Deliverable D 2.2
Evaluation/ Benchmark of available and conceptional multimodal mobility systems

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1. Executive Summary

The deliverable constitutes the outcome of Task 2.2 within Work-package 2. Activities of this task aim to evaluate existing multimodal and intermodal mobility systems and new approaches under development with a focus on (but not limited to) ground-bound systems.

In order to carry out the activities, first, a comprehensive overview of existing Pod systems and, with a particular focus on rail-compatible ones, handling systems and other relevant systems was carried out. Secondly, an in-depth assessment of these systems, was conducted based on a set of characterisation parameters that were defined for this project and considering four different value categories according to the guideline VDI 3780. Thirdly, an exploratory and qualitative user analysis was conducted to investigate key user acceptance aspects of a potential future Pod system.

The technological evaluation revealed that no single existing system or development concept stands out as a clear benchmark for Pods4Rail development, underscoring the significance of the research in Pods4Rail. However, several features and technologies from the reviewed concepts emerged as potential benchmarks for Pods4Rail's development, both from rail-related systems and from road and ropeway-bound designs. In alignment with this finding, the evaluation of the handling safety uncovered a noticeable shortcoming of current rail-related Pod systems.

The economical evaluation has shown that the compatibility of the systems with existing infrastructure is a critical criterion. This requirement has directly ruled out several potential benchmark concepts. Another key aspect revealed by the economic assessment is related to the optimization of efficiency, focusing on maximising both the payload-to-tare weight ratio and capacity while keeping manageable transport unit (vessel) dimensions.

The environmental evaluation revealed a clear trend showing economic efficiency and environmental quality criteria more overlapping rather than competing factors. Additionally, concerns about noise emissions could not be evaluated in this phase but should be addressed in the Pod development.

The primary challenge was limited data availability on most analysed concepts due to an early development stage of these concepts, demanding numerous parameter estimations. Additionally, while the majority of the systems analysed were of European origin—reflecting the current market landscape—our research did include some American and Asian Pod-like vehicle concepts and handling systems, such as Toyota e-Palette, Parallel Systems and RailRunner®. Nonetheless, the Asian market appears to be catching up, as evidenced by Kia's recent development of a road-bound Pod-concept published at the CES 2024 after the submission of this document. There is also an observed bias towards road-bound Pod systems in current research. The collected multimodal systems should be taken into consideration as precursor systems for the project goal of the development of an intermodal mobility system (see also D2.1 Definitions).

User interviews revealed a recurrent theme: The desire for an environment-friendly means of transport. Equally appealing was the notion of seamless mobility, entailing intermodality without the need to transition between modes, with a preference for a ground-based gliding system.

In conclusion, it can be stated that to comprehensively assess the technological landscape, it is essential that this "top-down" vision should be combined with a "bottom-up" analysis of Use Cases. The findings pave the way for future Work Packages in Pods4Rail, especially to WP4 “Socio-economical Evaluation and Requirements”, WP11 “Concept development for traffic coordination of Pods systems”, and WP13 “Concept for the handling, loading/unloading technologies”.

2. Abbreviations and acronyms

CAPEX	Capital Expenditure
CBTC	Communication Based Train Control
CCTV	Closed Circuit Television
CEN	Comité Européen de Normalisation (European Standards Committee)
EMC	Electromagnetic Compatibility
ERJU	Europe’s Rail Joint Undertaking
ERTMS	European Rail Traffic Management System
ESG	Environmental, Social, Governance guidelines
ETCS	European Train Control System
FT	Future Thinking methodology
GA	Grant agreement
GoA	Grade of Automation
LCA	Life Cycle Assessment
LIM	Linear Induction Motor
MAWP	Multi Annual Working Plan
OPEX	Operational Expenditure
P4R	Pods4Rail project
PIS	Passenger Information Systems
PM	Permanent Magnet motor
Pod	Decentralized, fully autonomous transport system
POF	Pathway of Future
R&D	Research and Development
SME	Small and Medium-sized Enterprises
TRL	Technology Readiness Level
TSI	Technical Specifications for Interoperability
TTW	Tank-To-Wheel
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
WP	Work Package
WTW	Well-To-Wheel

3. Background

The present document constitutes the Deliverable D2.2 “Evaluation/ Benchmark of available and conceptional multi-modal mobility systems” in the framework of the Flagship Area 7, project Pods4Rail as described in the EU-RAIL MAWP.

In today's era of increasing transportation demand, traditional transportation systems often fall short in meeting the requirements for faster, more cost-effective, user-centred and environmentally sustainable solutions. As a response to this pressing need, disruptive approaches have emerged as potential alternatives or complements to conventional systems. These innovative solutions emphasise the utilisation of railway systems as a sustainable mainstay for passenger and freight transportation in combination with cutting-edge technologies. While the design of operational management for such innovative system is contingent upon the system's scope and the implementation phase (assuming basic to advanced phases) defined in the later phases of the project, there is the need for utilising/ modifying as needed the existing technologies and understand the need for the missing ones. Accordingly, the deliverable aims to evaluate various multimodal mobility systems by addressing technical, economic, environmental as well as user-centred aspects with relation to passenger and freight transportation to gain important insights for future Pod-systems.

The aim of Pods4Rail is to substantiate the concept for a digitalised, decentralised mobility service with intermodal interfaces to different transport modes in order to carry out a concept for door-to-door transport chain based on rail, starting by 2025 and thus contribute to the necessary transformation of the European rail networks. Digitalisation and automation are playing an increasingly important role. Advances in technologies like autonomous driving represents an opportunity to shift the modal split towards rail transport. To gather all those important aspects, Task 2.1 defined the Pod-system (see D2.1). Task 2.2 considers this description wherever relevant.

4. Objective/ Aim

This document has been prepared to provide an essential pre-requisite of the project. In this context, Deliverable 2.2 aims to evaluate multimodal and intermodal mobility systems (focus on ground-bound systems but not limited to ground only).

Comprehensive data on multimodal and intermodal mobility systems were gathered and evaluated across a spectrum of relevant parameters. This entails an in-depth analysis of multimodal and intermodal transport systems and vehicle concepts, with a focus on road and rail vehicles, but not excluding other relevant modes of transport. The evaluation has considered a variety of evaluation criteria encompassing technical aspects, environmental and economic considerations as well as the user perspective. This assessment extends to both passenger and freight applications.

These parameters consider the ever-evolving technological trends, geographic and ecological challenges, system capacity, operational models, and more. Furthermore, they explore the contextual conditions influencing the implementation and use of intermodal transport systems for both passengers and goods, taking factors that affect both the technical and economic facets of such endeavours into account.

5. Overview of available and conceptional multimodal and intermodal mobility systems

5.1. Introduction

A key element for initiating the development of the Pod system is the preparation of an extensive overview of existing and conceptual intermodal and multimodal mobility systems (D2.1 for basic definitions). This overview compiles the systems developed in the last 20 years with potential for application in Pods4Rail, characterises various intermodal and multimodal vehicle concepts across various modes, as well as of handling systems and other related concepts and estimates the Technology Readiness Level (TRL) (HORIZON 2020, 2015) achieved. The collected multimodal systems should be taken into consideration as precursor systems for the project goal of the development of an intermodal mobility system (see also D2.1 Definitions).

It is important to note the limitations of TRL estimates of a research due to the nature of the data gathering method. Nevertheless, the TRL estimate is a relevant parameter for this overview and evaluation.

Chapter 6 of this document completes the evaluation process of the collected systems based on the characterisation parameters analysed in this chapter and on the application of the VDI 3780.

5.2. Overview of Pod systems

This overview covers a broad spectrum of Pod concepts from different transport modes and applications, which, with one exception (Siemens Cargo Mover), were introduced in the last 10 years or are still in development. The primary objective of Task 2.2. is not only to identify the best technology among intermodal systems but also to pinpoint systems or system-components that can serve as benchmarks for the technological development of the Pod system, for example from the development of new means of transport for multimodal use. The overview is organised according to the following categories of intermodal and multimodal systems:

- Existing Pod systems and those under development, with interfaces to railway.
- Existing and under development Pod systems in other transport modes, with a consideration of their potential for standardisation with other mobility modes.

Each of the collected vehicle concepts is analysed according to 29 parameters, such as transportation mode, TRL, as well as a collection of technical, economic, environmental and societal parameters. The following list shows a summary of the Pod-related concepts and their short descriptions.

Compact overview of Pod-systems and intermodal systems with interfaces to railway:

1. Siemens-moodley "one for all": Siemens' "one for all" system comprises compact transport units compatible with various carrier systems, enhancing passenger and cargo transport options across various modes: railway, road, ropeway, VTOL, Shipping. While it is in the early stages with a TRL of 1, its adaptability and compatibility are promising.

Figure 1: *Transport unit being conveyed from Road mode to Ropeway mode. Source: video credit of moodley / Siemens Mobility, Public Domain, 2022*

2. Parallel Systems: Parallel introduces an innovative transportation concept that combines autonomous electric bogies with different loading units like containers. These systems operate independently or form train-like configurations. Its TRL estimation of 5 reflects advancements in operational tests and coupling systems.

Figure 2: *Container being transported by Parallel bogies, rendering of interaction with additional bogies and aerodynamics. Source: video credit, ©Parallel Systems, 2023*

3. FlexSbus-LR (Aachen Rail Shuttle ARS): The ARS railbus is aimed both for passenger and freight transport in secondary lines and is estimated with a TRL of 4, indicating ongoing development. Special attention for Pods4Rail poses its concept of detachable chassis and passenger cell, which, in the current development, is only possible when the vehicle not in operation.

Figure 3: *Decoupling of chassis and passenger compartment design. Source: ©ifs, Benno Schiefer, RWTH Aachen University, 2022*

4. CargoMover®: CargoMover was a development in 2002 of an autonomous self-driven flat container railcar designed for door-to-door freight transport that reached a TRL of 7, reflecting extensive testing.

Figure 4: *CargoMover® derived from Windhoff 690 001 at the railway siding of the RWTH Aachen University. Source: Anselm F. Daniel on "Die Bahnseiten – dybas", ©dybas, 2003*

5. Minimodal Box (Boalloy): Minimodal was a flexible container system for small loads, whose reduced containers could be handled by a standard forklift. Despite reaching an estimate TRL of 8, it did not achieve a broad market entry and its production was discontinued.

Figure 5: *Minimodal freight system of Rail Freight Limited shown for the first time at the National Railway Museum in York in September 2002. Source: Railwatch, Public Domain, 2002*

6. Nevomo | (Cargo) MagRail: Nevomo's MagRail redevelops the additional drive mode by magnetic levitation for high-speed transportation on railway lines and serves both passengers and freight, including retrofit variants. A Pod-like cargo variant is planned. It has reached a TRL of 5 - 6, with demonstrated levitation over a substantial rail track.

Figure 6: *Nevomo's Cargo MagRail freight system visualisation. Source: video credit of Nevomo, rendering by B1 design, Public Domain, 2023*

Compact overview of Pod-systems in other transport modes:

1. U-Shift | DLR: The U-Shift electric vehicle concept offers autonomous, driverless modularity by separating the driving module from the transport capsule. It can be fitted with a passenger or with a freight capsule and has demonstrated significant progress with a TRL estimation of 5 - 7, including operational tests.

Figure 7: *U-Shift modular vehicle concept. Source: video credit of the German Aerospace Center, ©DLR Verkehr, 2020*

2. ConnX® | LEITNER: ConnX® is a ropeway-based system that seamlessly transfers cabins to autonomous track guided road carriers at stations, offering a versatile solution for both urban and challenging terrains. With a TRL estimation of 5 - 6, it has been tested in the transshipment from ropeway to road carrier.

Figure 8: *Docking of ropeway cabin onto road carrier. Source: ©LEITNER AG, 2023*

3. upBUS | RWTH Aachen: upBUS is a ropeway-based autonomous system with intermodality to road mode, autonomous and electric, with a TRL estimation of 5 - 6, already having tested the operation of the coupling system.

Figure 9: *Rendering of the upBUS in road mode. Source: RWTH Aachen University, Public Domain, 2019*

4. Rinspeed | Metrosnap: Rinspeed's MetroSnap was a concept in 2020 for autonomous electric minibus with a swap body system for both passenger and freight transport. It reached a TRL of 5 - 7.

Figure 10: *Rendering of the Rinspeed Metrosnap for the Geneva International Motorshow 2020. Source: ©Rinspeed AG, 2020*

5. Rinspeed | Snap: The Rinspeed "Snap" showcased in 2018 an intelligent chassis and Pod system primarily designed for passenger transport and with lifting transport unit (vessel), with a TRL estimation of 5 - 7.

Figure 11: *Rendering of the Rinspeed Snap for the Consumer Electronics Show 2018. Source: ©Rinspeed AG, 2018*

6. Rinspeed | Microsnap: Rinspeed MicroSnap was a concept of 2019 of an autonomous electric swap body mini-vehicle suitable for both passenger and freight, with a TRL estimation of 5 – 7.

Figure 12: *Rinspeed Microsnap for the Geneva International Motorshow 2019. Source: ©Rinspeed AG, 2019*

7. Citroën Autonomous Mobility Vision: Citroën's vision involves the Citroën Skate, a road carrier with spherical wheels, and three Pods offering unique services, combining different use cases and service in urban transportation, with a TRL ranging from 2 - 6.

Figure 13: *Citroën Skate round-wheel carrier and its three transport units Sofitel En Voyage, Citroën X JCDecaux, and Citroën X Accor. Source: ©Citroën, 2023*

8. e-Palette | Toyota: Toyota's e-Palette was a box-shaped development electric vehicle designed for autonomous Mobility as a Service, non-detachable "on the move". It reached an estimated TRL of 6.

Figure 14: *Rendering of the Toyota e-Palette. Source: ©Toyota, 2018*

9. Schaeffler Mover 1.0 | Poschwatta: Schaeffler's Rolling Chassis is a flexible and scalable platform for driverless road-bound transport, suitable for passenger, cargo, and special applications, with a TRL ranging from 2 - 7, including demonstrators with road approval.

Figure 15: *Visualisation of Schaeffler's modular concept with different cargo transport units, a passenger version of the rolling chassis and the drone variant. Source: ©Poschwatta, 2018*

10. Tesla's travel-Pod system | Fábio Martins: The conceptual Tesla Pod system presents an electric road-bound carrier that accommodates three different Pods for public, private, and freight transport, with a TRL estimation of 1 - 2, representing its early-stage design study.

