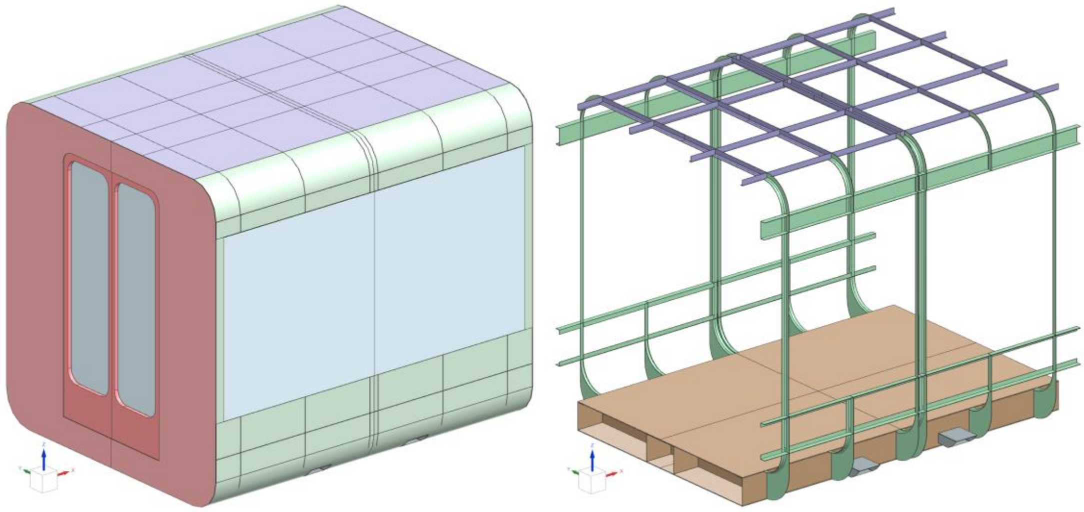


**Figure 18: Basic structure of the welded frame of 10 ft TU**

### 5.6.2 Manufacturing recommendations

All following manufacturing steps are only recommendations based on best practise solutions of respective applications. Nevertheless, other and new approaches can be followed within this project, e.g. by introducing new material and lightweight approaches, which will be carried out in later tasks.

Hybrid structure consisting of a steel base, i.e. floor and main frame made of high-yield steel welded frame and a composite body, i.e. sides, front and roof panels made from composite material. These composite materials can be used as an alternative to sheet metal panels.

Additionally, 3D printing shall be used for parts with complex geometry (such as connections to twistlocks, etc.). The main limitation of additive technology is higher price comparing to the conventional production. There is no problem with selection of 3D printed material, because 3D printed steels can have yield strength up to 2000 MPa.

There has to be considered the welding as a main production technology of frame. The panels (interior and outer panels) can be glued. The connection made by bolts has to be considered for parts, which are going to be replaced during lifetime of Pods (such as rubber transitions between Pods, HVAC, etc.)

The following railway-specific standards will be evaluated in the coming work packages to also meet further regulations and standards of other modes of transport (road, ship, cablecar, air). In this work, current standards from rail vehicle technology were shown as examples, although no guarantee can be given regarding their completeness and further investigations must be carried out specifically for cable car technologies.

Relevant standards:

- EN 45545 - Railway applications - Fire protection on railway vehicles - Part 1-7
- EN 50126 - Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1-2

Requirements for specific joints:

- EN 15085 - Railway applications - Welding of railway vehicles and components - Part 1-6
- DIN 6701-3 - Adhesive bonding of railway vehicles and parts - Part 3: Guideline for construction design and verification of bonds on railway vehicles
- DIN 25201-2 - Design guide for railway vehicles and their components - Bolted joints - Part 2: Design - Mechanical applications

# 6 Concept proposal for the interfaces

A first overview of all relevant TU interfaces is given in chapter. The specification of the Loading and Unloading procedure is shown in chapter 6.2. Based on this procedure a concept for interfaces between the TU and the HS will be given in chapter 6.3. To develop how to secure and connect the TU inside the CU, chapter 6.4 gives a coupling mechanism overview and definition for the Pod system. When more than one TU is loaded on one CU, there might be connections between these TU. The concept for the interfaces between different TU is presented in chapter 6.5.

## 6.1 Overview of Transport Unit interfaces

Within the Pod system, the TU is the part of the system, that will be shifted between different CU by using the HS infrastructure. Because of that, there are several physical interfaces of each TU, that have to be considered for the system development. The interfaces can depend on the type of TU as well as the CU, to where it will be loaded. If the TU is loaded on a CU next to other TU, or if it is being stored in a storage system or placed on the ground, additional interfaces can appear. Figure 19 and the following list shows a short overview of relevant interfaces of each TU.

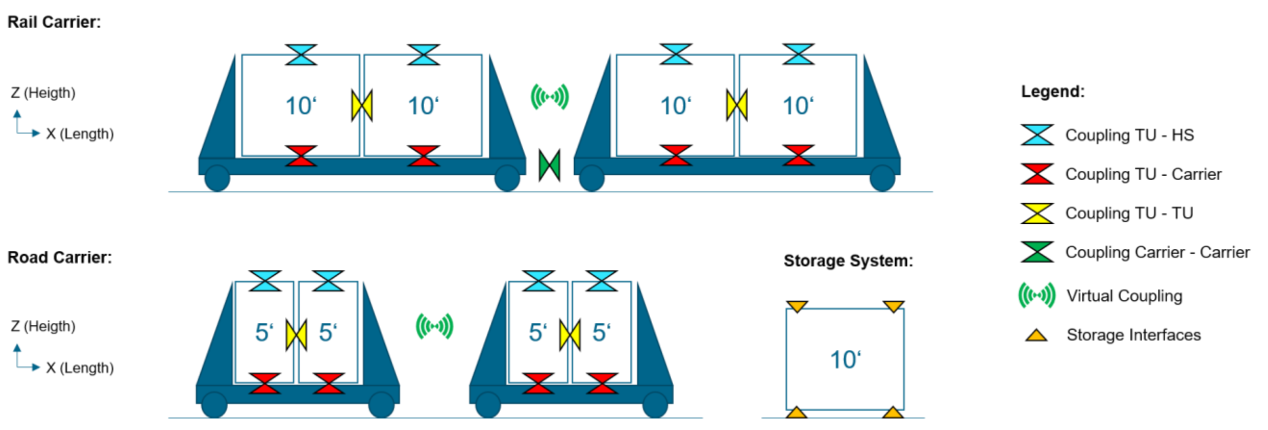



**Figure 19: Vision of the Pod system and schematic overview of interfaces of the Transport Unit**

**1. Interfaces for positioning the TU onto a Carrier Unit**

When the TU is loaded to a CU, it has to reach a specific position inside the CU to guarantee a safe and correct contact between the TU and the CU. Therefore, the HS has to place the capsule within a certain positioning tolerance and match the interface area of the CU with the interface area of the TU. Interfaces for positioning the TU could be specific contact elements or supporting structures inside the CU. This interface does not necessarily have to provide a mechanical interface, but positioning can also be carried out by sensors and/or, for example, by a camera synchronizing pixels provided for this purpose. Additional guide rails or similar structures could help to adjust the tolerance. The interfaces for positioning the TU onto a CU therefore define the movement and positioning of the TU inside the CU. A combination with the physical (mechanical) coupling / locking mechanism between TU and CU is possible and also makes sense in terms of functional integration and lightweight construction (see red symbols in Figure 19). The concept for these interfaces is described in chapter 6.2.

**2. Interfaces between the TU and the Handling System**

During the transshipment process, the HS will be used as the infrastructure for the loading and unloading process of the TU. Also, if a TU will be stored at the storage system, the HS has to remove it from the CU. Therefore, a physical interface between the TU and the HS has to be defined, to pick up the capsule (see blue symbols in Figure 19). Depending on the UC, the safety requirements or the power supply system, additional coupling interfaces have to be considered, e.g. an electrical coupling to supply the TU with electricity during transshipment. The challenge here is that, depending on the application, a seamless energy supply must be provided, for example. Any kind of communication between the interface TU-CU and TU-HS, but also in this case the internal power supply of a TU, must be provided. The concept for these interfaces is described in chapter 6.3.

**3. Physical coupling and locking interfaces between the TU and Carrier Unit**

After loading the TU to the CU, there must be a physical coupling to secure and connect the TU inside the CU (see red symbols in Figure 19). A **mechanical coupling** can be used as a locking mechanism to secure the TU inside the CU and prevent movement during the ride. The mechanical coupling transmits forces and has to comply with load and crash requirements of the Pod system. The **electrical coupling** is used to transmit energy between the TU and the CU. For all UC, where batteries or other power supply from the CU has to be connected with electrical devices inside the TU (or vice versa), an electrical coupling is needed. Additional **communication coupling** for transmitting signals wireless or hardwired can be used, if signals have to be exchanged between the TU and the CU. If it is needed to transmit liquids (e.g. water, oil etc.) or gases (e.g. compressed air etc.), an additional **media coupling** could be used. The choice and design of the coupling interfaces depends on the UC. The concept for these interfaces is described in chapter 6.4.

**4. Interfaces of the TU to another TU**

If more than one TU is placed inside the CU, there could be connections between each TU (see yellow symbols in Figure 19). E.g. For passenger transport it could be possible to connect the TU with doors in between. Depending on the UC, it might be achievable to have an electrical connection between each TU. For safety and comfort reasons, it might be necessary to lock each TU against each other. Depending on how the TU are arranged on the CU (the Pod configuration is in scope of Task 7.1), these interfaces could be on different sides. The concept for these interfaces is described in chapter 6.5.

**5. Interfaces of the TU to the storage system**

When the TU is not being used, it can be stored inside a storage system. Therefore, specific interfaces might be necessary (see orange symbols in Figure 19). If the TU is made for a UC to be placed on the ground (e.g. a mobile post station, shop floor UC, PRM unit etc.), interfaces like stands or other support elements have to be considered.

**6. Interfaces between different Carrier Units**

The Pods4Rail approach is mainly following a virtual coupling strategy as the fleet management of different CU. For increased safety and higher flexibility, a physical fall-back option will be foreseen as a CU-CU coupling. This WP is only focussing on interfaces of the TU´s, therefore the CU-CU interface is not the scope of this deliverable. Still, the potential coupling methods between different CU may be investigated in this task, due to the aim of standardisation and interoperability. Therefore, potentially suitable coupling methods for connecting one CU to another CU can be included in chapter 6.4 as a reference for the future developments (see green symbols in Figure 19). The actual concept development for these interfaces will be done in WP 14.

## 6.2 Specification of the Loading and Unloading procedure

In this chapter an analysis will be given, of how the TU can be loaded and unloaded to the CU (Figure 20. The loading and unloading process is also defined as the transshipment process (Pods4Rail D2.1, 2024) as visualized in Figure 20. The transshipment contains the transfer of a TU from one CU to another as well as delivering or receiving a TU from the storage system. The most suitable transshipment processes will be derived and explained and relevant interfaces for positioning the TU on the CU or the storage system are developed. A detailed process description of the transshipment is given in chapter 7 (Task 7.3).


**Figure 20: Transshipment process example, as in the concept “one for all” (moodley, 2024)**

In order to evaluate the suitability of possible HS, a short overview of different HS technologies is given in the following. Existing loading and unloading devices are mainly taken from (Pods4Rail D2.2, 2024) and their advantages and disadvantages are being assessed. Functional requirements are taken from (Pods4Rail D4.4, 2024) and safety requirements are included from (Pods4Rail D3.2, 2024). They are used to define evaluation criteria and their rankings for the HS evaluation. Finally, the most suitable technologies are handed over to the further concept development.

### 6.2.1 Functional requirements for the Loading and Unloading

Functional requirements regarding the HS were taken from WP 2, WP 3 and WP 4. These are requirements that influence the transshipment process and handling of the TU. The given requirements by previous WPs are extended with additional requirements addressing the infrastructure and development strategy, such as hardware complexity and expected usage of the system. These additional requirements were worked out during the development of the interface, as further important requirements had to be considered by detailing the concepts, which could not be recorded in detail beforehand. As the list only contains the most important aspects for an initial concept, a general review of all existing requirements is essential.

Each requirement set is being described with the following details:

- Requirement ID: Given ID from (Pods4Rail D4.1, 2024)
- Source: Source of the data, standards or reason of the requirement
- Requirement Input: Content of each requirement
- Output for TU design: Specific influence or design suggestion for the TU

**Table 20: Functional requirements regarding the Handling System (Pods4Rail D4.4, 2024)**

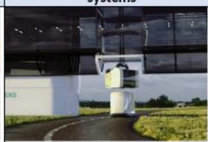
| Requirement ID | Source | Requirement Input | Output for TU Design |
|---|---|---|---|
| OPPL1.7; HS2.1; HS4.2 | Pods4Rail D2.1; Pods4Rail GA; Expert Knowledge | Switching of whole TU and different types of TU´s shall be enabled | Scalability from smallest/lightest to biggest/heaviest TU, independent of CU type. |
| OPPL1.9 | Pods4Rail D2.1 | Operation in railway, tram, metro, ropeway and road domain | Compatibility to rail, road and ropeway domain (foresee roof and bottom interfaces) |
| HS1.2 | Pods4Rail GA | The HS should handle passengers and freight. | HS must provide horizontal positioning of TU, no tilting allowed |
| HS2.6 | Expert Knowledge - Pods4Rail | The HS should be able to overcome the distance between relevant domains | HS must provide sufficient operation range and should be scalable in range |
| HS3.2 | Pods4Rail, D3.2 | The HS shall provide emergency exits for passengers during the transfer at any time | HS must allow easy access to TU at any time (i.e. near to ground level) |
| HS7.3 | (MSC, 2010) | Emergency shutdown procedure should be followed automatically or by remote control, after emergency stop was activated | Provide incident detection and emergency stop system for HS |
| New | Expert Knowledge - Pods4Rail, T7.2 | Handling system shall keep infrastructure complexity low (space and costs) | Simple, standardised solutions are preferred |
| New | Expert Knowledge - Pods4Rail, T7.2 | Handling system shall keep vehicle and TU complexity low (weight and costs) | If possible, no complex technology located inside CU and TU |
| New | Expert Knowledge - Pods4Rail, T7.2 | Handling system shall be able to turn TU´s direction | Provide turning space for TU |
| New | Expert Knowledge - Pods4Rail, T7.2 | Handling system shall be connected to storage system (can be limited to stations) | Provide interface to storage hubs, only needed in main hubs |
| New | Expert Knowledge - Pods4Rail, T7.2 | Small TU shall be able to be transshipped outside of the main hubs | Provide solution for transshipment without stations |

Table 20 shows, that most of the functional requirements were already specified in previous WPs. These contain information about the technical design of the operation system, the HS functionalities as well as some relevant safety features, that must be considered. Besides that, some additional general aspects have to be considered, e.g. regarding the system complexity. In general, the HS should not increase the vehicle complexity, therefore requirements could be to keep complex and costly components outside of the CU or the TU. These requirements have a main effect on the final vehicle weight and costs. Other requirements to be considered are the connectivity to stations and storage systems. Depending on the mobility concept, the transshipment can be done within a station or outside of stations. These factors have to be figured out in the following concept development.

### 6.2.2 Handling System overview and evaluation

Relevant HS from WP 2 can be clustered in 10 main groups, that are mainly different in the way of how a TU is moved. Table 21 and Table 22 give an overview of these groups including a short description of the system and the transshipment movements. This means for example, that a CU can have an integrated system to move a TU horizontally to the left or right side (such as HS01 or HS02). Another option is to use external devices to do the horizontal movement (such as HS03). If external systems are used to lift the TU vertically and move it in the air to another CU, they are grouped in HS04. Air handling can also be done with CU integrated devices (such as HS05).

**Table 21: Overview of Handling System groups (HS01 to HS05) (Kockums Industrier AB, 2024; Rinspeed AG, 2024; moodley, 2024; ÖBB Mobiler, 2024; BOXmover GmbH, 2024)**

| Number of group | HS01 | HS02 | HS03 | HS04 | HS05 |
|---|---|---|---|---|---|
| Name of HS group | Transformable Carrier Unit | Integrated horizontal transhipment device | External devices for horizontal transshipment | Air handling with external systems | Air handling with integrated systems |
| Picture |  |  |  |  |  |
| Short description [Short description of how the system works] | Active translatory and rotatory vehicle movement by "transformation" of the carrier vehicle. Carrier remains on its route, e.g. rail, the carrier of another mode of transport (e.g. road) must collect the TU directly | Translational movement transverse to the direction of travel of the TU from the carrier, TU is moved on fixed rails of the carrier | TU is pushed onto an external HS by a translatory movement. There it is (at least) mechanically fixed. This independent HS moves the TU to the next carrier or destination. | TU is picked up from the carrier by a crane or gripper mechanism and loaded onto the next carrier. The movement of the crane in the plane can be freely selected depending on the design; a rotational movement is possible at any time | TU is loaded onto the crane mechanism provided on the carrier |
| Transshipment of TU [Horizontal, vertical, free movement, hanging, standing] | Mainly in the plain, but at a limited angle, Vertical movement also possible thanks to lifting mechanisms in the carrier. 180° rotation only possible with additional mechanisms | TU is only (un-)loaded from the carrier at right angles to the direction of travel; in addition to the initial carrier, the TU must be picked up directly by another carrier or external handling system. | First translatory movement onto the HS, then free movement. Depending on the complexity of the HS, vertical movements are also possible | hanging transshipment, free movement | vertically |
| Example(s) from D2.2 [Source: D2.2] | HELROM | Mobiler Truck | Robotize pallet shuttle | Siemens moodley "one for all"; Cranes | BOXmover |

Other available systems on the market are automated robot handling (e.g. HS06) or manual or autonomous forklift systems (e.g. HS07). If the TU has only to be placed on ground, some analysed systems offer active lifting devices inside the TU (e.g. HS08) or CU integrated systems (e.g. HS09).

Another option for the TU transshipment would be a direct shift to another domain, for example to a ropeway infrastructure (e.g. HS10) without a dedicated handling device.

**Table 22: Overview of Handling System groups (HS06 to HS10) (Rinspeed AG, 2024; DLR, 2024; Rinspeed AG, 2024; Leitner AG, 2024)**

| Number of group | HS06 | HS07 | HS08 | HS09 | HS10 |
|---|---|---|---|---|---|
| Name of HS group | Robot handling | (Autonomous) forklift handling | Active Transport Unit Lifting Device | Active Carrier Lifting Device | Direct transshipment |
| Picture |  |  |  |  |  |
| Short description [Short description of how the system works] | TU is loaded from one carrier onto the other carrier by one or more robots. The robots can be permanently installed or self-propelled. | TU is loaded from one carrier onto another carrier by one or more stablisers. The stacker can move freely and can also transport the TU to its destination | TU is lifted by extendable supports and thus separated from the carrier. No movement in other directions. | Lifting mechanism of the carrier lifts the TU and enables vertical movement | TU is connected to the crane mechanism and becomes a Cable car; not a HS itself |
| Transshipment of TU [Horizontal, vertical, free movement, hanging, standing] | Translational and rotational movement, whereby rotation can only take place to a limited extent | Free movement, with only limited movement in the air | vertical | vertial, also translational through additional elements | vertically, whereby any type of movement is possible depending on the cable car movement |
| Example(s) from D2.2 [Source: D2.2] | Rinspeed Microsnap | Hans Turck GmbH (https://www.turck.de/en/height-control-and-3d-spatial-monitoring-on-autonomous-forklift-trucks-48541.php) | Rinspeed Snap | DLR U-Shift | ConnX - Leitner |

The overview of the HS shows the technology diversity on the market. Each system has their own advantages and disadvantages, depending on the requirements of the specific UC. That is why it is difficult to analyse the suitability for Pods4Rail without a more specific analysis of the actual tasks which the HS has to fulfil. In order to do a detailed suitability assessment and evaluation, four basic transshipment scenarios (TS) are being defined. The developed HS has to address all of these scenarios in order to guarantee flexibility and inter-modality (Table 23).

**Table 23: Definition of transshipment scenarios to be addressed by the HS**

| Scenario | Name | Domain | Description of scenario |
|---|---|---|---|
| TS01 | Picking up/Placing down TU on ground | Road only (also air and shipping, but not relevant here) | Picking up passengers or cargo from a starting point. Delivery of passengers or cargo to final destination. Passengers can enter/exit the TU on ground level. Also relevant for other UC: Shopfloor-TU, Energy-Supply-TU etc. |
| TS02 | Transfer of TU from road to rail / from rail to road / from rail to rail | Road / Rail | Transshipment of TU in a station within ground-bound domains. Usually no passengers are alighting because they stay inside the TU. For some situations passengers/cargo can additionally enter/exit the TU on a platform. |
| TS03 | Transfer of TU to other domains | Ropeway/ Air/ Shipping | Transfer of TU to secondary domains to increase flexibility and intermodality, such as ropeway/air mobility/ships. These domains are not part of the main (today existing) mobility hubs/stations. |
| TS04 | Transfer of TU to the storage system | All domains | Parking of a TU and/or CU within specific storage areas by handing the TU over to the storage system. |

Based on the functional requirements given in Table 20, the most relevant advantages and disadvantages are given in the following  and . Finally, the suitability of each HS group is being assessed based on the defined transshipment scenarios and the boundary conditions required for this scenario (e.g. degrees of freedom). If a system is suitable, it is highlighted with a green background. Not suitable systems are highlighted with a red background. Only the suitable (green) systems will be considered in the evaluation process.

**Table 24: Handling System assessment regarding suitability for Pods4Rail (HS01 to HS05), e.g. HS01, HS02, HS03, HS04, HS05 (Kockums Industrier AB, 2024; Rinspeed AG, 2024; moodley, 2024; ÖBB Mobiler, 2024; BOXmover GmbH, 2024)**

| Number of group | HS01 | HS02 | HS03 | HS04 | HS05 |
|---|---|---|---|---|---|
| Name of HS group | Transformable Carrier Unit | Integrated horizontal transhipment device | External devices for horizontal transshipment | Air handling with external systems | Air handling with integrated systems |
| Picture |  |  |  |  |  |
| Advantages [keywords] | - Quick and easy for small angles<br>- no additional/ external system necessary<br>- Low complexity | - integration of HS in Carrier<br>- Parallel loading processes possible | - Accuracy of carrier positioning not relevant<br>- High freedom of movement | - Accuracy of positioning of the TU can be equalised<br>- High freedom of movement<br>- High independence of the existing infrastructure<br>- quick | - flexible |
| Disadvantages [keywords] | - Limited freedom of movement<br>- Sequential TU handling<br>- Infrastructure requirements / space next to railway and direct overlap with road necessary | - limited freedom of movement<br>- no rotation<br>- Vertical movement not given<br>- exact positioning necessary for direct onward transport / or additional external HS necessary | - complex HS necessary / second carrier<br>- Space next to carrier necessary / no direct loading possible | - higher security aspects required<br>- Additional infrastructure required | - carrier dependent<br>- complex |
| Suitable for | none - not for more than one TU | TS02 and TS 04 | TS02 and TS 04 | all TS | none - not for more than one TU |

Group HS01 is not suitable for Pods4Rail due to a high complexity and limited flexibility of the transformable CU. An integrated horizontal transshipment device (HS02) can be used for a direct transfer of a TU from a CU to another or to the storage system. External devices increase the flexibility of the HS. That is why HS03 is considered suitable for rail to road transfer and a transfer to the storage system. HS04 is considered as suitable for every scenario. A CU-integrated system as in HS05 is not suitable for Pods4Rail due to its high complexity, especially when more than one TU has to be moved.

**Table 25: Handling System assessment regarding suitability for Pods4Rail (HS06 to HS10) (Rinspeed AG, 2024; DLR, 2024; Rinspeed AG, 2024; Leitner AG, 2024)**

| Number of group | HS06 | HS07 | HS08 | HS09 | HS10 |
|---|---|---|---|---|---|
| Name of HS group | Robot handling | (Autonomous) forklift handling | Active Transport Unit Lifting Device | Active Carrier Lifting Device | Direct transshipment |
| Picture |  |  |  |  |  |
| Advantages [keywords] | - Accuracy of positioning of the TU can be equalised<br>- High freedom of movement<br>- fast<br>- Scalable through more robots | - Accuracy of positioning of the TU can be equalised<br>- High freedom of movement<br>- Fast and flexible<br>- scalable due to more stabilisers<br>- Low safety concerns | - Independent<br>- Fast and flexible<br>- Low safety concerns<br>- cheap and simple | - fast<br>- scalable, when mechanism perpendicular to drive direction | - Independent<br>- fast and flexible<br>- Known system |
| Disadvantages [keywords] | - higher safety aspects required<br>- Limited range<br>- Accessibility for more than one TU | - Additional fixation necessary on rod fork<br>- greater space consumption | - no movement / only unloading and loading processes<br>- intermodality not given<br>- Precise positioning required during loading process<br>- Carrier must be narrow and flat | - no driect movement, only loading / unloading<br>- carier dependent | - higher safety requirements<br>- Intermodality only given to a limited extent |
| Suitable for | none - not for more then one TU | TS01, TS02, TS04 | TS01, TS04 | TS01, TS02, TS04 | TS03, TS04 |

Robot HS (such as HS06) are also not suitable for Pods4Rail because they are expected to be expensive, limited in range and also not possible for moving more than one TU from a CU. (Autonomous) forklift HS seem to be very flexible and therefore suitable for most of the transshipment scenarios. Integrated systems such as HS08 and HS09 are good solutions for quick and simple placing of the TU on the ground especially on the road domain, but their suitability is limited for other domains. Lastly, the direct transshipment (as in HS10) is very efficient for direct transfer to other domains and to the storage system, because an additional HS infrastructure is not needed at all. At the same time, this is a limitation, because the TU cannot be placed on ground and a transshipment from road to Rail-CU is not possible.

**Mandatory criteria, that have to be fulfilled by every system and general evaluation criteria**

Based on the functional requirements and the transshipment scenarios, defined in the previous chapters, the most relevant criteria are derived to evaluate each HS. The criteria together with a priority ranking are given in Table A1 and Table A2 (see appendix). The priority indicates the importance of each criteria according to the given specifications.

In order to develop a safe and supermodal autonomous system, some mandatory criteria are assumed, which have to be fulfilled by every HS. These criteria are not part of the evaluation process:

1. **UC coverage**: Every UC has to be possible with the desired system.
2. **Domain coverage**: Compatibility with rail, road, cable car and others. If the evaluation shows that one domain cannot be supplied with one system, a combination of several systems is possible.
3. **Safety**: Knowledge from WP 7: Every system can fulfil the safety requirements by following safety features as described in chapter 6.2.3.
4. **Positioning accuracy**: Basic accuracy is required due to automation (CU positioning, HS positioning). The automation system will fulfil the basic accuracy. The final accuracy (in mm-cm range) will be covered by the CU and TU interfaces.

**Evaluation of Handling Systems**

Every system is evaluated according the criteria mentioned in Table 26. Each criterion is given a number from 1 to 5 in order to rate its level of fulfilment. If the criteria is fulfilled very good, it is rated as “5” (highest number), if a criteria is fulfilled very poor, it will be rated as “1” (lowest number). The highest reachable rating is 5.00. In order to evaluate the best systems for each transshipment scenario, four evaluation tables are given separately according to their suitability.

The evaluation shows that placing the TU on ground with external systems (HS04 and HS07) is possible but not really suitable because the system has to be station bound or increasing the system complexity greatly. The best rated and most flexible system is the active TU lifting device (HS08). With a rating of 4.47 it is very suitable for easy and barrier free access to the TU. Two limitations appear: Every TU has to be equipped with this lifting system which is increasing the TU complexity, also the movement freedom of the TU is limited since it cannot be rotated. One question to answer in a later phase would be, if this system should be applied to every TU or only limited to specific UC to lower costs and complexity. In this case, integrated stairs or ramps inside the CU would be possible for easy entry of non-barrier free TU (as shown in Figure A1 in the appendix). HS09 follows the same approach as HS08, but the lifting system is integrated in the CU. This solution seems to be more cost efficient in the overall system, but the scalability and TU-capacity would be limited, therefore this solution is not suggested.

**Table 26: Evaluation of suitable Handling System technologies for transshipment scenario “TS01 - Picking up/Placing down TU on ground”**

| **Number of group** | HS04 | HS07 | HS08 | HS09 | |
|---|---|---|---|---|---|
| **Name of HS group** | Air handling with external systems | (Autonomous) forklift handling | Active TU Lifting Device | Active Carrier Lifting Device | **Weighting** |
| Mobility freedom | 1 | 2 | 5 | 5 | 14% |
| Complexity of CU | 5 | 4 | 5 | 2 | 6% |
| Complexity of TU | 3 | 4 | 2 | 5 | 6% |
| Complexity of HS | 1 | 3 | 5 | 5 | 10% |
| Design Freedom of environment | 3 | 4 | 5 | 4 | 13% |
| Scalability | 5 | 5 | 5 | 3 | 18% |
| Efficiency | 2 | 4 | 4 | 4 | 17% |
| Low-floor ability | 5 | 5 | 5 | 5 | 8% |
| Freedom of movement of the TU with HS | 5 | 4 | 3 | 3 | 10% |
| **SUM** | **3.19** | **3.89** | **4.47** | **3.99** | |

When it comes to the transshipment from one CU to another on the road and rail domain, the evaluation shows two systems that might be suitable for Pods4Rail (Table 27). The Best rated solution with a rating of 4.10 is HS02, because it can be used flexible without the need of stations and it shows a low system complexity. The direct transshipment is only possible, if different CU can be parked directly next to each other and on a similar loading height, which might not be possible everywhere. Also, it is not possible to turn or lift a TU while shifting, which is a limitation regarding the project goals. Nevertheless, this would be the suggested solution if the transfer should be possible without stations (as shown in Figure A2 in the appendix).

The best rated solution for a station based transshipment would be an (autonomous) forklift system as in HS07. Its main advantages are the ability to support different loading heights of the CU with optional low floor entry for passengers, it is movable in all directions and the system also offers the chance to directly connect to a storage system. Depending on the system infrastructure the HS could be implemented as guided vehicles (with fixed moving directions) or as autonomous movements with individual forklift devices (as shown in Figure A3 in the appendix). Such a system is similar to industry approved solutions; therefore, a good technical feasibility is expected.

The three lowest rated systems are not suggested for Pods4Rail due to higher system complexity (e.g. HS03 and HS04) or the limitation to the road domain (as in HS09). Especially an air HS inside a transshipment terminal would result in an immense complexity of the HS and infrastructure. For a better technical feasibility, the system could be reduced to smaller terminals. In general, it can be said, that all evaluated systems only have minor differences. There is no clear solution that fits best for every scenario, the suggested solution depends on the mobility requirements.

**Table 27: Evaluation of suitable Handling System technologies for transshipment scenario "TS02 - Transfer of TU from road to rail / from rail to road / from rail to rail"**

| **Number of group** | HS02 | HS03 | HS04 | HS07 | HS09 | |
|---|---|---|---|---|---|---|
| **Name of HS group** | Integrated horizontal transshipment device | External devices for horizontal transshipment | Air handling with external systems | (Autonomous) forklift handling | Active Carrier Lifting Device | **Weighting** |
| Mobility freedom | 5 | 3 | 1 | 3 | 5 | 14% |
| Complexity of CU | 3 | 3 | 5 | 4 | 2 | 6% |
| Complexity of TU | 5 | 5 | 3 | 5 | 5 | 6% |
| Complexity of HS | 5 | 3 | 1 | 3 | 5 | 10% |
| Design Freedom of environment | 3 | 2 | 3 | 2 | 2 | 13% |
| Scalability | 5 | 5 | 5 | 5 | 3 | 18% |
| Efficiency | 5 | 3 | 3 | 3 | 2 | 17% |
| Low-floor ability | 2 | 4 | 5 | 5 | 5 | 8% |
| Freedom of movement of the TU with HS | 2 | 4 | 5 | 4 | 2 | 10% |
| **SUM** | **4.1** | **3.53** | **3.36** | **3.67** | **3.31** | |

In general, only a few systems are useful to connect to other domains than rail or road (Table 28). Most likely those domains will carry the TU from above (based on today's standards). Examples are ropeways, drones or shipping cranes that are mainly connecting to the roof of the TU. Therefore, either a roof mounted system (=higher complexity of TU) or a bottom mounted system (=higher complexity of HS, as shown in Figure A4 in the appendix) is necessary for the Pods4Rail approach. A roof mounted system will increase the complexity of the TU structure, meanwhile a bottom mounted system will increase the complexity of the HS. When safety and efficiency aspects are considered, a bottom mounted system might be suitable for ground transfer (rail and road), meanwhile roof-mounted systems are suitable for other domains (air, ropeway, ships).