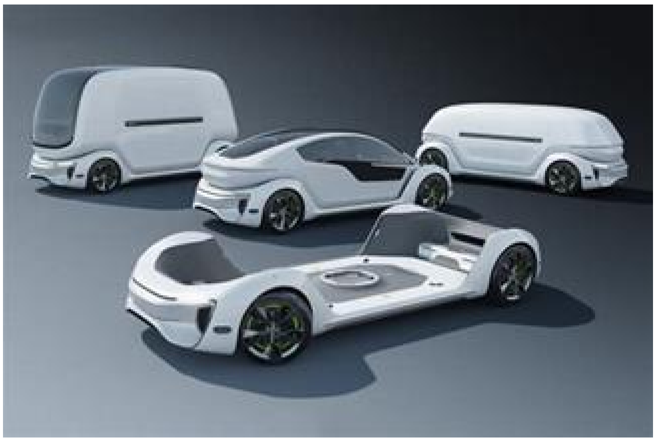


Figure 16: *Visualisation of the conceptual Tesla pod system with a carrier and the three envisioned transport units, published by Yanko Design. Source: ©Fábio Martins, 2019*

This task involves examining these systems from various angles, including technical, economic, and environmental perspectives. For this purpose, a set of parameters was defined, designed to capture the essence of these multimodal mobility systems:

Technical Parameters:

- Design / architecture: This parameter describes the presence or absence of a carrier, a transport unit (vessel), detachability, underframe configurations, and transport unit (vessel) composition.
- Configuration: Examining how the system is structured, from single-car setups to coupled pairs or autonomous configurations, this parameter offers insights into its operational dynamics.
- Transport unit - carrier coupling technology: Whether the coupling between the transport unit (vessel) and the carrier is achieved through electrical, mechanical, or communication-based means.
- Payload / tare weight: Understanding the system's capacity and its weight without payload.
- Types of homologation approvals: such as TSI (Technical Specifications for Interoperability), and any fire safety or tunnel safety standards, like EN 45545, that have been met.
- Propulsion system: Including options like Linear Induction Motors (LIM), Asynchronous Machines, Permanent Magnet (PM) machines, and more.
- Energy storage: Examining the energy storage solution used, whether if it is battery-based, relies on hydrogen fuel cells, contact lines, or other technologies.
- Electrical network: Understanding the electrical network parameters, including frequency (AC/DC), third rail systems, overhead lines, and voltage levels (e.g., 1.5 kV AC, 700 V DC).
- Transport unit - carrier energy transmission: how energy is transmitted between the transport unit (vessel) and the carrier components.
- Operational range (in km): system's range without charging, if applicable.
- Communications: such as GSM or 5G connectivity, and additional applications like Passenger Information Systems (PIS) and Closed-Circuit Television (CCTV).
- Grade of Automation: GoA for railway concepts and SAE for on-road vehicles.

- Train guard systems: including Communication-Based Train Control (CBTC) and European Rail Traffic Management System (ERTMS).
- Necessary infrastructure: Examining the infrastructure requirements, including platforms, chargers, and catenary lines, essential for the system's operation.
- Gauge: Determining the track gauge, if applicable.
- Depot required: Highlighting whether the system necessitates the establishment of depots for maintenance and operations.

Economical Parameters:

- Investment: Estimations of Operating Expenditure (OPEX) and Capital Expenditure (CAPEX)
- R&D investment: In case of demonstrations, the investment made in Research and Development (R&D) or product development.
- Financial reliability: Categorizing the system developer or manufacturer as a start-up, Small and Medium-sized Enterprise (SME), or corporate entity.
- Number of serial products / demonstrators.
- Industrialization capacities: Identifying the entities responsible for building the product and assessing their industrialization capacities.
- Business model and market: Exploring the business model adopted and the target market for the multimodal system.
- Approval date: The date of the system's initial application, test drive, or concept presentation.

Environmental Parameters:

- Life Cycle Assessment (LCA) or Pathway of Future (POF): Analysing environmental impacts such as CO_2 emissions per passenger and tonne-kilometre (CO_2/Pkm, tkm), energy consumption (kWh/Pkm, tkm), and alignment with environmental standards like Well-to-Wheel (WTW), Tank-to-Wheel (TTW), use of space.
- Alignment with ESG guidelines: Evaluating the system's alignment with Environmental, Social, and Governance (ESG) guidelines, including recycling rates, critical raw material usage, and sustainability practices.
- Ride dynamics (comfort): Assessing passenger comfort, considering factors like ride smoothness and stability.
- Thermal comfort: Evaluating the system's ability to maintain comfortable temperatures for passengers.
- Noise: Measuring the acoustic impact of the system during operation.
- Vibrations: Assessing vibrations generated by the system.
- EMC/EMV (Electromagnetic Compatibility): Examining the system's compliance with electromagnetic compatibility standards.

5.3. Overview of handling systems

As indicated in the task description, the deliverable not only focuses on rail vehicles but also considers other transportation systems. Specifically, it was identified that handling systems are a crucial element of the Pod and were researched into both current and past developments to better understand their impact on the project. This overview will also contribute to the activities in WP13 "Concept for the handling, loading/unloading technologies": In the intermodality process, the transhipment of the transport units (vessels) from one mode to another, in Pods4Rail planned as autonomous, is an integral part of the system. These systems are essential, but their role often go unnoticed.

Their main features were examined, whether they are designed for passengers or freight, their design, additional components on the transport unit (vessel), on the carrier and additional independent parts, as well as and their estimated Technology Readiness Level (TRL). The following list shows a summary of the handling systems examined and their short descriptions.

1. Pallet Shuttle: Developed by Robotise or similarly by Prime Robotics, these handling systems are designed for intralogistics, are in operation (TRL of 9) and consist of an independent and autonomous robot basket, allow for a horizontal transhipment, and require additional linear guides on both the transport unit (vessel) and carrier. The concept car of Rinspeed Metrosnap, mentioned in the previous chapter, utilises a similar handling concept.

Figure 17: *Example of a pallet shuttle model of Robotize, the GoPal U24W. Source: Robotize, Public Domain, 2023*

2. AAT Autonomous | Gaussin: The Autonomous Airport Transporter of Gaussin is a modular autonomous transporter with a horizontal rolling conveyor for smooth transport unit (vessel) transhipment, designed for airport cargo handling. TRL estimated of 7-8.

Figure 18: *Rendering of Gaussin's Autonomous Airport Transporter. Source: Gaussin Group, Public Domain, 2023*

3. AMDT (Autonomous) | Gaussin: Another airport vehicle from Gaussin Group, the Airport Multi Directional Transporter has a TRL estimated between 5-7 for its autonomous version and is fitted with a horizontal rolling conveyor, adjustable in height.

Figure 19: *Rendering of Gaussin's Airport Multi Directional Transporter in its autonomous variant. Source: video credit of Gaussin Group, Public Domain, 2023*

4. Rinspeed Snap (supplied by ESORO): The vehicle concept Rinspeed Snap, already listed in the overview of Pod systems, includes an interesting handling system by its car body supplier ESORO. It uses vertical shafts integrated in the transport unit (vessel) columns for a vertical linear lift. It reached a TRL of 5 - 7.

Figure 20: *Transport unit of the Rinspeed Snap with its supporting legs extended. Source: video credit, ©Rinspeed AG, 2018*

5. Rinspeed Microsnap (supplied by KUKA): The vehicle concept Rinspeed Microsnap, already listed in the previous overview employs automated robot arms for three-dimensional transhipment, conducting a light lift and horizontal movement. It requires the installation of the robot arms and reached a TRL of 5 - 7.

Figure 21: *Transport unit of the Rinspeed MicroSnap being transhipped by two KUKA robot arms. Source: ©Rinspeed AG, 2019*

6. UpBUS | RWTH Aachen: Developed in cooperation with DLR and Doppelmayr, this system is designed for road and ropeway transportation. Their current development stage focuses on dynamic coupling of an adapted rope-way grip.

Figure 22: *Screenshot of the transhipment test of the transport unit from the road carrier directly being coupled to the ropeway grip. Source: video credit of the RWTH Aachen University, 2021*

The following handling systems from the well-established intermodal or combined transport are also analysed in this overview. All of them reached a TRL 9 unless stated otherwise:

1. Mobiler: Operated by Rail Cargo Group, this system, dating back to 1995 consists of a horizontal container swapping mechanism, powered by a hydraulic system mounted on the truck.

Figure 23: *Horizontal handling of a Mobiler container from a truck to a waggon in parallel position. Source: Rail Cargo Group, ÖBB, Public Domain, 1995*

2. ContainerMover | InnovaTrain: Introduced in 2010, it employs a hydraulic system on the truck for horizontal semi-trailer or swap body handling.

Figure 24: Horizontal rail-road handling of a semi-trailer with the ContainerMover of InnovaTrain. Source: InnovaTrain, Public Domain, 2010

3. CargoBeamer: Developed in 2021, it executes quasi-horizontal loading and unloading of semi-trailers with a linear conveyor system.

Figure 25: *Several semi-trailers ready for the simultaneous transhipment. Source: ©CargoBeamer AG, 2021*

4. Modalohr: Launched in 2003, this system facilitates quasi-horizontal semi-trailer swapping and employs a pivoting pocket system with hydraulic support rollers.

Figure 26: *Pivot basket in diagonal position ready to be aligned with the train formation. Source: ©Lohr Industrie S.A., 2003*

5. HELROM: Helrom's Trailer Rail (former Megaswing Duo) uses special pocket wagons for semi-trailers with swivelling receptacle trays and hydraulic supports for stabilization.

Figure 27: *Rendering of the swivelling structure of Trailer Rail, former Kockums Megaswing Duo. Source: SGKV Intermodal Info, Public Domain, 2010*

6. RailRunner: RailRunner intermodal trains are assembled directly from the special designed RailRunner semi-trailers, using compact specialised bogies. This specially designed semi-trailer is coupled to the bogie. The highway wheels are raised pneumatically, allowing the highway wheels to clear the track, thus transforming the road vehicle to a rail vehicle. Train assembly requires no lifting of the semi-trailer.

Figure 28: *Detail of two semi-trailers coupled to the RailRunner® bogie. Source: RailRunner® North America, Public Domain, 2006*

7. CargoRoo: Two crawler vehicles pick up the semi-trailers placed on the side and drive them onto the wagons. The development of the technology in 1995 was discontinued due to restructuring measures and the integration of Adtranz as a 100% subsidiary of today's Daimler AG. It was later sold to Bombardier. It is estimated to have achieved a TRL 2.

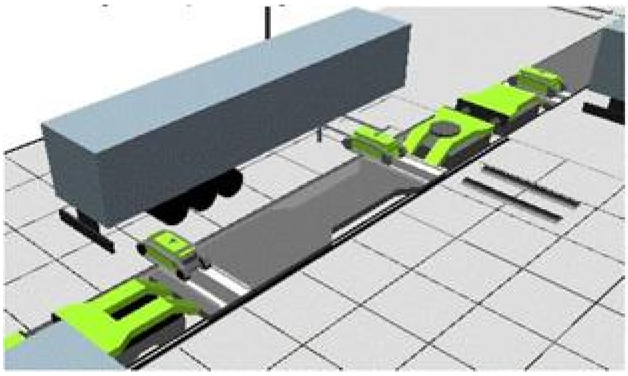


Figure 29: *Rendering of CargoRoo crawler vehicles picking up a semi-trailer. Source: Zukunft-Mobilität.de, ©CargoRoo, 2010*

8. BoxMover: The side-lifter loads and unloads containers via a pair of hydraulic powered cranes mounted at each end of the vehicle chassis. The cranes are designed to lift containers from the ground, from other vehicles including rolling stock, from railway wagons and directly from stacks on docks or aboard container ships.

Figure 30: *Sidelifter in operation. Source: BoxMover, Public Domain, 2010*

9. Kombilifter | Mercedes-Benz: The truck transports its cargo in a standardised swap body - an interchangeable swap body with fold-out support legs. The truck drives over the rails, lowers its chassis while extending the swap body support legs, and places the swap body over the track as if on stilts.

Figure 31: *Kombilifter swap body with extended legs positioned on the railway siding of the Mercedes-Benz factory in Stuttgart. Source: Mercedes-Benz, Public Domain, 1995*

10. Roll Hydro: It consists of four independent hydraulic jacks, activated by electro-pumps powered by an external generator.

Figure 32: *Container supported by the Roll Hydro hydraulic jacks. Source: Construction News, Public Domain, 1994*

11. Roller container | ACTS: Roller containers are containers that can be carried by trucks to be pushed to ground level by help of a hook and level arm with the container sliding on steel roller wheels. Rotatable frames support the quick transhipment of roll-off containers.

Figure 33: *Roller container with hook during transhipment of a 30 t container. Source: video credit, ©ACTS Abroll-Container-Transport-Service AG, 2019*

Inspired by the characterisation of the Pod systems in the previous chapter, an analysis of the various handling systems was conducted to provide a comprehensive understanding of their technical, operational and design aspects. The following 7 parameters have been defined to capture the essence of these handling systems:

- Short description of the handling system: A concise overview of the handling system's fundamental operation and purpose.
- Design/ architecture: Describes the primary design and architectural features of the handling system, including the movement type employed (e.g., hanging, lifting, picking, shifting, gliding).
- Additional handling components on the transport unit (vessel): Highlights any specialized components or mechanisms integrated into the transport unit (vessel) itself to facilitate the handling process.
- Additional handling components on the carrier: Identifies any supplementary handling components or equipment installed on the carrier that contribute to the system's overall functionality.
- Additional handling components trackside: Focuses on any infrastructure or equipment positioned trackside that plays a role in supporting the handling system's operation.
- Payload: Specifies the system's capacity in terms of the maximum payload it can handle efficiently.
- Propulsion system of the handling system: Explores the type of propulsion system utilized by the handling system itself.

5.4. Overview of swap body systems and small loading unit applications

Pod systems and handling systems were analysed in the previous chapters. Several swap body systems were already analysed as part of Pod or handling systems; however, those are especially adapted to the corresponding pod-systems and to certain carriers. Beside these, swap body systems that are independent from the vehicle models where they are mounted must be looked at. Depending on the transported goods, their properties, dimensions, etc., swap body designs and features are manifold. In Pods4Rail, the primary freight use case is posed by swap bodies for goods with high volume and low density. Conducting an analysis of standard swap body systems, small containers and standard loading units is crucial for determining the dimensions and design of the transport unit and, subsequently, the carrier. This analysis becomes a vital tool for project work in Task 4.4 “High-level functional requirements specification”, and for the Work-streams WS2 “Moving infrastructure vessel and operation system” and WS3 “Moving infrastructure carrier incl. locking and handling system”.

In addition to the Minimodal and Kombilifter solutions already mentioned in previous chapters, several swap body and small container applications with interfaces to railway might be of interest for the Pod development. The following list shows various swap body systems with potential for application in Pods4Rail:

1. Minimodal flexible small container system, whose reduced containers could be handled by a standard forklift (see chapter 5.2, Fig. 7).