The best rated and most suggested solution seems to be a direct transshipment (rating of 3.99 with HS10) due to the direct transfer of the TU between two domains. This supports the lowest complexity of the system because no actual HS infrastructure is required. Only two limitations appear with such a system: The structural complexity of the TU (this is only rated with the number 3, because anyway a stacking of the TU is requested for the storage system) and the low-floor ability in the transfer process (this could be solved with platforms in the stations). The air HS (HS04) is rated with a result of 3.25 and is not suggested for Pods4Rail, due to the high technical complexity and because interferences between the HS and other domains could appear, because domains such as ropeway and the HS would have to share the same interfaces which disturbs the handover of the TU. The (autonomous) forklift HS (HS07) is not suitable to do the full transshipment and is therefore not being evaluated in this scenario. But it can be mentioned that HS07 could also be used to move the TU from a rail or Road-CU to a dedicated loading zone to further transfer it to the ropeway, air or shipping domain.

**Table 28: Evaluation of suitable Handling System technologies for transshipment scenario "TS03 - Transfer of TU to other domains (ropeway, air mobility, shipping)"**

| **Number of group** | HS04 | HS10 | |
|---|---|---|---|
| **Name of HS group** | Air handling with external systems | Direct transshipment | **Weighting** |
| Mobility freedom | 2 | 5 | 14% |
| Complexity of CU | 5 | 5 | 6% |
| Complexity of TU | 3 | 3 | 6% |
| Complexity of the HS | 2 | 4 | 10% |
| Design Freedom of environment | 3 | 4 | 13% |
| Scalability | 4 | 4 | 18% |
| Efficiency | 2 | 4 | 17% |
| Low-floor ability | 5 | 1 | 8% |
| Freedom of movement of the TU with HS | 5 | 5 | 10% |
| **SUM** | **3.25** | **3.99** | |

The most variable options appear for the storage system transshipment scenario (Table 29). Seven different HS can be used in this case. Two of these systems show much higher ratings than the others: HS02 and HS07. The integrated horizontal transshipment in HS02 seems to be the best rated solution for a direct transfer from the CU to the storage system. But this system only works if the storage system has an own infrastructure for further movement of the TU. Because of that this system is only suggested if the CU to CU transfer is using the same hardware. The (autonomous) forklift handling in HS07 is considered as the most suggested solution, due to its compatibility to the storage system and a high flexibility of the system regarding the CU to CU transshipment. Only minor disadvantages appear in the mobility freedom because it is station bound and the infrastructure complexity, which is generally high. Both of these limitations can be weakened, if the storage system would be located inside or besides a transshipment station, because then the same infrastructure can be used. This aspect shows a potential system definition: The storage system should be located next to a transshipment station to reduce the system complexity and also environmental impact. To increase the system flexibility and efficiency, additional micro hubs could be used. In this case, the options HS08 or HS09 could be used for the road domain as extended storage possibilities.

**Table 29: Evaluation of suitable Handling System technologies for transshipment scenario "TS04 - Transfer of TU to storage system"**

| **Number of group** | HS02 | HS03 | HS04 | HS07 | HS08 | HS09 | HS10 | |
|---|---|---|---|---|---|---|---|---|
| **Name of HS group** | Integrated horizontal transship. device | External devices for horizontal transshipment | Air handling with external systems | (Autonomous) forklift handling | Active TU Lifting Device | Active Carrier Lifting Device | Direct transshipment | **Weighting** |
| Mobility freedom | 4 | 3 | 2 | 3 | 5 | 5 | 2 | 14% |
| Complexity of CU | 3 | 3 | 5 | 4 | 4 | 2 | 5 | 6% |
| Complexity of TU | 5 | 5 | 3 | 4 | 3 | 5 | 3 | 6% |
| Complexity of the HS | 4 | 3 | 2 | 3 | 5 | 5 | 3 | 10% |
| Design Freedom of environment | 4 | 3 | 3 | 4 | 2 | 2 | 3 | 13% |
| Scalability | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 18% |
| Efficiency | 5 | 4 | 4 | 4 | 2 | 2 | 4 | 17% |
| Low-floor ability | 3 | 4 | 5 | 5 | 4 | 4 | 3 | 8% |
| Freedom of movement of the TU with HS | 3 | 4 | 3 | 5 | 1 | 1 | 5 | 10% |
| **SUM** | **4.17** | **3.82** | **3.57** | **4.13** | **3.31** | **3.31** | **3.69** | |

### 6.2.3 Investigation of hazards and safety concept of the Handling System

#### 6.2.3.1 Hazards and safety concept

The following procedure fulfils high-level requirements listed in the (Pods4Rail D4.4, 2024) documents, all the procedure phases will explicitly refer to D4.4 when needed in order to illustrate that the required functions have already been specified.

The general safety context starts by presenting the main components of the system. The HS that handles a TU with passengers is considered as a transport system: it is transporting persons, even if it is just for a short distance. By the contrary, regarding the crowd, which is around the HS, this system is considered as a machine and classical protection means and procedures must be applied to protect persons outside of the TU (see various documents implementing Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery). It corresponds to the high-level requirement from the D4.4:

**Table 30: Functional requirement HS3.6 as taken from (Pods4Rail D4.4, 2024)**

| | | |
|---|---|---|
| HS3.6 | Automation Safety Functions | The HS shall provide relevant automation functions, e.g. automatic movements, detection of CU and TU, detection of obstacles etc. |

The above requirement mentions a particular service: "Obstacle detection". Detecting obstacles allows the presence of the crowd around the moving HS when the inertia of the system allows collision avoidance and harms (i.e. the speed is low). An example from a practical application is the boarding area of a cable car, where open, yet slow-moving machinery is in direct proximity to the passengers it is designed to transport. This functioning assumption is linked to another potential system function: the ability to close the system in order to ensure that no people are in the transfer zone when the HS is moving.

Assuming, that the two requirements are fulfilled: no people are in the transfer zone, or the HS is able to detect obstacle and stop without inducing damages or arming people, the three main specific hazards leading to a danger are:

1. People could be falling from the TU
2. The whole TU could be falling from the CU or from the HS
3. Accidents or emergencies could happen to the passengers inside of a TU

Actually, various kinds of problems could happen to passengers who are in a TU that is moved by a HS. People could suddenly face health problems or be offended from aggressions by other passengers. Fires might occur or passengers might get exposed to overheating or cooling. All these scenarios may be handled by means of an emergency button or mechanism, triggering a tailored emergency procedure. Indeed, alarm triggering corresponds to a high-level requirement of the D4.4:

**Table 31: Functional requirement OPPL5.11 as taken from (Pods4Rail D4.4, 2024)**

| | | |
|---|---|---|
| OPPL5.11 | Alarm management | The system shall allow to manage alarms and associated information |

During this emergency danger handling procedure, reliable communication means are important to identify the situation and trigger an adequate safety management process, the D4.4 says:

**Table 32: Functional requirement HS4.4 as taken from (Pods4Rail D4.4, 2024)**

| | | |
|---|---|---|
| HS4.4 | Communications | The HS shall be equipped with all necessary communication infrastructure for seamless connectivity to the operation system. |

Depending on the identified danger, crew intervention of fire-fighters, paramedics or the police might be necessary. In this case, the HS must be in a state that allows a safe crew intervention. Even when the solution is to evacuate passengers, the state of the coupling (TU towards HS) must be in a state that allows a safe exit as previously specified:

**Table 33: Functional requirement HS3.2 as taken from (Pods4Rail D4.4, 2024)**

| | | |
|---|---|---|
| HS3.2 | Automation Safety Functions | The HS shall provide emergency solutions for passengers (e.g. emergency exits for passengers during the transfer process, if applicable) |

A safe state is more restrictive than only stopping the CU or the HS. For a ropeway, for example, it may be better to move until a place can be reached where the rescue team can access the TU, or where a mobile ladder can be used. Stopping a ropeway over a river, for instance, could be a too difficult scenario. Anyway, all specific scenarios that might occur in one transshipment, should have been studied, as specified in the deliverable D4.4:

**Table 34: Functional requirement HS3.3 as taken from (Pods4Rail D4.4, 2024)**

| | | |
|---|---|---|
| HS3.3 | Automation Safety Functions | The HS must have action cards in place for emergency situations, including responses to unexpected events during loading, unloading, or transitions. |

Within these scenarios, there are various failure modes like loss of electricity. In this case, doors should not get unlocked before the TU reaches a safe state (which means, for instance, that the rescue battery should at least allow the system to reach a safe state). Moreover, all the communication needs of the TU are based on a rescue battery. In case of a motor failure in the HS, at least an energy source should be provided to the TU in order to preserve communication means and comfort functions (cooling, etc). This need is already identified in the framework of the D4.4

**Table 35: Functional requirement HS5.2 as taken from (Pods4Rail D4.4, 2024)**

| | | |
|---|---|---|
| HS5.2 | Power supply | The Handling system should be seamlessly powered, including a protection or safety plan for loss of electricity |

Another hazard, which was listed above, is passengers falling from the TU or the TU falling from the CU. In order to prevent the whole TU falling from the CU, a requirement can be: "the coupling between the CU and the TU should not be unlocked when the CU is moving." It is easy to check that the unloading process presented in the current deliverable is fulfilling this requirement. An alternative requirement could be: "when the CU is moving, the coupling with the TU is always locked".

This requirement can allow dynamic unloading without stopping the CU if the coupling with the HS is locked before unlocking the CU coupling. As it is not the choice performed by the current deliverable, the first requirement is more efficient. This safety discussion is also taking a part of the transshipment process description within chapter 0.

#### 6.2.3.2 Safety discussion about passengers being in the wrong place

This section contains a discussion of a specific Pods-related situation, that might happen to passengers, specifically within the railway domain. When several TU are mounted on one Rail-CU, a passenger can be allowed to move freely between the TU (e.g. going to a sanitary unit). Here the following situations could appear:

- A TU will be removed together with the passenger inside this TU
- A dedicated Passenger Unit will be removed without the passenger being inside
- The way of a passenger could get interrupted between his current location and his dedicated TU, because a TU in between was removed

If somebody remains in the wrong unit of a CU, for example in a sanitary unit or in the wrong TU when the connected TU is removed, the corresponding passenger is blocked inside the wrong TU. The passenger is blocked until a new TU is connected to the unit where he is located. In this case, the passenger is not considered in a danger zone, because he is in a physically closed TU. Even in the case when a passenger has to wait twenty minutes within a sanitary unit, it cannot be considered as a safety problem if the corresponding passenger is aware of his or her situation.

This leads to formulate the following requirement: "Passengers should be made aware of the situation by the means of automatic messages triggered before a connected TU is removed". The first message should be sent a couple of minutes before the connection gets lost, so that passengers may organize themselves. In today's train operation the following example is the state of the art: access to train platforms is forbidden a specific period of time before the train starts, in order to potentially avoid dangerous scenarios. This way of common practice has proved its efficiency.

The TU can be seen as swap bodies/containers for which no properly fitting standards exist today. Therefore, existing standards are the only ones that can be used as a guide, what brings up the need to analyse regulations e.g. for railway, buses or cable cars. To make an assessment possible, the specification of a railway exit door (TSI Loc and Pass) is used as an example. It has two main consequences:

1. You cannot open the door if the CU is moving.
2. You are only able to trigger an emergency stop (the corresponding device mentions "all abuse will be systematically prosecuted"): when you stop, then you may go out, but you triggered an alarm and the crew members are aware of the situation.

The CU is not allowed to move when an exit door is opened, or an alarm must be triggered before the CU or the HS will stop. Consequently, in the worst case, the situation is the same as one of a train, that stopped on the track. A message can appear, saying: "do not go out of the train", or "exiting the TU is only allowed with a stopped TU in front of the dedicated exit platform". If the CU is stopped in front of an exit platform, the CU surface is not made to be accessed by passengers, but it is safe enough for maintenance tasks performed by staff members. Consulting the matrix of risk of (DIN EN 50126-1), the severity of the potential accident is not so high that it is not compatible with the probability of the scenario. This first analysis leads us to an acceptable level of the corresponding risk from a railway point of view.

Regarding the scenario for Road-CU, the same hazards may appear, but the risk for passengers is much less (except in the case of a highway). This is for example, because Road-CU are used for shorter distances of travel, they do not load as many TU as Rail-CU and they also do not feature sanitary units. In most cases only a single 10 ft TU will be loaded, or two 5 ft units that are not connected to each other.

The conclusion of this safety discussion is, that passengers that are in the wrong TU may be inconvenienced or have their travel delayed, but they are not at any particular safety risk, as long as common design and communication principles are fulfilled.

#### 6.2.3.3 Safe procedure of transshipment for the Handling System

Using the above safety principles that are grounded on already existing high-level requirements of the D4.4, an exemplary unloading procedure is presented is the following. The term “procedure” is understood using the common definition: “a series of actions conducted in a certain order or manner”. For a technical procedure description, please also see chapter 0.

The procedure starts with a HS and the loaded supply CU in the transshipment area. Any steps of the procedure can be interrupted by an emergency cycle consisting of:
Moving safely to a safe state and stopping.

Moving safely means that specific hazards are avoided:

- All TU doors are locked
- At least one mechanical and electrical coupling is locked (CU or HS).

Safety conditions for authorizing the unloading are:

1. The HS coupling with the TU is locked (there should be relevant information available through communication exchanges. The reliability of the service should be at a level allowing the risk to the corresponding hazards to be kept to an acceptable level).
2. The HS shall always communicate (provide and receive) specific feedback data about the process status according to the defined process description for safe loading and unloading.
3. All the exit doors of the TU are locked. Exit doors of the TU includes the side doors that may lead to another TU put on the same CU: the goal is to prevent passengers falling through an open door. In the case of several TU on the same CU, passengers may access to neighboured TU. For this reason, a warning message should be sent to passengers before locking the doors (warning belongs to the initialization, such as locking the doors).

The second phase is: Moving to a transfer state.
In the case of hoist transfer or ropeway, it corresponds to lifting the TU to a height where the HS can initiate a lateral movement. To ensure a safe movement, two information are needed:

- No obstacle on the trajectory (D4.4 HS 3.6)
- Receiving the information that the targeted place is free (for example, no TU on the CU where the HS wants to put this TU).

The third step is to perform a lateral movement towards the receiving CU or an unloading area.
The initialization conditions are:

- Being at the required location
- Receiving the needed information (D4.4 HSD3.5) from the receiving CU (when the target is a CU).

The fourth phase is going down to the target place (in case of ropeway and hoist). Here, it has to be checked that the correct information is received before unlocking the coupling system towards the TU (Coupling with the receiving CU is locked).

The fifth phase is, to lift up the HS and move it away.

The ending phase allows to unlock the exit doors (towards another TU or to the outside of the system constituted by the coupling.

### 6.2.4 Description of the loading and unloading procedure and interfaces for positioning the Transport Unit on a Train Carrier Unit

**System definitions for the loading and unloading strategy**

The comparison and evaluation of several HS technologies within this task (chapter 6.2.2) has shown, that there is no clear best technology which can be directly and exclusively applied to Pods4Rail. The evaluation process showed that the most suitable solution depends on the system boundaries and the transshipment scenarios. Also, in case of safety requirements, the hazard and safety assessment (chapter 6.2.3) made clear that every system can be safe, as long as efficient safety features are being established. Because of that some general system definitions and assumptions are being introduced in Table 36, in order to define an overall safe, functional and efficient loading and unloading procedure. Since these aspects can affect the whole Pods4Rail system, it is highly suggested to re-analyse these system definitions within later WPs.

**Table 36: System definitions and approach for Pods4Rail concept**

| Topic | Main question | System approach, suggested for Pods4Rail |
|---|---|---|
| Transshipment flexibility | Should it be possible to transfer the TU from CU to CU anywhere or only at stations? | The main transfer should be limited to stations due to the high complexity of the HS infrastructure and the Pods4Rail approach: Road-CU (and other domains) are used as suppliers for Rail-CU.<br>Road-CU (and others) are able to pick up and drop TU anywhere. Rail-CU don´t need to place a TU on ground. |
| TU accessibility | Do the TU have to be placed on ground or can the CU be equipped with a lifting device? | The TU should be able to be placed on the ground because some UC demand for easy accessibility and flexibility. To reduce the TU complexity, this feature can be limited to specific UC (e.g. PRM or shopfloor). Other solutions like CU-integrated lifting devices could be used additionally. |
| System complexity | Should we follow the "one for all" approach and develop one standard HS for every task or can we have different HS variants for different tasks? | A general "One for all" approach is not suggested because it will rapidly increase the complexity of the system. It is expected to be more efficient to have specialised solutions depending on the transshipment scenario. Nevertheless, the HS should be as standardised as possible and variants should be combined, if suitable. |
| TU storage systems | How is the accessibility, location and type of storage system? | The main storage systems should be connected to transshipment stations and provide space for stacking and parking of TU. Also parking of Road-CU is possible.<br>Additionally, smaller hubs (e.g. only a parking space and TU-storage without stacking) can be installed anywhere but should be limited to smaller sizes. |

**Description of the Loading and Unloading Procedure**

By following these system boundaries and assumptions, the TU is decided to be compatible to HS07, HS08 and HS10. Those three HS technologies will address all relevant transshipment scenarios:

- TS01: Picking up/Placing down TU on ground —> HS08: Integrated lifting device inside TU
- TS02: Transfer of TU from road to rail —> HS07: (Autonomous) forklift system
- TS03: Transfer of TU to other domains —> HS10: Direct transshipment
- TS04: Transfer of TU to the storage system —> HS07: (Autonomous) forklift system

For transshipping the TU from CU to CU on ground level, an (autonomous) forklift system can be used (HS07). This system can also provide the transshipment to the storage system, located in the station. To use such a system, the TU must provide a bottom structure which fits to standardized forklift devices. Today, a variety of forklift systems are available on the market: From standard forklift trucks to forklift adapters for cranes, up to fully automated high-bay warehouse solutions. Also, the possible size of loads varies from standard pallets up to fully loaded shipping containers. This system allows fully automated as well as manual handling and could therefore be used for service or transport tasks out of the normal operating conditions. Figure 21 shows some options for suitable systems. The design proposal of the required interfaces is described in chapter 6.3.


**Figure 21: Forklift handling devices, used in industry. a) Forklift trucks and empty handlers for shipping containers. b) Mobile forklift adapter for cranes. c) Automated high-bay warehouse mover (J&S Maritime Ltd, 2024; Palfinger AG, 2024; CDN, 2024; Pressebox, 2024)**

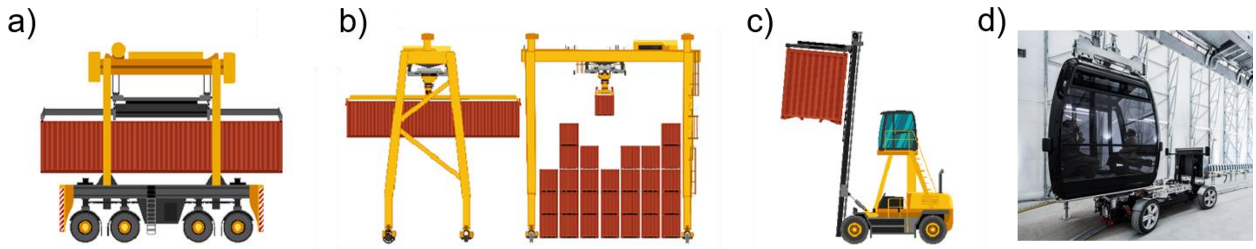



**Figure 22: Roof handling devices, used in industry. a) Straddle/Shuttle Carrier for shipping containers. b) Stacking/Gantry crane. c) Top pick crane truck. d) ConnX prototype by Leitner AG (J&S Maritime Ltd, 2024; Leitner AG, 2024)**

For placing the TU on ground, an integrated lifting device (HS08) is implemented inside the TU. To use this system, relevant TU have to be equipped with electric cylinders in all corners. This system should be limited to the most relevant TU, also it could be limited to the road domain because there is the biggest demand for this system. This also means, that Road-CU have to be as flat and narrow as possible, to allow the TU to lift itself vertically before it will be able to lower itself to the ground level. Figure 23 shows relevant technical solutions for a lift-able TU from industrial standards as well as automated vehicle concepts. If the CU will be able to leave the TU in driving direction (i.e. towards the front), systems like shown in pictures a) to d) would be possible. The legs inside the TU could be vertically pushed or using a folding mechanism. In both ways the legs have to be wider than the CU, to allow its free movement. If the TU will be pushed away sidewise (which is not considered in our approach, but would still be possible), then a system like a scissor lift table inside the TU bottom structure would be possible (as shown in picture e). The limitations appear, that the lifting mechanism is increasing the TU complexity, costs and weight. Options for improving the technology are to narrow the CU with a CU-integrated lifting device for smaller lifting movements. The exact positioning and type of such a system would be subject for future WPs and Tasks when the TU-equipment is developed in more details.

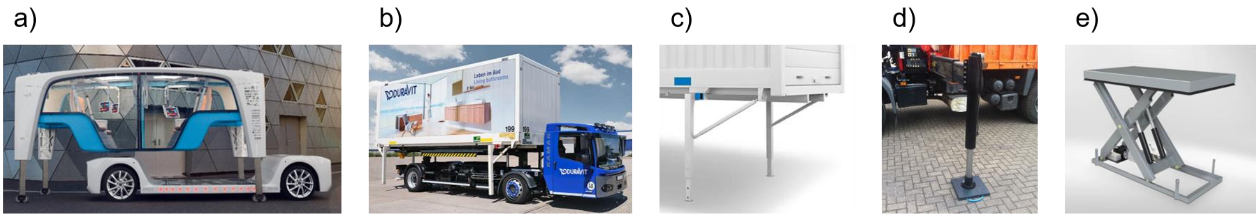



**Figure 23: Concepts for TU-integrated lifting devices. a) Rinspeed Snap concept. b) Truck and trailer swap body platform with rotating stands. c) Detail view of rotating stands. d) Crane stands with horizontal and vertical movements. e) Scissor lift table (RinSpeed AG, 2024; Logistra, 2024; Mein Lagerraum$^{3}$ GmbH, 2024; RZ GmbH, 2024; Alfotec GmbH, 2024)**

**Loading interfaces between TU and CU**

In all those scenarios, every TU will be moved vertically from the CU. This affects the CU design in that way, that the interfaces and geometry shall support the vertical movement of the TU together with a flat CU design for enabling the TU lifting device. For a successful loading and unloading, the main factors are a precise positioning without clashing of one TU into another TU as well as a system that can overcome a tolerance while locking the TU.

As stated in chapter 6.2.2, a basic accuracy is required for the automation system. This includes the CU positioning within the transfer zone as well as positioning the HS and TU for doing the transshipment. Based on today's automation systems that where analysed in this task, the accuracy can be expected to be in the range of 20-30 mm by the year of deployment. The final positioning accuracy of the TU towards the CU is then less than 20 mm and will be covered by the coupling mechanism.

As stated in chapter 6.4.2, an automatic twistlock mechanism will be chosen for locking the TU to the CU. Every twistlock system has an integrated tolerance for its positioning on the CU (due to movable ground plates) as well as a tolerance in its locking pin, due to its conical geometry. The combination of these two geometries allows to overcome the necessary tolerance range for the transshipment process. Because of that, additional guide rails are not needed.

A drawing of the complete CU to TU connecting area with the use of a twistlock pattern will be shown in chapter 6.4.6.

## 6.3 Concept for interfaces between the Transport Unit and the Handling System

Based on the previous elaborations and definitions, this chapter defines the necessary requirements and dimensions of the interface solutions between the TU and the HS proposed in chapter 6.2.2. The focus here is on the three different interface requirements:

1. Transshipment with an integrated lifting device, according to TS01 (Picking up/Placing down TU on ground – road only)
2. Transshipment with an (autonomous) forklift system, according to TS02 or TS04 (Transfer of TU from road to rail / from rail to road / from rail to rail / Transfer of TU to the storage system)
3. Direct transshipment, according to TS03 (Transfer of TU to other domains – Ropeway, Air, Shipping)

For a detailed description of the scenarios TS01 to TS04, see Table 23. The requirements for the interface of the three required solution variants are first described below, followed by a more detailed description of the interface. In the following, fork pockets refer to the openings into which the individual forks of the forklift are inserted.

### 6.3.1 Requirements regarding the interfaces between the Transport Unit and the Handling System

The requirements that apply to all HS and transshipment processes as well as the specific requirements for the respective transshipment processes are listed in the following tables. The first column contains a clear designation and name, the following column describes these in more detail and the last column finally defines the outputs for the concretisation of the TU-HS interface. Only the specifications directly relating to the interface are considered. Not, however, the requirements that apply to the general TU concept (e.g. RGEN3 in Table 37: here it is not considered that the TU requires an antenna, but that electromagnetic compatibility should only be considered in CAD). The requirements are based on the previous deliverables, the previous work in this deliverable and the exchange between the experts involved within WP 7. For this reason, no precise sources are cited.

The following Table 37 defines the requirements that apply to all transshipment processes.

**Table 37: General requirements for the HS-TU interface**

| Naming | Description | Rough Specification |
|---|---|---|
| RGEN1 Compatibility | Each TU should be operated with all external HS in each TS (exception: TS01 - only realised for specific purposes) | TU must have the same HS-interface pattern or be designed so, that a scalable HS can transport any form of TU. |
| RGEN2 Direction | The TU must always be lifted in a vertical direction before it can be moved in another direction. | Provide sufficient space in the vertical direction / flat interfaces are preferable |
| RGEN3 Telecoms | Reliable telecommunication for exchange of information during un-/loading should be available. The bandwidth requirement is not high | Observe electromagnetic compatibility when changing the state of the power supply |
| RGEN4 Robustness | TU must be sufficiently robust in the area of the HS mountings to absorb forces / loads. Edges and corners must be reinforced accordingly. | Integrate structural parts to HS-Interfaces |
| RGEN5.1 Accessibility | The interfaces must be accessible to the HS at all times. They must not be permanently covered | Interfaces must be installed on both sides of the TU in the direction of travel. A roof interface must provide sufficient space all round |
| RGEN5.2 Accessibility | Interfaces of different domains (e.g. CU-TU interface and TU-HS interface) must not collide with each other and must always be accessible | Maintain sufficient distance and consider other interfaces from the start (e.g. corner castings for twistlocks) |
| RGEN6 Emergency exit | The HS must not block the emergency exits or additional emergency exits must be available. | The interface must be positioned so, that the HS does not block all emergency exits. |
| RGEN7 Markings | Interface and HS be designed so, that relevant lights / markings remain always visible | Interface must be designed that it is not in the way of relevant markings / lights |
| RGEN8 Monitoring | The interfaces must be monitored, to ensure the right connection and to detect damage early. | Integration of appropriate reliable sensors in each interface |
| RGEN9 Redundancy | Catastrophic failure of the entire connection must be prevented. Loosening / failure of one interface must not lead to a critical failure. | The interface must be designed to be redundant or sufficiently robust |
| RGEN10 | EN 15056+A1 Cranes - Requirements for container handling spreaders | Follow the standard to be universal in usage with common lifting devices |
| RGEN11 | ISO 3874:1999 (26 9345) Series 1 containers - Handling and fixing | Follow the standard to be universal in usage with common lifting devices |

**Requirements for the TU-HS interface for the transshipment scenario TS01**

The following Table 38 lists specific requirements for the interface between TU and HS for placing the TU on ground. The focus here is primarily on the possible realisation of the lifting mechanism.

**Table 38: Requirements for the HS-TU interface for an integrated lifting device**

| Naming | Description | Rough Specification |
|---|---|---|
| RILD1 Lifting Path | The interface/lifting path must be designed so that the TU is lifted high enough for the CU to pass underneath. | The lifting path must be at least 1200 mm for compatibility with existing swap bodies. If it is assumed that the lifting mechanism only applies to newly developed CU, a lifting mechanism of 840 mm must still be provided. (Outer diameter of the smallest standard tyre for a VW bus (215/65 R16 C; 686 mm (Porsche Austria, 2024)); a structure of 100 mm and an additional lifting travel of 50 mm to decouple the TU from the CU. Prerequisite: Chassis can be lowered |
| RILD2 Extendable feet | The extendable feet must pass to the side of the CU so that the CU can pass underneath. | The TU has a width of 2438 mm, the max. width for a road vehicle is 2550 mm. Each foot may therefore be a maximum of 56 mm wide. Or extend the ft sideways using an additional mechanism. |
| RILD3 Secure Locking | In the event of an unplanned malfunction, the lifting mechanism must assume a safe state. Ideally, it should drive down to the ground in a controlled manner. | No direct requirement for the CAD. |
| RILD4 | Object detection: It must be ensured that nothing is under the TU when it is placed down (animals, objects, etc.) | 1-2 optical sensors that analyse the parking area |

**Requirements for the TU-HS interface for the transshipment with an (autonomous) forklift truck (TS02, TS04)**

The specific requirements for the TU-HS interface for a transshipment with an (autonomous) forklift truck are defined below in Table 39. This primarily concerns TS03, i.e. handling from road to rail and vice versa, but also rail-rail handling and handling in a storage system.

**Table 39: Requirements for the HS-TU interface for an (autonomous) forklift system**

| Naming | Description | Rough Specification |
|---|---|---|
| RFLS1 Standardisation | Forks must fit / be standardised for different types of forklift trucks (heavy-duty forklift trucks and smaller forklift trucks / pallet trucks) | A detailed elaboration follows in chapter 6.3.2 |
| RFLS2 Locking | Interface must provide locking mechanism for safe passenger transport. | Mechanical locking of forks |
| RFLS3 Weight distribution | With unequal mass distribution the TU or the interface must be designed so, that it can compensate for a shift in the centre of gravity. | Each interface must be designed with a sufficient safety factor. |
| RFLS4 Dimensions | Fork pockets should be designed in accordance with the applicable standards and ensure sufficient tilting stability. | Distance between pockets: 900 mm - 2050 mm |
| RFLS5 Accessibility | For maintenance purposes / locking, the fork pockets should not be completely closed | Distance between openings at least 200 mm |
| RFLS6 Failure management | In case of system failure, the safety of the forklift trucks drivers (if any) should be ensured | Refer to industrial requirements of forklift operations |

**Requirements for the TU-HS interface for direct Transshipment (TS03)**

Further requirements are needed for direct transfer in accordance with the options described in chapter 6.2.4. On the one hand, the interfaces on the roof must be considered and, on the other hand, devices for possible fork transport must be provided, which are similar to classic forklift transport. These requirements are listed in Table 40.

**Table 40: Requirements for the HS-TU interface for a direct transshipment**

| Naming | Description | Rough Specification |
|---|---|---|
| RDT1<br>Energy supply | No energy needs to be transmitted during the transshipment process as the TU has its own energy supply.<br>The exception to this is direct and permanent transshipment with a ropeway or drone, where an electrical or signalling interface is required. | Interface must be provided, as all TU should be the same.<br>In case of failure, the duration of the safe state is related to the duration of the energy supply of the TU. |
| RDT2<br>Locking | If the TU is lifted on the roof or with a fork system, these interfaces must ensure safe transport. | Mechanical locking must be provided. |
| RDT3<br>Roof Locking | The HS must be fixed to the roof at minimum two points for stabilisation. Also, for an HS based on a forklift system | Provide at least two interfaces |
| RDT4<br>Accessibility | A sufficient number of doors/emergency exits must always be accessible and must not be blocked by the interface/the HS. Also valid for PRM facilities. | Position the interface so that at least one door is accessible. |
| RDT5<br>Hole pattern | Interface must be designed so that a scalable HS can serve any size of TU, whereby only 5 ft and 10 ft containers are occupied by passengers. | Standardized hole pattern according ISO668 |

### 6.3.2 Specifications of the interfaces between the Transport Unit and the Handling System

In this chapter, sketches are created that consider the above-mentioned requirements for the HS-TU interface. Firstly, the roof interface for direct transshipment is discussed below, followed by the required interface to an (autonomous) forklift system. The first is also a corresponding interface for the TU-CU interface and is processed in parallel to Chapter 6.4.6.

**Specifications for the TU-HS interface for direct transshipment to ropeways or drones (TS03)**

In accordance with the contents of chapter 6.4 and the further discussions in WP 7, the existing connection type for ISO containers was discussed as the interface for the CU-TU and TU-HS interface. These have corresponding corner castings at the corners as shown in Figure 24 (left). These corner castings have the outer dimensions shown in Figure 24 (right). The exact dimensions of the holes in the corner castings can be found at various manufacturers. These differ depending on whether they are attached to the top or bottom of the container. The corner castings used here were taken from (Navacqs, 2024). These installation spaces must be kept free during the development of the TU. While the hole pattern of the corner castings and the mechanical connection points are highly relevant for the CU, it is assumed for the roof connection that it is a scalable HS that can serve the relevant devices for 5 ft containers as well as for 10 ft and 20 ft containers. As the HS will only be defined in WP 13 and at the same time the TU should be as standardised as possible, it is assumed that even if the requirements only call for 2 connections in the roof area, a corner casting will still be fitted at each corner.