Figure 34: *Minimodal small-sized containers being handled by a standard forklift. Source: Rail Freight Limited, Public Domain, 2002*

2. Kombilifter swap body system for rail-road handling on a level ground track (see chapter 5.3, Fig. 33).

Figure 35: *Kombilifter swap body with extended legs positioned on the railway siding of the Mercedes-Benz factory in Stuttgart. Source: Mercedes-Benz, Public Domain, 1995*

3. Cargo Rail Lines, CaRL® was a project funded by the German federal government starting in 2002 of a rail freight system for the delivery of small-sized shipments based on so-called “Fifty boxes”, containers with half the size (length) of a swap body WB C 745 (3700 x 2440 x 2500).

A central component of CaRL® was the innovative loading system consisting of a set of two parallel conveyors for the loading of each freight waggon. The “Fifty boxes” were placed from the lorries onto the first conveyor, which took them to the freight waggon. A rail-mounted turntable, positioned directly next to the waggon, picked up the Fifty box and handled it onto the waggon, where it was automatically fixed. The same turntable was utilised to unload Fifty boxes onto the parallel conveyor belt (Gediehn, Siemens Industrie Sektor Mobility, IL CP, 2010).

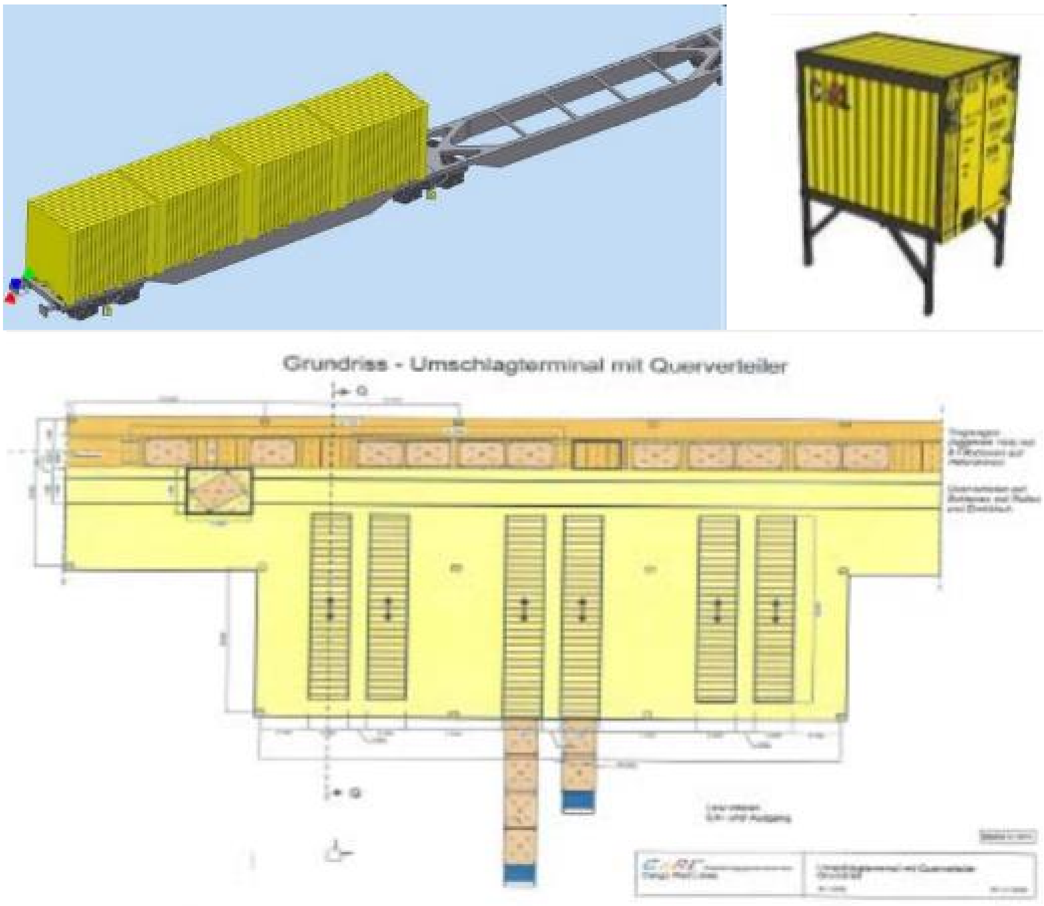


Figure 36: *Rendering of the “Fifty box” small container and its visualisation as a four-container group on a freight waggon. The scheme below them shows the handling area with parallel conveyor belts and a track for the turntable. Source: ©Siemens IL CP, 2010*

4. Combibox was a small container concept tested in Zurich in 2001 based on 1.8 m long containers (1.8 x 2.5 x 2.33). Its aim was to create a container for transporting goods that can be transported both individually and in large numbers to a defined distribution point near the final destination. Small vehicles with individual “combiboxes” would cover the last mile. It required special handling equipment (Stadt Zürich, Tiefbauamt, 2014).

Figure 37: *Combibox carried by an adapted van and being transhipped on to a freight waggon. Source: Tiefbauamt der Stadt Zürich, Public Domain, 2002*

The aforementioned solutions by Minimodal, Kombilifter, CaRL®, and Combibox are attempts from the last 10 to 20 years that have not prevailed in the market, illustrating the complexity of market penetration for a similar Pod system concept.

The following solutions are based on standardized swap bodies:

5. Göbel Liftcontainer is a steel swap body C7.45 version with four remote controlled hydraulic extendable lifting cylinders with a load capacity of up to 20 tonnes. All 4 cylinders can be synchronously or separately controlled (Liftcontainer, 2020).

Figure 38: *Liftcontainer with folded legs and, secondly, with extended legs prepared to be docked on to a truck. Source: ©Liftcontainer.de, 2020*

6. Talson T.SWAU BK is a lightweight swap body (C7.45) design made of a special aluminium sandwich composite material, 750 kg lighter than conventional C7.45. In addition, modular aluminium side panels made of six separate plates enable the replacement of damaged panels instead of changing the entire box side. It also includes the patented Talfix® fixation system with multiple holes to allow different loading models in one swap body.

Figure 39*: Rendering of a Talson aluminium swap body and picture of the interior design with Talfix® fixation system. Source: ©Talson Trailer, 2019*

7. Refrigerated Swap Body: Designed for temperature-sensitive goods, these have built-in refrigeration units to maintain a specific temperature range.

Figure 40*: Swap body cool box "Duoplex steel" of Krone. Source: ©KRONE Commercial Vehicle, 2016*

8. Curtain-Sided Swap Body: designed with flexible sides (curtains) that can be opened for easy loading and unloading, ideal for bulky cargo.

Figure 41*: Swap curtain boxes of Krone. Source: ©KRONE Commercial Vehicle, 2016*

9. Tank Swap Body: Used for transporting liquids, these are essentially tankers that can be mounted on different transport vehicles.

Figure 42*: Intermodal 407 tank containers. Source: ©EXSIF Worldwide, 2023*

10. Hazardous Material Swap Body: Specifically designed for transporting hazardous materials, these comply with strict safety and containment regulations.

Figure 43*: Rosenbauer HAZMAT WLA for hazardous materials or decontamination operations. Source: ©Rosenbauer, 2023*

It should be noted that, for practical logistics, especially in a system as extensive as Pods4rail aimed at broad application, it is critical to align with well-established and commonly used loading units in the market, notably the Euro pallet. Altering this standard size would not be advisable, as it could prevent the successful implementation and acceptance of a Pod system in freight transportation.

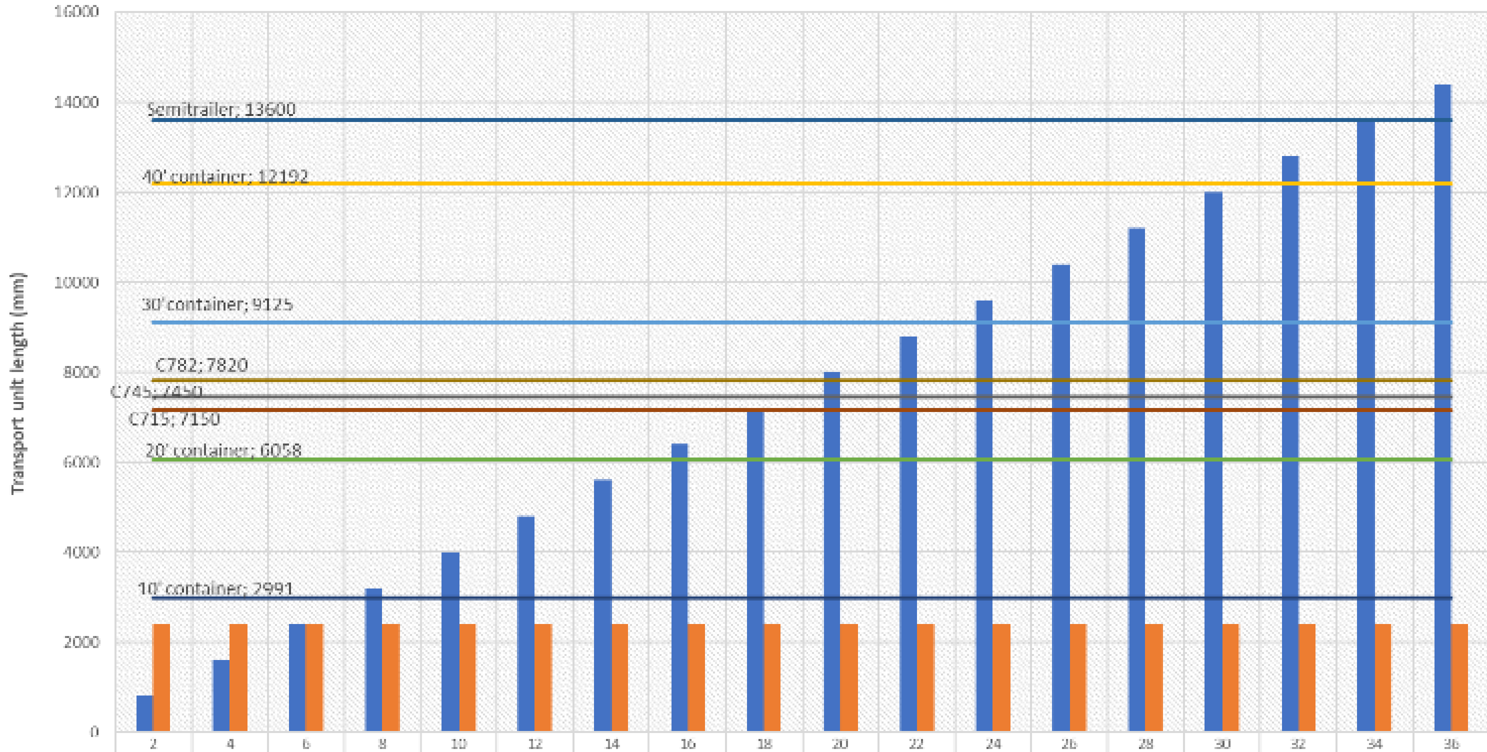
The following are the standard loading units and their dimensions, that should be considered when designing freight transport units and carriers and the combined uses cases with passengers (from Berndt 2001 and Troche, 2005).

Loading Unit	External Dimensions l x w x h [mm]	Payload [kg]	Features
Pallets	Euro-pallet EUR 1: - 800 x 1200 x 144 (UIC data sheet 435-2) Euro-pallet EUR 2: - 1000 x 1200 (UIC data sheet 435-5) Flat pallet (DIN 15146-4) - 1000 x 1200	1500 point load 4000 area load	Mostly made of wood and held together with nails. Also made of plastic or metal.
Small Container	e.g., DB Cargo Logistics box – 2440 x 2440 x 2250		Standardised small containers
ISO-Container	1A (40 ft) – 12192 x 2438 x 2438* 1B (30 ft) – 9125 x 2438 x 2438* 1C (20 ft) – 6058 x 2438 x 2438* 1D (10 ft) – 2991 x 2438 x 2438* *HC (High Cube) – 2896	26,480 (30,480) (25,400) (24,000) (10,160)	Standardised corner fittings, global use, internal dimensions not adapted to Euro pallets, door openings (minimum) 2286 x 2134 (W x H)
Euro-Container	40 ft – 12192 x 2500 x 2600 30 ft – 9125 x 2500 x 2600 20 ft – 6058 x 2500 x 2600	Similar to ISO-Containers	Similar to ISO containers, used in continental traffic, internal width (2400) adapted to Euro pallets, lighter than ISO containers, stackable 3 high
Swap Bodies	C 715 – 7150 x 2550 x 2725 (4045) C 745 – 7450 x 2550 x 2725 (4045) C 782 – 7820 x 2550 x 2725 (4045)	(16,000) (16,000) (16,000)	Similar to large containers, but with support legs, various types: box types, open structures with tarpaulin and flatbeds with side walls
Semi-Trailer	Various: e.g., 2, 3 axles, mega trailer, semi-trailer with tarpaulin 13600 x 2480 x 2700 – 34 Euro pallets	up to 25,000	Distinction between crane-liftable and non-crane-liftable
Roll Container	e.g., DB – 1040 x 920 x 1435	500 (640)	Used for transport in trucks and trains, manually moved
Air Freight Container	Many possible variants: e.g., Main Deck Pallet P6P, PMC – 318 x 244 x 244	(6,663)	Not equipped with wheels, transported on roller floors

Loading Unit	External Dimensions l x w x h [mm]	Payload [kg]	Features
	Air Cargo Container AA2 – 318 x 224 x 160 Lower Deck Cont. DQF, LD8 - 244 x 153 x 160 Lower Deck Cooltainer RAP – 318 x 224 x 160	(5,318) (2,322) (5,713)	

Table 1: Standard loading units

The following graphic shows the different standard loading units (swap bodies C 715, C 745, C 782; 10', 20', 30' and 40' containers and semi-trailer) described by their length (L) and width (B) in the vertical axis, and their capacity to transport Euro-pallets EUR1 (horizontal axis), taken in this example as the base for measurement estimations and considered in transversal position. For instance, it can be derived from the graphic that a transport unit length of 8 m could hold any of the three standard swap body types or 20 Euro-pallets:



	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
L	800	1600	2400	3200	4000	4800	5600	6400	7200	8000	8800	9600	10400	11200	12000	12800	13600	14400
B	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
40' container	12192	12192	12192	12192	12192	12192	12192	12192	12192	12192	12192	12192	12192	12192	12192	12192	12192	12192
30' container	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125
20' container	6058	6058	6058	6058	6058	6058	6058	6058	6058	6058	6058	6058	6058	6058	6058	6058	6058	6058
10' container	2991	2991	2991	2991	2991	2991	2991	2991	2991	2991	2991	2991	2991	2991	2991	2991	2991	2991
C715	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150
C745	7450	7450	7450	7450	7450	7450	7450	7450	7450	7450	7450	7450	7450	7450	7450	7450	7450	7450
C782	7820	7820	7820	7820	7820	7820	7820	7820	7820	7820	7820	7820	7820	7820	7820	7820	7820	7820
Semitrailer	13600	13600	13600	13600	13600	13600	13600	13600	13600	13600	13600	13600	13600	13600	13600	13600	13600	13600

Figure 44: *Capacity of standard loading units to transport Euro-pallets EUR1*

5.4.1 Overview small loading unit applications

Other small loading units like grid boxes, which are based on Euro-pallets EUR1 dimensions and reinforced by a metal structure to carry can be easily handled by forklifts and are applied in railway concepts such as cargo trams. They consist of a steel frame grid construction and a baseboard (usually a Euro-pallet). In recent years, wire mesh pallets have gained increased importance. Especially small parts and pressure-sensitive packaging are well protected in the boxes and are ideal for transport. The wire mesh pallet is standardized and must be marked with the name of the manufacturer and the year of construction. With external dimensions of 1240 mm x 835 mm x 970 mm (l x w x h) and a load capacity of up to 1,500 kg, it is particularly suitable for heavy and bulky items in warehouse logistics, such as manufacturing parts or production waste.