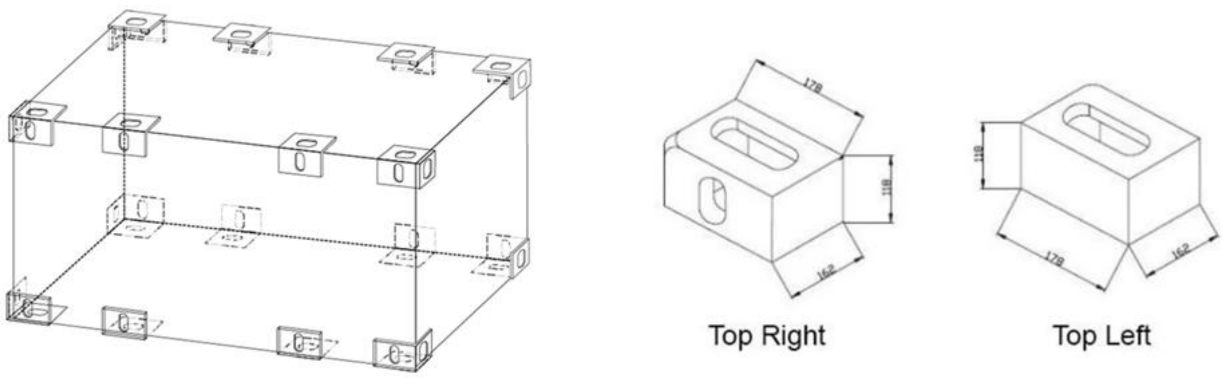



**Figure 24: Corner Castings for ISO-Containers according ISO 668 (NowLearn.net, 2024; All Things Containers, 2024)**

The exact position of the individual corner castings according to ISO 668 - 2020-01 is shown in Figure 25 below. The dimensions of the 10 ft and 20 ft containers are taken from the standard, the values for the non-standardised 5 ft container were scaled according to the other two containers. The distances C1 and C2 have not been changed. These devices/corner castings arranged in the roof should be used by the HS engaging with the roof in order to lock and also to stabilise the TU. These areas must be structurally designed in such a way that they guarantee sufficient structural integrity by lifting at these points, even with an unfavourable weight distribution / centre of gravity position. The centre attachment points of the 20 ft container with the distances S2 and S3 are not considered relevant for the TU-HS and TU-CU interface for TU newly developed in this WP. The mechanical locking should be carried out exclusively via the corner castings. For this reason, the installation spaces for this are also neglected in the TU design below. Should a TU / freight container nevertheless have and require this interface, it can be operated by the CU or the HS.

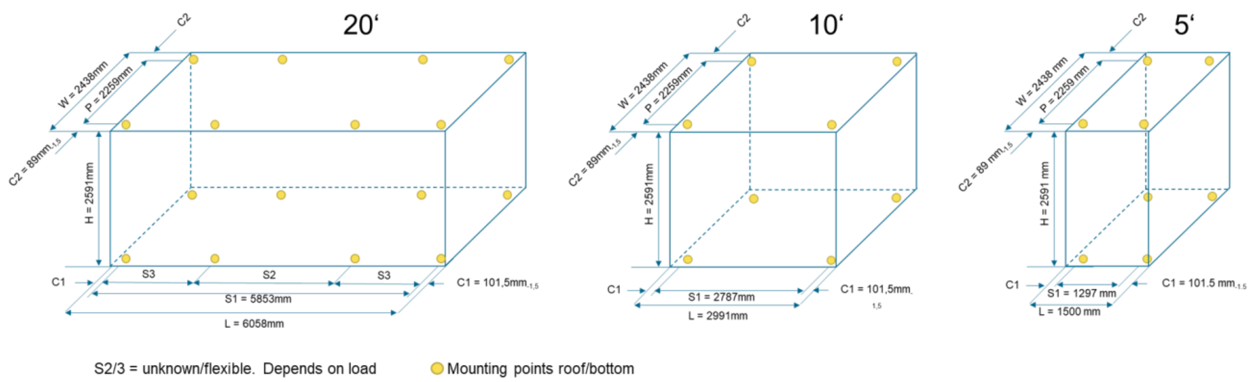



**Figure 25: Measurements for Corner Castings (yellow points). The values S2 and S3 for 20 ft Container are flexible and depend on the load according to (ISO668, 2020)**

Structural integrity is not relevant for the electrical and signalling interface in accordance with Chapter 6.4.3 and Chapter 6.4.4. In order to keep the cable routes as short as possible, a connection point in the roof area should be provided that is as central as possible. Furthermore, the TU must be able to be picked up by the HS from both sides. Due to the required symmetry, the electrical interface must therefore be mounted in the centre of the roof. In order to provide an interface that is as simple and economical as possible, the interface in the roof area and in the floor should be designed identically. This should fulfil the requirements of plug type 2 in accordance with (DIN EN IEC 62196-2:2024-03). The installation space for the charging socket in the vehicle is approximately 80 mm x 80 mm x 75-90 mm (WxHxD). The implementation in the vehicle can be seen in Figure 26 for a conventional electric vehicle. This includes the actual charging socket, the cable connections and the necessary electronics. Additional space must be planned for cable routing and secure fastening within the vehicle body, e.g. by placing a sheet metal part. Furthermore, this interface must have a dust and waterproof cover that is automatically pushed aside during the connection process.

**Figure 26: Electrical Interface/Coupling with a Type 2 charging connector; Installation space of approx. 80 mm x 80 mm x 75-90 mm (WxHxD) (Golem.de, 2024; Schwäbisch Hall AG, 2024)**

While the geometry of the electrical interface can be customized, the normative boundary conditions apply to the mechanical interface with the corner castings. The dimensions and position of these cannot therefore be changed. This has an influence on the rest of the packaging, such as the air conditioning system, which must be positioned according to the set boundary conditions.

**Specifications for the TU-HS interface for the transshipment with an (autonomous) forklift truck (TS02 and TS04)**

While the corner castings are standardised and fixed, especially for direct transshipment, there are fewer fixed requirements for the interface of a transshipment process with a forklift system. The TU should be able to be transported with an (autonomous) forklift truck or similar. A device, e.g. in the form of fork pockets, must be provided for this purpose. The necessary dimensions and recommended positions are shown below. The forklift pockets must be arranged according to the centre of gravity, so that the TU is as balanced as possible. The design requirements for each forklift pocket (either for the forklift truck or pallet trucks) depend on the actual device which is used. Only general geometry configurations can be given here. It is important to mention here that both the forklift and the HS must have scalable forks / mounts between 900 mm and 2050 mm (see Table 39). A uniform distance between the fork pockets across all TU sizes is not feasible, as the stability of the large 10 ft and 20 ft TU is not given due to the necessary small distance between the 5 ft TU.

As mentioned above, it is important that the fork pockets do not collide with the corner castings. Figure 27 shows the dimensions and possible arrangements. It is clear that with a 5 ft container (Figure 27, a)) there is no room for additional fork pockets for pallet trucks. Only classic fork pockets can be used here. As described in the requirements, these should be as far apart as possible to ensure maximum stability. The arrangement in relation to the door cut-out is also critical. It is important to ensure that there is sufficient structure between the corner castings and fork pockets to carry the loads that occur. The size of the 10 ft container allows the integration of fork pockets for a pallet truck (Figure 27, b)). The distance between the fork pockets for a forklift was chosen so that it is one third of the width of the TU. This ensures that the TU sits stably on the forks and that the load is well distributed. Similarly, we recommend widening the distance between the forks of a 20 ft container to the maximum possible (2050 mm) so that the distance is also one third of the container width. Furthermore, the distance of 1000 mm chosen for a 10 ft container means that a possible door could be placed in the centre and the lifting points would no longer be in the area of structural weakening due to a door.

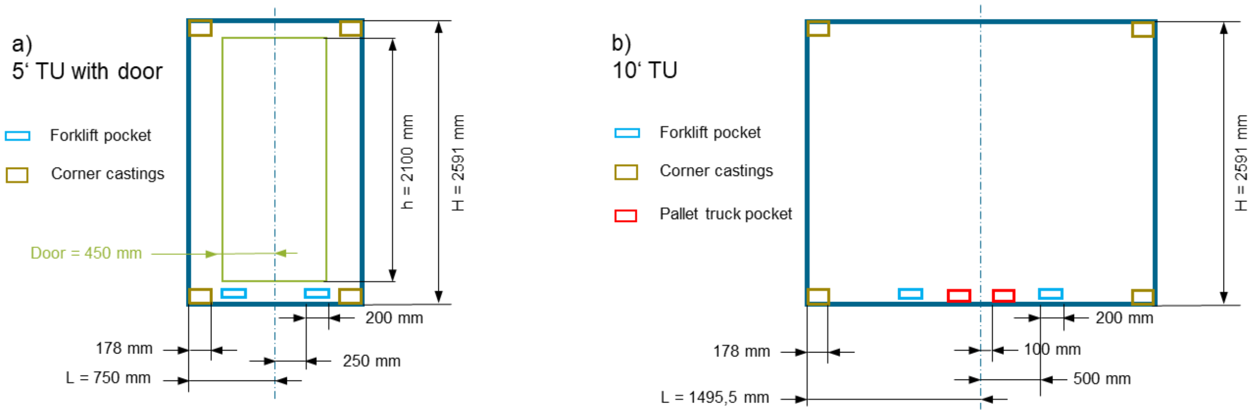



**Figure 27: Side view of the packaging of corner castings and forklift pockets for the a) 5 ft and the b) 10 ft container**

**Specifications for the TU-HS interface for placing a TU on the ground (TS01)**

For the pure lifting of a TU from the CU, an essential aspect is that the required interface does not collide with the existing corner castings. It is therefore imperative that these comply with the relevant requirements and dimensions. Reference is made here to standard (DIN EN 284:2007-01), which describes the design of such mechanisms for swap bodies and their dimensions. Another possibility is to realise an extendable lifting mechanism for a 5 ft container above the corner castings or for a 10 ft container between the corner castings and fork pockets. As described in the previous chapter, this mechanism must then have a lifting height of 1050 mm when used purely in road transport and with the CU developed in Pods4Rail. Otherwise, a lifting height of

1200 mm is required. It is important to ensure that the mechanism extends to the side and is wider than the CU itself. The mechanism can be electric, pneumatic or hydraulic. Electric control is preferable due to the ease of maintenance and the fact that no pipework is required.

## 6.4 Concept for the physical coupling and locking interfaces between the Transport Unit and the Carrier Unit

In the following, various coupling mechanisms are presented and evaluated for the TU to CU interface. The required interface solutions are divided into mechanical, electrical, signalling and media (water, gas, etc.) coupling mechanisms according to their intended use. However, the same approach and methods of the solution finding was followed for all mechanisms.

Firstly, possible interface solutions were assigned to their intended use and their relevant coupling type-specific data (e.g. fixed spatial directions for mechanical coupling devices) were researched.

Secondly, relevant evaluation criteria were then compiled, described and weighted by the project's group of experts. The weighting describes whether the criterion has a low importance (value = 1), a medium importance (value = 2) or a high importance (value = 3) for the selection process or implementation in the Pods4Rail system. The following evaluation criteria, including their weighting, are shown in Table 41 for all individual coupling methods.

Subsequently, all coupling mechanisms and interface solutions were evaluated with regard to the specific evaluation criteria and their fulfilment by the selected method in the expert group with at least three experts. The rating scale was standardised to an integer value between 1 and 5. A score of 1 means poor fulfilment or "no possibility of fulfilment" and a score of 5 means the best possible fulfilment of the specific criterion. This score is then multiplied by the value of the weighting. The concept with the highest score can be regarded as the most suitable solution. Due to the different number of evaluation criteria and the partially differing weighting, there are also different maximum values for the various interface solutions. For mechanical couplings and the coupling for media, the score varies between 14 and 70 points, for electrical solutions between 17 and 85 points and for signal couplings between 18 and 90 points.

The evaluation method applied in chapter 6.4 is similar to the method applied in chapter 6.2. Also, both chapters were being developed simultaneously.

**Table 41: Definition of evaluation criteria for different coupling methods; *Rating for signal couplings: 2; **Rating for signal couplings: 3**

| Evaluation criteria for different coupling methods | Explanation | Importance of criteria (Multiplication-Factor) 3 = Most important 2 = Medium 1 = Least important |
|---|---|---|
| Price/ Costs | Costs for implementation in Pod system | 1 |
| Grade of automation | Possibility for fully autonomous Pod system | 3* |
| Complexity of CU | Space consumption, weight, moving parts, additional parts, support structures | 2 |
| Complexity of TU | Space consumption, weight, moving parts, additional parts, support structures | 2 |
| Standardisation | Suitability for all TU´s and CU (one solution for the Pod system) | 3 |
| Safety | Fulfil safety requirements, emergency solutions | 2 |
| Maintainance | Simplicity, reachability, exchangeability etc. | 1** |
| Electric parameters (Only for Electrical Couplings) | Ability for sufficient power supply | 3 |
| Communication parameters (Only for Signal Couplings) | Ability for sufficient signal transfers, coverage, scalability | 3 |

The following sub chapters include a brief description of the various interface solutions of the different coupling methods that are suitable for the TU-CU interface. The evaluation matrix for these solutions is then presented. The two most promising methods are then described in more detail. Finally, the solution that is most suitable for the further development in the Pods4Rail concept is then defined.

### 6.4.1 Requirement specification for the mechanical, electrical and communication interface

In order to find suitable coupling methods, the most relevant functional requirements are summarised in Table 42. The input is taken from WP 2, WP 3 and WP 4 and added with specific design suggestions for the interface development.

**Table 42: Functional requirements for the TU to CU coupling system (Pods4Rail D4.4, 2024)**

| Requirement ID | Source | Requirement Input | Output for TU Design |
|---|---|---|---|
| HS6.2 | Expert Knowledge - Pods4Rail | ISO 3874:1999 (26 9345) Series 1 containers - Handling and fixing | Follow the standard in order to be universal in usage with common lifting devices |
| TU_S1; TU_S2 | Pods4Rail GA | Same contact points and interfaces | Standardised mounting points and coupling devices for all applications |
| TU_S3 to TU_S6; CS5.1; CS6.1; CS8.1 | Pods4Rail GA; Pods4Rail D2.1; DACcelerate S2RE Project Deliverable D3.2 | Mechanical force transmission, electricity transmission, communication transmission, medium transmission, if needed | Provide mechanical coupling for all UC´s. Provide electrical, signal, medium couplings depending on UC. |
| CS1.2; CS10.1 | Pods4Rail D4.1; DACcelerate S2RE Project Deliverable D3.2 | Coupling/uncoupling shall be fully automatic, semi-automatic or manual | Provide automatic and manual solution for all coupling systems. |
| CS1.3; CS1.5; CS1.6 | DACcelerate S2RE Project Deliverable D3.2; Pods4Rail GA | The coupling assembly shall be easy, quick, and safe, as simple as possible, strong enough to maintain the TU in its position, standardized | Provide simple, standardised and/or standardisable solution |
| CS1.9; CS4.2; RT6.4 | Pods4Rail D4.1; DACcelerate S2RE Project Deliverable D3.2; Pods4Rail GA | Compatible with all the contemplated different sizes of TU, with uniform and suitable interface | Scalable interfaces should be provided for all TU-sizes |
| CS1.11 | EuroSpec - Automatic Coupler | The coupling system shall be equipped with a heating system for defrosting | Provide possibility for (electrical) heating system, if needed |
| CS1.14 | DACcelerate S2RE Project Deliverable D3.2 | Both mechanical and electrical connection shall be detected by sensors/switches and physical visualization. | Provide sensors/system to monitor coupling status (digitally and to be monitored by an operator) |
| CS2.4; CS2.5 | EuroSpec - Automatic Coupler | Short maintenance times without special tools or dismounting main parts | Coupling mechanisms should be easily accessible and low complex |
| CS4.1 | UIC code 571-4 | The coupling should follow the UIC code 571-4: Standard Wagons - Wagons for Combined Transport - Characteristics. | TU should be easily connected and transported by regular wagons for combined transport |
| CS9.2 | EuroSpec - Automatic Coupler | The electrical connections shall have the adequate characteristics and protections determined by the corresponding standards (e.g. EN 60529, EN 50124). | Follow standards and provide weather resistance and corrosion protection measures |
| CS11.1 | Pods4Rail D2.2 | Produce a noise to inform when the coupling process has been successful | Coupling systems shall create natural or synthetic sounds |

The list of requirements from Deliverable D4.4 shows that the most relevant general design principles are the aim of standardisation (e.g. HS06, TU_S1, CS9.2), scalability (e.g. CS1.9, CS4.2, RT6.4) and the wish to keep complexity low (e.g. CS1.3, CS1.5, CS1.6) in order to be compatible to today's standards as well as to be flexible for all possible TU configurations. It will be a benefit to use high amount of relevant connections and transport possibilities, standardized and used nowadays.

Specifically, for the mechanical connection between the CU and TU (see chapter 6.4.2) an automatic system, without operator intervention shall be foreseen. In D4.4 a manual connection was considered for emergency situations and failures in the automatic system, therefore a fall-back solution can be implemented. The mechanical connection should be flexible, but stable and safe enough to prevent unwanted relative motions. Additionally, it must enable the connection of electrical power (see chapter 6.4.3) and of signals (see chapter 6.4.4).

Each TU should be equipped with its own small power source, e.g. a lithium battery. When placed on the CU, the TU would establish a connection to a central source, enabling the recharge of its battery. During operation, the electrical consumers inside the TU such as HVAC unit, lighting or the CCTV system would then be powered by the CU source. While handling or lifting, it would need to be powered from the TU's own battery for a short period of time.

Water (or media) transfer is not expected to be incorporated (see chapter 6.4.5). However, incorporation of service unit, i.e. with a toilet, could be considered.

Based on the specified UC of the Pods4Rail project, following recommendations for the mechanical, electrical and communication interface shall be taken into consideration:

1. When the TU is loaded on the CU, the energy transfer should come from the central source, i.e. the CU, to the individual TU. The main idea is that the electrical linkage will happen simultaneously or shortly after the mechanical connection with usage of the electrical connector located in the same place for all dimensions of TU. This will ensure connection for all possible TU configurations. Additionally, each of the individual TU shall be equipped with its own battery that would be charged when the TU connects to the CU. The CU has to be equipped by counterparts for electrical connectors, so charging will be not possible by usage of regular CU or trailers. The commonly used maintenance-free batteries can last approximately 10 to 12 years without the need for maintenance, thus eliminating the safety risk of power loss in the TU.
2. If the current European standards are respected, the forces transmitted within the mechanical connection should be the same or rather higher than those given in the strength requirements for the Pod.
3. Each TU should be equipped with an onboard control unit to ensure efficient communication and to enable remote operation. Because of that, there should also be a WTB gateway, through which the operator gives various instructions, e.g. to open the doors. It can be assumed that there will not be any operating staff in the TU. Therefore, the necessary level of inter-communication between the passengers and the driver or other staff shall be ensured. In addition to that, the TU shall be able to transmit information about its current health or load status towards the operation system and also to receive data from other system elements.
4. In the event of electrical blackout, the HVAC and the emergency lighting should continue to operate. This would be possible by equipping each unit with its own battery with a sufficient capacity, as discussed previously.

### 6.4.2 Comparison of mechanical coupling methods

This chapter focuses on analysing and evaluating different mechanical coupling methods (MCM) for the Pods4Rail project. We found out that mechanical couplings can be used either for a connection from TU-TU or for the connection from TU-CU. In this chapter we only discuss the mechanical couplings suitable for CU to TU connection. Mechanical couplings suitable for TU to TU connection will be discussed in chapter 6.5.

**Suitable options for the mechanical coupling**

Six of the analysed coupling mechanisms are suitable for the TU-CU interface and are therefore described shortly in the following.

**MCM01: Touch-down pin**

The simplest form of coupling the TU with the CU is a plug-in system. For this system, one side of the system, for example the CU, requires a pin at defined positions and the counterpart, in this case the TU, a precisely fitting recess. The TU can then be placed on the CU using the HS. This simple coupling method, known as the "touch-down pin", is widely used in the rail vehicle sector for classic freight wagons and the containers are standardised accordingly. The advantages of this system are its simplicity, flexibility and the fact that it is a widely used standardised system. Automation is not yet possible and would have to be developed (VTG AG, 2020).

**MCM02: Twistlock**

ISO twistlocks are a more advanced form of Touch-down pins. They are used to securely fasten ISO containers to means of transport such as ships, railway wagons and lorries. The functionality of twistlocks is based on a simple but effective locking mechanism. A typical twistlock consists of a rotating bolt and a locking mechanism. The bracket on the container into which the twistlock is inserted is designed to receive the bolt and activate the locking mechanism when the twistlock is correctly inserted. The actual locking process is carried out by turning the bolt. The rotation of the bolt causes the locking mechanism to lock into the bracket, which holds the container securely in place. Nowadays this mechanism is being done manually, for an autonomous system it could be automated (JOST, 2024).

**MCM03: Hook lockings**

Hook lockings are suitable for quick and easy assembly and disassembly. They are often used in the transport and logistics industry to secure loads on lorries, trailers or other means of transport. They offer a quick and secure fastening solution for various types of cargo. Even in areas with extreme requirements, such as construction machinery, hook latches are used to secure attachments such as buckets, grabs or hydraulic hammers to construction machinery. They offer great potential despite their simple design. By positioning pins or rods, the easily automated hook lockings can accommodate the TU with a relatively large tolerance compensation, in which the hooks enclose the rods or pins and bring them into the required position (K + G Tectronic GmbH, 2024).

**MCM05: Fifth wheel coupling**

A common coupling method between truck and trailer for articulated lorries is the fifth wheel coupling. The fifth wheel coupling is provided by the CU vehicle and consists of a plate with a built-in locking mechanism. The trailer has the counterpart, the so-called kingpin. So the trailer rests on the coupling. The main advantages of this system are the secure connection and continued manoeuvrability. In the context of Pods4Rail, its use only makes limited sense, as rail-bound vehicles or the TU intended for them do not require independent manoeuvrability. The system could therefore be reduced to the simple principle of the above-mentioned touch-down pin (SAF-HOLLAND SE , 2024).

**MCM07: Clamping mechanism**

A mechanical coupling between the TU and CU can also be achieved using a force-fit clamping mechanism. The TU positioned by other devices can be firmly connected to the CU using hydraulic clamping jaws, for example. The advantage here is that the device for the mechanical connection is not required on the TU, which means that the TU is less complex.

**MCM12: 4-point linear coupling**

The coupling mechanism is locking the TU by pushing an electric linear actuator (located in the CU) into the bottom structure of the TU. Each TU therefore has a geometrically fitting part. Due to the 4-point locking, the TU is locked in all directions. No additional transmission of electricity etc. included. The locking can do a positioning of the TU in a small range, if the dimensions are according to the load limits (DLR, 2024).

**Evaluation of all suitable concepts**

The evaluation table of the six suitable options is shown in Table 43. The first column shows the evaluation criteria, the second column shows priority criteria as a multiplication factor with the given points of the evaluation. The evaluation points have a range from 5 (very good fulfilment of criterion) to 1 (very poor fulfilment). The highest rated solutions can be seen as the most suitable coupling method.

**Table 43: Evaluation table of suitable mechanical couplings for the TU-CU connection**

| **Evaluation criteria for MCM** | **Importance** | **MCM01: Touch-down pin** | **MCM02: Twist lock** | **MCM03: Hook lockings** | **MCM05: fifth wheel coupling** | **MCM07: Clamping mechanism** | **MCM12: 4-point linear coupling** |
|---|---|---|---|---|---|---|---|
| Price/ Costs | 1 | 4 | 4 | 4 | 3 | 2 | 2 |
| Grade of automation | 3 | 1 | 4 | 5 | 5 | 5 | 5 |
| Complexity of carrier | 2 | 4 | 4 | 4 | 3 | 3 | 2 |
| Complexity of TU | 2 | 4 | 4 | 4 | 2 | 3 | 2 |
| Standardisation | 3 | 5 | 5 | 4 | 2 | 3 | 2 |
| Safety | 2 | 3 | 4 | 4 | 4 | 4 | 4 |
| Maintainance | 1 | 5 | 5 | 5 | 3 | 2 | 2 |
| **Total** | | **49** | **60** | **60** | **45** | **48** | **41** |

**Description of fitting solutions and choice of most suitable option**

Among previously described parameters, there are other significant factors connected with selected mechanical couplings.

**MCM02: Twistlock**

Twistlock is able to lock all directions through the locking mechanism. The required space for this type of mechanism is around 200x300x200 mm and it can be fully automated. This type of mechanism is located in horizontal level of the CU. There has to be a counterpart in the TU. It has a high level of flexibility, because it can be lowerable and foldable. There has to be a power supply in case of complete automated solution.

The standardisation of twistlocks according to ISO standards enables seamless interoperability between different means of transport and container types. This means that containers, or in this case TU, can be quickly and efficiently secured to the various CU vehicles regardless of their origin or destination, without the need for special adaptations, especially if ISO containers are used.

This process of connection is typically performed manually by an operator by turning the bolt with a suitable tool device. But there are already fully automated solutions which is suitable for the TU-CU connection. There is also an option of emergency manual decoupling by turning the pin and pulling it out, so that safety requirements can be fulfilled.

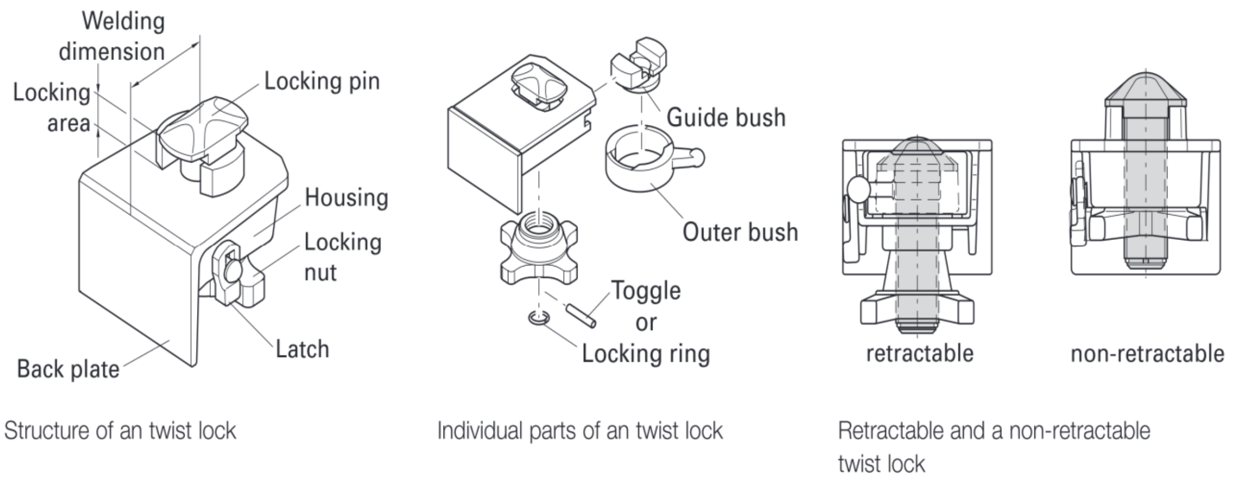



**Figure 28: Description of the working principle of an automated twistlock mechanism (JOST, 2024)**

**MCM03: Hook locking**

There is the possibility to lock all directions by this coupling method. The required space is around

110x100x65 mm for one hook locking. Hooks can be fitted in the floor or on the inside. They can be designed so that they disappear into the housing of the CU and only move out of their positions for locking.

This type of connection has a high flexibility, and through the hooks the TU can be pulled into the correct position. There has to be a standardized solution in order to have a solution applicable to various types of transport and handling devices. At least with regard to the diameter of the bars and the position of the hook. It is possible to consider high degree of automation for this method. There is low maintenance necessary for this coupling because of its simplicity. It is necessary to provide a power supply (pneumatic or electric) in order to ensure unlocking of this mechanism. The manual unlocking is possible during the emergency situation.

**Figure 29: Picture of an example hook locking mechanism (K + G Tectronic GmbH, 2024)**

After comparison of the Twistlock and Hook mechanism, the twistlocking mechanism was selected as the most suitable option for this project. Due to generally known and standardized applications of this connection type, a wide usage and intermodality can be expected from this solution. Also, it is possible to easily automate the system and safety measures are high. Since classical twistlocks are mainly used in railway and ship applications, the suitability for Road-CU and ropeways has to be assessed in the concept development, but the general principle is expected to be suitable for every domain.

### 6.4.3 Comparison of electrical coupling methods

Electrical connectors are vital components in vehicles. The type of connector depends on its function and the criteria for selecting the type are diverse: resistance to shock loads and vibrations, safety for technicians or operators handling them, ease of connection and disconnection, size, weight, power and cost.

The use of electrical power for many functions has led to an increasing demand for a variety of specific high-voltage connectors. While road vehicles powered by internal combustion engines (ICE), for example, do not typically carry voltages higher than 12 V DC, electric traction vehicles operate at between 275 and 800 V and larger systems, such as railways, carry even higher loads and there are an increasing number of shielded connectors capable of carrying up to 1,000 V.

Moreover, in addition to carrying higher voltages and currents, connectors for electric vehicles must carry high-speed digital and analogue signals in environments with high electromagnetic interference (EMI). They must also be designed to be safe and prevent arcing and accidental touching of live contacts, while being easy to use, which may be unsuitable for high temperatures and large connections.

In an all-electric architecture, most of the current handled by the connectors goes between the electric motor, the battery pack, the charging unit and the power electronic converter.

In addition to high-voltage connectors, ancillaries such as high-voltage connectors for control units, low-voltage connectors for sensors and actuators, and terminals for signal transmission must also be considered, bearing in mind that modern processor systems consume more power than their predecessors. This chapter is also linked to chapter 5.3.4 Energy balance, where general specifications regarding electrical consumers are made. Because of this, the option of wireless power transfer was not considered (only conductive energy transfer), because it was not suggested by the respective chapter. A wireless charging solution could still be interesting as a power supply system for the CU, similar to the way trams work without catenary.

**Suitable options for the electrical coupling**

The analysed electrical coupling mechanisms that are suitable for the TU-CU interface are described shortly in the following.

**ECM01 and ECM02: Automatic Coupler and Digital Automatic Coupler**

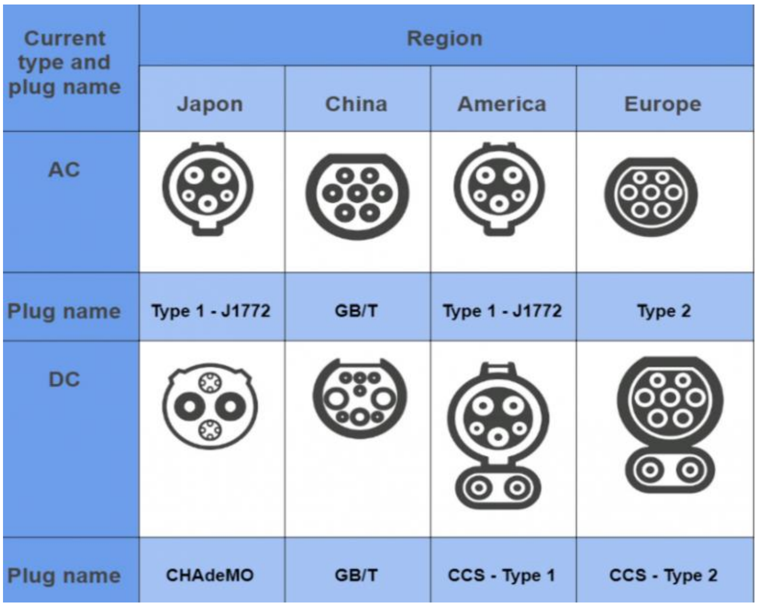
It includes mechanical, electrical, pneumatic and data automatic coupling, and remote uncoupling of freight Rolling Stocks. These systems are not considered here because it is part of the mechanical coupling systems between CU only and therefore not in scope of this deliverable. In general, the electrical components of these systems could still be from interest, but the options explained in the following, are more specialised and therefore more suitable (DACcelerate, 2022; EuroSpec, 2016).

**ECM03: Charging connectors**

Charging ports for electric vehicle connectors also need to be considered. There are a number of standardised classes for male and female plugs, which can be divided according to charging speed, whether AC or DC charging, and their "Type" (as defined in (DIN EN IEC 62196-2:2024-03) for conductive charging of electric vehicles).

The Type 1 connector is common on Japanese and American road vehicles, and incorporates five pins: one to supply main power, one as a neutral or secondary power pin, one for ground, a proximity pin (which acts similarly to a HVIL) and a control pilot pin (which communicates data between the charging point and the vehicle). A clip for the hitch is also a typical feature.

German car manufacturers developed the Type 2 connector to allow for three-phase AC charging and, as a result, the standard comes with two additional power terminals instead of one (for a total of three). Type 2 connectors also typically integrate a ground pin, a neutral pin, a proximity pin and a control pilot pin, for a total of seven. Some examples of charging connectors are shown in Figure 30.



| Current type and plug name | Region | | | |
|---|---|---|---|---|
| | Japon | China | America | Europe |
| AC | | | | |
| Plug name | Type 1 - J1772 | GB/T | Type 1 - J1772 | Type 2 |
| DC | | | | |
| Plug name | CHAdeMO | GB/T | CCS - Type 1 | CCS - Type 2 |

**Figure 30: Charging connectors examples (EV Expert, 2024)**

Vehicles with higher power requirements should be designed with fast charging connectors, which can be found on motorways or in dedicated parking areas. A car charged at such a point will typically recover 80-100% of its full power within an hour.

**ECM04: High-voltage connectors (HVIL connectors)**

In general, anything above 60V is considered 'high voltage', so precautions must be taken to make the electrical contacts 'touch proof' or 'finger proof'. For this reason, high voltage connectors have much higher walls around the contact points than low voltage designs to prevent accidental contact with a live part.

Terminals are typically embedded in insulated sockets to reduce the potential for short circuits between two or more terminals, with greater creepage (the minimum distance along the surface of a solid insulating material between two conductive parts) and clearance (the minimum distance in air between two conductive parts) separating the terminals compared to connectors in other categories. Environmental sealing must also be incorporated to protect against problems such as moisture or heat build-up.

Some examples of high-voltage connectors are shown in Figure 31.

**Figure 31: High-voltage connectors (E-Mobility Engineering, 2024)**

High voltage connectors can be divided into classes according to current carrying capacity and wire size. At the lower end of the scale, where relatively few kilowatts of power are required - for example, in an on-board charging system - there may be connectors designed for 20-30 A, with conductor cross-sections down to 3 or 4 mm, possibly with a voltage range up to 600 or 700 VDC. For something heavier, such as a DC-AC inverter, the current and cable diameter may need to be increased. Connectors for such applications typically work with cables up to 6 mm thick and currents from 32 to 40 A, with voltages from 750 to 850 VDC.

In the case of connectors for electric and hybrid powertrains, vehicles may require current ratings of 200 A. In this case, the cable cross-section of the connectors is required for the powertrain. In this case, cable cross sections can vary widely, from 25 to 50 mm (as vehicle manufacturers choose to replace copper power cables with thicker aluminium ones to save weight), and DC voltages can be as high as 850 V or 650 V.

For larger vehicles, connectors must be able to withstand 300 A and integrate cables up to 75 mm in diameter.

**ECM05: Fastened connectors**

Fastened connectors (see Figure 32) are ideal for applications with low mating cycles and a need for greater vibration tolerance. Some connector types for high-voltage powertrains have taken the 'screw' concept and re-applied it by constructing a hyperbolic socket, which distributes forces such as friction over far more of the mating pin surface than typical designs. This makes mating/unmating much easier and improves vibration resistance while also reducing damage from fretting corrosion.

**Figure 32: Fastened (E-Mobility Engineering, 2024)**

**ECM06: Data connectors**

These connectors are used to transmit the information streams that electric vehicles need from safety features such as cameras and sensors around the vehicle, as well as energy monitoring and analysis systems, thus requiring an increase in the number of high-speed data connections in vehicles. To handle all these data protocols, vehicle manufacturers can choose between an Ethernet connector or an RF coaxial connector.

On the other hand, if an EV uses sufficiently powerful processors, it may be able to perform sufficient analysis without needing the level of data provided by coaxial cables, in which case Ethernet should meet the connection requirements.

In addition to the increasing use of Ethernet and coaxial connectors, FAKRA (Facharbeitskreis Automobil) radio frequency connectors remain a popular standard for communications up to 6 GHz. Although they do not cover frequencies up to 9 GHz like coaxial RF connectors, FAKRA connectors are widely used in GPS antennas, engine management systems, navigation systems and other critical subsystems.

Some examples of data connectors are shown in Figure 33.

**Figure 33: Data connectors (E-Mobility Engineering, 2024)**

**ECM07: 7/13 electric pole connectors**

The connection between the car and the trailer or caravan is created by putting the plug of the object you wish to tow in the socket on your car. The two plugs that are most common are the 7-pin and 13-pin plugs. In general, bike CU, older trailers, boat trailers or horseboxes are equipped with a 7-pin plug. In more modern models of these tow objects, the 13-pin plug is more and more common. A caravan always has a 13-pin plug. In Europe, both 7-pin (ISO 1185:2003; ISO 1724:2003) and 13-pin (ISO 11446-2:2012) are common. The 13-pin version provides more services than the 7-pin, a more positive locking and also better protection against moisture and contamination. The connectors are designed for 12V systems.

**ECM08: Rail Power Connectors**

This solution covers power connectors for all critical power applications on rolling stock, for example used for Traction Motor Systems, Inter-vehicle Applications, Converters/Electrical box Outlets, Permanent Magnet Motor Applications, Underframe/Roof Applications, Train Line Power Applications and Auxiliary Power Supply. Multiple possible configurations are possible with just 10 connector variants, allowing flexible design solutions. This system can be used for static and dynamic applications which creates multiple design possibilities. No further connections are required with this solution and only one component per connection is needed, with several poles (Glenair, 2024).

**ECM09: Electric multicoupler**

This connection system consists of a fully configurable multi-coupling plate with various plugs and connection options. All connectors are mounted on one base plate. All opposite connectors are mounted on an opposite plate. The system has one active component inside the CU, driven by an electric actuator, the other component is fixed to the TU.
An example of multicoupler can be seen in Figure 34.

**Figure 34: Automatic Multicoupler by Stäubli (Stäubli International AG, 2024)**

**Evaluation of all suitable concepts**

The same method as in chapter 6.4.2 is followed for the choosing of the most suitable coupling method. Table 44 gives an overview of the presented electrical coupling methods and evaluates the advantages and disadvantages of each selected criteria.

**Table 44: Comparison of the different electrical coupling methods**

| Evaluation criteria for ECM | Importance | ECM01: Digital Automatic Coupler (DAC) | ECM02: Automatic Couplers | ECM03: Charging connectors | ECM04: High voltage connectors (HVIL) | ECM05: Fastened connectors | ECM06: Data connectors | ECM07: 7/13 electric pole connectors | ECM08: Rail Power Connectors | ECM09: Electric Multi Coupler |
|---|---|---|---|---|---|---|---|---|---|---|
| Price/ Costs | 1 | 3 | 3 | 4 | 5 | 5 | 5 | 3 | 5 | 4 |
| Grade of automation | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Complexity of carrier | 2 | 1 | 1 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Complexity of TU | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Standardisation | 3 | 3 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 |
| Safety | 2 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Maintainance | 1 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Electric parameters | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 |
| TOTAL | | 63 | 69 | 80 | 78 | 78 | 78 | 73 | 75 | 74 |

As conclusion, with regard to electrical connection systems, it should be noted that there is no optimal solution to cover all possible connections that may arise. In this sense, there are several systems to consider. On the one hand, HVIL connectors will be the technology to be used for the most demanding electrical connections, such as the power system. Secondly, since this is a battery-electric vehicle, the choice of a charging connector is also necessary. Finally, connectors such as data connectors, or electrical multi couplers will be needed for digital connections, if a conductive signal transmission is preferred. Other connectors such as 7/13 pole connectors may also be required for possible couplings between TU or with additional accessories, such as tows. For the following concept development, the combination of charging connectors and HVIL connectors is chosen to provide a high coverage of applications, also according to the energy balance parameters set in chapter 5.3.4. Both of them also showed the best rating results.

### 6.4.4 Comparison of communication coupling methods

Several technological solutions can be considered for communication assuring reliability and precision during signalling and connection among involved elements. In particular, new standards and techniques for vehicle to infrastructure (V2I) and vehicle to Everything (V2X) can be taken into consideration. The IEEE 802.11p has been developed for wireless access in vehicular environment, where short response in highly dynamic contexts is tacked. For determining distance measurements during dynamic coupling manoeuvres precisely, another key technology to be explored is Ultra-Wideband, which may also allow supporting location and tracking strategies in the context of signalling and coupling methods.

Moreover, there are near field-based identification systems that could complement the communication signalling when elements are close to provide additional information during coupling. In this sense, the solution can be composed of a combination of heterogeneous technologies instead of a single interface, in order to provide robust communication along with additional coupling information.

As highlighted before, some of them can be a complement of others, such as in case of location and identification strategies during signalling. A short description of the most representative technologies is presented as follows.

**SCM03: Wireless Communication**

A Wireless access for vehicular environment with IEEE 802.11p is suitable for highly dynamic vehicle to everything environments, without the need of specific infrastructure, and with self-configurable devices. It is based on the Physical and MAC layers of the IEEE 802.11a adapted to vehicular communications, including enhanced capabilities for reliable authentication and connections in dynamic and timely critical contexts (IEEE SA, 2024).

**SCM04: Distance measuring and positioning**

Ultrawideband for precise distance measurement in signalling and coupling, could provide benefits in exchanging additional data associated to coupling distance during communication, by using very precise ranging technology. It is based on the IEEE 802.15.4z which defines secured and enhanced physical and MAC layers for Ultra-Wideband wireless communication (IEEE SA, 2024).

**SCM06: Next generation signalling**

Sidelink for direct device-to-device and V2X signalling, over 5G and beyond (5G Sidelink), is based on 5G technology to establish direct communication but without cellular infrastructure. This approach provides high versatility, flexibility for dynamic communications with a robust and secure device to device data exchange. It allows different spectrum configurations, from license to non-license bands, bringing adaptability to a high range of devices. This will ultimately provide benefits in terms of interoperability and scalability (Qualcomm Technologies, Inc., 2024).

**SCM08: Next generation positioning**

System positioning and location for coupling manoeuvres based on 5G NR and GNSS, can expand the capabilities of the communication signalling system by providing precise location during coupling, as additional information to enhance the connection, communication and coupling in Pods4Rails, particularly for autonomous self-managed elements (Decarli, Guerra, Giovannetti, Guidi, & Masini, 2024).

**Evaluation of all suitable concepts**

A summary of the evaluation criteria and results for the most representative signalling/communication coupling technologies assessed are shown in Table 45. The whole evaluation table is shown in appendix Table A3.

**Table 45: Summary of the signalling/communication coupling evaluation**

| Evaluation criteria for SCM | Importance | SCM03: Wireless Communication | SCM04: Distance measuring and positioning | SCM05: Near identification | SCM06: Next generation signalling | SCM08: Next generation positioning |
|---|---|---|---|---|---|---|
| Price/ Costs | 1 | 4 | 4 | 5 | 3 | 3 |
| Grade of automation | 2 | 4 | 4 | 3 | 5 | 5 |
| Complexity of carrier | 2 | 3 | 4 | 3 | 3 | 3 |
| Complexity of TU | 2 | 3 | 4 | 3 | 3 | 3 |
| Standardisation | 3 | 5 | 5 | 5 | 5 | 5 |
| Safety | 2 | 4 | 3 | 3 | 5 | 4 |
| Maintainance | 3 | 5 | 5 | 3 | 4 | 4 |
| Communication parameters | 3 | 4 | 3 | 3 | 4 | 4 |
| **Total** | | **74** | **73** | **62** | 74 | 72 |

It can be seen that the next generation signalling based on 5G Sidelink and the Wireless Communication based on IEEE 8011p obtained the best results as candidates for communications, and indeed they are the main solutions for the V2X future realization, although they can be combined with positioning and distance measuring systems. The former one has the advantage of high testing and practical evaluations, so it can be a strong candidate for real implementation in the near future. For the Pods4Rail concept, a wireless signal transfer is followed according to the evaluation results without conductive connector technologies.

Figure 35 shows as an example how these technologies can allow creating synergies to exploit their benefits in V2X and smart mobility contexts.

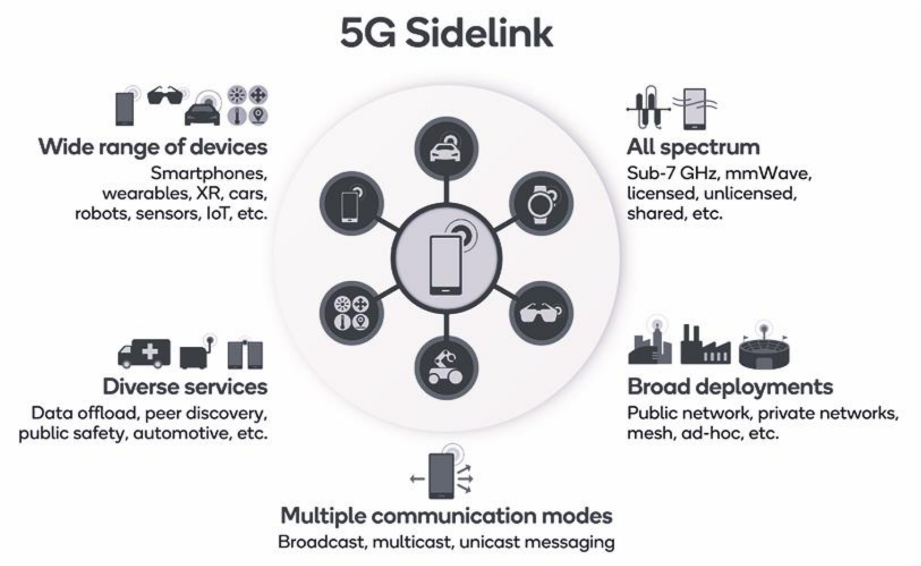



**Figure 35: Features of 5G Sidelink technology (Qualcomm Technologies, Inc., 2024)**

### 6.4.5 Comparison of coupling methods for media

The comparison of possible coupling methods for media such as water or gas followed the same process as the previous selection of coupling methods. It proved expedient to implement the interface via a safety valve (see Table 46 and Figure 36). In addition to the low space requirement and the associated high flexibility, this offers the advantage of high standardization and low maintenance, among other things due to the fact that no energy supply is required. The comparison can be found in detail in Appendix Table A4.

**Table 46: Evaluation of the three possible coupling methods for media**

| Evaluation criteria for COM | Importance | COM01: Multi-line compact quick coupler DIN 3852 | COM02: Safety valve | COM03: Multi Coupler by Stäubli |
|---|---|---|---|---|
| Price/ Costs | 1 | 4 | 5 | 4 |
| Grade of automation | 3 | 2 | 5 | 5 |
| Complexity of carrier | 2 | 4 | 5 | 4 |
| Complexity of TU | 2 | 4 | 5 | 4 |
| Standardisation | 3 | 3 | 5 | 4 |
| Safety | 2 | 4 | 4 | 5 |
| Maintainance | 1 | 3 | 5 | 4 |
| **Total** | | **46** | **68** | **61** |

**Figure 36: Safety valve (Parker Hannifin Europe Sàrl, 2024)**

Based on the defined UC and the framework conditions defined in the previous WPs, an exchange of liquid (e.g. water, fuel, oil, etc.) or gaseous media (compressed air, hydrogen, etc.) between TU and CU is not expedient. While freight containers either have no need or function autonomously (e.g. refrigerated containers), an exchange would be conceivable for TU with the purpose of transporting passengers. Due to the requirement that the TU should also be operational outside of a CU, a complete decoupling of the media makes sense. This means that essential functions such as the functionality of the doors (e.g. using compressed air or electric motors), cooling circuits or, in the case of wet rooms, the fresh water supply and waste water collection must be provided by the TU. Even if the latter would make sense for space reasons, there are disadvantages with regard to the overall concept if it is channelled into a central storage tank of the CU via a coupling. The CU would have to be reserved regularly for filling cycles and long pipework may be required. A self-sufficient sanitary unit is therefore also preferable.

It can be seen that the transfer of media such as gas, water or oils in a system analysed in Pods4Rail is not expedient and the TU should function independently of the CU with regard to these couplings. But should it be useful in future projects or extensions to provide an interface between CU and TU for the exchange of media, then the above-mentioned solution of the safety valve is the best solution.

### 6.4.6 Description of chosen coupling mechanisms for Pods4Rail

This chapter includes the description of the coupling mechanisms between TU and CU that were chosen in the previous chapters 6.4.2 to 6.4.5. Based on the chosen technology specifications a concept is being developed, that shows the position and rough package of each component as well as its working principle in a simplified 3D model. This deliverable is only providing a general proof of suitability, but it cannot provide a detailed technical concept of each technology. Therefore, the results of this deliverable are handed over to following WPs. As defined in chapter 6.4.5, no coupling of media is provided and therefore not part of this chapter.

**Mechanical coupling and locking of the TU on the CU**

The TU configuration on the CU follows a specific pattern, that follows the measurements and positioning of the Twistlock mechanism according to the ISO668 standard (as defined in chapter 5.2 and 6.3.2). The actual and final locking allocation depends on the final TU sizes (defined in WP

8 and WP 9) as well as the needed distance between each TU on the CU, so changes might still appear in future works. Another uncertainty is the actual dimension of the automated locking mechanisms, which will be finally developed in WP 12 together with the integration in the CU in WP 14. Nevertheless, an estimate of the distances between the TU was made in Chapter 6.5.2.

All mounting points have slotted holes so that they can be moved within a small range to adapt to movements along the x-axis of the vehicle. By the use of movable connectors along the x-axis of the CU it can be guaranteed, that every TU can use the same connectors in the CU. This kind of scalability allows every combination of TU (5 ft, 10 ft or 20 ft) on the CU and also adapting on the move, if different types of TU shall be loaded. Figure 37 shows the interface pattern, if only 5 ft TU are placed on the CU with a total capacity of 25 ft (as suggested in chapter 5.2). For this kind of configuration all interfaces are active because every single TU has to be locked and electrically connected.

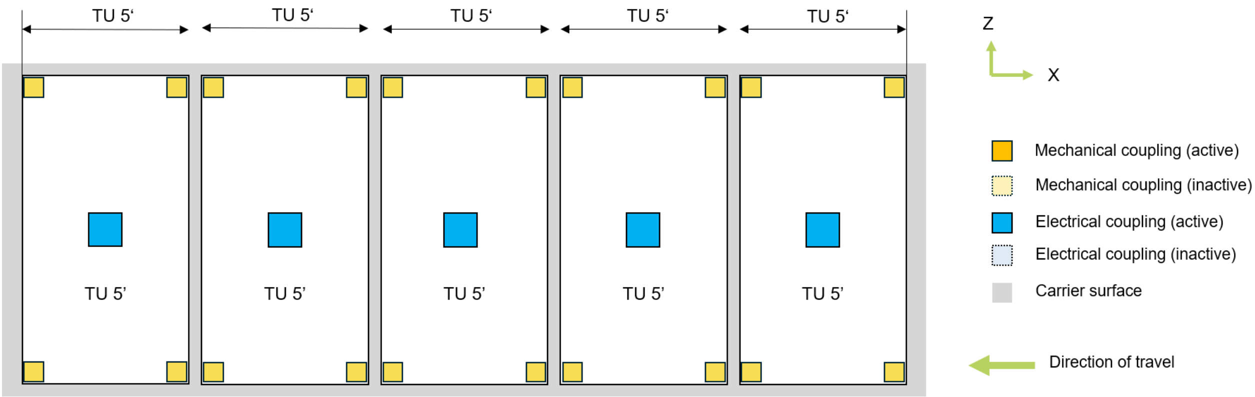



**Figure 37: Qualitative mounting points configuration on the CU based on 5 ft TU**

Figure 38 shows the configuration if 10 ft units are loaded on the CU. In this case, the 10 ft units can use the same corner fittings like the 5 ft units, but only half of them are needed. The others can be deactivated. A 5 ft unit (e.g. a Entrance/Exit Unit) is located between the 10 ft unit.

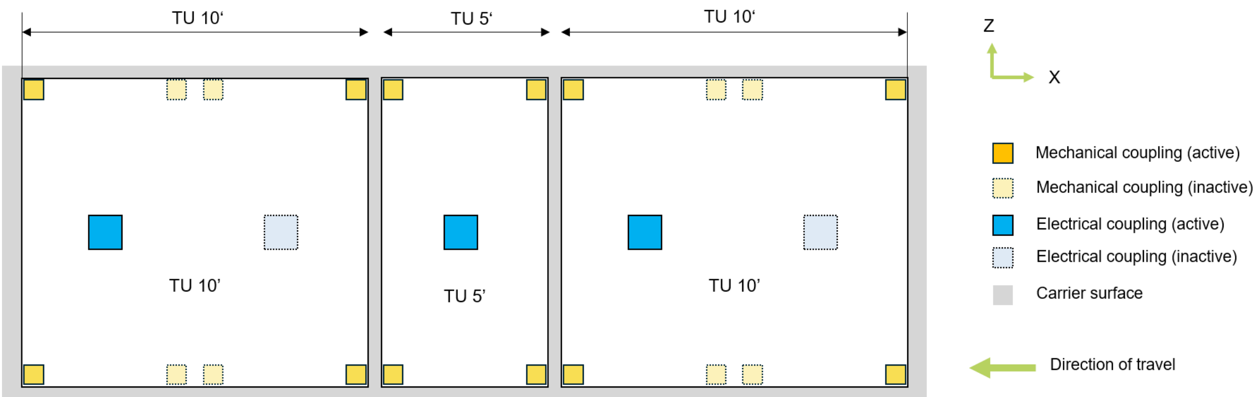



**Figure 38: Qualitative mounting points configuration when 10 ft TU are used**

Figure 39 shows the configuration if a 20 ft unit is loaded on the CU. It follows the same pattern and, in this case, one more 5 ft unit can be located next to the 20 ft unit.

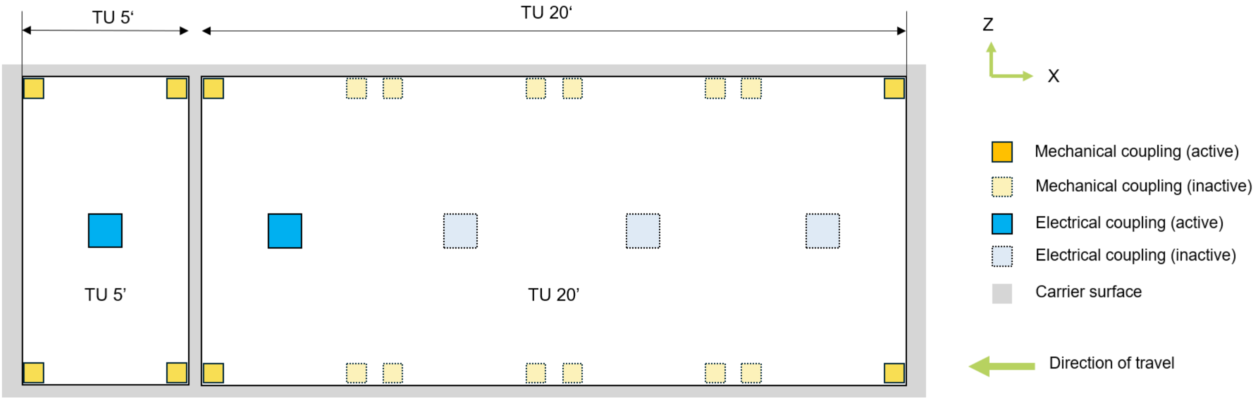



**Figure 39: Qualitative mounting points configuration when 20 ft TU are used**

Figure 40 shows the mechanical and electrical couplings in an active state (above) and in an inactive state (below) by pushing them up or down. All inactive connectors and couplings can be hidden inside the CU. This kind of mechanism is only needed, if the couplings should be protected against weather or damage while they are not being used. It is not compulsory to use this mechanism, if the TU bottom geometry is designed in a way, that only the necessary couplings are being connected.

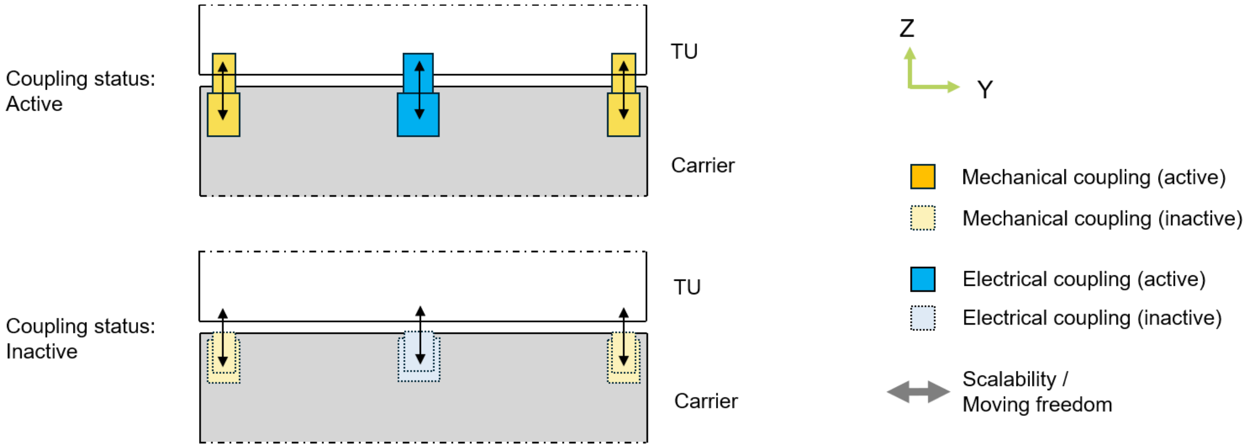



**Figure 40: Mounting points and electrical couplings can be activated and deactivated**

While the positioning of the corner castings for the 10 ft and 20 ft containers is standardised. The corner castings of the 10 ft and 20 ft containers must be placed on the very outside in accordance with the specifications of ISO 668. But the position of the corner castings for the newly introduced 5 ft TU must be a little bit indented. This is essential, as this is the only way to create a pattern of twistlocks in the CU that allows all loading configurations without the need for additional or movable twistlocks. The requirement for a loading area that can transport five 5 ft TU results in a total of 10 different configurations, as shown in Figure 41.

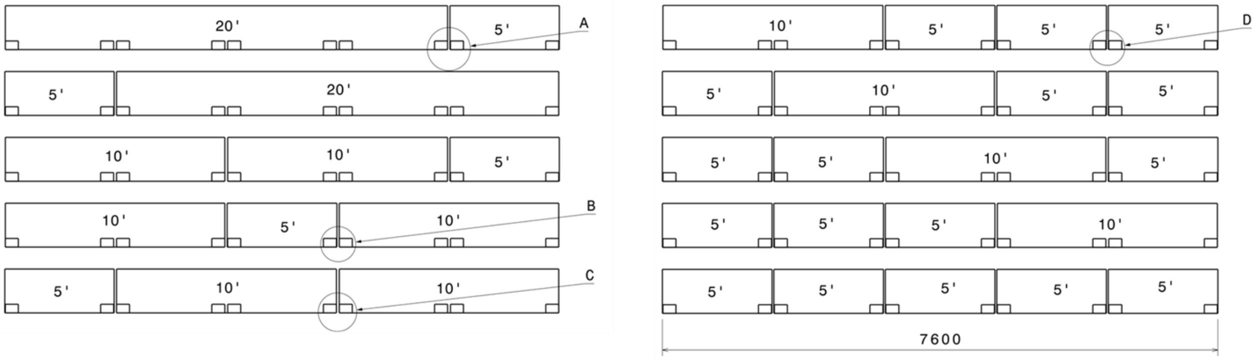



**Figure 41: Possible loading configuration for a 25 ft loading area on a Rail-CU**

These configurations and the boundary condition that the corner castings of the 10 ft and 20 ft TU must be positioned on the very outside result in the distances between the TU shown in Figure 42 and the distance between the corner casting and the outer skin of the 5 ft TU. Figure 42 shows the in Figure 41 mentioned Details. Under the given boundary conditions the distance between a 5 ft and 10 ft respectively 5 ft and 20 ft should be 32.5 mm (Figure 42, Detail A and Detail B), the distance between two 10 ft TU should be 40 mm (Detail C) and the distance between two 5 ft TU is 25 mm (Detail D). These distances ensure a standardised hole pattern on a 25 ft CU so that as few twistlocks as possible need to be installed and they do not need to be moved. In order to standardise the hole pattern in this way, the corner castings of the 5 ft TU (1500 mm length) must be indented by 7.5 mm. It should be noted that a 5 ft TU placed on the outside extends the required loading area by 7.5 mm compared to the 10 ft or 20 ft TU. so the maximum loading length of a 25 ft CU is assumed to be 7600 mm. However, the exact pattern and positioning must then be worked out in more detail in WP 13 and WP 14.

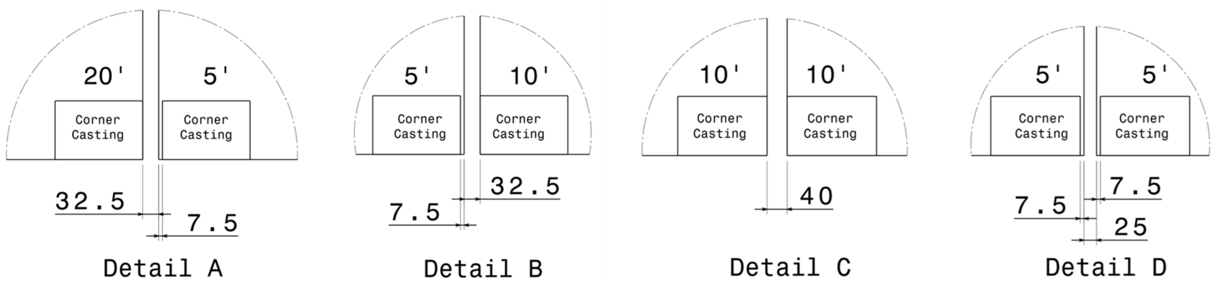



**Figure 42: Detail view of the different distances between the TU**

If a twistlock is required, it is extended and is in the "unlocked" state (Figure 43: fully automatic twistlock, a) unlocked and b) locked state, a)). When the TU is placed, a sensor, for example triggered by a mechanical pin, recognises that the TU is on the CU. The teeth of the twistlock are then folded out in an orthogonal direction and the TU is locked (Figure 43, b)). The twistlock is now in the "locked" state. The dimensions of the fully automatic twistlock are shown in the illustration below. The twistlock consists of two parts. The lower unit contains all the mechanics and electrics for controlling the twistlock mechanism. This is also where the screw connections or weld seams to the rest of the structure are to be attached. The upper part contains the actual locking mechanism of the twistlock. This means that the TU or the container sits on the plateau of the lower box. It should be noted that if the locking mechanism is retracted by 100 mm, the box must be larger so that there is space for the upper part in the lower box.