Figure 45: *Grid-boxes with metal items stacked in a warehouse. Source: ©proLogistik group, 2023*

Figure 46: *Grid-boxes being loaded by a forklift onto a Dresden CarGoTram. Source: ©Sachsen Fernsehen, 2017*

Cargo-bike containers, like the ONOMOTION ones with 2.1 cubic metres capacity and length of 1.70 metres have been tested in similar environments.

Figure 47: *A cargo-bike container is transhipped onto a tram at the BVG's Berlin Lichtenberg tram depot. Source: ©ONOMOTION, 2021*

Figure 48: *A cargo-bike air-freight container unloaded from a Frankfurter tram. Source: ©VGF, 2023*

Air freight containers, also known as Unit Load Devices (ULDs), are specially designed containers used in aircraft to transport cargo efficiently and securely and might match with cargo use cases in Pods4Rail. There are several types of ULDs, each designed for specific types of aircraft and cargo. Here is a list of common air freight containers:

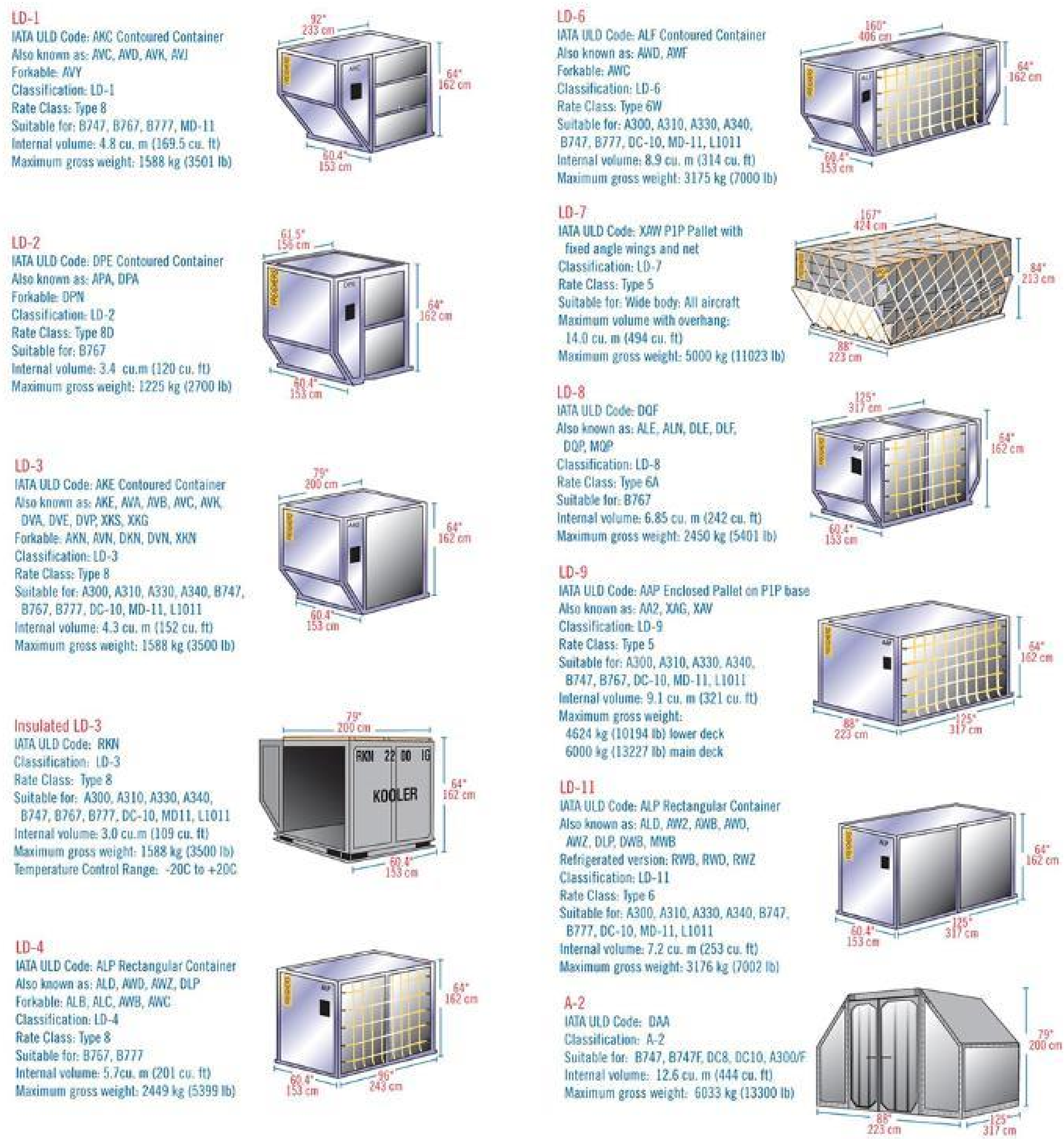


Figure 49: *Air freight, Unit Load Device (Types & Dimensions), Source: ©TVM Global, 2015*

Additionally, the usual dimensions of pack stations should be considered for a comprehensive analysis of the Pod dimensions. Shipments to a "pack station" shall have a minimum size of 15 x 11 x 1 cm and a maximum size of 75 x 60 x 40 cm (DHL, 2023). The maximum allowable weight is 31.5 kg.

Figure 50: *Pack station of DHL with display and U-form. Source: ©DHL Paket GmbH, 2023*

The compartment size dimensions of “Pack stations” are the following:

	App-controlled pack station without display	Standard pack station with display
S	8 x 43 x 63 cm	9 x 43 x 61 cm
M	18 x 43 x 63 cm	17 x 43 x 61 cm
L	38 x 58 x 63 cm (or 30 x 43 x 63 cm)	37 x 43 x 61 cm
XL	43 x 63 x 78 cm	44 x 61 x 76 cm

Table 2: Compartment size dimensions of a DHL-Packstation

5.5. Other related concepts

While researching Pod system concepts, other innovative existing or still developing concepts from the last 20 years offering unique approaches to multimodal and railway transport have been collected. The primary objective of this task is not only to identify the most suitable concepts among multimodal and intermodal systems but also to pinpoint systems or system-components even when not Pod-related. The systems listed below can serve as partial benchmarks for enabling technologies or other components which are necessary for the successful finalisation of the project and, therefore, offer an added value. From cargo-trams, autonomous light trains and autonomous battery-powered freight railcars, to underground cargo capsules and shared ride services, each system brings its own set of features, that might serve as an inspiration for different Work-Packages in Pods4Rail. This overview includes an estimation of the potential application of concepts or parts of them in the project. This list is limited to systems which offer additional value to the Pod-design. Here is a summary of the other related concepts:

1. Cargo Trams:
   - Description: As mentioned in the previous chapter, small loading units have been used in cargo-tram applications. The following is a sample of Cargo-Tram projects:
     - CarGoTram Dresden (DVB) was a purpose-built tram manufactured by Schalker Eisenhütte, first launched in 2001 and whose operation was finally suspended in 2020. It was designed for the transport of automotive parts from a freight terminal to the Volkswagen owned Gläsernemanufaktur. The only two units produced run up

to three times per day covering a 5.5 km urban route shared with passenger services on the city's 1,450 mm gauge tram network, substituting three 18 m lorries with its 214 m^3 capacity. It was a bidirectional vehicle consisting of 5 segments in a standard formation of three all-freight units and two combination freight-and-control units reaching 59.4 m length, 90 t weight, 2.200 mm vehicle width, and maximum speed of 50 km/h.

  - Cargo Tram Zürich operates since 2003 as a tram-railcar carrying bulky waste waggons. They operate 10 to 12 times per year and accept single objects weighing a maximum of 40 kg and 2.5 long.
  - Cargo Trams from Frankfurt (VGF) since 2018 and Berlin (BVG) since 2021 have been researching the transport of cargo-bike containers and in Frankfurt also of roll-containers in passenger designed low-floor trams, for the service of KEP delivery.

- Potential for Pods4Rail: Medium-high, since the loading units could be suitable to several Pod use cases, and the low axle load of trams could fit good to the secondary lines that some use cases of Pods4Rail aim to make use of, despite the reduced vehicle width compared with heavy trains.

Figure 51: *Dresdner CarGoTram only cargo raised floor cargo-tram vehicle concept with open curtain side for the loading process. Source: ©Sachsen Fernsehen, 2017*

Figure 52: *Cargo-bike container being loaded into a Frankfurter Tram. Source: ©VGF, 2021*

2. CargoCap:

- Description: CargoCap is designed as a stand-alone, high-performance and easily expandable system for underground transportation in tube systems with a diameter of only 2.80 meters, with an estimated TRL 2 - 4. It utilises autonomous, electric and fully automated transport vehicles called "Caps" independently of above-ground traffic congestion and weather conditions, which are loaded with two to three pallets or containers of standard dimensions each.
- Potential for Pods4Rail: Low potential due to the infrastructure concept requiring the installation of an underground pipeline network. However, if an existing underground network is available, there is potential for a cargo-Pod concept. Pods4Rail can also benefit from the development of CargoCap concerning platooning technology and CargoCap Hubs' management.

Figure 53: *Visualisation of the CargoCap transport unit at the freight loading area. Source: ©CargoCap GmbH, 2017*

3. Cargo Sous Terrain:
   - Description: CST is a Swiss project with a concept similar to CargoCap of an autonomous underground transportation system with an estimated TRL 2 - 4. This system involves transport units carrying two to four Euro-pallets. It aims to operate at 30 km/h within a tunnel network to be constructed in Switzerland. In urban areas, multifunctional hubs equipped with vertical capsule lifters would facilitate urban logistics.
   - Potential for Pods4Rail: Low potential due to the infrastructure concept requiring the installation of an underground pipeline network. However, if an existing underground network is available, there is potential for a cargo-Pod concept. Pods4Rail can also benefit from the development of CST traffic management technology and CST Hubs' management.

Figure 54: *Visualisation of the underground traffic of CST autonomous transport units. Source: Cargo sous terrain, Public Domain, 2021*

4. Light Rail Vehicles:
   - Description: Several projects tackle currently developments of non-detachable Light Rail Vehicles, especially for branch lines, such as Coventry's Very Light Rail (TRL 6-8), the developing concepts (TRL 2-4) of Draisy (SCNF), Train Leger Innovant, EcoTrain and TaxiRail® in France, as well as the modular in length NGT-Taxi from the DLR in Germany.
   - Potential for Pods4Rail: Various features of these vehicles are of interest for Pods4Rail, as most of these concepts will have a battery-electric powertrain, light-weight construction, modular design (NGT-Taxi) and autonomous driving technology. Pods4Rail is in contact with ERJU's Flagship Area 6 project, in order to regularly check for synergies.

Figure 55: *Rendering of the light rail vehicle from the German Aerospace Center, NGT-Taxi. Source: ©DLR, Robert Hahn, 2023*

Figure 56: *Visualisation of the light rail vehicle from TaxiRail®. Source: video credit, ©TaxiRail®, 2022*

5. Flexmove | AKKA:
   - Description: Flexmove (Ferromobile) is a two-road-vehicle project involving the development of an autonomous light vehicle for branch lines. It is designed to operate on both road and rail and has an estimated TRL 5.
   - Potential for Pods4Rail: Low potential for Pods4Rail, but a detachable version of the vehicle

could be interesting for some use cases. A two-road carrier has also potential for Pods4Rail.

Figure 57: *Adapted road vehicle of the Flexmove project during tests on railway track. Source: ©AKKA, 2022*

6. Flexy | SNCF:
   - Description: Flexy is designed to transition seamlessly from rail to road at level crossings, offering advantages of both bus and train operation for local transportation. Estimated TRL 3 - 4.
   - Potential for Pods4Rail: Low potential for Pods4Rail, but a detachable version of the vehicle could be interesting for some use cases. A two-road carrier has also potential for Pods4Rail.

Figure 58: *Visualisation of the Flexy two-road vehicle concept driving on the railway close to a level crossing. Source: ©SNCF, 2021*

7. Monocab OWL:
   - Description: Monocab-OWL is a small 2-axle monorail system with unique stability features and compartments for passengers or cargo.
   - Potential for Pods4Rail: Low potential for Pods4Rail, but a detachable version could be promising for bidirectional traffic in single-track lines, aligning with Pods4Rail goals.

Figure 59: *Monocab being tested with a provisional support. Source: ©Monocab OWL, 2023*

8. MOIA:
   - Description: Adapted non-detachable van with up to 5 ride-pooling passengers. TRL 8 - 9.
   - Potential for Pods4Rail: Partial potential, particularly the operation of the last-mile/first-mile ride-pooling.

Figure 60: *Tailor-made MOIA van. Source: ©MOIA, 2023*

9. Easymile - Barkarby autonomous on-demand transit (DRT):
   - Description: Autonomous on-demand minibuses with speeds up to 25 km/h like the Easymile operating in the Barkarby area (Sweden) and other locations. Similar concepts are developed by Navya and the Hamburg Autonomous Shuttle HEAT. TRL 7. Has been in operation 2018-2023, with increasing complexity (line-based 2018-2021, zone-based on-demand 2022-2023).
   - Potential for Pods4Rail: Partial potential, especially for last-mile/first-mile passenger transportation, with the potential to learn from various trials. Studies on operations evaluation and user acceptance can provide input to the project's passenger transport use cases.