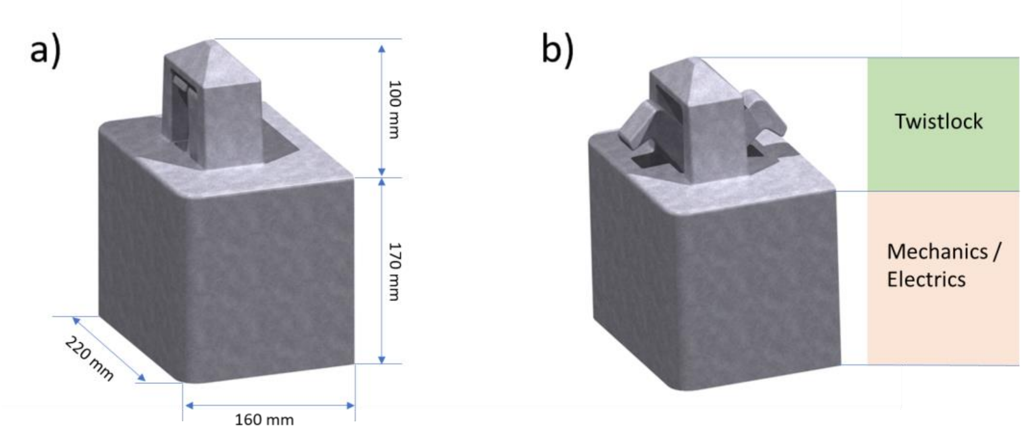



**Figure 43: fully automatic twistlock, a) unlocked and b) locked state**

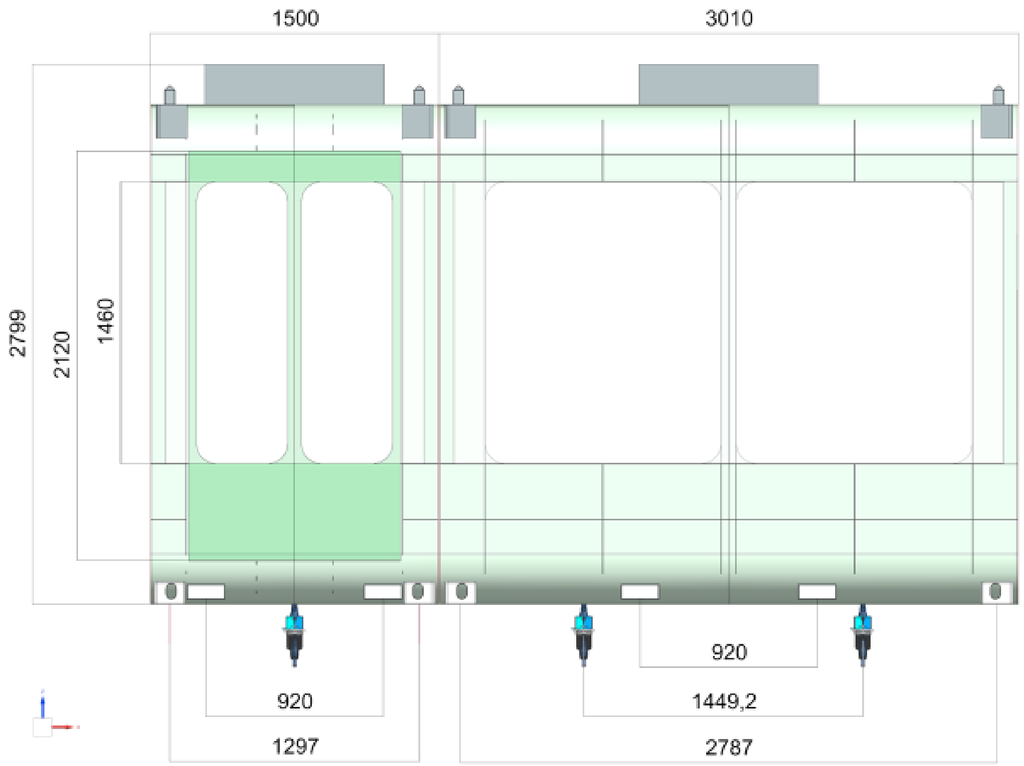



**Figure 44: Dimensions of main TU parameters and interfaces**

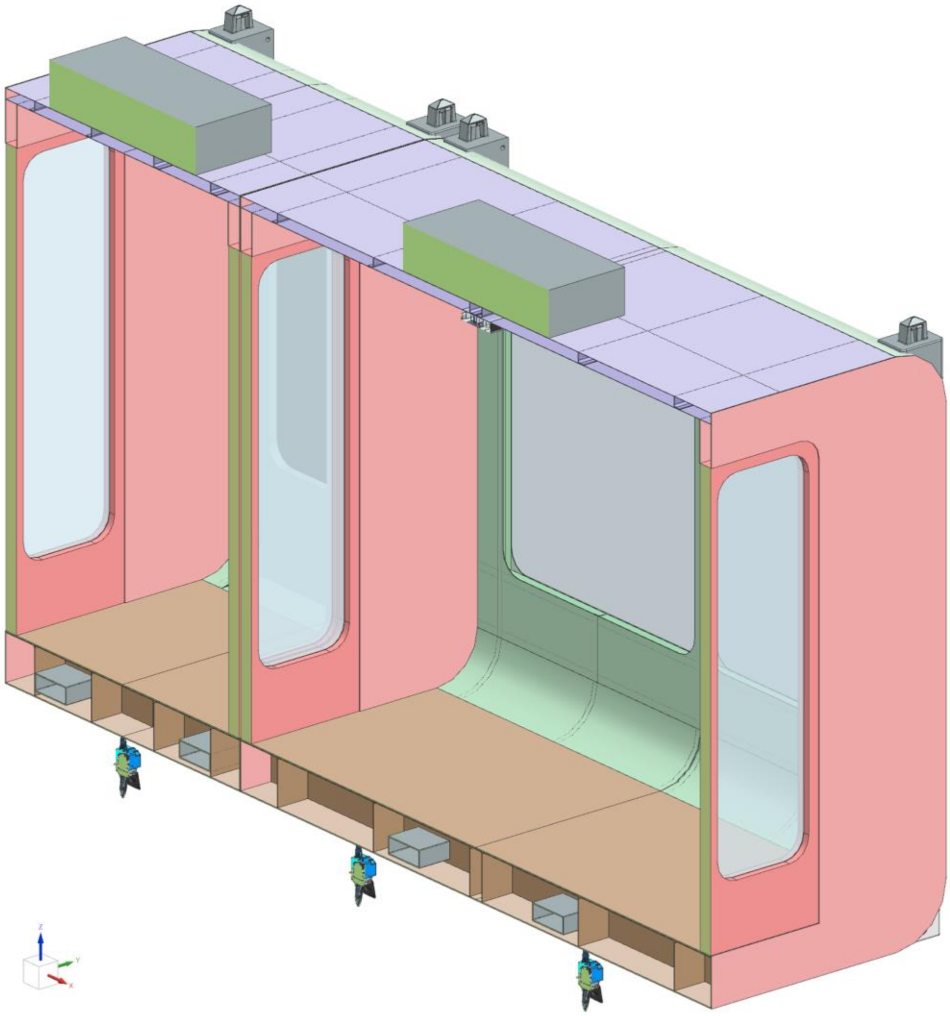


**Figure 45: Three-dimensional view of interfaces inside the TU**

**Electrical connection between TU and CU**

According to chapter 6.4.3, the electrical coupling shall be a combination of Type2 charging connectors and High Voltage connectors. The position of the electrical coupling always has to be in the middle of a 5 ft unit (as shown in Figure 37), so that every TU can be placed in both driving directions. The connector pins and socket have to be symmetrical to its centre to achieve the required symmetry. The connectors shown in chapter 6.4.3 have to be adapted for a symmetrical layout. Also, a manual coupling will not be necessary anymore due to its automation. For bigger TU such as 10 ft and 20 ft, the TU can use either more than 1 of the available connectors or choose between one of them. Unused connectors can be deactivated.

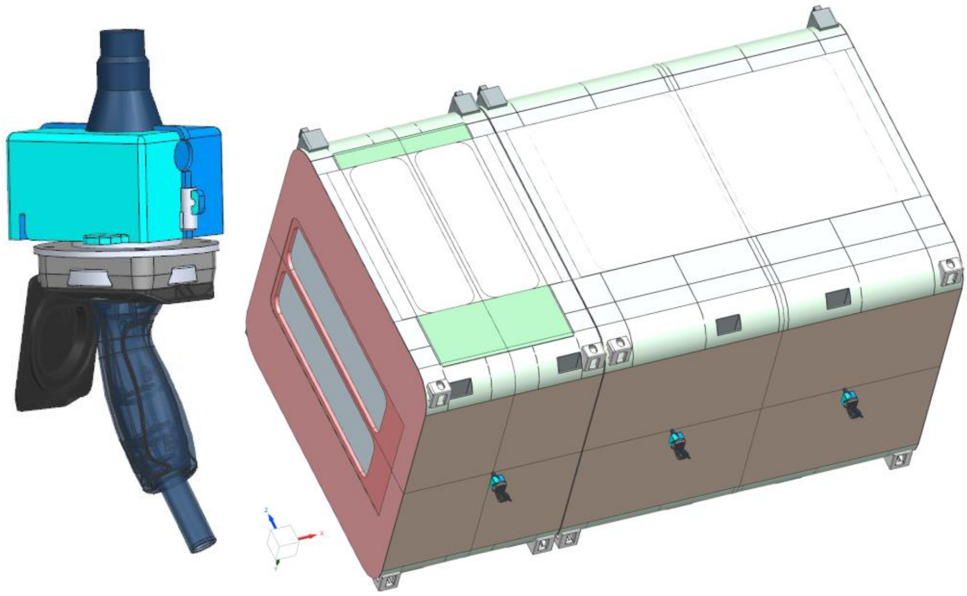


**Figure 46: Electrical connector (left) and positioning in the TU-bottom (right)**

**Communication and signalling between the TU and the CU**

As defined in chapter 6.4.4, the signal and communication coupling will be done wireless and therefore no physical coupling is provided in the TU model. It is assumed, that only relatively small components are being used and their position is also flexible. These components include for example WIFI routers (see Figure 47), antennas, processors and cables. These components don´t need a lot of space and can be arranged at any position inside the TU. Only some limitations appear: e.g. for the best signal transmission it must be ensured, that the components are not covered or surrounded by steel structures from the TU body. If these components are placed somewhere below the exterior panels at the TU roof or sides, good transmitting results can be expected.

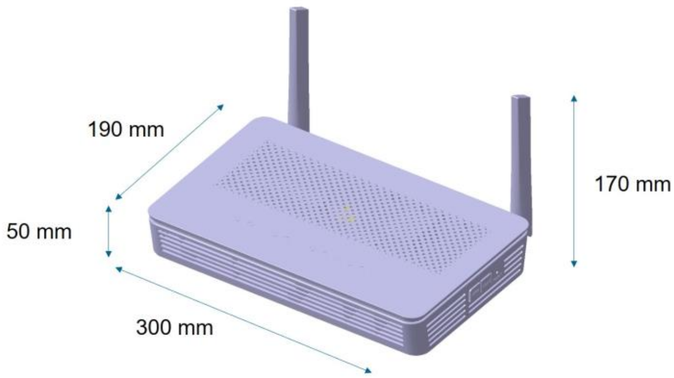



**Figure 47: Exemplary model of a WIFI router for wireless communication of the TU (actual components can vary)**

## 6.5 Concept for interfaces between two Transport Units

This chapter discusses the concept for the interfaces between two TU. The focus here is on the interface that is needed when at least one TU is involved, that provides the transport of passengers. An interface is not necessary for TU with the purpose of transporting freight or an interface between two conventional ISO containers. With regard to the reduction of noise and aerodynamic resistance due to a possible gap between two cargo TU, a cover would be possible if the gap is too large. However, this cover must be an additional component or part of the CU, as existing ISO containers do not provide these cover parts, which is why it is not discussed further in WP 7 which focusses on the TU development.

In the following, the requirements from the previous WPs relating to the interface TU-TU are first summarised and expanded and then further specified for actual use.

### 6.5.1 Requirements regarding the connections between different Transport Units

In the Pods4Rail work to date, the main focus has been on the requirements for the CU, the CU-TU interface, the TU-HS interface and the TU itself. The requirements for the TU-TU interface were not explicitly elaborated in the previous WPs. The following therefore lists the safety aspects relating to the interface TU-TU from WP 3 and the functional requirements from D4.4. In addition, based on expert knowledge (EK) within WP 7, the other requirements to be considered that have not yet been explicitly listed are discussed. The respective output for the TU design is derived at the same time. A distinction must be made between two cases of the interface, as these have both different requirements and the resulting different specifications.

- Case 1: The interface is between two TU, each with a UC that provides passenger transport.
- Case 2: The interface is between a TU with a UC that provides passenger transport and
  - a TU that does not provide for the transport of passengers
  - the CU
  - neither CU nor TU, e.g. is travelling in a group where a neighbouring TU has been unloaded, or is currently in the transshipment process

For both cases, the conditions for the requirements are defined separately in the following Table 47 if necessary. Each requirement set is being described with the following details:

- Requirement: Short name of the requirement
- Requirement description: Content of each requirement, depending on Case 1 and 2
- Output for TU design: Specific influence or design suggestion for the TU, summarised for both cases, as the TU remains the same
- Source: Source of the data, new defined requirements, based on the expert knowledge (EK) in this task are marked with New – EK

**Table 47: Requirements for the TU-TU connection**

| Requirement | Requirement description | Output for TU design | Source |
|---|---|---|---|
| TT1: Emergency exit | **Case 1**: Escape route must still be available, can also go through other TU, but must then be marked accordingly<br>**Case 2**: A safe escape route must still be available despite any locked doors. This also applies if doors cannot be used due to neighbouring TU (e.g. Cargo TU) | Lateral exit from the TU must be guaranteed in an emergency.<br>In case of use for lateral exit, the door may allow identifying whether the exit goes to outside or in another TU | D3.2 |
| TT2: Fire protection closures | **Case 1 and 2**: Room-sealing effect and thermal insulation.<br>Fire resistance duration 15 or 30 minutes. | Interface must have a room-enclosing effect, doors must be fire doors | D3.2 |
| TT3: Partition walls | **Case 1 and 2**: Partition walls that can withstand a fire for at least 15 minutes are required between the potential source of fire and the cargo being transported. | Covered by TT2 | D3.2 |
| TT4: Exterior Lighting | **Case 1:** Lighting shall comply with rail/road and must be visible if necessary. Neighbouring TU can take over the task.<br>**Case 2:** Lighting shall comply with rail/road and must be visible if necessary. Even when the other TU (e.g. Cargo-TU) does not provide lights | Necessary lights of the TU must be visible independently of the neighbouring TU. Either through the neighbouring TU or by overhanging the adjacent cargo container, for example. | D4.4 TU_K1 / TU_K2 |
| TT5: PRM Accessibility | **Case 1:** The transition must be designed to be barrier-free as soon as a TU is connected to UC PRM<br>**Case 2:** No further requirements | Provide or at least enable barrier-free transition | D4.4 TU_N5 / TU_N6 |
| TT6: Door opening | **Case 1:** Users shall be able to: open doors from outside and inside (normally + manual fallback)<br>**Case 2:** Doors must be securely locked. Emergency opening still possible, but a safe condition of the TU must be achieved (especially during air transport) | Provide manual opening, but must be designed in such a way that unintentional opening during the journey/transshipment process is not possible. TU must achieve a safe state for (manual) emergency opening | D4.4 TU_N7 / TU_N8 |
| TT7: Tightness | **Case 1:** Tightness (dust, rain, ...) between TU and the TU itself must be guaranteed. Ideally also aerodynamic sealing.<br>**Case 2:** Tightness (dust, rain, ...) of the TU must be guaranteed. | Seal must be considered in the external dimensions of the TU, mountings for locking mechanism must continue to be identical to ISO containers, which do not provide space for e.g. sealing lips | New - EK |
| TT8: Transition platform | **Case 1:** Transition must be safely guaranteed<br>**Case 2:** No further requirements | Gap must be (mechanically) covered (sealing lips are sufficient to a certain extent), slip resistance and fire protection are basic requirements | New - EK |
| TT9: Width of the TU | **Case 1:** If TU varies in width, it requires a connection unit<br>**Case 2:** Independent unit, no further requirements for TU-TU interface | Standardised position of the TU transition with passenger transport | New - EK |
| TT10: Symmetry | **Case 1:** Transition must also be guaranteed for asymmetrical TU. | Centre aisle required, or TU may only have one loading direction | New - EK |

| | | | |
|---|---|---|---|
| | **Case 2:** No requirements for TU-TU interface | and cannot be loaded in any direction | |
| TT11: Outer edges | **Case 1 and 2**: There must be a clear outer edge beyond which nothing protrudes (e.g. lights) otherwise it may not be possible to dock the TU to the other TU | TU-TU interface must take outside lines into account, this also applies to necessary visible markings and attachments | New - EK |
| TT12: Positioning | **Case 1:** Precise positioning necessary to ensure safe transition between TU and TU. **Case 2:** No positioning requirements other than that the coupling devices must be in line with the CU. | Guidance between the individual TU necessary, mechanically or optically possible | New - EK |
| TT13: Electrical / Signalling Couplings | **Case 1:** An electrical interface between TU and TU should be provided to exchange important information (e.g. door malfunction, toilet occupancy, destination of the other TU, etc.). **Case 2:** Not necessary, happens via the connection to the CU | An electrical interface between TU and TU should be provided | New - EK |
| TT14: Mechanical Couplings | **Case 1:** The transition between the TU should be possible without danger, if necessary (with large bridging or large tilting moments) a mechanical interlock should be provided **Case 2:** Not necessary, happens via the connection to the CU | Check to what extent TU can move against each other; a mechanical mechanism is required for large displacements | New - EK |
| TT15: Vibration / Shocks | **Case 1 and 2:** Shocks or vibrations should not be transmitted between the TU. | TU-TU interface must provide damping elements / protection against impacts | New - EK |

### 6.5.2 Specification of the interfaces between different Transport Units

**No physical connections between Transport Units are necessary**

In Pods4Rail, it was determined under the given conditions that the mechanical interlocking to the CU is sufficient and that an additional mechanical interlocking between the TU is not necessary and does not provide any added value. Regarding electrical connections the situation is the same: since both TU will be located on a CU and being powered by the CU in such a connection, it is not necessary to transmit power through additional connectors. Also, within chapter 6.4.4, it was decided to use a wireless communication standard between all elements of the Pod system (CU and TU) and also as communication with the operation system (see chapter 7). This enables a simpler and more maintenance-friendly architecture with less susceptibility to faults. This means that neither a mechanical nor a physical electrical coupling is required for the TU-TU interface; the already installed wireless interface is sufficient.

**Evaluation of interfaces for special purposes**

For some specific purposes a physical coupling between TU may still be needed, e.g. for dedicated power supply units or specific service units. For the evaluation of these mechanical, electrical or signalling couplings, the same procedure was followed as in chapter 6.4. The outcome is, that a so-called tension locking mechanism is recommended for any mechanical connection. Tension lockings are suitable for really quick and easy assembly and disassembly. They are often used in the transport and logistics industry to secure loads on lorries, trailers or other means of transport. They offer a quick and secure/firm fastening solution for various types of cargo. They offer great potential despite their simple design, especially when manual adjustment is relevant. By positioning hooks or similar devices, they accommodate the TU with a relatively large tolerance compensation. This mechanism is dedicated to be manually, an additional automated version is still possible by adding electric actuators. A tension locking is required on each side for securing. The complexity and maintenance are relatively simple and requires little effort. The size of the device can vary, but they are usually relatively small and have an average size of (l x w x h) 24 x 13 x 65 mm.

Regarding electrical connections, no specific solution is given at this point, due to the individual demands of the UC. This means, that the electrical connection should be implemented according to the specific TU technology. For example, if a power supply system is used, the energy transfer must follow the available connectors at the power unit. According to chapter 6.5.1, only the transport of relevant data and information is of essential importance in any purpose (TT 13 in Table 47). For situations, where the installed wireless communication is not sufficient enough, data connectors are used (according to ECM06), which were also evaluated as very good and suitable for this field of application. In contrast to the best evaluated variant in chapter6.4.3, charging connectors are not used, because they don´t enable transfer via Ethernet or RF coaxial connectors and are therefore not suitable for signalling coupling.

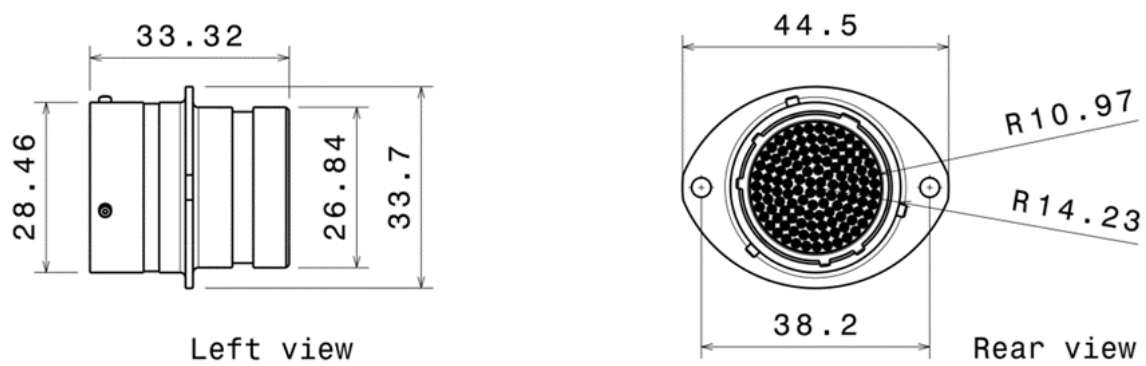



**Figure 48: Sketch of data connector (TE Connectivity, 2024)**

**Rubber lips for isolation in every passenger use case**

The transition between the TU must be both safe and tight in accordance with TT7 and TT8. For this purpose, it is advisable to fit a rubber lip on both sides of the TU as an isolating material between different TU. This rubber lip must either be retracted to position the TU and be able to be extended after positioning or be so durable that it allows positioning even when extended but also guarantees tightness at the same time. A rough estimate of the distances between the TU was made, but according to Chapter 6.4.6 this must be analysed in more detail in the development phase of the following WPs. In summary it can be seen that the range of distance between two TU is just within 25 mm (between two 5 ft TU) and 40 mm (between two 10 ft TU).

## 6.6 Concept for interfaces of the Transport Unit to the storage system

When a TU is currently not needed or when it has to go to a service, it can be parked in a storage system. Within chapter 6.2 several options were described how the TU can be stored. Following situations have to be considered:

1. Handling of the TU in an (autonomous) storage system
2. Parking the TU inside the storage system
3. Stacking of several TU inside or outside the storage system
4. Standing or parking the TU on the ground

For the first and second scenario, the TU might be moved inside the storage system with a specific intra-logistics device, similar to a high-bay warehouse. As defined in the previous chapters, the same interfaces will be used for this, because the transshipment device is expected to be the same for the storage system. More specifically, the forklift pockets as well as the twistlocks (or corner castings) shall be used for the storage system handling. As shown in Figure 49, the TU can be placed on a storage rack, why it makes sense to use the corner castings as contact points when the TU is being parked inside. In this way it can be assured that a safe stand is achieved, additionally the TU could also be locked in its parked position by locking the corner castings (this is optional and would increase the storage system complexity).

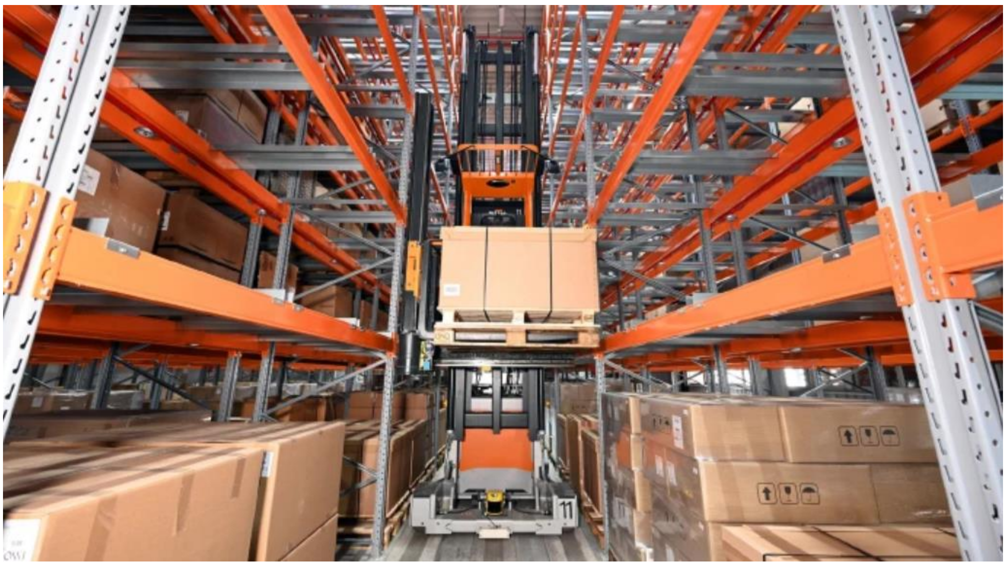


**Figure 49: Example of automated high-bay warehouse storage system (Pressebox, 2024)**

Another way of storing the TU are by stacking one TU on top of another TU. For this scenario, it is recommended to use the corner castings and twistlock mechanisms according to the ISO 668 standard similar to ISO-Container handling. In that way a secure and stable connection can be created for several TU. For standardised ISO containers, “the bottom unit could support a stack of six fully loaded 40ft containers and eight fully loaded 20 ft containers” according to (McGrath RentCorp, 2024) based on usual load conditions in freight sector. Since stability and lightweight limitations appear and also the space of considered storage system is expected to be limited, it is suggested to limit the maximum allowed number of TU to 3-5 units. A specific requirement for this case was not given in this WP, therefore it has to be calculated again in the end of the project, when the detailed TU concept is completed and the weight balance gets clearer (e.g. after WP 9). In general, it is suggested to store the TU without stacking because of higher safety and flexibility of the overall system. The stacking of more TU is also possible but geometry of HVAC unit and corner castings has to be adapted for this option. This task will be solved within following WPs.

The last scenario is parking or placing the TU on the ground by taking it off the CU. Also, in this scenario, the corner fittings of each capsule can be used as the stands and contact points towards the ground. In this way, every TU can stand on four points to ensure equal load distribution and the rest of the bottom structure is being protected.

# 7 Concept proposal for the operation system

The following concept proposal, as already described in the project proposal and in the existing deliverables, is intended to provide a concept of a fully automated supermodal mobility system for passengers and goods which is sustainable, collaborative, interconnected, digital, on-demand, standardized, scalable and suitable for several transport modes with focus on rail. Such systems allow higher flexibility through supermodality, building on the concept of considering mobility as a service (MaaS) and utilising the existing infrastructure. Hence, it becomes imperative to consider various aspects of necessary modifications. Such aspects are crucial for ensuring full deployment of the system.

To embed the resulting concept in the research and development landscape, a closer look at the operational processes was taken that are influenced by such a Pod solution and derive recommendations for action, specify the operational processes in more detail and define the new subcomponents required for this and those to be modified. The first relevant step is to focus on the reference architectures that are already implemented in the System Pillar. To this end, an overview of Reference Control Command and Signalling Architecture (RCA) and Open Control Command and Signalling Onboard Reference Architecture (OCORA) is provide, and the processes already defined here and explain how these relate to the Pod concept. As already described in D4.4 (cf. Figure 31), the railway infrastructure will not be examined in more detail in the context of the project, but the focus will be on the onboard system, so it is focused on OCORA in the more detailed analysis and not take a closer look at RCA in this context. As a cross-domain approach is pursued, at least l a look outside the box for the system specification was taken and the automotive area and the system-relevant State-of-the-Art (SotA) was examined. An important point to mention here is the Software Defined Vehicle (SDV) Architecture in the automotive domain. Finally, the aspect of automation and high automation by considering the findings of existing work and also the ongoing research work from the EURail context (especially R2DATO) and the publications of EULYNX in order to provide requirements for the innovative concept will be addressed.

## 7.1 Architectural considerations

### 7.1.1 Railway architecture - RCA and OCORA

As in all other transport/mobility domains, the rail industry is currently discussing various levels of automation to improve efficiency and safety. An important step here is the harmonisation of processes and interfaces, as well as agreement on open architectures. To this end, the European railways have already launched initiatives such as Reference Control Command and Signalling Architecture (RCA) and Open Control Command and Signalling Onboard Reference Architecture (OCORA). While the RCA initiative focuses primarily on the infrastructure side (explicitly CCS), OCORA concentrates on the architecture of a future onboard system. Both initiatives focus primarily on defining interfaces and agreeing on relevant system components that are required for automation and safe operation in the railway sector. The result should be a modular, functional architecture that also considers current research topics such as cloud technologies or high-performance computing (HPC) to promote innovation. Security issues that need to be clarified at the architectural level also play a decisive role here. As there are naturally also overlaps in the interaction and communication between train and infrastructure, both initiatives are working jointly towards a generic safe computing platform approach for onboard and trackside CCS applications (and possibly other railway applications), in particular aiming to decouple applications from the underlying computing platform, considering their very distinct life cycles, and to achieve platform independence.

Due to the heterogeneity of European railways, the challenge also lies in formulating the current status and communicating necessary changes to the TSI. The two initiatives RCA and OCORA have agreed on a general terminology for this, which can be seen in Figure 50.

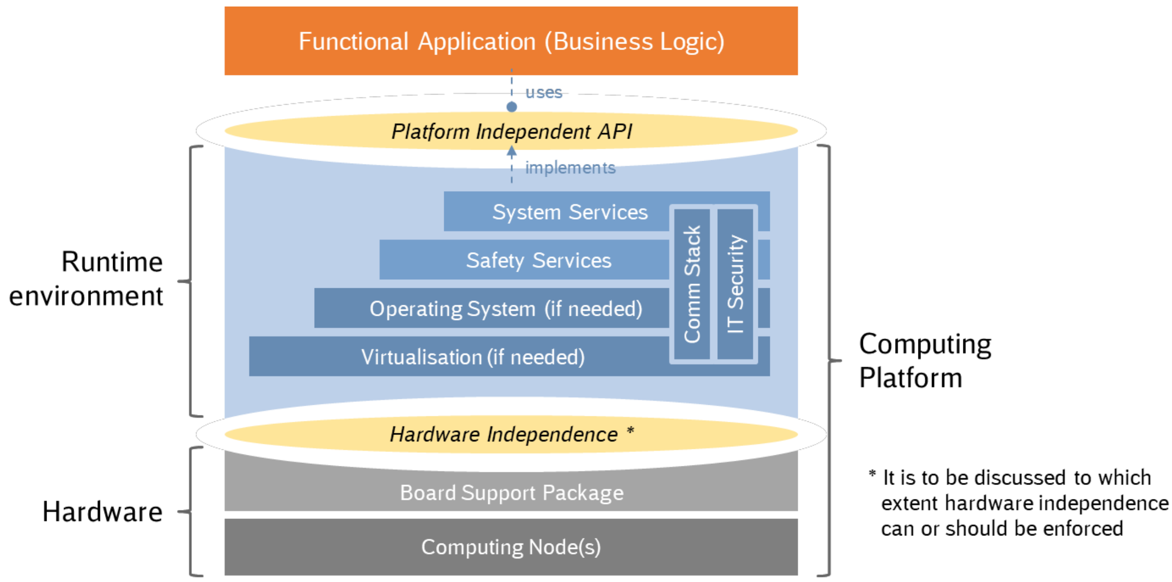



**Figure 50: General computing platform principle and terminology (Marsch, et al., 2024)**

### 7.1.2 Safety aspects

To address safety aspects in the structure of the operation system modules description, it is advisable to follow general rules when implementing safety-critical systems. Processes to be executed should be clearly separated, preferably already at hardware level, to ensure that the state of one process is not unintentionally changed by another process. If this is not possible, the use of safe methods for memory allocation and deallocation on the same hardware must be considered in order to avoid memory leaks and fragmentation.

In addition, aspects of error monitoring and self-healing play a decisive role in fail-safety. To this end, approaches such as contract-based design can be considered as early as the design phase and monitors can be developed or derived from this in order to monitor the safety-critical and relevant properties during the operating time. The monitoring should thus provide the opportunity to initiate the elimination of error states without human intervention whenever possible or, in the worst case, to lead to a safe system state. In particular, the issue of ensuring real-time properties, i.e. the fact that time-critical operations are executed within specified time limits, in order to guarantee the stability of time-dependent applications. General resource monitoring must also be mentioned and considered at this point. In general, a modular structure of the system solution is recommended in order to be able to realise the above-mentioned criteria. However, this characteristic of the modularity of a complex system also results in strict control and standardisation of the interfaces between the units in order to avoid unexpected interactions. Another advantage of modular design is the fact that units can be easily updated or replaced without affecting the overall operation. This also plays a decisive role in terms of sustainability, as the system can be used for longer and new system updates can be integrated into operations more quickly and easily.

### 7.1.3 Automotive architectures

Software-Defined Vehicles (SDVs) represent a transformative approach in the automotive industry, where the functionality and capabilities of a vehicle are predominantly driven by software rather than hardware.

Traditional vehicles use numerous Electronic Control Units (ECU) distributed throughout the vehicle, each responsible for specific functions like engine control, braking, or infotainment. SDVs consolidate many of these functions into a few high-performance centralized computing units. These central units leverage powerful processors and advanced computing architectures to manage complex tasks and coordinate vehicle operations. SDVs employ a modular software architecture that separates the vehicle's functions into distinct layers. This separation typically includes a base layer for basic vehicle controls, a middleware layer for communication and data management, and an application layer for user-facing features. This modularity allows for easier updates, upgrades, and customization of vehicle functionalities (see Figure 51).

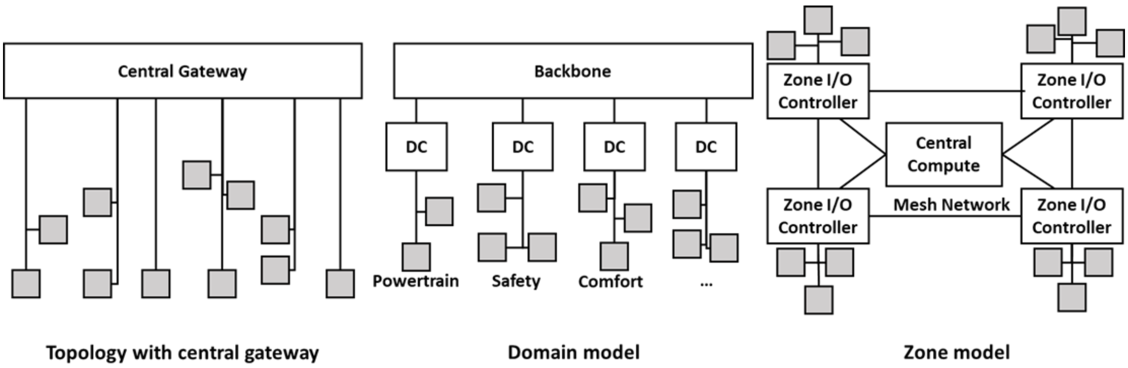



**Figure 51: Topology models for E/E architectures (Haeberle, et al., 2020)**

One of the significant advantages of SDV is the ability to receive Over-the-Air (OTA) updates. This capability enables manufacturers to deploy new features, security patches, and performance improvements without requiring physical access to the vehicle. OTA updates ensure that vehicles remain up-to-date with the latest technologies and safety standards, providing a continually improving user experience. SDV are designed with robust connectivity options, including cellular, Wi-Fi, and V2X (vehicle-to-everything) communication. This connectivity is essential for real-time data exchange, remote diagnostics, and cloud-based services. Cloud integration allows for extensive data analytics, AI-driven insights, and the potential for autonomous driving capabilities.