Figure 61: *Easymile autonomous minibus driving in Barkarby (Stockholm). Source: Drive Sweden, Public Domain, 2018*

10. Schaeffler-VDL-Mobileye:
    - Description: Various concepts of autonomous shuttles with speeds up to 70 km/h are being developed by Schaeffler, VDL, and Mobileye and ZF, offering battery-propelled road vehicles for passenger transportation. TRL 7 - 9.
    - Potential for Pods4Rail: Partial potential for last-mile/first-mile autonomous passenger transportation.

Figure 62: *Impression of the autonomous driving shuttle vehicle that Schaeffler and VDL Groep plan to develop and produce together. Source: ©Schaeffler AG, 2023*

11. Einride:
    - Description: Einride uses self-driving and remote operation technology for autonomous electric trucks in the U.S. and Europe. TRL 7 - 9. Both reduced-size and full-size, fixed body and flat-bed/ modular. Currently operates on public roads and at customer sited in Sweden with remote oversight and drive capability.
    - Potential for Pods4Rail: Low to medium potential for Pods4Rail, as there is no rail integration and no passenger transport, but there is some potential as an autonomous cargo-Pod handling system, based on the reduced-size system.

Figure 63: *Visualisation of an Einride autonomous lorry carrying a container. Source: ©Einride, 2023*

6. Evaluation/ Benchmark of existing technologies

6.1. Introduction

One of main objectives of the Europe's Rail Joint Undertaking, as outlined in FA 7, is to explore unconventional and emerging flexible guided transport systems. This strategic objective is closely aligned with Europe's mobility challenges anticipated for the next few decades, as identified in the European Railway Master Plan and the European Multiannual Work Plan (MAWP) and their call for an immediate improvement in the further development and implementation of rail transport. This vision forms the overarching goal of Pods4Rail to explore seamless integration of various modes of transportation to enable the operation of smaller, faster, and more frequent train services.

This primary goal sets the base for the creation of technology evaluation criteria and their hierarchy for their application to both the Pod system and for the overview of existing precursor systems.

For the evaluation of available and conceptional intermodal mobility systems, it was decided to follow the technical values described in the VDI 3780, Guideline of Technology Assessment Concepts and Foundations. VDI 3780 is a guideline developed by the Association of German Engineers (VDI), aiming to provide practical insights into the process of technology assessment. It helps individuals involved in technological developments, including engineers, scientists, planners, and managers, make informed and transparent decisions about technology. The guideline takes a forward-looking approach, offering recommendations and criteria for evaluating technology and its potential impacts.

Given the comprehensive nature of the VDI 3780 process, meant for the thorough technology assessment of one technology, in WP2 - Task 2.2 it was opted to focus primarily on the technical values described in the guideline. This choice aligns with the objective of the current task, which involves creating an overview of existing intermodal systems. These systems have been clustered into 16 concepts and evaluated employing a more streamlined approach.

The process of technology assessment will be continued during WP4 - Task 4.2: Use Case SWOT-Analysis. In that task, the assessment of specific use cases and their respective technologies and impacts will be conducted in a more detailed manner.

6.2. Evaluation

The values in technical action are described and prioritised in VDI 3780 and are shown in Fig. 51, including their respective instrumental and competitive interdependencies.

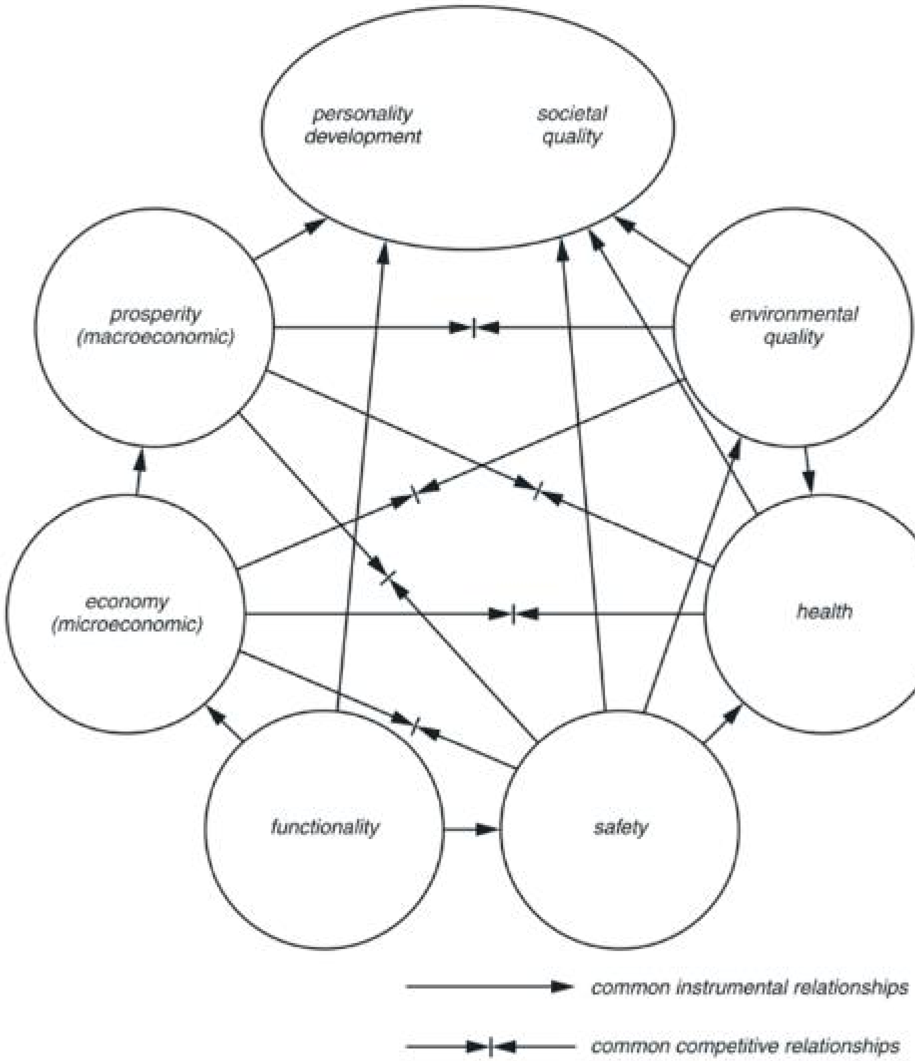


Figure 64: *Values in technical action (VDI 3780, 2000, p. 23)*

Considering the objectives of the Pod development in the Pods4Rail Grant Agreement and guided by the definitions in VDI 3780, these values were applied to the assessment of precursor systems as follows, broken down by specific aspects of the project, emphasizing both their individual significance and the hierarchies that guide the interdisciplinary evaluation:

1. Functionality: Rail-bound, Autonomous and Intermodal
    - The functionality of a technological system is its ability to produce desired effects under specific conditions. It should meet practical human needs and be effective, efficient, and balanced in terms of simplicity, robustness, precision, reliability, and efficiency.
    - The supermodal Pod system aims to combine transport modes seamlessly, focusing on autonomous rail-based transport and autonomous mode changes. A Pod system without railway mode is not within the scope of the project and would not provide the basic functionality desired. Similarly, autonomous transport in all the modes served with the Pod is at the core of the functionality. Therefore, these three criteria - rail-bound, grade of

automation and intermodality - are applied in the first place when assessing the functionality of precursor systems.
- The scalability to form Pod or vehicle sets (modularity) and the extensive reach to outlying regions or peripheral areas, together with the range without charging have been identified as significant criteria for achieving a flexible Pod functionality.

2. Safety and Economic Efficiency
   - Safety and Economic Efficiency are given equal priority in the guideline and have a competing relationship. Considering the concentration of disruptive innovations required for the development of a Pod, it was decided to prioritise Safety before the Economic Efficiency criteria. Furthermore, profitability is better protected in a safe mobility system.
   - Safety:
     - Safety entails the absence of dangers to life and limb, including the prevention of property damage. Risk is a crucial factor, and safety requirements should eliminate potential risks through technological means.
     - Safety, both technically and in terms of perceived safety, is paramount. It was identified that the safety in three Pod-processes is particularly relevant, and the systems were evaluated accordingly: Safety of the processes of swap handling, coupling of additional modules (e.g. virtual coupling) and of the charging of the energy storage system (e.g. battery).
   - Economic Efficiency:
     - Technical decisions must consider austerity due to limited resources. Economic rationality aims to maximize the ratio of benefits to costs, whether by minimizing costs or improving production output. Efficiency and profitability are crucial aspects of economic considerations.
     - The criteria of Economic Efficiency that were identified for the project and the evaluation of existing systems are also common with Environmental Quality. A key objective of Pods4Rail is making use of existing infrastructure with only very minor modifications. The suitability for the existing infrastructure, as well as the payload efficiency, i.e. the estimated ratio between payload and tara weight, were identified as criteria for this economic assessment. The third criterium is based on the (estimated) maximum capacity of the vehicle in terms of persons or tons to be transported, which is also an important descriptive parameter when assessing the suitability of a system.

3. Environmental Quality
   - Environmental quality refers to the state of the natural environment, and technology plays a significant role in shaping it. There are anthropocentric and physio-centric perspectives on environmental protection, with technology influencing the balance between these perspectives.
   - As indicated in the previous paragraph, the identified evaluation criteria for Economic Efficiency and Environmental Quality are the same: suitability for the existing infrastructure, maximum capacity and payload efficiency. These parameters are evaluated from an environmental point of view at this stage.

4. Health, Personal Development, and Societal Quality

- Personality development involves fulfilling one's potential in interaction with the environment, while societal quality encompasses the character of interpersonal relationships and social circumstances. Technology affects freedom of action and the balance between individual freedom and societal order.
- The project aims to protect and support various segments of the population, including the elderly, students, women, and residents of rural residents, by providing accessible and convenient transport. A criterion of accessibility has been identified accordingly.
- In addition, passenger comfort and convenience will be of significant importance in order to position passenger Pods as viable alternatives to private motorised transport for commuters, rural residents, industrial workers, business travellers, and tourists.
- The values of this last chapter are analysed in detail in chapter 6.1.4 of this document and provide the context for the Use Case analysis in WP4.

6.2.1. Technological Evaluation

The goal of this chapter is to enable a technological ranking of the overview of Pod-systems based on the interdisciplinary expert ratings collected from the opinions of experienced experts from the project team. These experts have a broad background in studying and working with both multimodal and railway systems and shared their useful knowledge and observations for the evaluation. The big aim here is not just to see which multimodal systems are the best technology-wise, but also to spot which systems – or even just parts of them – could serve as benchmarks for the technological development of the Pod.

"Benchmarking in technology assessment is the process of measuring the performance of a technology against established standards, best practices, or the performance of leading technologies in order to identify gaps, drive improvements, and support strategic decision-making" (Camp, 1989).

The technological evaluation considers the criteria found in the previous chapter under Functionality, Safety, and Societal quality. For the purpose of the technological evaluation, ranking scales were adopted for each of the specific parameters:

- TRL estimation (HORIZON 2020, 2015) from the characterisation chapter:
  - 5 - TRL 9
  - 4 - TRL 8 - 9
  - 3 - TRL 5 - 7
  - 2 - TRL 2 - 4
  - 1 - TRL 1

- Functionality (I): Rail-bound concept. Ranking scale:

- 5 - Yes
- 4 - Currently under development with TRL 7 - 9
- 3 - Currently under development with TRL 4 - 6
- 2 - Currently under development with TRL 1 - 3
- 1 – No

- Functionality (II): Full autonomous drive concept according to GoA (IEC, 2014) and SAE J3016 levels (SAE, 2021). Ranking scale with four levels, but ranging from 1 to 5 to keep a homogeneous structure:
  - 5 - Yes. GoA/4-SAE/5
  - 4 - Driverless, with attendant: GoA3/SAE4
  - 3 - Concept prepared for autonomous driving.
  - 1 – No

- Functionality (III): Intermodality concept to rail-mode, from road or ropeway mode. Ranking scale:
  - 5 - Yes, rail-road-ropeway
  - 4 - Yes, rail-road
  - 3 - No, but road-ropeway and planned for rail
  - 2 - No, but road-ropeway
  - 1 – No

- Functionality (IV): Modularity - Rapid scalability to train formations (virtual coupling/DAC). Ranking scale:
  - 5 - Yes, virtual coupling
  - 4 - Yes, automatic coupling
  - 2 - Conventional railway coupling
  - 1 – No

- Functionality (V): Range without charging. Ranking scale with four levels, but ranging from 1 to 5 to keep a homogeneous structure and based primarily on estimations:
  - 5 - Estimated greater than 150 km
  - 3 - Estimated 50 to 150 km
  - 2 - Estimated lower than 50 km on road or rail
  - 1 - Not self-propelled

- Safety (I): Safety of the swap handling. Ranking scale:
  - 5 - Ground handling, horizontal
  - 4 - Ground handling, three dimensional without external infrastructure
  - 3 - Ground handling, three dimensional with external infrastructure
  - 2 - Aerial (non-crane)
  - 1 - Crane or non-detachable "on the road"

- Safety (II) and (III):

- Safety of the charging/power supply system
- Safety of the virtual or automatic coupling of additional modules:
    - These criteria are not applicable to the current evaluation, due to the early stages of these technologies and the subsequently lack of available data. However, they will be relevant in the future development of the Pod.

- Societal Quality and Personal Development (I) and (II):
  - Accessibility: 100% low entry
  - Comfort
    - These criteria are not applicable to the current evaluation, since all concepts for passengers consider low entry designs and lack available data about comfort features. However, they will be relevant in the future development of the Pod.

As in the previous overview chapter, the evaluation is organised according to the following categories of intermodal and multimodal systems:

- Existing Pod systems and those under development, with interfaces to railway
- Existing and under development Pod systems in other transport modes

Results of the technological evaluation of existing pod systems and those under development, with interfaces to railway:

System	Evaluation. TRL (estimation)	Functionality (I): Rail-bound concept	Functionality (II): Full autonomous drive concept	Functionality (III): Intermodality concept to rail mode, from road or ropeway mode	Functionality (IV): Modularity (rapid scalability to train formations - virtual/automatic coupling)	Functionality (V): Range without charging	Safety (I): Swap Handling
 Siemens - moodley "one for all"	1 - TRL 1	5 - Yes	5 - Yes. GoA4/SAE5	5 - Yes, rail-road-ropeway	5 - Yes, virtual coupling	3 - Estimated 50 - 150 km	2 - Aerial (non-crane)
 Parallel Systems	3 - TRL 5	5 - Yes	5 - Yes. GoA4/SAE5	4 - Yes, rail-road	5 - Yes, virtual coupling	3 - Estimated 50 - 150 km	1 - Crane or non-detachable "on the road"
 FlexSbus-LR (Aachen Rail Shuttle ARS)	2 - TRL 2 - 4	5 - Yes	4 - Driverless, with attendant, GoA3-SAE4	1 - No	1 - No	- Estimated 50 - 150 k	1 - Crane or non-detachable "on the road"
 CargoMover	5 - TRL 7	5 - Yes	5 - Yes. GoA4/SAE5	4 - Yes, rail-road	2 - Conventional railway coupling	1 - Self-propelled bycombustion engine	1 - Crane or non-detachable "on the road"
 Minimodal	4 - TRL 8 - 9	5 - Yes	1 - No	4 - Yes, rail-road	2 - Conventional railway coupling	1 - (only container waggion)	3 - Ground handling, three dimensional with external infrastructure
 Nevomo (Cargo) MagRail	1 - TRL 2	5 - Yes	5 - Yes. GoA4/SAE5	4 - Yes, rail-road	1 - No	1 - Not self-propelled or combustion engine	1 - Crane or non-detachable "on the road"

Table 3: Abstract of the technological evaluation of rail-related pod systems

From the evaluation table in Table 3, the following insights can be derived for each system:

- Siemens-moodley "one for all": This system is in the early stages of its TRL but scores high in all functionalities, indicating its potential in future rail-bound autonomous operations. Its estimated range without charging is moderate, and its aerial swap handling safety concept scores lower than average.
- Parallel Systems: With a moderate TRL, this system has partial developed functionalities and good intermodality capabilities. It also offers an estimated moderate range without charging and an average safety score in swap handling.
- FlexSbus-LR (Aachen Rail Shuttle ARS): This system is also in its early developmental stages, with strong rail-bound and autonomous drive concepts. However, it lags in intermodality and modularity, since it is non-detachable "on the road".
- CargoMover: This system stands out with its fully developed TRL. It excels in functionalities but has a combustion engine concept from 2002.
- Minimodal: This system reached a high maturity level and scored good in its handling

method; however, it is a concept from 2002, non-autonomous and not self-propelled.

- Nevomo | (Cargo) MagRail: This system, with its moderate TRL, offers robust functionalities. However, it falls short in modularity and is not self-propelled.

The polygonal illustration in Fig. 65 graphically represents the performance of each rail-related Pod-system across the different technological parameters. Based on this graphic, it seems that most of the technological criteria are completely fulfilled, so that the analysed concepts could serve as partial benchmarks. It must be pointed out that two parameters fall behind:

- Range without charging: scores are medium, suggesting that further development of the energy storage technologies and concept is required.
- Safety of the intermodal handling: scores are low, suggesting that this feature should be elaborated in the development of rail-related Pod systems.

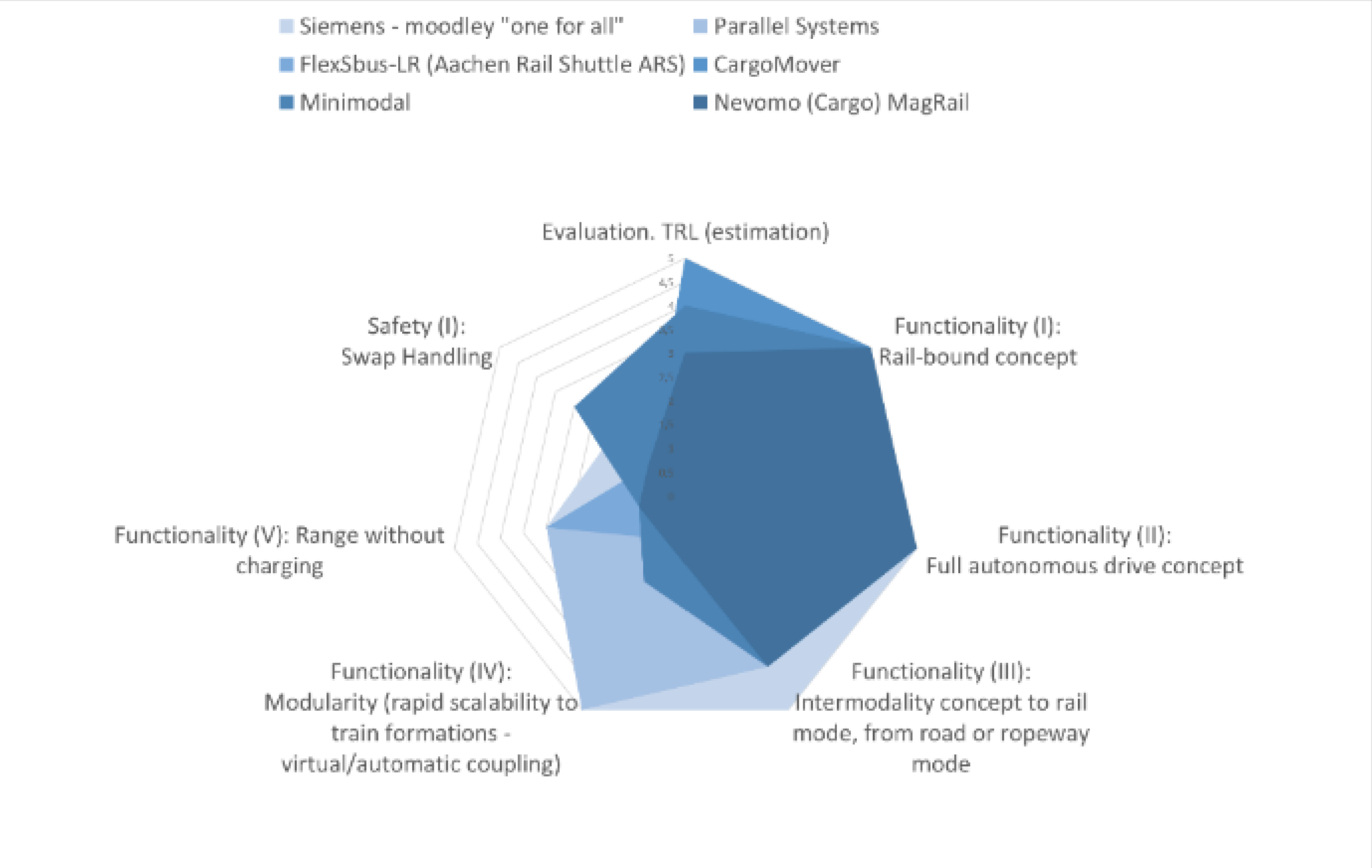


Figure 65: *Illustration of the technological evaluation of rail-related Pod systems*

Results of the technological evaluation of existing and under development pod systems in other transport modes:

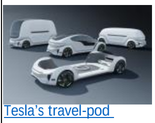
System	Evaluation. TRL (estimation)	Functionality (I): Rail-bound concept	Functionality (II): Full autonomous drive concept	Functionality (III): Intermodality concept to rail mode, from road or ropeway mode	Functionality (IV): Modularity (rapid scalability to train formations - virtual/automatic coupling)	Functionality (V): Range without charging	Safety (I): Swap Handling
 U-Shift - DLR	3 - TRL 5 - 7	1 - No	4 - Driverless, with attendant, GoA3-SAE4	1 - No	1 - No	3 - Estimated 50 - 150 km	5 - Ground handling, horizontal
 ConnX® - LEITNER	3 - TRL 5 - 6	1 - No	3 - Concept estimated to be prepared for automated guided driving.	2 - No, but road-ropeway	1 - No	2 - Estimated < 50 km on road or rail	2 - Aerial (non-crane)
 upBUS - RWTH Aachen	3 - TRL 5 - 6	2 - Currently under development with TRL 1 - 3	3 - Concept estimated to be prepared for automated guided driving.	3 - No, but road-ropeway and planned for rail	1 - No	2 - Estimated < 50 km on road or rail	2 - Aerial (non-crane)
 Rinspeed - Metrosnap	3 - TRL 5 - 7	1 - No	5 - Yes. GoA4-SAE5	1 - No	1 - No	3 - Estimated 50 - 150 km	5 - Ground handling, horizontal
 Rinspeed - Snap	3 - TRL 5 - 7	1 - No	5 - Yes. GoA4-SAE5	1 - No	1 - No	3 - Estimated 50 - 150 km	4 - Ground handling, three dimensional without external infrastructure
 Rinspeed - Microsnap	3 - TRL 5 - 7	1 - No	5 - Yes. GoA4-SAE5	1 - No	1 - No	3 - Estimated 50 - 150 km	3 - Ground handling, three dimensional with external infrastructure
 Citroën Autonomous Mobility Vision	2 - TRL 2 - 4	1 - No	5 - Yes. GoA4-SAE5	1 - No	1 - No	3 - Estimated 50 - 150 km	5 - Ground handling, horizontal
 e-Palette | Toyota	3 - TRL 5 - 7	1 - No	4 - Driverless, with attendant, GoA3-SAE4	1 - No	1 - No	5 - Estimated > 150 km	1 - Crane or non-detachable "on the road".
 Schaeffler Mover 1.0 - Poschwatta	3 - TRL 5 - 7	1 - No	3 - Concept estimated to be prepared for autonomous driving.	1 - No	1 - No	3 - (Estimated) 50 - 150 km	5 - Ground handling, horizontal
 Tesla's travel-pod system - Fábio Martins	1 - TRL 1	1 - No	5 - Yes. GoA4-SAE5	1 - No	1 - No	3 - (Estimated) 50 - 150 km	5 - Ground handling, horizontal

Table 4: Abstract of the technological evaluation of Pod systems in other transport modes

From the evaluation table in Table 4, the following insights can be derived for each system:

- U-Shift | DLR Verkehr: With a TRL 5-7, the U-Shift is not rail-bound but has full autonomous driving capabilities. It can reach a 100 km range without recharging. One of its main strengths is the safety of its ground level handling, which does not require separate infrastructure capsule change.
- ConnX® | LEITNER: With an estimated TRL between 5-7, it is not rail-bound but it is being prepared for automated guided driving. It introduces road-ropeway intermodality but lacks modular scalability, except in ropeway mode. It can cover less than 50 km and employs aerial non-crane handling.
- upBUS | RWTH-Aachen: Positioned at TRL 5-6, it is developing its design also towards rail intermodality. It is prepared for autonomous driving and offers road-ropeway intermodality. The range is estimated as low in road mode and it is designed with aerial non-crane handling system.
- Metrosnap | Rinspeed: It reached a TRL 5-7, was not designed for rail but could drive autonomously. Its electric range of 130 km without charging is slightly above average and it was equipped with horizontal ground handling.
- Snap | Rinspeed: This system reached TRL 5-7, was not rail-bound but could drive autonomously. It reached an average electric range of 100 km without charging and employs a three-dimensional ground handling method with integrated lifting shafts and without external infrastructure.
- Microsnap | Rinspeed: This system reached TRL 5-7, was not rail-bound but could drive autonomously. It reached an average electric range of 95 km without charging and employs a three-dimensional ground handling method with external infrastructure.
- Citroën Autonomous Mobility Vision: An experimental system at TRL 2-4, while it is not rail-oriented, it is designed for full autonomous driving on the road. It covers an estimated 50-150 km electric range and is fitted with horizontal ground handling.
- e-Palette | Toyota: At TRL 5-7, it did not offer rail functionality but was designed for full autonomous driving with attendant. It reached more than 150 km range without charging and was non-detachable on the road.
- Schaeffler Mover 1.0 | Poschwatta: With a TRL of 5-7, it is not designed for rail intermodality but is designed for full autonomous driving on the road. It is estimated to reach a medium electric range and is equipped with a horizontal ground handling design.
- Tesla's travel-Pod system | Yanko Design: A nascent system at TRL 1, it is not meant for intermodality to rail, will be fully autonomous, it is estimated to offer a medium electric range and is fitted with horizontal ground handling design.

The polygonal illustration in Fig. 66 graphically represents the performance of each Pod-system of other transport modes (non-rail-bound) across the different technological parameters.

Based on this graphic, it seems that some of the technological criteria are completely fulfilled, so that the analysed concepts could serve as partial benchmarks. The following particularities must be underlined:

- Road-bound concepts appear to be relatively advanced in their development of autonomous driving and battery propulsion technologies.
- Road-bound and ropeway-bound systems show little development towards intermodality to railway vehicles, underscoring the need for the research in Pods4Rail.
- Road-bound systems lack the scalability to couple several waggons/ vehicles which is common use within railway concepts.
- The safety of the handling process achieves high scores in road-bound concepts, showing robust concepts that can serve as a benchmark for Pods4Rail.

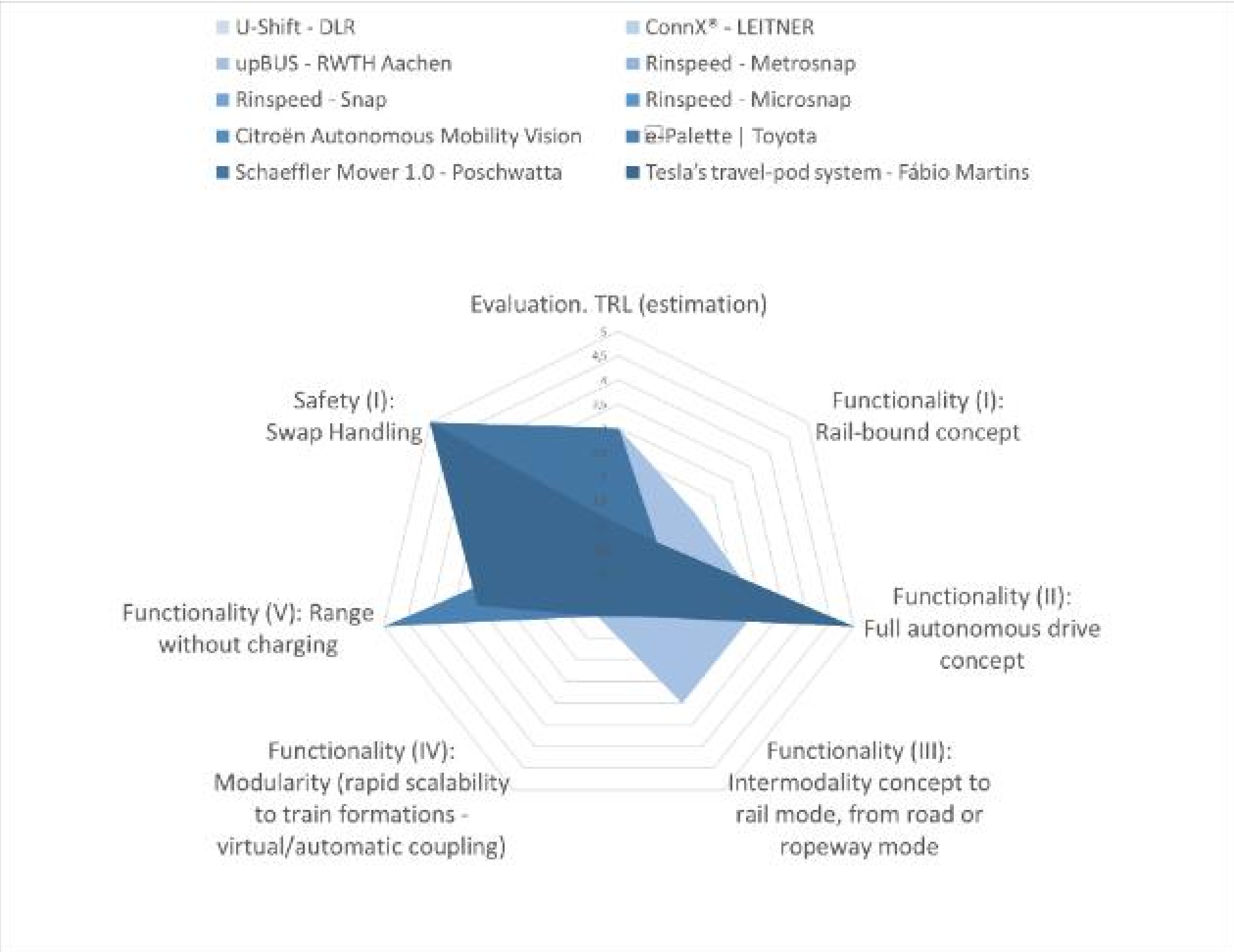


Figure 66: *Illustration of the technological evaluation of Pod systems in other transport modes*

The two polygons from Fig. 65 and Fig. 66, when examined closely, demonstrate a complementary relationship of the technological capabilities of rail-related Pod systems and Pod systems in other transport modes, as shown in the combined graphic of Fig. 67., in which a high score of every parameter is reached by at least one of the mobility concepts. The robust parameters of handling systems and electric range for road-bound transport could serve to enhance and complete the attributes portrayed in the initial polygon chart for rail-bound Pod-systems. This synergy between the two polygons suggests that these system components should be keenly observed as a benchmark in the development of Pod systems.