With the increasing reliance on software, ensuring robust cybersecurity measures is paramount. SDVs incorporate advanced encryption, authentication, and anomaly detection systems to protect against cyber threats. Safety-critical functions are designed with redundancy and fail-safe mechanisms to ensure reliability and resilience.

The benefits of Software-Defined Vehicles include improved vehicle lifecycle management, as SDVs can be continuously improved and personalized over their lifespan, adapting to new regulations, customer preferences, and technological advancements without needing hardware changes. The ability to add new features and improve existing ones through software updates ensures that customers have access to the latest innovations and a more engaging driving experience. The decoupling of hardware and software development allows for faster innovation and deployment of new technologies. Manufacturers can experiment with and implement new ideas more quickly than with traditional vehicle architectures. While the initial development of SDVs might be cost-intensive, the long-term benefits include reduced maintenance costs, fewer recalls, and the potential for new revenue streams through software and services.

However, there are challenges and considerations to address. Integrating software components from various suppliers and ensuring compatibility and reliability can be challenging. Standardization and robust testing protocols are essential. With increased connectivity and reliance on software, SDVs are more susceptible to cyberattacks. Ensuring robust cybersecurity frameworks is crucial to protect both vehicle integrity and user data. Navigating the regulatory landscape for software updates and data privacy can be complex. Manufacturers must ensure compliance with varying international standards and regulations. Educating consumers about the benefits and functionalities of SDVs is necessary for widespread adoption. Ensuring user-friendly interfaces and reliable performance is key to gaining trust.

The European Software-Defined Vehicle of the Future (SDVoF) initiative recently published a vision and roadmap paper outlining the interplay between on-board and off-board/cloud services (see Figure 52). To this end, it is crucial to consider the architecture on the three levels of hardware, middleware (API framework) and software. It is also necessary to offer a software development kit (SDK) to support DevOps to enable a continuous development and deployment of the software (CI/CD pipeline).

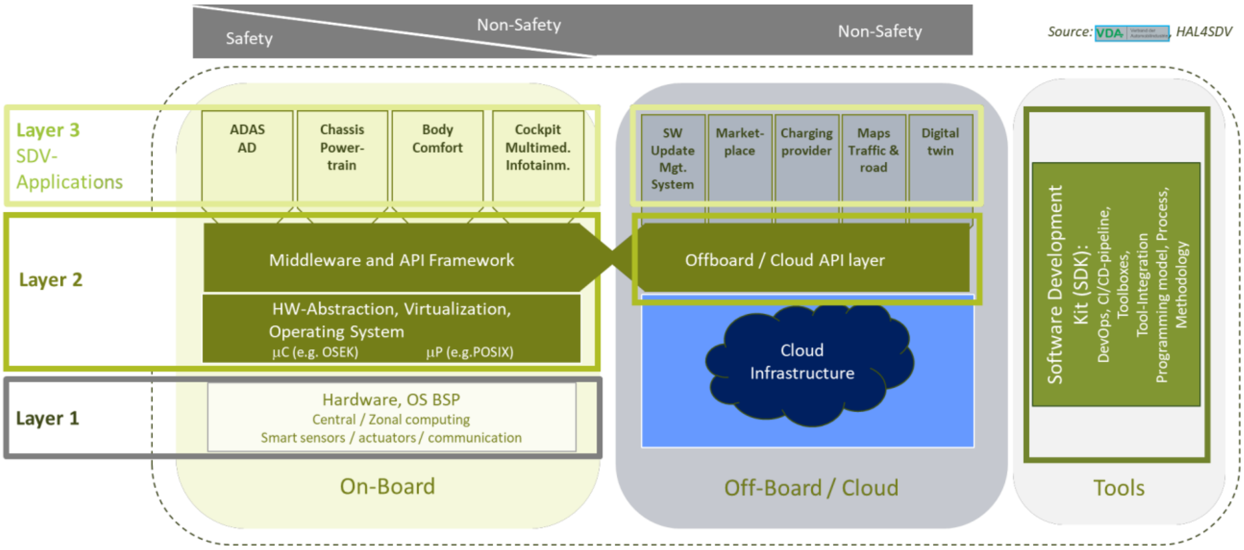



**Figure 52: Basic structure of SDVoF HW/SW stack (FEDERATE Consortium, 2024)**

On the infrastructure site the current state of the art in the automotive domain is V2X, or Vehicle-to-Everything. It is a communication technology that enables vehicles to communicate with each other (V2V), with infrastructure (V2I), with pedestrians (V2P), and with networks (V2N). This interconnected system aims to improve road safety, reduce traffic congestion, and enhance the overall driving experience by allowing vehicles to share information about their speed, position, and the surrounding environment. V2X leverages various communication protocols, including Dedicated Short-Range Communications (DSRC) and cellular networks (C-V2X), to facilitate real-time data exchange.

## 7.2 Identification of operational processes

In the following subsections, the operational processes to be supported by the Pods operations system and its architecture outlined in the previous section are specified in more detail. Since we expect the backbone of future Pods networks to be based on existing rail infrastructure in Europe, we decided to build on top of state-of-the-art with respect to existing EU standards and harmonization in the area of operational planning and effective live operations.

### 7.2.1 Planning of operations on the Pods network

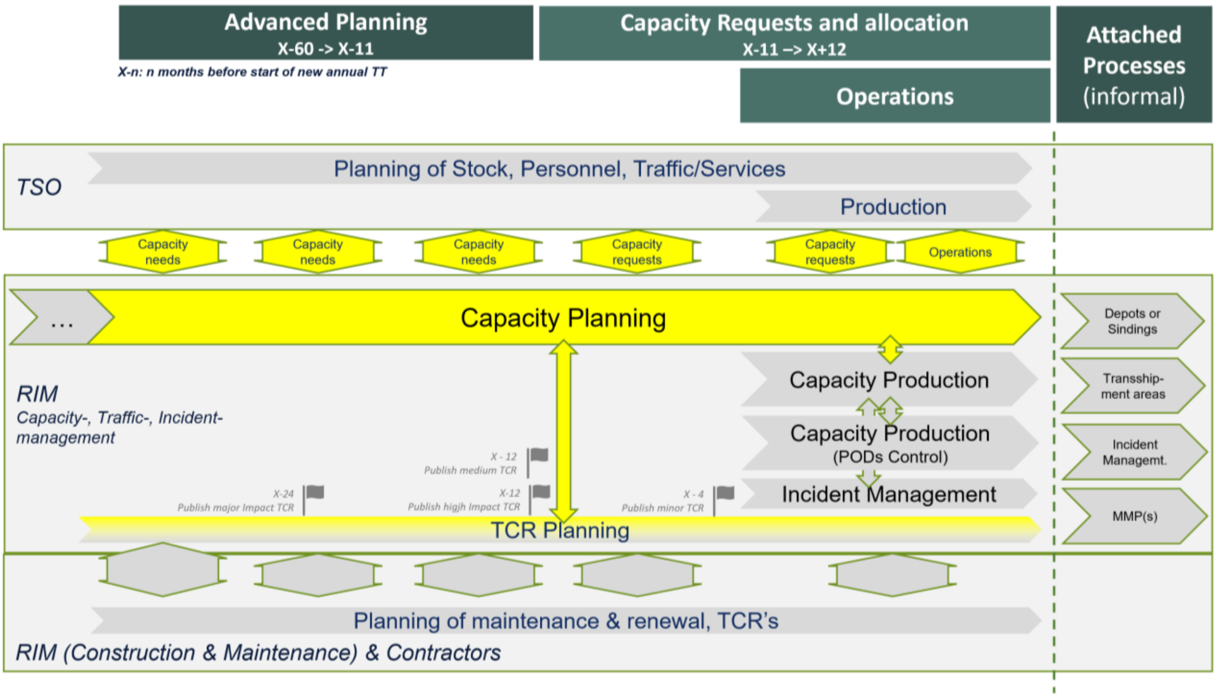



**Figure 53: Process of the Pods network capacity planning process (EU-Rail System Pillar - Task 3, 2024)**

Being one of the most important resources used for operating the Pods, the rail network capacity and its foreseen operational use needs to be planned and managed to ensure a maximum of traffic efficiency on the track sections of the network. When taking a closer look on the Pods set up, it is obvious that the Pods Carrier Unit (CU) is the element consuming the network capacity in disregard of the TU loaded upon them. Since the network capacity is limited, the allocation of the capacity required for the Pod trips is made available by Rail Infrastructure Managers (RIM) for a competing group of different Transport Service Operators (TSO) being interested in using the network to operate their Pods fleet. The described process is illustrated by Figure 53 above, indicating the RIM's role which we are focussing on in yellow colour. It is widely following the existing European Capacity Management and Planning approach for the rail network of the EU as specified by Europe's Rail System Pillar, Task 3.

The track capacity being made available for Pod trips is planned by RIMs based on forecasted traffic demands in different phases for multiple years ahead, including the short-term planning phase within the current year. The overall planning horizon depends on the size of the network so that RIMs of smaller (national) networks may provide a capacity plan only for the current year plus the next. The planned capacity is offered to the TSOs which respond with capacity orderings to reserve the capacity for expected number of Pod trips of the TSOs on a given line section and for a given time interval.

At the same time, Temporary Capacity Restrictions (TCR), caused by e.g., track maintenance, repair and renewal or adverse weather / environmental conditions need to be published and considered for the planning.

1. **Coordinating and publishing of TCRs (RIM)**

The coordination and publishing of TCR is a horizontal process managed by RIM, going along all phases of capacity planning, see also Annex VII of the Directive 2012/34/EU (EU.2012/34-VII). The coordination is required to prevent areas from being disconnected from the rest of the network for some time or to keep the impact on planned trips limited. For this purpose, different methods as e.g., clustering of TCR are applied which need to be performed using commonly agreed principles in a constant communication process together with all stakeholders involved. For capacity planning of the Pods network, the coordination of TCR and related communication is envisaged following a modern maintenance planning approach as described in (IAM4RAIL D8.1, 2024).

The required process activities involve

- Defining TCR and TCR window planning principles
- Use available methods (e.g., clustering) to minimize overall TCR capacity impact
- Coordination among the relevant stakeholders
- Consultation with TSOs and other relevant stakeholders
- Preparation of TCRs in the capacity plan
- Publishing of TCRs

2. **Handle annual capacity requests (RIM and TSO)**

Latest 15 months ahead of setting a new annual capacity plan in force (day 'X'), the RIM are performing feasibility studies and consultation with stakeholders to set up the initial capacity offer for their network which is published 12 months ahead of X, i.e. at X-12. Anticipating expected traffic demand, the TSO start to request network capacity for expected trips based on the offered and available capacity. These requests can be submitted until a certain deadline which is typically X-8. If two TSO request the same capacity for different Pod trips, such conflicting requests are coordinated by the IM to ensure best outcome. This may lead to minor or even major changes to the initial requests. Finally, a new annual capacity plan, based on long-term TSO traffic expectations is established and published by the RIMs. This annual plan provides the basis for early ticket sales for trips planned by end customers using the Pods of the TSO.

The required process activities are

- Performing feasibility studies, stakeholder consultation (X-15 to X-12)
- Publishing the initial capacity offer (X-12)
- Processing annual capacity requests (X-12 to X-8)
- Provision of confirmations of annual capacity requests / capacity offers to TSOs

### 3. Handle late capacity requests (RIM and TSO)

Capacity requests issued by TSO between X-8 and X-2 are processed on a first come-first served base. The requests may be related to offered capacity still available as published at X-12 or to unplanned capacity. The process results in an overall aligned, feasible capacity plan which can be safely operated, considering the needs of passenger and freight transport demand of different TSO which are sharing one and the same rail network. This annual capacity plan is published at X-2 and used as the basis for the operating period X to X+12.

The required process activities are

- Processing late capacity requests between X-8 and X-2
- Provision of confirmations of late capacity requests / capacity offers to TSOs
- Publishing the resulting capacity plan as annual plan at X-2

### 4. Handle ad-hoc or short-term capacity requests (RIM and TSO)

Once the annual capacity plan was published at X-2, TSO still have the option to issue capacity requests until the day of operation of the respective Pods using the capacity of concern. Again, the requests are processed on a first come-first served base but also different other allocation rules apply e.g., for dimensioning timing allowances for the Pod trips. The resulting capacity plan is handed over to operations as *Agreed Daily Plan.*

The required process activities involve

- Processing of capacity requests issued after X-2 until day of operation, latest X+12
- Provision of confirmations of ad-hoc / short-term capacity requests / capacity offers to TSOs

### 5. Handle capacity change or cancellation requests (RIM and TSO)

The TSO may issue requests to change or cancel already allocated capacity between X-5 and X+12. Typical reasons for cancellations or changes of allocations are change in the expected demand or operational problems. The issued requests may also involve changes or cancellations of parts of the allocated capacity in terms of subsets of the intended running days or parts of the trip routes for the Pods.

The required process activities are

- Processing of capacity requests issued after X-2 until day of operation, latest X+12
- Provision of confirmations of capacity change or cancellation requests

### 6. Handle capacity alterations (RIM and TSO)

Between X-5 and X+12, the RIMs could face reasons to request alterations to capacity already allocated by TSO. The alterations may involve adjust, replace or withdraw capacity. Typical reasons are re-prioritization of track maintenance or accidental restrictions like broken tracks or switches. Any capacity alteration is to be confirmed or refused by the TSO.

The required process activities include

- Identification of needs for alteration of existing capacity allocations between X-5 and X+12
- Provision of proposed alterations of allocated capacity to involved TSO
- Processing of alteration confirmations or refusals

### 7. Provide initial Operational Plan to Operations (RIM)

To feed the Operations with latest agreed plans, an initial daily Operational Plan is generated from the capacity plan between X-1 week and X+12. The generation includes the check for route compatibility of the assigned rolling stock (vehicles) and load / cargo type including, e.g., axle load or hazardous goods information. The check also considers time dependent route restrictions.

Articles 21 and 23 of Directive (EU) 2016/797 (EU.2012/797) on Interoperability introduce the process for obtaining authorisation of a vehicle for an area of use and the route compatibility checks that must be done to ensure route compatibility before the authorised vehicle(s) can be used. For the content of the route compatibility checks, please refer to The Technical Specifications for Interoperability on Operations (OPE TSI), section 4.2.2.5 and the therein mentioned Appendix D1 (ERA, 2024).

The required process activities include

- Generation of daily Operational Plan between X-1 week and X+12
- Route compatibility check for Operational Plans
- At least once a day: Provision of daily Operational Plan (*Agreed Plan*) to Operations for a moving time window of the next 7 days

### 8. Planning of Pods trip timetables (TSO)

TSO are performing an assessment of expected demand for future Pods trips on the rail network. The demand forecast is based on trip timetables in the past and assigned information about number of transported passengers or transported cargo and load. Together with developing socio-economic indicators such as e.g., number of people living and working in different areas or future opening or closing of factories or production sites, and availability of competing transport systems, this information can be used to derive future trip timetables fitting to the needs of the end customers for a couple of years ahead. The resulting model also includes the number of TU of different types expected to be used for each trip. It is updated on a regular basis to ensure a best match with the effective network capacity being requested to operate the trip timetables. At the same time, rotation plans for CU and transported TU are derived from the trips timetables to provide the required size of the CU and TU fleet considering contingency, CU maintenance intervals and depot locations. Additionally, the number of required staffs for operating the timetable is assessed to compare with existing staff and take early actions, e.g., for hiring new staff members if necessary.

The required process activities include

- Trip demand forecast and assessment
- Provide future trip timetables to feed capacity requests and TU managing entities
- Provide rotation plans for CU and TU
- Manage resources (CU, staff) against trip timetables

### 7.2.2 Management of operations on the Pods network

The management of operations on the Pods network is performed using a system called POMS (Pods Operations Management System) being used by the RIM and keeping control about all operations in a rolling time horizon including the current day plus one or optionally more days. Key elements of this system are to support supervisory control and implementation of aligned traffic control decision for the Pods in case of incidents or disruptions. It is supporting the process illustrated by Figure 54, showing the scope of RIM activities which, we are focussing on in yellow colour. The underlying approach is partially based on the up-to-date view on specifications for rail Traffic Management Systems as available through the EU-Rail System Pillar.

In the following, we will use the term 'train' as a synonym for one or multiple, virtually coupled CU.

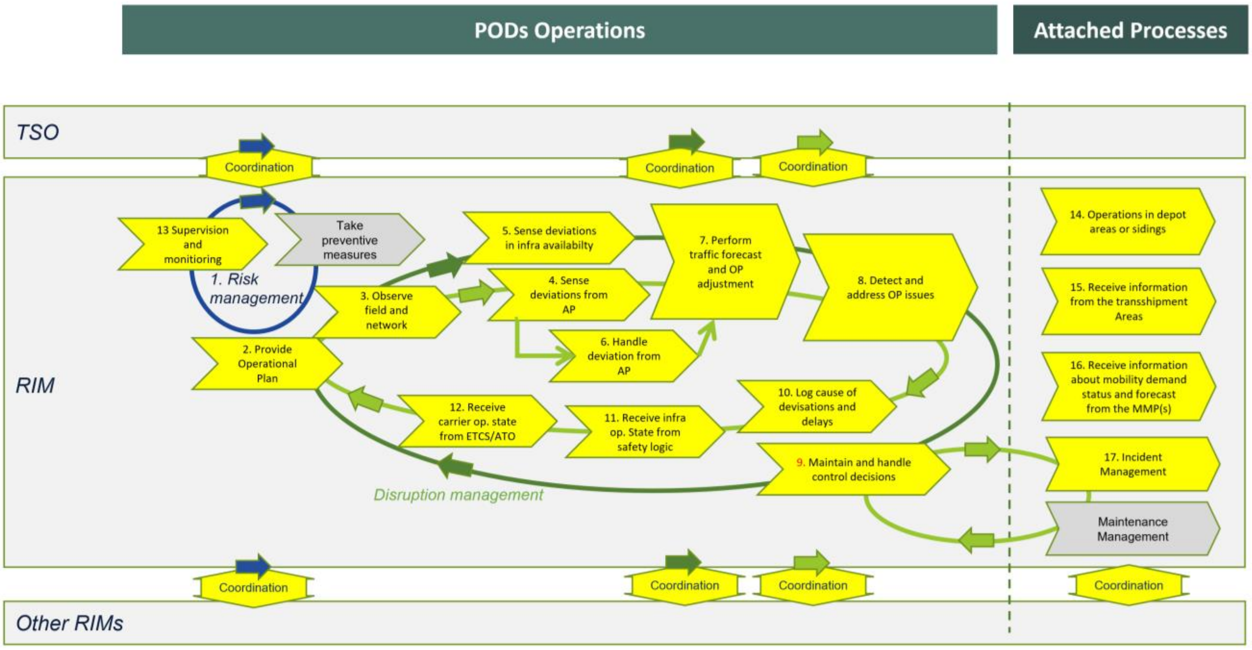



**Figure 54: Process of Pods operations management (Capacity Production) (EU-Rail System Pillar - Task 3, 2024)**

## 1. Manage operational risks (RIM and TSO)

As part of risk management, external events causing operational issues such as strikes, bad weather conditions etc. during Pods operations are considered. The risk handling follows a standard assessment procedure which triggers preventive measures to mitigate the risk. when the estimated risk of possible events becomes high enough. This also includes sharing this risk / coordinating measures with other involved parties.

Process activities:

- Receive / request assessment information
- Determine if risk profiles exceed agreed threshold
- Determine if risk needs to be shared with other parties
- Determine if measure(s) must be coordinated with other parties
- Take preventive measures (e.g., reduce number of trips / CU for trips due to storm)
- Follow/exchange progress.

## 2. Provide Operational Plan (RIM)

The current version of the Operational Plan as managed by the POMS is provided to the ATO-Execution and Plan-Execution function of the ETCS Hybrid Level 3 (Hybrid Train Detection) based Command and Control System (CCS) to steer the trains with respect to demanded earliest and latest arrival times at trip locations which could also be intermediate operational locations not involving planned stops. At the same time, the updated Operational Plan is made available to the connected Mobility Management Platform(s) (MMP) to keep end customers informed about delays and incidents in conjunction with their booked trips.

The important operational constituents of the Operational Plan are the description of movements, a set of restrictions (including TCRs with assigned incident information) or eventually warning measures existing along the route of the movements.

After having received the *Agreed Plan* from the network capacity planning, the POMS copies it into its Operational Plan data structure and amends it with the operational constituents mentioned above. Starting from now, the Operational Plan is continuously updated following real-time CU position feeds and Pods operations management decisions taken. The Operational Plan carries all information necessary for its execution.

Process activities:

- The Agreed Plan is received from network capacity planning, according to a predefined and agreed topological representation of the controlled area.
- The received plan is complemented with operational information and continuously updated following CU position reports and Pods operations management decisions.
- The Operational Plan is provided to ATO-Execution and Plan-Execution functions of the CCS in a convenient advance.

### 3. Observe field and network status at real-time (RIM)

The POMS and its operator observe any movements of controllable and relevant observable objects which include movable rail-bound objects currently on the tracks as well as non-rail-bound objects currently on or near the tracks. Other field status information like GNSS based CU positions, track circuit / protection section occupancy, or other asset status are constantly reported to the POMS to update the POMS views and logs and to feed the deviation detection.

The information made available ensures an up-to-date view on the situation and the state of the Pods operation on the rail network to detect and understand risks and to maintain situational awareness.

Process activities:

- Monitor field and network status
- Detect and understand current or upcoming issues
- Mark for direct follow up

4. **Sense deviations from the Agreed Plan (RIM)**

Due to reported CU positions indicating a location where the CU should have been earlier, the respective CU is identified as running late when comparing the updated Operational Plan with the Agreed Plan. Also, the opposite case may happen indicating CU running earlier. The deviation is detected by the POMS and indicated in the control views of the system. This capability is also supported with configurable colours indicating the extent of running late or early. Something similar holds for other operational objects like TCR. If operational TCR are not started or released as planned, this is indicated by the system requiring attention of the operator.

When deviations are detected (in other processes) they are evaluated if a feedback to network capacity planning should be given to improve future capacity plans and resulting agreed Plans.

Process activities:

- Compare updated Operational Plan including CU positions reported at specific times with the Agreed Plan to detect deviations.
- Compare reported begin and end of TCRs with begin and end times given in the Agreed Plan. For each TCR, the displacement between its current state and the originally agreed one is verified

5. **Sense deviations in infrastructure availability (RIM)**

It is important to identify faulty field elements, occupied sections with defective trains, and TCR induced by Incident Management and to identify possible resulting issues with the Pods operating on the network. The issues are often related to non or constrained capability of using the infrastructure resource being affected causing delays or re-routing needs or even cancellation of the directly impacted trip but also other trips having assigned the same CU or TU according to the TSO rotation planning.

Process activities:

- Consuming the messages coming from connected field systems or components and evaluating them.
- Check whether the information received will cause issues with planned trips currently being executed or planned
- Identify impact for the trips

6. **Handle deviation from the Agreed Plan (RIM)**

Once deviations from the Agreed Plan impacting the Pods operation have been detected, operational measures are taken to minimize the impact. This involves inter alia, changing the order of CU expected to appear at certain locations, changing the platform tracks currently assigned at planned stops, changing crossing locations or cancellation of trips, short turning, skipping stops etc.

Deviations from the Agreed Plan (early arrivals or delays) are handled in a target-oriented way to get back on schedule according to the Agreed Plan as soon as possible. However, the deviations are not necessarily leading to substantial delays e.g., at commercial stops or impacting other trains to receive substantial delay. In these cases, operational control decisions are not necessarily to be taken.

If deviation of operational TCR from planned TCR are detected, this is indicated by the system requiring attention of the operator. This is especially given in the case that the operational TCR is not started / released as planned or not planned at all, i.e., a new one typically induced by the incident management. The TCR residing in the Operational Plan can be updated in these cases either by integrated systems responsible for managing the TCR as e.g., maintenance management systems, or by manual changes performed by the operator. When deviations are detected (in other processes) they are evaluated if a feedback to network capacity planning should be given to improve future capacity plans and resulting in Agreed Plans. This also includes automated synchronization of operational TCR information with the planning process if the start time or the end time of the TCR in the Operational Plan is set to a time later than the current time plus 24 hours and hence, relevant for planning and consideration in the Agreed Plan. Also, cancellation of an existing and set-up of a new operational TCR being relevant for planning is communicated back to planning.

Process activities:

- Operational control decisions are taken so that the intended level of service can be reached again as soon as possible. Typical control decisions examples are
    - Holding back a CU A at a in front of a switch for letting another CU B pass by.
    - Holding back a CU A for awaiting arrival of CU B and TU transshipment from A to B at a station or transshipment point until a certain maximum time threshold is exceeded according to current Operational Plan.
    - Set a maximum speed restriction for a CU A on a defined line section on its planned route.
    - Activate/de-activate enforcement of platooning for two or multiple CU running after each other.
- Required changes of operational TCR (i.e., residing in the Operational Plan) are performed either automatically triggered by integrated systems or manually by the POMS operator according to available information from operations.
- New, cancelled operational TCRs or changes of TCRs are synchronized with the capacity planning process if they are relevant, i.e., having an impact on the next day's Agreed Plan.

### 7. Perform traffic forecast and automated Operational Plan adjustment (RIM)

The traffic forecast for the rail network is calculated every n seconds where n should be between less than 1 and 10 seconds. It considers the current status of operational TCR and CU positions with their routes and timing in the existing Operational Plan, the Agreed Plan and active train control decisions. As a result, the updated Operational Plan reflecting the forecast result is used to identify issues and address them by deciding and implementing new or updating existing control decisions to automatically adapt the Operational Plan for the involved controllable objects in the next cycles of forecast calculation and Operational Plan adjustment.

Process activities:

- Perform a traffic forecast as an automated function of the POMS, considering the capabilities and behaviour of the CU and the signalling / interlocking, ATO and ETCS L3 systems.
- Update the Operational Plan automatically based on the forecast result and active control decisions.

### 8. Detect and address Operational Plan issues automatically (RIM and TSO)

In principle, issues identified in the current Operational Plan are related to non-tolerable deviations of the current Operational Plan from the Agreed Plan which have not been addressed yet. This is mostly because of upcoming extensive delay of CU with respect to their planned trip. The extensive delay of CU following their assigned trips is indicated to the operator in the POMS views using e.g., heat map coloured indications with respect to the current delay incurred.

A built-in system logic provides a set of appropriate control decisions and assigned parameters to address the issues by reducing the delays and hence, the related issues. In cases where control decisions reflecting TSO CU or TU links to other trips (ensuring the TSO rotation plans) are infringed, the TSO is in charge to update the rotations and replace the impacted links with new ones leading to automated generation of related new control decisions. The existing set of decisions is updated with the new ones leading to decision de-activations, changes or activations being applied for the next Operational Plan adjustment. The decision of cancelling trips is not a automatically generated control decision but needs to be initiated manually by the operator in case of observing continuous increase of the delay level. Cancellation of trips are to be communicated and aligned with the responsible TSO representative, also to assess and identify consequential effects impacting the Operational Plan.

Process activities:

- Indicate extensive delay of CU following their assigned trips in the views
- Provide a set of appropriate control decisions and assigned parameters to address the extensive delays
- Update existing control decisions with newly provided ones
- Cancel trips manually to address continuous increase of the delay level if required (POMS operator in alignment with TSO)

### 9. Maintaining and handling of control decisions (RIM and TSO)

Control decisions are created, activated and de-activated automatically to reduce the need of manual interventions by the POMS operator as far as possible. However, control decisions can also be created, activated and de-activated manually. Additionally, the operator may decide to protect a control decision from being automatically overridden by the automated updating cycles.

The operator uses the POMS decision support module for addressing larger disruption scenarios leading to more complex change scenarios for the Operational Plan and assigned control decisions to be obeyed. Different change scenarios can be compared and studied with respect to their impact and effect before deciding and activating a selected scenario. For ensuring the alignment of the decisions taken, TSO representatives can be involved by workflow means sharing the scenario views. They provide their formal consent for the envisaged decision scenario managed by an approval workflow capability.

Control decisions not anymore influencing their referenced controllable objects are automatically deprecated. Any activation, change or de-activation of control decisions is logged in the operational log provided by the POMS.

Control decisions may indirectly de-activate themselves depending on assigned conditions and parameters as e.g., maximum time thresholds.

Process activities:

- Provide manually a control decision and assigned parameters if required (POMS operator)
- Protect manually provided control decisions against automated updates if required (POMS operator)
- Use a protected workspace of the POMS to provide manually one or more sets of (alternative) control decisions and assigned parameters to study and address larger disruption scenarios (POMS operator)
- Decide for one set of control decisions in the workspace to be activated including TSO representative if required in a (shared) workflow for final approval.
- Automatically deprecate control decisions not anymore influencing their referenced controllable objects
- Continuously check for fulfilled conditions assigned to control decisions to suppress the related control action

### 10. Log cause of deviations and delays (RIM)

When substantial deviations occur, the (root) cause is registered for later reporting, accountability, performance analysis and billing. A cause for each deviation is assigned automatically as far as possible. However, it is also possible to let the operator assign it manually by selecting from a list of predefined causes/ categories. The cause for the secondary deviations as a consequence of root causes or secondary deviations are automatically assigned.

Process activities:

- Register root causes of substantial deviations automatically after they occur

- Register root causes of substantial deviations manually after they occur (POMS operator)
- Register causes for the secondary deviations as a consequence of root causes or secondary deviations automatically after they occur

**11. Receive infrastructure operating state from safety logic (RIM)**

The POMS continuously receives details on the infrastructure operating state from underlying systems. The information comprises status of field elements, track section occupations and operational TCR including deviations from the planned characteristics and failures. It is transferred to the POMS using standard interfaces like SCI-OP (RCA, 2022) or upcoming TMS/CCS Model based interfacing using the EU-Rail Integration Layer approach, see (X2Rail-2-D6.1, 2020), (X2Rail-4-D9.1, 2021) and System Pillar Task 2 (for TMS/CCS Model).

Process activities:

- Receive details on the infrastructure operating state

**12. Receive CU operating state from ETCS and ATO (RIM)**

The POMS continuously receives CU status information from ETCS and ATO via standard interfaces like SCI-OP (RCA, 2022) or upcoming TMS/CCS Model based interfacing using the EU-Rail Integration Layer approach, see (X2Rail-2-D6.1, 2020), (X2Rail-4-D9.1, 2021) and System Pillar Task 2 (for TMS/CCS Model). The status information includes the CU position, door status of the TU assigned to the CU and detected emergency. Further future capabilities being relevant for communication with the POMS are expected to be provided by the activities in EU-Rail's FP2-R2DATO project and follow-ups in Flagship Area 2.

Process activities:

- Receive CU status information from ETCS and ATO

**13. Supervision, monitoring and alarm management (RIM and TSO)**

The operational process of supervision and monitoring is supported by the POMS making use of appropriate views visualizing the incident and delay information as well as other deviations from the Agreed Plan. The POMS operator and TSO operational staff are following the updated information being shown.

Alarms are raised in case of required attention or action in conjunction with e.g., abnormal operating states of critical assets or reported incidents. The alarms include an alarm ID, a severity category, a clear description, affected CU (s)/trip(s), a time stamp and alarm status. The alarms are managed by the POMS operator in terms of changing the status for confirming notification and action taken. All status changes of alarms are logged in a secure manner for juridical records.

If needed, the POMS operator and TSO representatives are able to initiate verbal communication with the passengers located in TU attached to selected CU, see also no. 17 below.

Process activities:
- POMS operators and TSO perform supervision and monitoring using the POMS views
- Alarms are raised in case of required attention or action
- Alarms are managed by operator and TSO representative
- Alarm management activities are logged in juridical recording
- Initiate and perform verbal communication with affected passengers

**14. Operations in depot areas or sidings (RIM and TSO)**

Movements of CU with or without attached TU going to and from depot areas or sidings to be parked, cleaned, inspected, maintained or repaired, are locally controlled using remote control devices by authorized staff. The local management of the track capacity in these areas is based on planned track reservations and movements to and from the reserved track sections as well as locally defined TCR. Specific views of the POMS are available supporting this planning process down to real-time time scales.

The goal of this process is to provide early information about potential issues in making CU or TU available at the requested times and giving estimated times of availability of the CU and TU in the planned trips departing track of the station.

The updated Operational Plan with its planned arrival times and tracks and relevant CU/TU information is used to feed the local capacity plan to ensure any preparatory measures can be taken in-time. At the same time, the estimated times of availability of the CU and TU in the planned trips departing track of the station are used to update the Operational Plan accordingly.

Process activities:
- Local control of CU with or without attached TU in depot areas or sidings
- Local planning and management track capacity in depot areas or sidings
- Feed relevant planned arrival times and tracks and relevant CU/TU information of the Operational Plan to local capacity management
- Feed estimated times of availability of the CU and TU in the planned trips departing track of the station from local capacity management into the Operational Plan.

**15. Receive information from the Transshipment Areas (RIM)**

The capability to exchange TU between CU of the same and of different transport modes is key to the operational characteristics of the Pods system. The exchange process itself is described as Transshipment Process in more detail in section 7.2.8 below. The handling process in these areas also comprises exchange of TU between CU and storage areas which might be attached to the

Transshipment Areas.

The process status of the HS in Transshipment Areas is sent to the POMS for indication of progress in the unloading, loading and locking process to the operator using the POMS views. An estimated time of finalization of the transshipment process is performed using AI technology considering the specifics of the area, the current status of it and a moving window of historical information, providing the basis for simulations and continuous training of the machine learning feature.

The resulting estimated overall handling time is reported back to the POMS and included as updated 'dwell time' at the transshipment are feeding the Operational Plan.

Process activities:

- Receive process status of the HS in Transshipment Areas
- Visualize progress of the handling process in the POMS views
- Provide estimated handling time in transshipment area and update Operational Plan accordingly

#### 16. Receive information about mobility demand status and forecast from the MMP(s) (RIM and TSO)

The MMP) of the TSO features a component for providing the status and anticipated mobility demand of passengers in the future. This function is based on AI technology, the current trip booking status and the trip searches / requests performed by travellers in the past (FutuRe D6.2, 2024).

The status and forecast of passenger demand are transferred from the Mobility Management Platform(s) of the TSO(s) to the POMS (FutuRe D6.2, 2024). This information includes

a) the number of passengers expected to on-board or off-board the TU placed on the CU at its trip stops including the departure and destination stops;
b) the number of passengers expected to be on-board of the TU placed on the CU between any two subsequent trip stops including the departure and destination stops; and
c) the number of expected passengers to travel between any two stop locations of the Pods rail network in defined time intervals, e.g., of one or two hours.

The information included in a) is used by the POMS to feed the Operational Plan with the estimated duration of stops. This is accomplished by

- deriving the required time for the passengers to individually on-board and off-board; and
- considering the effect of people (crowds) on the platforms or in stations causing hindrances for passengers trying to on-board.

The information included in b) is used for feeding the CU prioritization for taking appropriate control decisions minimizing the overall impact of control decisions whereas the information given by c) leads to additional short-term capacity requests for adding CU trips or changing the TU assigned to already planned CU to upgrade passenger capacity.

Process activities:

- Send mobility demand forecast information from the MMP into the POMS on a regular basis
- Use the demand forecast information for estimating the duration of stops, prioritize CU for effective control decisions, adding trips or enhancing TU, i.e., increase total seat capacity of TU attached to a CU in planned trips
- Apply change the Operational Plan accordingly

**17. Incident Management (RIM and TSO)**

Information about incidents is received by the Incident Management function from different channels including emergency hotlines, supervised field status including anomalies directly reported by track, CU or TU sensors, or reported by asset management or local operational staff. The received incident information is logged and reported to liaise with operational staff of RIM, TSO and emergency / rescue staff for follow-up.

In general, the management of incidents is following existing emergency procedures available for different types of incidents. In the following, a general description is given focussing on handling of an incident's impact of the Pods operations.

After having identified the incident impact area and classified the incident's nature and severity, the required type of constraint for the Pod operations is defined and one or more operational TCRs are set up securing the Pods operations and activities in the impact area. The TCR are updated as soon as new or more detailed information can be assigned. The TCR reflect the current constraints and their impact on Pods operations with assigned forecasted duration and linked comments relevant for the MMP and its mobility information channels to inform connected end customers. Assuming the availability of a modern intelligent asset management system (IAMS), an *estimated time-to-repair* delivered by such a system is used as initial input for deciding the forecasted duration of the TCR (IAM4RAIL D2.2, 2024). This information is updated automatically once the maintenance management system and its digital planning component, see also DMPS system in (IAM4RAIL D8.1, 2024) comes up with a planned begin and end time of repair activities liked to the TCR.

The impact of the incidents on the Pods operations is handled by keeping the related TCR in the Operational Plan up-to-date and being considered for the next cycle of adapting the Operational Plan addressing the current TCR status, see also no. 6 (Handle deviation from the Agreed Plan) above.

Incident managers may initiate verbal communication with passengers located in one or more TU attached to specific CU being affected by incidents. The communication line is bi-directional to let the incident manager assess the situation and to give instructions or advice.

To ensure a sustainable safe operation of the Pods, regular activities are performed preventing incidents. Such activities comprise regular inspection and prescriptive maintenance (IAM4RAIL D9.1, 2024) of operational asset like CU, TU, track, signalling components or transshipment components. The operational computer components and installed software is vulnerable to cyber security threats. Therefore, regular updating of the installed software with available security patches is essential.

Process activities:

- Acquire information about incidents
- Log and report incidents
- Liaise with operational staff of RIM, TSOs and emergency / rescue staff for follow-up.
- Provide and update operational TCRs reflecting the impact on Pods operations and including comments for feeding the MMP
- Handle the impact of incidents on Pods operations by managing the related TCRs in the Operational Plan accordingly
- Initiate and perform bi-directional communication with affected passengers in TU
- Perform preventive measures

### 7.2.3 Carrier Unit Positioning

The CU positioning function is a basic function required for the POMS. A CU position shall be transferred in real time. In today's railway operations control technology, train or vehicle positioning is usually performed using the detected occupancy status of specific sub-sections of the tracks as e.g., track circuits or protection sections defined between balises. These 'linear' types of positioning have some major weaknesses. Firstly, depending on the environment or degradation status of the railway infrastructure, the track circuit-based positions are not accurate in terms of sometimes issuing 'ghost occupations', i.e., they are not caused by train / vehicle axles closing the circuit. Secondly, they do not allow to indicate whether a train/ vehicle has come to a stop or not. And thirdly, it is not clear where the train or vehicle is exactly which is problematic in the light of the Pods characteristics since some these sections may often be longer than 1 km. Anyway, this information is important to provide an overall best quality of knowing where a Pods CU is by combining the existing 'linear positioning' with the GNSS based 'spot positioning'.

The localisation Unit is in charge of estimating the position but not of transmission.

Most of the trains in Europe are today localised based on a GNSS-based component embedded either in the train, or on tablets equipping drivers. Moreover, more and more wagons are also equipped for fleet management and maintenance services. GNSS chips provide cheap and continuous position information. Some can rely on batteries (for wagons for example). The accuracy is in the order of a metre, and frequency of the position is typically 1Hz.

However, GNSS as a stand-alone solution does not provide the performance expected for safety-critical applications as in the case of the European Railway Traffic Management System. For these applications, accuracy can be an objective (in particular, when aiming to distinguish between parallel tracks) but integrity is even more challenging. Integrity is the ability of the system to prevent the use of a GNSS-based position when the required performance cannot be reached. This is performed by associating to each position a confidence interval, reflecting a level of uncertainty.

Classical ERTMS positioning solutions today rely on the use of physical balises placed on the tracks, allowing the train to estimate its position when crossing the balises. Between balises, odometric equipment calculates the distance travelled by the train from the last balise. For every travelled distance the accuracy shall be better or equal to ± (5m + 5% s). The fixed ± 5m tolerance is intended to cover the longitudinal uncertainty of the balise reader in detecting the balise reference location. As odometer cumulates drifts along its run, balises plays a role of regular error resets.

To reduce equipment and maintenance costs, increase network efficiency, Europe is driving a roadmap towards the adoption of EGNSS in signalling applications. GNSS-based localisation units are under development, relying on the use of multiple sensors such as IMUs, digital maps or odometers.

IMU and odometers provider higher frequency data, with good accuracies but suffering from biases. Because of measurement integration in time, bias is accumulating in time and errors are following a growing ramp. GNSS receivers typically provide 1hz positions, but their accuracy and reliability strongly depend on the local environment along the antenna. Indeed, satellite signal reflections on buildings, station walls or roofs, or trees along the track create delays and loss of availability sometimes that can appear to look like random errors. Moreover, typical GNSS accuracy will show that estimates can be close to the track but not on the track, that may require some techniques called map-matching to project the GNSS estimate on the track and be usable in a railway framework. Fusion solutions are then developed to take benefit of the heterogeneity of these sensors and provide an accurate and safe train on-board localisation function.
The development of these GNSS-based solution can be considered today available for non-safety critical requirements and is on development in many big European programs funded by Europe’s rail, the EUSPA, ESA or national programs. Demonstrators are expected in the next years, that will pave the way for its use in the CU.

### 7.2.4 Platooning, Virtual Coupling and Convoys

The term *Platooning* is originating from the sector of road-based truck operation. In 2016, the *ACE*A (Association des Constructeurs Européens d'Automobiles, European Automobile Manufacturers' Association) initiated *the European Truck Platooning Challenge* (ACEA, 2016) in which 6 truck manufacturing companies joined together to perform the first platooning field test in Europe. In the Pods context, the idea of using the railways related technology for *Virtual Coupling* (VC) is foreseen to allow the CU running behind each other in ‘platoons’ by making use of very short, relative braking distances. This is achieved by means of a virtual link that regulates and minimises headways of the virtually coupled CU with the same (or similar) dynamic behaviour as if they were mechanically coupled. The virtual link is expected to facilitate a radio-based synchronization of the braking process performed by the CU.

In the recent past, there have been a number of projects receiving European funding for the conceptual work in the area of virtual coupling of train sets. In the Pods system context, trains or train sets can be assumed as one or multiple virtually coupled CU. Thus, the available conceptual work is seen as relevant for the virtual coupling concept of the Pods system.

In the former European Horizon 2020 programme *Shift2Rail*, the Innovation Programme (IP) 2 with its Technical Demonstrator *TD 2.8 Virtual Coupling* delivered the respective results which are seen as the major constituents for the Pods concept. These results were created in the following projects under Shift2Rail IP2: Besides identifying operational procedures and testing methods for Moving Block signalling, the project MOVINGRAIL (MOving block and VIrtual coupling New Generations of RAIL signalling) assessed related relevant communication technologies and impacts of Virtual Coupling on different segments of the railway market.

The WP 3 activities where summarized in the following deliverables:

- D3.1 Virtual Coupling Communication Solutions Analysis; the authors analysed current technical communications solutions, that could be exploited to implement virtual coupling on a real railway. This analysis has been performed on a theoretical basis, and resulted in an assessment of the state-of-the-art in communications systems that are candidates for implementation in a final virtual coupling solution.
- D3.3 Proposals for Virtual Coupling Communication Structures; concluded that the communications architecture for virtual coupling should be based around 5G principles with a cellular network connection for long distance communication and a Peer to Peer direct link similar to IEEE802.11 (Wi-Fi), but fully integrated into 5G, for short range communication. It should be noted that 5G was chosen as the most modern mobile radio communication standard at the time of the project which would be still valid today. However, the activities for setting up the future standard 6G started in 2017 to achieve transfer rates up to 400 Gbit/s until earliest 2030 whereas 5G achieves a theoretical maximum of 20 Gbit/s.

In WP 4 the following relevant deliverables where made available:

- D4.1 Market Potential and Operational Scenarios for Virtual Coupling; includes
    - the evaluation (SWOT analysis) of the attractiveness of Virtual Coupling (VC) for the market segments high-speed, main line, regional, urban/suburban, freight; and
    - defined operational scenarios for each of them.
- The following challenges where identified:
    - Safety challenges
        - Distance at diverging junctions: Switches might not have enough time to be moved and locked in between consecutive trains with potential risks of train derailments. Recommendation: apply absolute braking distance in this case.
        - Communication frequency: Risk for collisions when braking information is not broadcasted timely. Recommendation: select a communication technology that ensures sufficiently frequent information exchange.

      - Platooning trains with different characteristics: In the case that trains have different braking characteristics, the following train might overshoot its MA. Recommendation: exchange information about breaking capabilities and adjust braking rates accordingly.
  - Technological challenges
      - Communication architecture: A V2V communication layer which complements RBC to train communication for communication position, speed, acceleration reliably at high frequency needs to be deployed.
      - Interface with TMS and IXL: The main challenge is to understand whether trains can still be controlled by central TMS or individually. Interlocking areas controlled by on-board system using train to IXL interface thinkable, could improve safety at level crossings (e.g., when train detection is removed with moving block).
      - ATO Interface: Generally, a problem that already exists. Requires VCTS-specific functions for keeping relative distance and considering individual braking performance.
  - Infrastructure and operational challenges
      - Platform length for platoons: Longer platforms might be required to allow platoons of multiple trains to stop at the same track. Segregation of a platform might be required to avoid confusion when trains of a platoon have different destinations.
      - Train planning rules: The running time of a train in a platoon depends on the characteristics of the platoon (thus, the other trains).
      - Engineering and operational rules:
          - "On the fly" coupling/decoupling would allow more flexible service but is only suitable for market segments where the distance to stations/junctions is sufficiently high.
          - Switches might not have enough time to be safely moved and locked at diverging junctions, thus absolute braking distance should be imposed at the switch to tolerate switch failures.
          - Cooperative management of railway traffic is required.
          - Protocols for traffic management and train-to-trackside communication might be modified
- The deliverable concludes that, once having overcome challenges of initial invest and needs for changing operational rules and procedures, Virtual Coupling has the potential to revolutionise and improve current train operations so to induce a sustainable shift to railways.
- D4.3 Application Roadmap for the Introduction of Virtual Coupling; this deliverable suggests to distinguish between the non-vital VC-concept for Platoons and the vital VC-concept for Convoys which we also foresee for the Pods. In the light of ensuring minimization of the relative braking distances between the Pods using radio communications, it is valid to use the term *Convoy* instead or Platoon for the Pod System in the future.

Based on the MOVINGRAIL output (MOVINGRAIL WP3 and WP4, 2019/2020), the project X2Rail-3 Advanced traffic management and control for railways delivered the following relevant results.

WP 6 Virtually Coupled Train Sets (VCTS) – Concept and Safety Analysis

- D6.1 VCTS Concept and Application condition analysis; resulted in a number of advantages of the VCTS approach compared to existing classical railway signalling approach (X2Rail-3-D6.1, 2020):
  - To replace the mechanical coupling, in order to enhance efficiency and flexibility of the consist building procedure
  - To increase line capacity by reducing the (train) headways
  - To reduce maintenance cost in relation with best use / max capacity of the line
  - To increase competitiveness making more efficient goods and passengers transportation over the railway network with respect to the road transportation
  - To improve the use of the existing station platforms. One platoon can be shared using several platform tracks
  - To reduce global investment costs by adding on board and trackside signalling/electronic systems, instead of tracks or heavy changes of the infrastructure
  - To increase operational flexibility ensuring interoperability
  - To save cabling, materials, weight and design constraints of on-board rolling stock

  Application of the WP 6 results to the Pod System would allow the virtually coupled CU to safely maintain a controlled headway between them, which is typically shorter than the conventional absolute braking distance between trains. Each CU manages the computation of its headway based on:

  - its own specific braking characteristics
  - the characteristics of other 'virtually coupled' CU
  - the current dynamic information as speed, position, etc. of all CU.

  All CU of the virtually coupled Convoy cooperate to exchange the relevant data for implementing a coordinated supervision of movements, based on the characteristics of all CU belonging to the Convoy. This leads to the maximisation of the network capacity, by allowing CU to run at a distance (i.e., headway) that is the minimum achievable with a specific technology.

- D6.2 Performance and Safety Analysis (confidential); included a parameter study and comparison between relative braking distances used with VC and absolute braking distances of classical signalling (X2Rail-3-D6.2, 2020). Applying the results of the D6.2 to the Pod System provides
  - the definition of the Relative Braking Distance (RBD) as 'The required distance between CU that guarantees safe braking to standstill'; and
  - a reduced coupling and decoupling time of up to 40 % compared to todays' technology.

In WP 7 Virtually Coupled Train Sets (VCTS) – System Specifications and Business Model, two deliverables of interest were identified:

- D7.1 Technical Feasibility Analysis (X2Rail-3-D7.1, 2020); The most critical aspects for VCTS implementation were identified as:
  - Precise supervision of the distance and relative dynamics between the coupled vehicles (CU)
  - Fast and accurate brake control with precisely adjustable braking effort
  - Availability of suitable T2T-communication technologies and the respective frequencies
  - Reliable and continuous supervision of not only the train (CU) integrity but also the Convoy integrity

- D7.5 Analysis of the Business Model (X2Rail-3-D7.5, 2024); providing the analysis of the application of VCTS in some selected markets including the best strategy and vision which might foster the introduction of such innovative system.

### 7.2.5 Automated Pods Operation

Besides the Moving Block and Virtual Coupling, the CU running prediction used in the POMS for generating updated Operational Plans needs to consider the specific running behaviour of the CU in relation to the automatic operation of the CU.

Automatic Train Operation (ATO) is a method of operating trains automatically where the driver is not required or required for supervision at most . In the context of train control technology, ATO represents a subsystem, which performs automated functions like planned stops, speed adjustments, door openings and closings, usually performed manually by the driver. Since the Pods assigned to CU running as a single vehicle or in a Convoy will not be controlled by drivers, an Automatic Pods Operation (APO) is to be defined an implemented accordingly. As in previous sections, the term 'train' in ATO is to be interpreted as a single CU or a Convoy of CU.

- According to the International Association of Public Transport (UITP), different degrees of automation, called Grades of Automation (GoA) are defined for the ATO, going up to GoA 4 which indicates a fully automatic control of a train without any on-board staff. In the following, a short explanation of the different GoA is given GoA 0: The train is operated on-sight i.e., no automation.
- GoA 1: The train is operated manually by a driver who controls starting, stopping, operation of doors and handling of emergencies or sudden diversions.
- GoA 2: The train is operated semi-automatically; starting and stopping are automated but a driver still operates the doors manually and drives the train, if required.
- GoA 3: The train is operating without a driver, but train staff still operates the doors manually and takes over driving the train in case of emergencies.
- GoA 4: The train is running unattended; starting and stopping as well as operation of the doors are fully automated.

Following the requirement for the Pods system to operate automatically, it is obvious that the GoA 4 is the grade of automation of relevance for the APO.

In more detail, the Grade of Automation 4 for the APO would require

- All operations of GoA 2:
    - Accelerating and stopping the CU/Convoy
    - Supervising
    - speed and braking when exceeding speed limits (similar to Automated Train Protection for trains)
    - Determining the CU/Convoy's position on the track

    - Transmitting data from the CU/Convoy to a wayside monitoring system and requesting authorization for the route
- All operations of GoA 3:
    - System monitors all platform elements
    - System stops the CU/Convoy if there are obstructions which are partially or fully on track
    - System protects crews at a track level
- System opens and closes doors of the TU attached to the CU (s)
- System determines if it is safe to depart the CU/Convoy from a station
- Systems performs self-tests
- System detects emergency situations
- System can take the CU/Convoy in and out of the depot

The core conceptual and specification work for the ATO up to today was performed in previous public funded projects in the context of national funding programmes and also the Shift2Rail programme. A number of relevant deliverables are to be noted specifically in this context.

Shift2Rail, Innovation Programme (IP) 2, Technical Demonstrator TD 2.2 ATO up to GoA 4 (unattended operation for trains).

X2Rail-1 (2015) Start-up activities for Advanced Signalling and Automation Systems:

- WP 4: ATO over ETCS
- This WP addressed the Automatic Train Operation over ETCS (European Train Control System). It started from the current experience in urban applications and some existing main line applications in order to address all the market segments of Main Lines (High Speed Line, Low Traffic/Regional Lines, Urban/Suburban, Freight) and to extend these applications from fenced systems (urban rail) to open systems (single EU Railway Area). The work focussed on GoA 2 starting from inputs from Ten-T 3rd call (ATO over ETCS - Technical Interoperability Requirement for GoA 2). The operation concepts were updated according to the results of the European NGTC project and existing standard IEC 62290-2. A feasibility study and preliminary design were delivered for GoA 3 and GoA 4 solutions (incl. IEC 62267).
    - D4.1 (X2Rail-1-D4.1, 2020): ATO over ETCS – GoA 2 Specification; this document contains the ATO over ETCS GoA 2 specifications which were used for the Reference Test Bench and the Pilot Tests developed and demonstrated in X2Rail-1 Work Package 4.

D4.3 (X2Rail-1-D4.3, 2019): AoE_GoA 3_4_Preliminary_Specification; includes the System Requirements Specification for ATO GoA 3_4. In this document the different sections are focussing on description of the different operational contexts, related actors, logical architecture with its main logical components and their interfaces, functions or roles performed by the actors and the logical components, UC, and the data exchanged through the logical interfaces.

X2Rail-4(2019) Advanced signalling and automation system - Completion of activities for enhanced automation systems, train integrity, traffic management evolution and smart object controllers:

- WP 3: ATO up to GoA 4 Specification

- The specification was performed in two steps associated with two separate activities, GoA 2 specification (quick win) and GoA 3/4 specification (preliminary and built upon GoA 2). The resulting specification documents were submitted to the ERA.
    - D3.1 GoA 2 Specification (X2Rail-4-D3.1, 2022)
- WP 4: Development of prototypes; not directly relevant for the Pod Systems concept.
- WP 5: Testing of prototypes; not directly relevant for the Pod Systems concept. However, the preliminary version of the GoA 3/4 Specification provided in WP 3 was updated with the experiences gathered from development and testing of the prototypes to build the first release version of it.
    - D5.1 GoA 3/4 Specification v1.0.0 (X2Rail-4-D5.1, 2023)

Shift2Rail, Innovation Programme (IP) 5 Technologies for Sustainable & Attractive European Rail Freight; TD 5 -3 Operation:

SMART (2015): Smart Automation of Rail Transport: The SMART project focussed on development of a prototype of an autonomous obstacle detection system, and a real-time marshalling yard management system. Relevant deliverables are (SMART, 2015):

- D1.1 Obstacle Detection System Requirements Specification
- D4.1 Overall framework architecture and list of requirements
- D5.3 Algorithms for modelling and real time optimization of marshalling process
- D6.1 Architectural design of the information system for supervision

SMART2 (2019): Advanced integrated obstacle and track intrusion detection system for smart automation of rail transport: The project built on top of the results of the project SMART by advancement, innovation and implementation of SMART2 on-board long-range all-weather obstacle detection (OD) and track intrusion detection (TID) system. Two new systems were researched and developed: advanced SMART2 trackside (TS) /airborne OD& TID system. All three systems were integrated into a holistic OD& TDI system via interfaces to central Decision Support System (DSS). Relevant deliverables (SMART2, 2019):

- D1.1 Freight specific use cases for obstacle detection and track intrusion systems
- D1.2 Analysis of requirements and definition of specifications for obst detection & track intrusion

Shift2Rail, Innovation Programme (IP) X Complementary Projects:

TAURO (2020): Technologies for the AUtonomous Rail Operation: This project identified, analysed and finally proposed suitable founding technologies for the future European automated and autonomous rail transport to be further developed, certified and deployed through the activities planned for the European Partnership for Transforming Europe’s Rail System. To achieve this, the partners have broken the work down into four technical WPs that each deal with separate system elements contributing to the goal of the project. These four areas of work are:

- Environment perception for automation

- Remote driving and command
- Automatic status monitoring and diagnostic for autonomous trains
- Technologies supporting migration to ATO over ETCS

Relevant deliverables (TAURO, 2020):

- D1.1 - Specification and Design of a Common Database for Rail AI Training and Testing
- D1.3 - Digital maps for new train location technologies
- D1.5 - Requirement specification for indoor environment perception systems
- D2.1 - Specification of the Remote Driving and Command

Nationally funded project safe.trAIn (SAFE-TRAIN, 2022); Germany: Development of AI-Enabled Automated Trains : This project aimed to lay the foundations for the safe use of AI for driverless rail vehicles and thus address the greatest technological challenge for the introduction of driverless regional transport.

- WP 3: Safety Architecture for AI-based Functions in GoA 4 Operation
- This WP covered the development of an integrated basis for requirements and architecture as well as overall system implementation (system under test) and the safety case for the AI-based object detection of a driverless regional train. It was subdivided into 4 topic areas:
  - Requirements
    - Based on results from WP 1 and findings from research projects at the national level (e.g., ATO-Risk, ATO-Sense) and at the European level (e.g., X2Rail, TAURO), the requirements to be met by a driverless regional train with an AI-based object detection system will be collected, prioritized, and integrated into an overall structure. This will be supplemented by the definition of the operational design domain, in which the environmental conditions (operational, climatic and weather-related constraints), including the persons, obstacles and systems interacting with the system, are recorded.
  - Architecture
    - Based on the defined requirements, an architecture for a "driverless regional train" was drawn up for the object detection system, the sensor fusion and the sensor system, in which the interfaces between the functions were defined at all 4 architecture levels and the RAMS requirements (reliability, availability, maintainability and safety) as well as NFRs (non-functional requirements) were taken into consideration.
  - Implementation
    - In the third subarea of WP3, the overall system was implemented and integrated as a software solution. The ML functions/models provided for in the architecture were implemented here. These formed the basis for the methods and metrics developed in WP 2 for investigating the trustworthiness and validation. In addition, a hardware demonstrator was developed and tested for the sensor system.
  - Safety case procedure
    - The final subarea covered the development of a concept for a safety case for a driverless regional train with an AI-based object detection system, combining the results of the upstream activities in the area of requirements, architecture and

metrics. The structure of the safety case served as the basis for evaluation in the virtual test environment (WP 4) and subsequent assessment.

The work on the Automated Train Operation topic is continued in the current EU-Rail Programme in the Flagship Area 2 (Digital & Automated up to Autonomous Train Operations) within the Project R2DATO, WP 4 to 12 and others. The FA 2 projects are cooperating with EU-Rail's System Pillar for sector involvement aiming on EU- harmonized specifications which will be relevant for the FA 7 projects developing the Pod system.

### 7.2.6 Moving Block signalling system

In section 7.2.4, the current status of conceptual work for Virtual Coupling (VC) was shown and introduced with respect to applying it to the Pods operations. The CU running in a Convoy are automatically synchronizing and aligning their braking activities while maintaining safe braking distances between them. However, Convoys of CU or single CU running on the track sections of a railway network are to be protected by signalling systems in a classical manner with respect to the European Traffic Management and Train Control System (ERTMS/ETCS). The ERTMS/ETCS specifications have become part of, or are referred to, the TSI for (railway) control-command systems. As such, they form part of the European legislation and are managed by the European Union Agency for Railways (ERA), see also ERA Library (ERTMS, 2024).

In the ERTMS/ETCS LEVELS factsheet#2 issued by the ERTMS project in 2024, we find the following explanation:

Currently, there are four ERTMS/ETCS levels (L0, LNTC, L1 and L2). The different ERTMS/ETCS application levels are a way to express the possible operating relationships between track and train. Level definitions are related to the trackside equipment used, to the way trackside information reaches the on-board units, and to which functions are processed in the trackside and in the on-board equipment respectively. Different levels have been defined to allow each individual railway administration to select the appropriate ERTMS/ETCS application trackside, according to their strategies, to their trackside infrastructure and to the required performance. Furthermore, the different application levels permit the interfacing of individual signalling systems, and train control systems to ERTMS/ETCS. The ERTMS/ETCS "levels" define different uses of ETCS as a train control system, ranging from track to train communications (Level 1) to continuous communications between the train and the Radio Block Centre (Level 2). Level 2 fixed unit / moving block, formerly Level 3 which has been merged into Level 2 with the CCS TSI 2023, enhances ETCS' potential. This enhancement results in increased capacity, reduced costs by eliminating trackside equipment for train detection, and efficiency gains through heightened automation. ERTMS/ETCS Level 0 is used for operation on non-equipped (unfitted) lines or on lines equipped with train control system(s), but operation under their supervision is currently not possible. In ERTMS/ETCS Level NTC train equipped with ERTMS/ETCS operates on a line equipped with a national system.' (ERTMS, 2024).

In the Pods system context, the term 'train' used above can be assumed to refer to one or multiple virtually coupled CU for the Pods. In principle, the Pods system can operate with any block-based signalling system. However, a maximum efficiency of the Pods system is expected when using moving blocks as e.g., in *ERTMS/ETCS Level 2 moving block* instead of fixed blocks.

Important conceptual work on the moving block operations topic has been performed in the recent years in the Shift2Rail programme context. Figure 55 shows the overall flow of the work within Shift2Rail's Technical Demonstrator *TD2.3 Moving Block* in the projects X2Rail-1 (WP 5), X2Rail-3 (WP 4) and X2Rail-5 (WP 4).

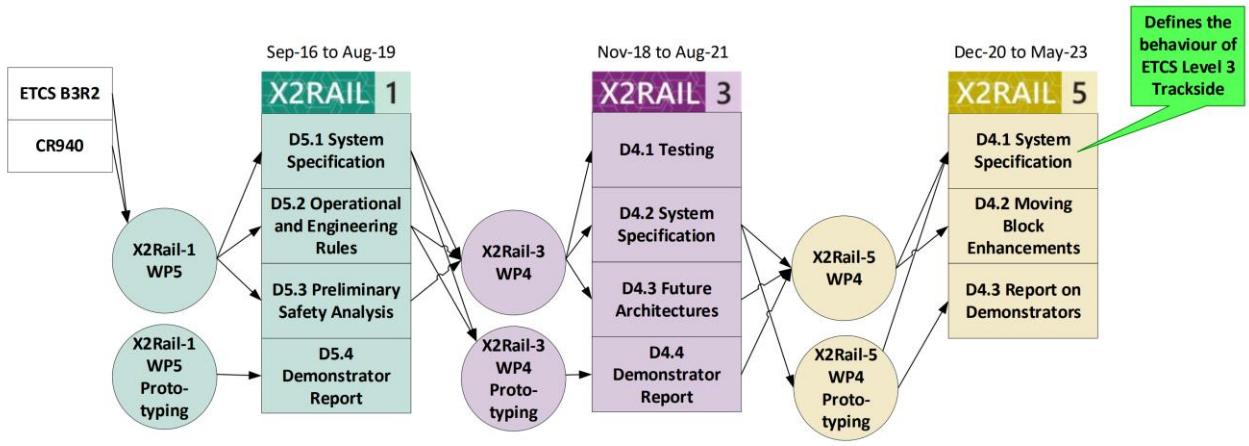



**Figure 55: Overview of TD2.3 Moving Block in X2Rail-1, X2Rail-3 and X2Rail-5 (X2Rail-5-D4.1, 2022)**

In the X2Rail-5 deliverable *D4.1 Part 1 Introduction* (X2Rail-5-D4.1, 2022), an overview is given about the work in the three projects X2Rail-1, X2Rail-3 and X2Rail-5.
The work in X2Rail-5 resulted in specifications of

- System Definition
- System Requirements (including the concepts of Train Location, Track Status and Reserved Status)
- Operational Rules
- Engineering Rules
- a Preliminary Hazard Analysis

for the ETCS Level 2 moving block (former Level 3) system, relative to an ETCS Level 2 fixed block system.

The work on the Moving Block topic is continued in the current EU-Rail Programme in the Flagship Area 2 (Digital & Automated up to Autonomous Train Operations) within the Project R2DATO, WPs 13 to 16.

### 7.2.7 Freight specific approaches

#### 7.2.7.1 Self-driving freight waggons

In the following, two examples of innovations for providing future oriented solutions for specifically rail freight operations will be introduced and discussed.

The first autonomously driving freight wagon was realised in 2003 with the CargoMover. This idea of autonomous freight wagons has been picked up by creative start-ups such as e.g., *Parallel Systems* in the U.S. (Parallel Systems, 2023). The suggested autonomous rail freight wagons carry a standard container whereas the wagon itself is equipped with battery storage, electric motors, and sensors for autonomous driving. The concept by Parallel Systems is at its second prototyping stage also implementing a first solution to dynamic virtual splitting and coupling to form platoons in later operations. A comparison with other systems can be found in Pods4Rail D2.2, 2024.

The major issues regarding this approach are

- The quality of obstacle detection is questionable because of the technical approach, all sensors will have to be placed under the freight load (container) leading to significant restrictions in environment supervision.
- Reliability at all weather conditions.
- Currently, no multimodality is foreseen.
- Massive number of charge/discharge cycles could impede vehicle operation and availability.
- For the time being, the CAPEX and OPEX are deemed to be highly unattractive in relation to the gained advantages.

Another concept in this area used by the Nevomo features their *MagRail Booster* (NEVOMO, 2023) which is based on retrofitted rolling stock for freight combined with electromagnetic propulsion using a linear motor that enables independent movement without a locomotive. In 2023, tests of such a system started on a conventional railway track section in Nowa Sarzyna (Poland). The modified wagons are expected to operate autonomously, either in platoons or individually. They also will feature automated splitting and joining with wagons. The wagons will be able to make use of existing train protection technology to ensure safe operations
The capability for fully autonomous operation is currently not described. Also, in this case, multi-modality is not considered. CAPEX and OPEX can be seen as reasonable since the concept is rather based on retrofitting of existing than on investing in new vehicles. However, the linear motor-based propulsion may be an issue hindering the introduction of such a system in larger scales.

These and similar existing or new activities will need to be observed in the next years to ensure a best outcome for overall Pods operations management.