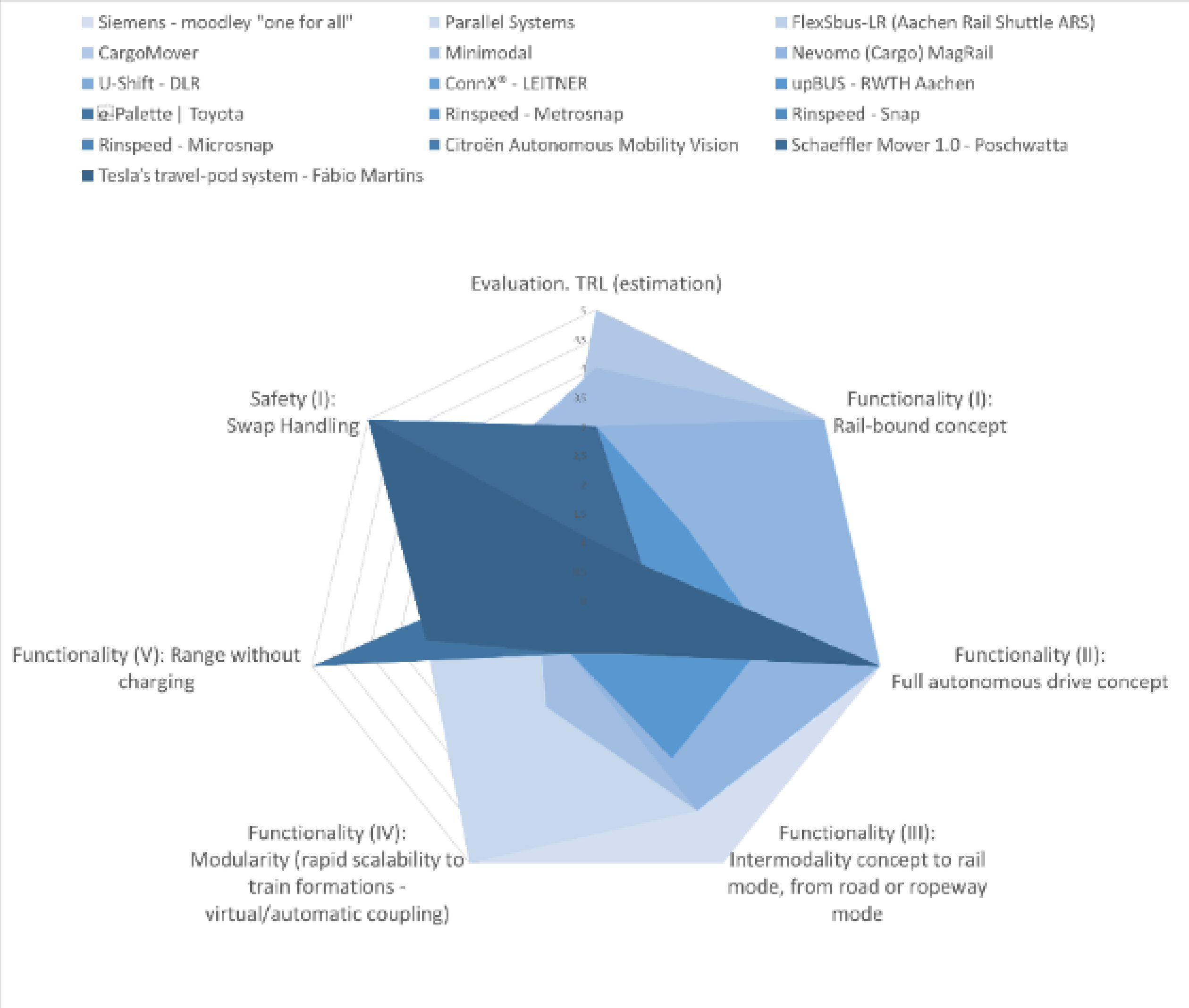


Figure 67: *Combination of Fig. 65 and Fig. 66 for the illustration of the technological evaluation of Pod systems in railways and in other transport modes*

6.2.2. Economic Evaluation

Economic Efficiency

Using the same method as in the previous chapter, this section establishes an economic ranking of existing and developing Pod systems, as well as rail-bound and other modes of transportation. The evaluation of these systems is conducted using the criteria mentioned in Chapter 6.2 under Economic Efficiency, which include suitability for the existing infrastructure, capacity, and payload efficiency.

For the economic evaluation, the following ranking scales are used:

- TRL estimation (s. chapter 6.2.1)
- Economic Efficiency (I): Suitable for existing infrastructure. Ranking scale:
    - 5 - estimated high
    - 4 - estimated medium-high
    - 3 - estimated medium
    - 2 - estimated medium-low
    - 1 - estimated low
- Economic Efficiency (II): The estimated ratio between payload and tara weight. Ranking scale:
    - 5 - estimated high
    - 4 - estimated medium-high
    - 3 - estimated medium
    - 2 - estimated medium-low
    - 1 - estimated low
- Maximum capacity of the vehicle. Ranking scale:
    - 5 - estimated high
    - 4 - estimated medium-high
    - 3 - estimated medium
    - 2 - estimated medium-low
    - 1 - estimated low

Results of the economical evaluation of existing and under development Pod systems:

System	Evaluation. TRL (estimation)	Economy and Enviro (I): Suitable for existing infrastructure	Economy and Enviro (II): (Estimated) Maximum capacity of the vehicle	Economy and Enviro (III): Estimated ratio between payload and tara weight
 moodley "one for all" mobility system	1 - TRL 1	3 - estimated medium	3 - estimated medium	3 - estimated medium
 Parallel (moveparallel.com)	3 - TRL 5 - 7	5 - estimated high	5 - estimated high	5 - estimated high
 FlexSbus-LR (Aachen Rail Sh	2 - TRL 2 - 4	5 - estimated high	5 - estimated high	5 - estimated high
 CargoMover	5 - TRL 9	5 - estimated high	5 - estimated high	4 - estimated medium-high
 Midimodal Boxes	4 - TRL 8 - 9	5 - estimated high	5 - estimated high	4 - estimated medium-high
 Nevomo | (Cargo) MagRail	3 - TRL 5 - 7	1 - estimated low	5 - estimated high	4 - estimated medium-high
 U-Shift | DLR Verkehr	3 - TRL 5 - 7	5 - estimated high	4 - estimated medium-high	4 - estimated medium-high
 ioBUS - (rwth-aachen.de)	3 - TRL 5 - 7	3 - estimated medium	5 - estimated high	5 - estimated high

Table 5: Abstract of the economical evaluation of Pod systems

For each system, the evaluation table in Table 5 shows the following findings:

- Siemens-moodley "one for all": The existing road infrastructure can be used directly. However, it is necessary to adapt the cable car infrastructure for this system, as well as to adapt train and intermodal stations for the lift and linear shift pod handling foreseen in its concept. The capacity was classified here as average, as there are Pod systems of varying sizes. There is no information available regarding its weight and the evaluation is based on an estimation.
- Parallel Systems: This system does not require any new infrastructure since it can use the existing rail system, what has a positive impact on economic efficiency. The capacity is high because the system is capable of transporting a standard container. Due to a lack of information about the weight of the system, the assessment is based on an estimate.
- FlexSbus-LR (Aachen Rail Shuttle ARS): The FlexSbus-LR would not require major adaptation of the infrastructure of the secondary lines, where it is aimed for. The vehicle is designed to transport around 80 passengers. The information available regarding its low-weight construction design leads to a and the high score in this criterion.
- CargoMover: The CargoMover could make use of the rail system, thereby eliminating the necessity to invest in new infrastructure. This system had a high capacity, as it could substitute two trucks. Due to the lack of information about the weight of the system, the payload assessment is based on an estimate.
- Minimodal: could also make use of the available rail system, eliminating the necessity to invest in new infrastructure, since standard forklifts were sufficient for the handling. This system had a high capacity, as it could load up to 6 small containers (2.5m x 2.5m x 2.3m).
- Nevomo | (Cargo) MagRail: With this system, the weight is limited by the magnetic levitation technology, which has an impact on the capacity of the containers and also on the payload. In addition, the use of magnetic levitation technology is associated with high investment costs for the infrastructure. The system can transport a container, so the capacity is rated as high.
- U-Shift | DLR Verkehr: The U-Shift can use the existing road. The capacity is approximately 16 passengers (standing and seated), with a payload of 1 ton for the passenger capsule and 2 tons for the cargo capsule. The weight of a U-Shift driveboard prototype in an early development stage is 2.5 tons, the weight of the empty capsule is 2.3 tons (passenger) and 0.4 tons (cargo). Considerable weight optimisation is assumed for a series vehicle.
- upBUS - RWTH-Aachen: An interesting feature of the system is the possibility of using capsules both on carriers for the road and on ropeways. This is an attractive and innovative advantage in urban areas, for example, where the road network is often at its capacity limits and the alternative is to use airspace. In terms of costs, one advantage is that the existing road infrastructure can be directly utilized. However, the system also possesses a disadvantage, as the construction of the necessary cable car system is expensive. The capacity of the capsule for passenger transport is around 20 people. There is no information available regarding its weight and the evaluation is based on an estimation.

The polygonal illustration in Fig. 68 graphically represents the performance of each rail-bound Pod-system and the Pod systems of other transport modes (non-rail-bound) across the different economical parameters and including the TRL to keep the development stage as a reference.

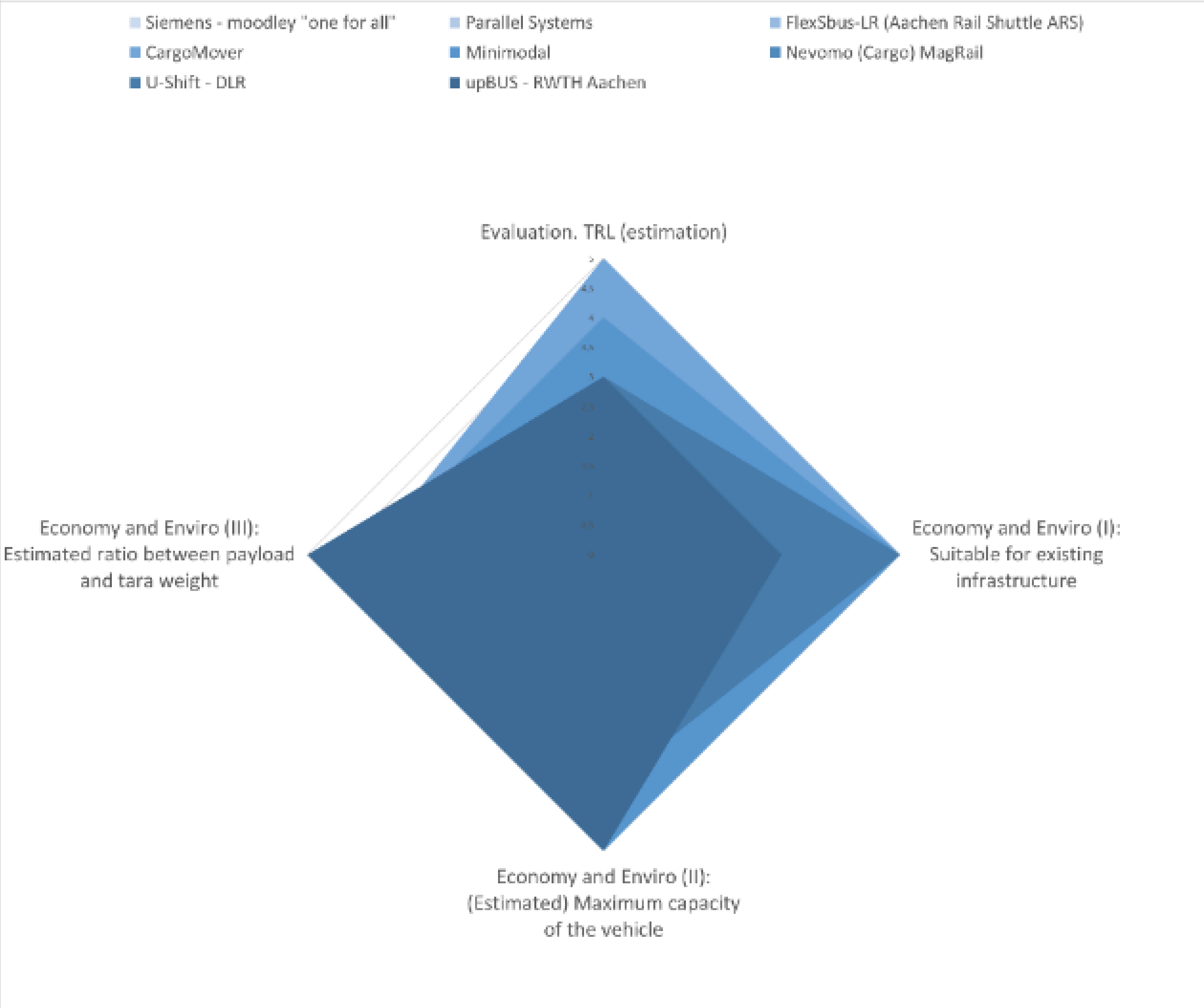


Figure 68: *Illustration of the economical evaluation of Pod systems*

6.2.3. Environmental Evaluation

The environmental evaluation considers the criteria defined in the introduction of this chapter, 6.2, from the application of the VDI 3780 guideline. The environmental evaluation revealed a distinct trend where economic efficiency and environmental quality criteria are closely intertwined, presenting themselves as synergetic rather than conflicting parameters. The common evaluation parameters of suitability for existing infrastructure, maximum capacity, and payload efficiency, shall be considered in the Pod development viewing them through an environmental lens.