### 7.2.7.2 Physical Internet

Another area of innovation in freight rail operations is the Physical Internet (PI). According to (Montreuil, 2012), the concept of the PI in logistics refers to an open global logistics system founded on physical, digital, and operational interconnectivity, through encapsulation, interfaces and protocols. The overall idea is to reverse the unsustainability situation existing in today's logistic systems by replacing current logistical models. This different approach could lead to an increase of global logistic performance. It is based on applying concepts from internet-based data transfer to the logistics processes. This primarily considers the abstraction of the Internet packet-based transfer featuring the processing by different systems and through various networks because of a standardized packet definition and separation between the content and the control related parts of a packet. Applied to logistical networks, this would involve encapsulating freight in smart, eco-friendly and modular containers of different sizes and types. These modular and composite containers (*π-containers*) would be continuously monitored and routed, exploiting their digital interconnection through the Internet of Things (IoT).

The concept also foresees to make use of globally unique IDs and tags for the containers contributes to identification, integrity, routing, conditioning, monitoring, traceability and security through the PI.

A number of national and international public funded project activities in relation to the PI have been performed in the last years to assess different options of implementations with different focuses. Some of them addressed the area of collaborative planning of flexible logistic chains, some other were considering road-based transportation only since the highest gains of efficiency are expected for the road-based transportation. The implementation of a Road-Based Physical Internet (RBPI) involving a limited scope of modifications of existing vehicles is expected to become reality until 2030.

Since 2015, the research Alliance for Logistics Innovation through Collaboration in Europe (ALICE, 2015) is working on implementing the PI-Roadmap which is seen an important element towards $CO_2$ emission reduction targets of the EU.

## 7.2.8 Operational description of the transshipment process

For a safe and seamless deployment of the Pod system and the handling of the CU and TU, there is a need for standardised information about the transfer process and definitions. Information like when does the transshipment process start and end, is crucial for a smooth operation within the transport system. Also, it is relevant to define the separate steps of the transshipment process, to coordinate the interactions between CU, TU and HS and their interfaces smoothly. This chapter is introducing a step-by-step process description and definition of relevant process elements. This should only be a draft, that can be improved in following tasks.

**Description of the transshipment area and CU types:**

The HS is made to load and unload TU from CU on different transport modes and by that making the supermodal transport system possible. This requires the definition of the relevant CU types and operational areas of the HS. To understand how the transshipment area could look like and how the HS operates during the loading and unloading process, Table 48 introduces some definitions, that could be used for further developments. For signalling and safety measures, each CU type has a specific ID, to give information about its type, size and available interfaces. Also, the TU have a specific ID to inform about their type, size, interfaces and the load that is carried.

**Table 48: Description of the transshipment area and CU types**

| Term | Short | Description |
|---|---|---|
| Supply Carrier Unit | SC | CU, that delivers a TU (full CU) |
| Receiving Carrier Unit | RC | CU, that receives a TU (empty CU) |
| Transshipment Area | TA | Area within range of HS with specific safety measures |
| Supply Zone | SZ | Area within range of HS to unload the Supply CU. |
| Receiving Zone | RZ | Area within range of HS to load the Receiving CU. |
| Handling Zone | HZ | Operation and movement area dedicated to the HS. |
| Storage Area | SA | Area to store unused CU and TU. It can be within the range of the HS or a separate system can be used. |

The transshipment area is the dedicated area inside the transport system, where the transshipment process can take place. This area differs to the rest of the transport system in that case, that CU can arrive and depart for the purpose of loading and unloading. In the transshipment area, specific safety measures can be applied due to the existence of the HS as well as the potential movement of passengers. Figure 56 shows a schematic top view of the transshipment area and its relevant sub zones.

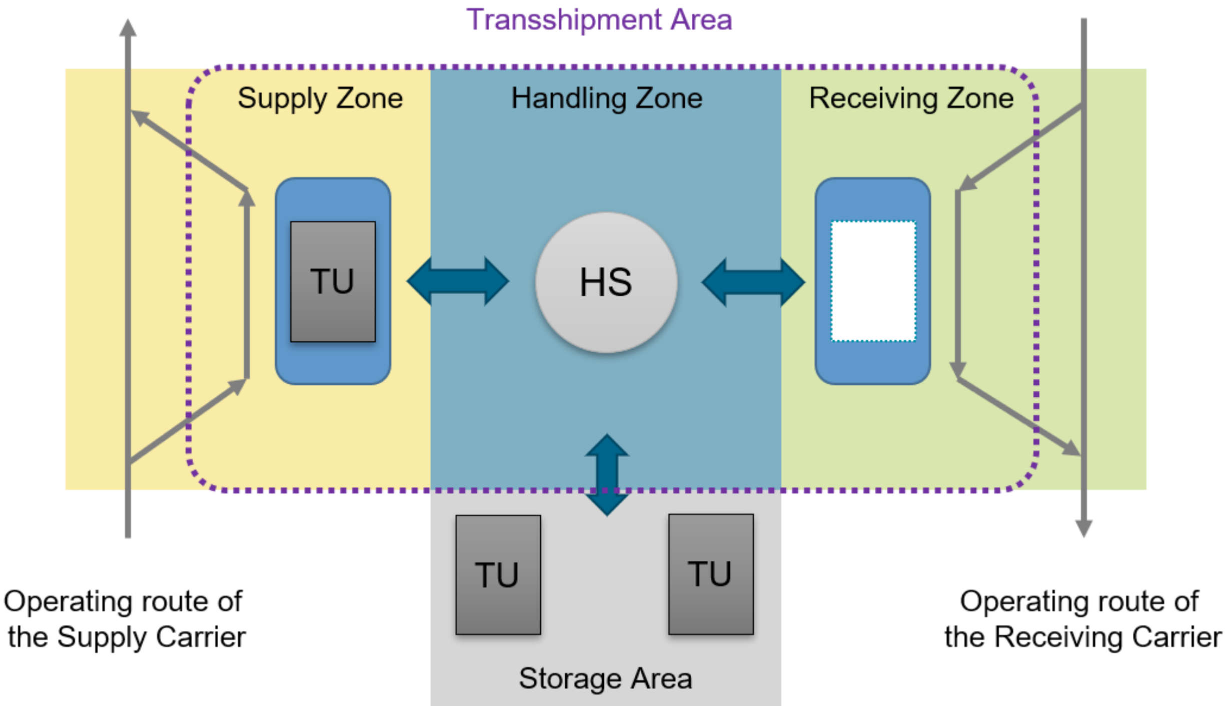



**Figure 56: Schematic view of the Transshipment Area**

**Description of the transshipment process phases and steps:**

Table 49 shows a possible chain of actions that can be followed within the transshipment process. The first phase (step 1a - 6a) is describing the arrival and positioning of the supplying CU. It is used to position the CU correctly and to identify the type of TU and load that will be transferred. As a result, the supplying CU is ready to unload. The second phase (step 1b - 4b) is the arrival and positioning of the receiving CU. As a result, the receiving CU is ready to load. In the third phase (step 7 - 11), the HS can unload the TU from the supplying CU. The fourth phase (step 12 - 14) is loading the TU to the receiving CU. The last phase (step 15 - 19) is to return the HS to its standby position and to release both CU. The system is then ready for the next cycle.

**Table 49: Description of the transshipment process steps**

| Phase | Step | Description of Step | State of Activity (1 = active, 0 = not active) |
|---|---|---|---|
| 1 | 1a | Supply CU is entering the transfer zone (= start of process) | CU: 1 - Handling System: 0 |
| | 2a | Supply CU has stopped in right position | CU: 1 - Handling System: 0 |
| | 3a | Supply CU has been identified (Type and ID of CU) | CU: 1 - Handling System: 0 |
| | 4a | TU has been identified (Type and ID of TU) | CU: 1 - Handling System: 0 |
| | 5a | Load has been identified (Indicators: Type of load, weight, weight distribution, priority for transfer) | CU: 1 - Handling System: 0 |
| | 6a | **Supply CU is ready to unload (= successfully unlocked TU)** | CU: 1 - Handling System: 0 |
| 2 | 1b | Receiving CU is entering the transfer zone | CU: 1 - Handling System: 0 |
| | 2b | Receiving CU has stopped in right position | CU: 1 - Handling System: 0 |
| | 3b | Receiving CU has been identified (Type and ID of CU) | CU: 1 - Handling System: 0 |
| | 4b | **Receiving CU is ready to load (coupling mechanism opened)** | CU: 1 - Handling System: 0 |
| 3 | 7 | Handling System has adapted to TU | CU: 0 - Handling System: 1 |
| | 8 | Handling System is connecting to TU | CU: 0 - Handling System: 1 |
| | 9 | Handling System successfully connected to TU | CU: 0 - Handling System: 1 |
| | 10 | Handling System is unloading TU | CU: 0 - Handling System: 1 |
| | 11 | **Handling System successfully unloaded TU** | CU: 0 - Handling System: 1 |
| 4 | 12 | Handling System is loading TU | CU: 0 - Handling System: 1 |
| | 13 | CU successfully locked TU (mechanical coupling --> electric coupling) | CU: 1 - Handling System: 0 |
| | 14 | **Handling System successfully loaded TU** | CU: 0 - Handling System: 1 |
| 5 | 15 | Handling System is moving back to waiting position | CU: 0 - Handling System: 1 |
| | 16 | Handling System successfully moved back to waiting position | CU: 0 - Handling System: 1 |
| | 17 | Supply CU may leave transfer zone | CU: 1 - Handling System: 0 |
| | 18 | Receiving CU may leave transfer zone | CU: 1 - Handling System: 0 |
| | 19 | **Handling System is ready for next transshipment (= end of Process)** | CU: 0 - Handling System: 1 |

Each phase is shown here as chronological actions. Depending on the safety concept of the transshipment, it could also be possible to allow parallel actions (e.g. parallel movement of all CU and the HS). How each element is allowed to move depends also on the operating system and the installed control mechanisms. These details cannot be discussed here. Since the Pod system will have a high degree of automation it would be recommended to allow parallel movements for better efficiency of the system. These aspects are recommended to discuss in future developments.

**Signalling during transshipment**

During the transshipment process, every system element (i.e., Supply CU, Receiving CU, HS, TU) is indicating the process status with specific signals. Those signals will be used for example to indicate the state “ready to unload” by the supplying CU. The signal indicates that the locking mechanism is opened and the HS is allowed to connect to the TU. The way of how signals will be transferred and processed is not part of this task.

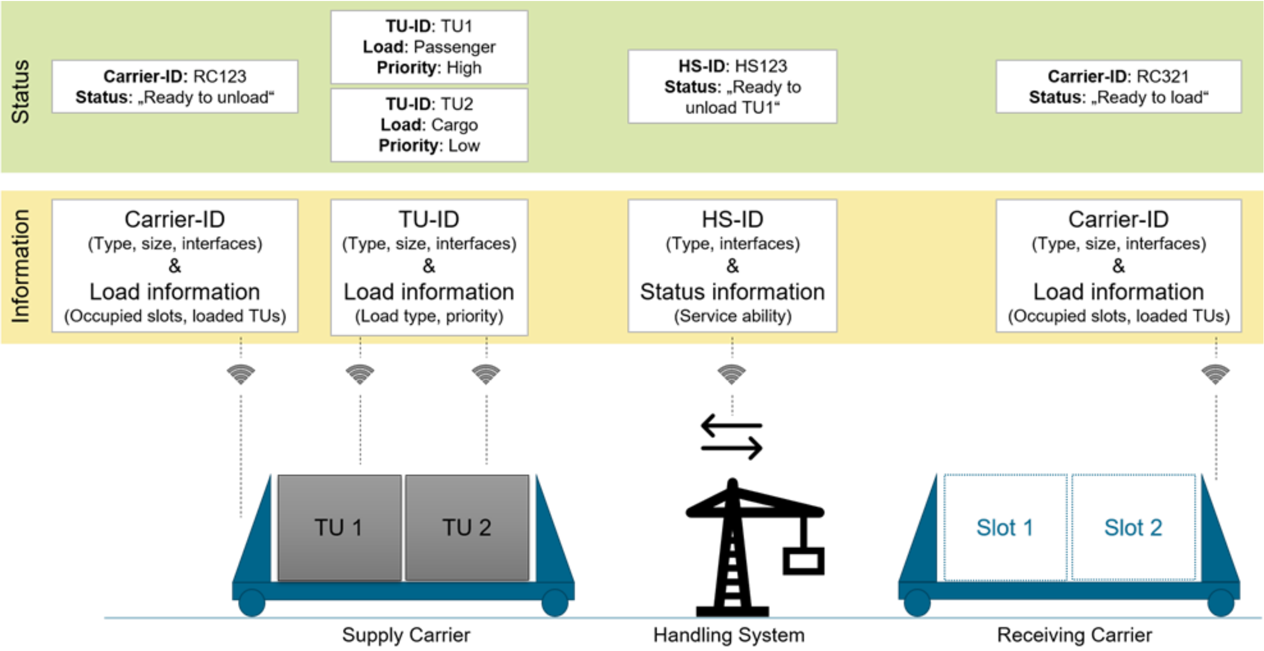



**Figure 57: Example of signal information and status reports of relevant system elements during the transshipment process**

In the example shown in Figure 57, the Supply CU is loaded with two TU, one of them with a higher priority. The Supply CU sends its ID and the information that it is fully loaded. After the correct positioning inside the Supply Zone it sends the signal "Ready to unload". Both TU also send their ID with load information and priority status. After the Receiving CU arrived in the Receiving Zone, its CU-ID together with the information, that 2 slots are still available are being sent. After the Receiving CU prepared for loading, it sends the status "Ready to load". The HS accepts all those signals, adapts to the interfaces of TU1 and sends the status "Ready to unload TU1". Now the transshipment process can be done.

### 7.2.9 Integration of operational and mobility information

The Mobility Management System as the traveller facing part of the system, retrieves operational information from the TMS to mainly enable its journey planning functionality. It makes use of the timetable information, the real-time information including operational short-notice changes and incident information from the TMS. The PIS may also contain its own incident management functionality to edit the incident information from the TMS to be more traveller friendly and to add incident information from outside the scope of the TMS which still impact the travel experience of the travellers. All this information is used to respond to journey planning requests from travellers and to keep travellers informed during their trips.

In addition to the PIS, the Mobility Management System provides a Booking & Ticketing system which enables travellers to purchase tickets to be eligible to go on the planned trips. Booking & Ticketing enable the PIS to include the ticket information as offers during the journey planning to provide travellers with appropriate information for the proposed trips. Furthermore, the traveller may choose to pay the ticket up front before going on the trip or the traveller chooses to use the XiXo functionality. XiXo (Check-In Check-Out, Check-In Assisted Be-Out, or Be-In Be-Out) describes various models of at least partially automated recognition of the itinerary of the traveller as they go on their trips. After agreeing to this ticketing model, the traveller will be charged after their trips with the optimal tickets for their trips in a defined past time window. For the trip recognition, the XiXo requires the Journey Planning functionality of the PIS to reconstruct the trip with logged trip meta information such as regular position data of the traveller.

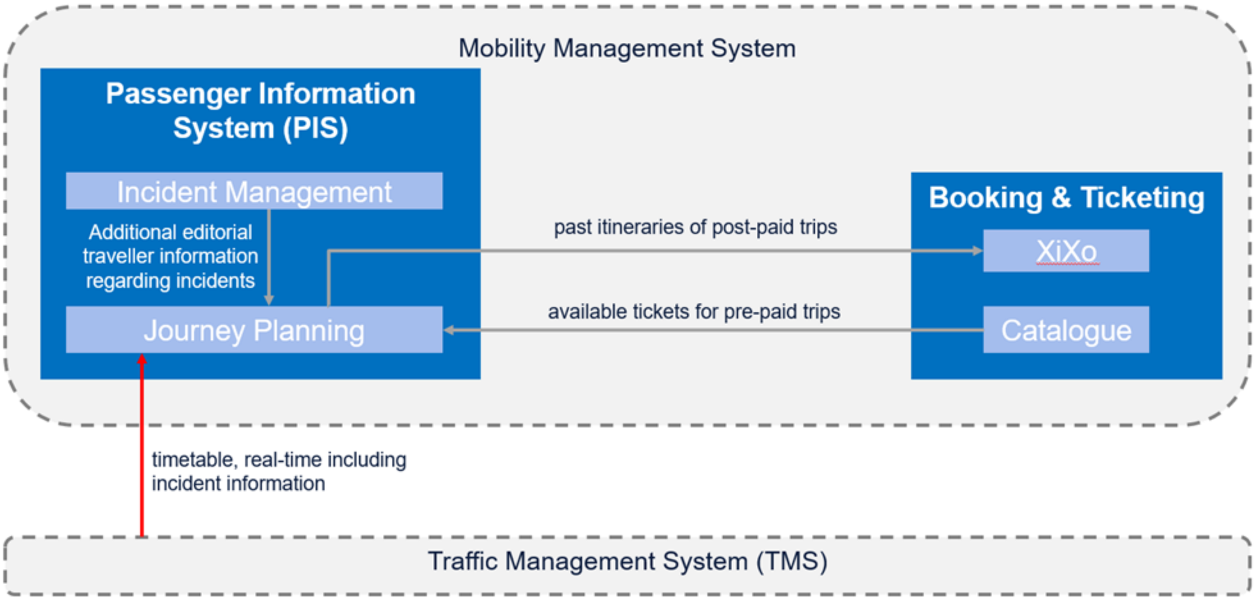



**Figure 58: Processes Mobility Management System**

The described processes already work in the public transport domain. Pods may be included in the information that the PIS receives from the TMS in regards to timetable, real-time, and incident information. The Journey Planning functionality may consider Pods to be a kind of demand responsive transport (DRT) which also already exist in the public transport domain. There may be potential to improve the modelling of exchanges of CU in the journey planning to better reflect the Pods operation in practice with Pod specific requirements and information. The incident management functionality of the PIS may take advantage of the existing support through the Journey Planning and could be further extended to enable more Pod specific traveller information. If the Pod system is operated entirely by one operator, then the booking & ticketing processes benefits from the reduction of complexity. The catalogue of tickets may make use of the "exchange-less" nature in which the travellers remain in the Pod until their final destination to come up with new ticket options. XiXo could take even more advantage of the lowered complexity regarding the trip reconstructions for the post-payment because current ambiguities mainly during exchanges would not occur.

# 8 Conclusions

Building on the previous work, **chapter 5** discusses the basic design for passenger and freight transport. Based on the UC considerations, a 5 ft, 10 ft and 20 ft passenger unit and a 10 ft and 20 ft cargo unit seem to be the best possible standard TU sizes for the Pod system. The 5 ft TU is mainly used for special requirements, such as access and exit at a conventional platform. 10 ft and 20 ft for freight transport arise from existing container solutions in road and sea freight transport. The loading capacity on the train CU can be limited to 25 ft, meanwhile a Road-CU could load up to 10 ft, with several options for arranging different TU. A combined transport of freight and passenger on a train CU is also possible. The TU can be characterized by a safe and reliable design, with the HVAC system being the main energy consumer in a TU. All results from chapter 5 will be further developed in detail in the following WP 8 and technical reviews will be carried out.

In **chapter 6**, the required interfaces of a TU to all peripheral systems were analysed and elaborated. Four relevant interfaces were defined for this purpose: TU to CU / HS / TU / Storage System. These interfaces have a decisive influence on the overall concept and packaging as well as the operating system due to unique handling processes and component assemblies. Based on given requirements and new analysis, various types of interface solutions were evaluated and systematically assessed.

It was found out, that the transshipment process can be grouped into four different scenarios, covered by different expected technologies. In order to use a HS that is as standardised as possible despite these different scenarios and requirements, it is recommended to only place down a TU on the ground for special applications (e.g. PRM-transport) and only in road applications. The TU could then carry an integrated lifting mechanism. For transshipping a TU between rail, road and other domains, as well as the storage system, two different types of interfaces are suggested. On the one hand fork pockets, whereby the HS (equipped with scalable forks) could load the TU and on the other hand via corner castings in the roof area. It was found out that a transfer between rail and road should only take place in stations and not on the open track, so that the complexity of the system might be minimised and a solution compatible with existing HS can be created. Nevertheless, if flexible non-station-based transshipment should be done, other solutions like direct transshipment from CU to CU are feasible. Within this task only technical aspects were analysed; therefore, it is highly suggested to assess passenger acceptance for the chosen solutions of this proposal.

The corner castings and twistlock solution used in the roof can also be used in the floor structure to mechanically fix the TU to the CU. This enables compatibility with existing freight containers. While the TU only has to provide the corner castings, the CU (development in WP 14) is suggested to provide the fully automatic twistlocks. These should be retractable and only raised and activated when required. A possible twistlock pattern was calculated for this purpose in this task. This shows that the distances between the individual TU deviate to a limited extent. However, the twistlocks don´t have to be movable, regardless of the configuration, and the smallest possible number of twistlocks can be provided. The distance between two TU could lay between 25 mm and 40 mm. Although a mechanical connection between a TU and another is not expected to be necessary, a rubber lip should be provided to close the space and also to guarantee a tight and secure transition between two TU.

No clear optimum solution for the electrical connection was found in this WP. For the following concept development, the combination of charging connectors and HVIL connectors was expected to achieve a high coverage of applications, also in accordance with the defined energy balance parameters from chapter 5. The signal transmission for the Pods4Rail concept should be wireless according to the evaluation results. This type of connection is also suggested for the TU-TU interface, as no electrical energy needs to be exchanged there, only data and signals.

The proposed Pods operation system concept, developed in **chapter 7**, is based on the UC and high-level requirements defined in WP 4 and addresses essential system modules and operational processes required for operating the Pods. These comprise the areas of interfaces, traffic coordination for the CU, TU/CU and network management. It is shown how the operational modules and processes could be working in the overall system including the necessary information exchanges to ensure smooth operations also considering aspects of safety critical situations. TSO related needs with regard to TU management and especially associated logistics networks used by freight TSO, have been addressed by the need for active participation of the TSO in the operational planning and management process. The Pods coordination and network management is focussing on rail since it involves more complex operational, technical and organizational aspects to be considered than other modes like waterways or road.

It is expected that other ongoing project activities related to new transport systems will need to be further monitored to support a fast and efficient prototyping of the operational constituents for the future Pods network operations.

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# Appendices

**Handling System evaluation process (see chapter 6.2)**

Relevant criteria are being derived based on the functional requirements, given in Table A1. The weighting rating is given in percent. It is used as a multiplication factor for the evaluation results.

**Table A1: Evaluation criteria for evaluation process**

| **Evaluation criteria for Handling Systems** | **Explanation** | **Weighting of criteria (Multiplication-Factor)** |
|---|---|---|
| Mobility freedom | Independent of stations or station-based (fixed stations = 1, "flexible station (e.g. forklift) = 2, usable everywhere = 5) | 14% |
| Complexity of CU | Part numbers, lightweight construction, costs, etc. | 6% |
| Complexity of TU | Part numbers, lightweight construction, costs, etc. | 6% |
| Complexity of the HS | Automation, costs, feasibility | 10% |
| Design Freedom of environment | E.g. Is a separate lane required? Does a safety area need to be set up? Can the area be used for other purposes at the same time? | 13% |
| Scalability | Are different TU sizes/loads covered? | 18% |
| Efficiency | Several TU can be handled simultaneously; duration of transshipment | 17% |
| Low-floor ability | Easy accessibility for passengers, freight | 8% |
| Freedom of movement of the TU with HS | How can the TU be moved with this HS? Possibility to turn, possibility to overcome long distances or high altitudes. | 10% |

Table A2: Rating of evaluation criteria for the Handling System evaluation. Each criterion in one column is compared to the criteria in one line. If the criteria in one column is more important than the criteria in the according line it will receive the number 2 (less importance = 0; same importance = 1). Green fields are filled out by the team members, grey fields are filled out automatic.

**Table A2: Pairwise comparison of the Handling System evaluation criteria**

| Pairwise comparison of the evaluation criteria | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mobility freedom | Complexity of carrier | Complexity of TU | Complexity of Handling System | Design freedom environment | Scalability | Efficiency | Low-floor ability | Movement flexibility of the TU |
| Mobility freedom | | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| Complexity of carrier | 2 | | 1 | 1 | 2 | 2 | 2 | 1 | 1 |
| Complexity of TU | 2 | 1 | | 1 | 2 | 2 | 2 | 1 | 1 |
| Complexity of Handling System | 1 | 1 | 1 | | 1 | 2 | 1 | 1 | 1 |
| Design freedom environment | 1 | 0 | 0 | 1 | | 1 | 1 | 1 | 2 |
| Scalability | 1 | 0 | 0 | 0 | 1 | | 1 | 0 | 0 |
| Efficiency | 1 | 0 | 0 | 1 | 1 | 1 | | 0 | 0 |
| Low-floor ability | 1 | 1 | 1 | 1 | 1 | 2 | 2 | | 1 |
| Movement flexibility of the TU | 1 | 1 | 1 | 1 | 0 | 2 | 2 | 1 | |
| Sum | 10 | 4 | 4 | 7 | 9 | 13 | 12 | 6 | 7 |
| **Weighting [%]** | **14%** | **6%** | **6%** | **10%** | **13%** | **18%** | **17%** | **8%** | **10%** |


**Figure A1: Examples of CU-integrated entry systems as possible solutions for overcoming the distance from loading height/ entry height towards the ground to reach easy accessibility (picture sources from manufacturers)**

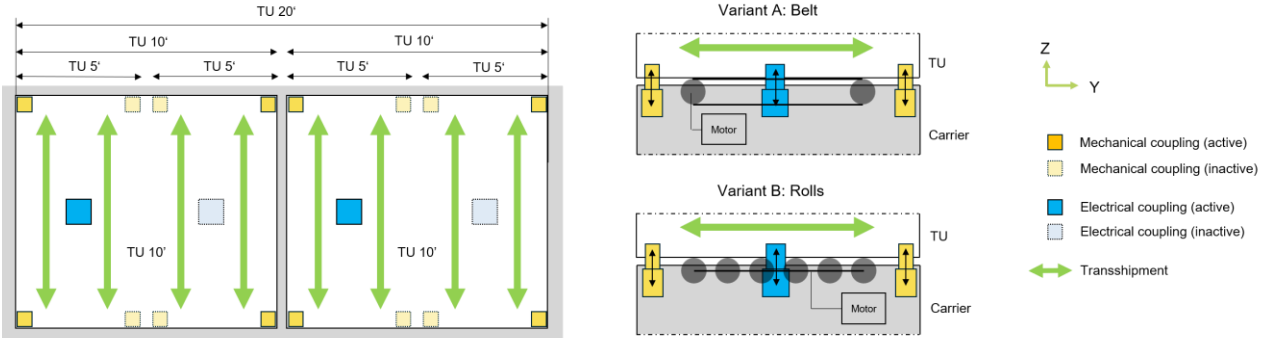



**Figure A2: Possible concept idea for CU-integrated transshipment device for horizontal movements of the TU**

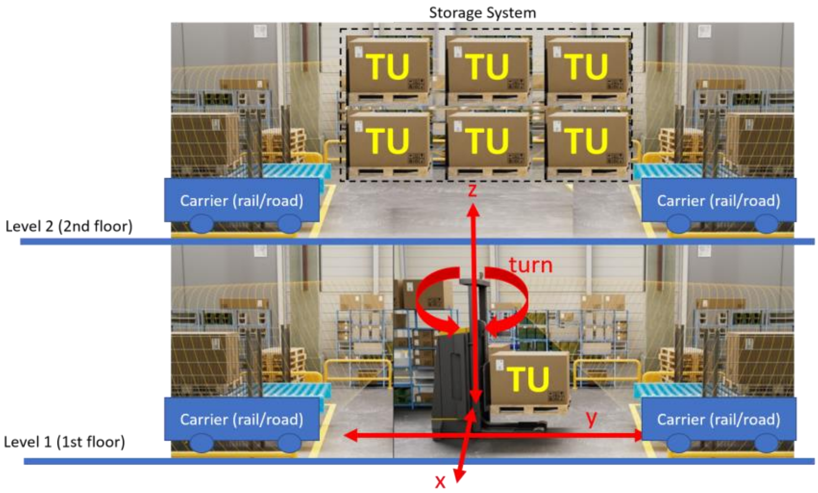



**Figure A3: Possible concept idea for the (autonomous) forklift handling and storage system**

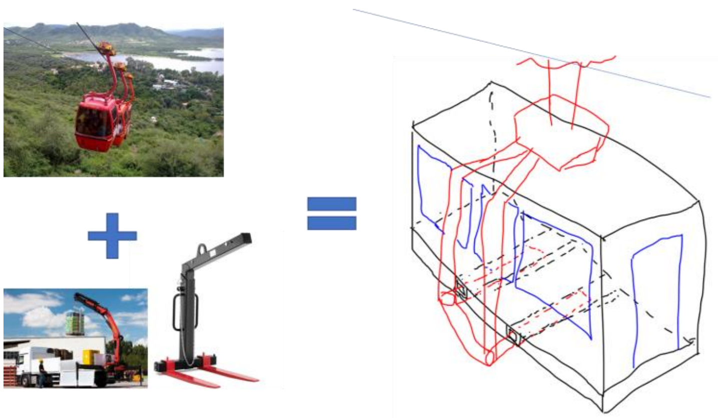


**Figure A4: Possible concept idea for ropeway adapters with the use of forklift pockets in the bottom structure**

### Table A3: Complete evaluation table of Signal Coupling Methods (SCM)

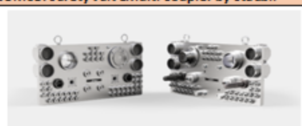
| Evaluation criteria for SCM | Importance | SCM01: Data comunication system | SCM02: HITRONIC data system optical transmissions | SCM03: Wireless Communication | SCM04: Distance measuring and positioning | SCM05: Near identification | SCM06: Next generation signalling | SCM08: Next generation positioning |
|---|---|---|---|---|---|---|---|---|
| Price/ Costs | 1 | 2 | 2 | 4 | 4 | 5 | 3 | 3 |
| Grade of automation | 2 | 3 | 3 | 4 | 4 | 3 | 5 | 5 |
| Complexity of carrier | 2 | 2 | 2 | 3 | 4 | 3 | 3 | 3 |
| Complexity of TU | 2 | 2 | 2 | 3 | 4 | 3 | 3 | 3 |
| Standardisation | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Safety | 2 | 5 | 5 | 4 | 3 | 3 | 5 | 4 |
| Maintainance | 3 | 3 | 4 | 5 | 5 | 3 | 4 | 4 |
| Communication parameters | 3 | 2 | 2 | 4 | 3 | 3 | 4 | 4 |
| **Total** | | **56** | **59** | **74** | **73** | **62** | **74** | **72** |

## Comparison of coupling methods for media

Compilation of possible coupling methods for the realization of an interface between CU and TU for the transmission of media (such as gas, water, ...):

### Table A4: Possible Coupling methods for media transmission

**COM: Coupling of Media**

| coupling method | COM01: Multi-line compact quick coupler DIN 3852 | COM02: Safety valve | COM03: Safety valveMulti Coupler by Stäubli |
|---|---|---|---|
| picture |  |  |  |
| short description | Fast connection/disconnection of several lines at once | Directly controlled safety valve for nominal pressure max 420 bar | A fully configurable multi coupling plate with several connection options. All connectors are mounted on one base plate. All opposite connectors are mounted on an opposite plate. The system has one active component inside the carrier, driven by an electric actuator, the other component is fixed to the TU. Options for media: Pneumatic, Gas, Hydraulics. |
| Source | Parker store, www: parkerstore.com | Parker store, www: parkerstore.com | https://www.staubli.com/de/de/fluid-connectors/produkte/multikupplungen/kundenspezifisch-automatik.html?f1=divisions%3Afluid-connectors%2Fexternal%2Fproduct-name%2Fmcs |
| Connectiopn types | Up to four hydraulic lines + electrical connections can be connected at the same time | Safety valve - 3/8 BSPP, connect to pipe | Great variety of standardised connectors for electricity, signals and media. Depending on individual application |
| are further connection required? | Electrical connection | No electrical connection required | no (all hard wired connections can be integrated) |
| required / recommended number | Any number according to the specific situation | Any number according to the specific situation | 1 |
| space required (l x w x h) [mm] | From 3/8 to 3/4 inch | The built-in space is small, approx. 80x80x 220 mm | Depending on configuration: Approx. 300 x 150 x 350 mm |
| location | Location according to the specific situation | Location according to the specific situation | flexible, preferred in horizontal/vertical direction in bottom structure |
| requirements for the carrier | suitable for carier | suitable for carier | Space for assembly, weather protection for pins |
| requirements for the TU | suitable for TU | suitable for TU | Space for assembly, weather protection for pins |
| Flexibility | high | high | Flexible, customizable, exchangeable |
| Complexity | high | high | Low, due to complete assembly, but more accoracy needed than wireless systems |
| Standardisation | DIN 3852 | standart solution | Not in mobility, but several use in machines |
| possible degree of automation | manual connection | fully-automatic | Fully automatic |
| Maintanance | The device requires almost no maintenance. Periodic inspection is suitable | The device requires no maintenance | - |
| Power supply requirements | The couplet requires a control voltage supply | Does not require energy supply | Depending on configuration. Low consumtion due to small electric actuator (12V/24V) |