Nonetheless, a detailed environmental evaluation according to these criteria is not feasible at this stage, due to the early stages of the development of some of the concepts and the lack of available data in the other cases. Since the applied method in this Task will be utilised in forthcoming Work-packages, it is worth mentioning that characterisation parameters such as Life Cycle Assessment (LCA) or Pathway of Future, including metrics like CO_2/Pkm, kWh/Pkm, and CO_2eq. t/km, from well-to-wheel (WTW), tank-to-wheel (TTW), to an all-encompassing cradle-to-cradle should be considered in the following Pod development. In addition, an evaluation of the Pod should be designed to align with ESG (Environmental, Social, and Governance) guidelines, considering factors like recycling rates, content, and the need for critical raw materials.

Noise emissions, which is a significant environmental concern, is not a common parameter with the Economic Efficiency, and was identified as a parameter of interest. An evaluation of the noise emissions of the selected handling system for the Pod is highly recommended.

6.2.4. User perspective

This section describes the application of a scenario-based interviewing technique for the investigation of the user perspective regarding potential future Pod systems use contexts. The goal was to qualitatively test the technique with a small group of users for future application. Inquiring technologies with potential future users marked by low Technical Readiness Level requires appropriate research methods. That is, because classic usability and user experience research methods can usually only be applied to existing technology artefacts. The field of *prospective ergonomics (PE)* provides methods for exactly such situations. In 2009, Robert and Brangier proposed to complement classic ergonomics with this strategic perspective, in order to identify needs and use cases for speculative future scenarios and technologies. Martin, Bonneviot and Brangier (2022) proposed to utilise the human capacity to engage in *future thinking (FT)* for PE research. The basic premise of this method is, that humans are well capable of imagining the future and that this ability could be harnessed for studying forthcoming technology artefacts like intermodal Pod systems. To read about the procedure and methodology, please see Annex 1.

6.2.4.1. Results of the user research

This section will present the results obtained through exploratory, qualitative user research. To that end, the main findings for each interview question will be stated and at the end of this section, a short summary of the results will be provided. In general, participants expressed very positive attitudes towards the concept.

<u>Question 1: Now that you have heard a detailed description of the Pod-concept and have envisioned it, how do you like the concept? Why?</u>

- Pods were perceived to be efficient because they can serve multiple purposes at once (e.g. simultaneous transport of passengers and freight).

- It was generally expected that Pods would exert a positive effect on the environment because trips would be saved and the expended energy would be shared by multiple user groups.
- Participants expected Pod-mobility to be convenient, due to the elimination of the need to switch of having to switch modes of transport was perceived as a real benefit.
- In general, participants expressed that they would prefer sharing a Pod over owning a car.

<u>Question 2: For which use cases or applications could you see yourself using Pods?</u>

- Participants reported that they would use Pods much like currently existing means of public transport.
- They voiced that they would use Pods for any distance that is too far to walk.
- Depending on the available space inside the Pods, participants would use them to transport heavy freight such as furniture (e.g. when buying a rug or table and having to bring it home).

<u>Question 3: Does the concept of intermodality provide benefits for your mobility? I.e. because you need to switch modes of transport regularly.</u>

- The main benefit participants reported was increased reliability of their mobility because they could not miss connections anymore.
- People with impaired mobility would also benefit from Pods because changing means of transport is not always barrier-free.

<u>Question 4: Where do you see limitations or issues with the concept?</u>

- The main concern of participants was how to ensure availability and short wait times when demand is high.
- Participants would only use the service if wait times are short. Uber was referred to as a provider that usually achieves adequate wait times.
- In the scenario participants envisioned, it was described that cargo was added to the Pod. Participants thus expressed that this process must not cause delays.
- The question of how to implement a dense network of virtual stops for railway Pods was raised.

<u>Question 5: Which features or aspects would you like to see added?</u>

- Special-purpose Pods were expressly desired. There should be additional Pod concepts for camping, sleeping, working and cargo transport.
- Participants uttered the desire for a scheduled pick-up service, e.g. for the commute to/ from the workplace. This could be implemented through a recurring appointment or a feature that synchronises the booking app with one's personal calendar.

<u>Question 6: Would you generally feel safe?</u>

- In general, participants responded that they would feel very safe inside the Pod and that they expect the technology to be sufficiently mature until the year 2050.

- A question that was posed, was how the Pod would handle unexpected situations. For example, what would happen when a child would suddenly run onto the streets?
- Additionally, a female respondent voiced that she could feel unsafe because of other passengers present in the Pod. She thus expressed the desire for a feature that would ensure that she would never share the Pod with people she previously has had negative experiences with.

Question 7: Would you feel safe during the mode change?
- Participants were very confident that they would trust the coupling process ("just like a train adding another waggon").

Question 8: Would you like to be belted?
- The majority of participants would feel safe without a belt.
- Few participants would make it dependent on the travel speed of the Pod. For road travel, it was reported that a belt might be desirable for speeds exceeding 30 km/h. For railway travel, a belt might be desired for speeds exceeding 100 km/h.
- Only one participant uttered the desire to be belted at all times.

Question 9: Do you want to hear a sound when the coupling is happening, or do you not want to hear anything?
- The majority of participants reported that they would like to hear or feel some kind of feedback when coupling was successful.
- This would provide them with reassurance of the safety of the process.
- It did not seem to matter whether the coupling sound was mechanical or artificial (i.e. played through speakers). It was more important that the sound is rich and pleasant.

Question 10: Would you prefer the mode change to occur through the air with a crane or through a sliding mechanism?
- This was by far the clearest response: All participants preferred the sliding mechanism on the ground.
- The crane solution was perceived as potentially uncomfortable. One reason for this impression was that winds might set the Pod into a swinging motion mid-air.
- It was also asked where the cranes would be placed. From the responses, it appears that the sliding mechanism was imagined to be much more compact.

Question 11: Is it okay for you when freight is added during your trip? Why yes, why not?
- Sharing the Pod with freight was expressed to be desirable due to transport efficiency, economic and environmental benefits.
- However, the addition of freight cargo should not cause delays or other inconveniences.
- The cargo should be stored a level below the passengers. In the scenario that was read to participants, freight was loaded on top of their Pod. Almost all participants expressed feeling uneasy with this solution.

Question 12: How comfortable would you feel with such an intelligent, autonomous system?

- Participants predicted very high trust in the system due to expected increases in technological maturity achieved by 2050.
- The current traffic situation was perceived to be much more dangerous than a future transport system dominated by autonomous Pods.

<u>Question 13: Would you be ready to share the Pod with others? How many? Why yes, why not? Or would you prefer to use it alone?</u>

- Participants reported very high willingness to share the Pod with other passengers.
- Sharing the Pod was perceived as one of the main benefits of the concept.
- However, the Pod should not be as crowded as currently existing means of public transport.
- Additionally, participants reported that there would be times (e.g. after work) when they would prefer the comfort, quiet and private sphere of travelling alone.

<u>Question 14: Would you prefer to remain in the Pod for the whole journey to change modes less often or would you prefer to be able to stretch your legs during the ride?</u>

- The overwhelming majority of participants would want to make full use of the Pod system by completing their journey without switching means of transport.
- Only one participant responded that she would like to leave the Pod for very long journeys (duration of appx. six hours).

<u>Question 15: Now imagine an emergency occurred: How would you like to evacuate from the vehicle?</u>

- Evacuating through the door was the most frequently mentioned exit strategy.
- Evacuating through the windows was also mentioned often.
- Only few respondents voiced that they would evacuate through the roof.
- It was very important to participants that they could open doors, windows and hatches mechanically.
- Additionally, participants reported a strong desire for autonomy. They would not want to wait for a technician to arrive to rescue them.
- In general, existing solutions from public transport were often referred to as good solutions.

<u>These findings well illustrate the desirability of the concept. Some of its key-features were highlighted as particularly positive:</u>

- Efficiency gains and environmental benefits through sharing Pods with other passengers and cargo.
- More reliable and convenient travel due to not having to switch means of transport.
- More convenient travel through door-to-door mobility, especially when transporting heavy goods.

These aspects even led one participant to reconsider whether it would be necessary for her to live in the city. In her mind, Pod mobility solutions could negate many of the drawbacks currently associated with living outside the city because they would enable her to quickly gain access to all relevant services and her social network. In short, Pod mobility may help to diffuse the boundaries between urban and rural locations of residence.

It should be highlighted that all findings remain speculative due to the nature of the research topic. For instance, most participants reported that they would be willing to travel without being belted. This view, however, is strongly skewed by the expectation that autonomous Pod systems will be highly reliable and safe. As one participant pointed out, he anticipated that he would vigilantly read the news in the future to check for any Pod-related accidents. Trust in Pod solutions will thus be dependent on a myriad of contextual factors.

Despite this note for caution, it is encouraging that the study participants shared such positive views towards the core features of the concept. Pod mobility appears to be a viable solution in the minds of the respondents.

6.2.4.2. Discussion of the applied method for the user research

After having completed eight interviews, it can be reported that the FT-method worked to investigate the user perspective on potential future Pod-systems. While it was the aim to incorporate as many methodological recommendations as possible, contextual constraints confined the extent to which this aspiration could be realised. For one, the time-horizon in the project Pods is the year 2050. As usual, the demand for methodological rigour had to be balanced with real-world requirements. While the authors recommended not to exceed time horizons that are greater than six months for future thinking interviews, the authors were optimistic that the method could also be applied to longer timeframes. The method was assembled based on the authors' broad experience with qualitative research methods and in a way that suited the project's goals the best. As adumbrated in the previous paragraph, the research design was validated by the results of the study, since rich and meaningful data were obtained for all interview questions.

It was decided to only include a limited number of activities in this study, in order to maintain a concise study format. Participants were required to reflect on their current mobility behaviour, generate a broad future vision of their lives, to listen to the scenario and to answer a number of interview questions. It would be feasible to shorten the first two exercises of the study because it should be sufficient to expedite the warm-up exercises without elaborating them in much detail, if time is of the essence. Nonetheless, it is recommended to thoroughly prepare participants for the visioning exercise, in order to obtain optimal results.

The importance of the warm-up exercises should be stressed. First asking participants about their current mobility behaviour served two purposes: It provided valuable background information to better understand their current mobility patterns and it also primed participants to think deeper about how they use transport. This became evident during subsequent tasks, when the participants' responses revolved around transport topics even though they were not directly asked about it.

In the same vein, it was important to let participants build a broad future vision of their own live during exercise two. Furthermore, it is important to stress that this exercise was not about accurately predicting the future but rather to stimulate the participants thinking.

Lastly, the importance of visual aids should be stressed. At the beginning of the study, participants were shown images of the DLR U-Shift prototype and a 3D-render of the upBUS concept. These stimuli made the rather abstract concepts more tangible and provided a frame of reference for the subsequent exercises. It would be interesting to explore the potential of virtual and augmented reality during future studies.

All in all, it can be concluded that under the right conditions, FT can serve as a powerful PE research method to investigate potential future Pod-systems. Enabling visioning of a future scenario by means of a mental journey worked well for gauging participants' attitudes towards a technology marked by a low to medium technical readiness level. This required properly preparing participants for the exercise through use of suitable warm-up exercises, though. Additionally, the methodological issue of constructing a specific future must be carefully considered in order to not overly skew responses.

7. Conclusions

This deliverable reports the results of the activities of Task 2.2 in Work-package 2 with the aim of collecting and evaluating the existing intermodal and multimodal mobility systems. The deliverable is composed of two main sections: the overview section provides an overview of existing technologies and new approaches of Pod-systems with potential for its application in Pods4Rail, with a particular focus on rail-compatible ones, as well as an overview of handling systems and other relevant concepts. Main characteristics of these systems were gathered (where available) according to a set of parameters defined for this task, including factors such as Technical Readiness Level (TRL), modes, passenger/ freight (or both) application, autonomy level, payload, among others. The second section reports the results of an exploratory, qualitative and user-based analysis of the systems provided in section 5. The primary objective of Task 2.2. is not only to identify the best technology among intermodal and multimodal systems but also to pinpoint systems or system-components that can serve as benchmarks for the technological development of the Pod system.

The evaluation section was based on the characterisation parameters collected for the overview and on the application of the technical values described in the VDI 3780, Guideline of Technology Assessment Concepts and Foundations, emphasizing factors including economy, functionality, safety, environment, personal development and societal quality.

One of the main results of this task is that no single existing system or new approach offers a comprehensive benchmark for the Pod, highlighting the need for Pods4Rail research. However, components from several analysed systems stand out as potential benchmarks:

- Siemens-moodley "one for all" intermodal seamless mobility concept.
- Lightweight rail design for secondary lines by the Aachener Rail Shuttle and its detachable concept (when not in operation).
- External design elements from Nevomo Cargo MagRail (e.g. size, chassis concept with integrated front and back structures for sensors, see Figure 6).
- Automatic coupling from Intramotev TugVolt's rail freight concept.
- Minimodal freight waggon bundling up to six small containers that can be handled by standard forklifts.

Additionally, some non-railbound Pod-like systems provide benchmark components for Pods4Rail:

- DLR U-Shift's modular concept and its passenger/cargo docking system.
- The innovative gondola designs of upBUS and LEITNER ConneX® ropeways.
- Rinspeed's road vehicle concepts that allow vessel detachment by either lifting the cabin or using 100% horizontal handling.

Rail-related passenger Pod system concepts received lower scores regarding their handling systems. Other transport modes with Pod systems scored better, indicating potential inspiration for rail Pod systems from the other transport modes and from the handling systems' overview.

Given the project's objectives, the definition of both the economic and environmental evaluation criteria reflected a high degree of coincidences, showing a trend in technological and scientific research, by which economic efficiency and environmental quality are two sides of the same coin.

It is also important to note that the overview of handling systems with potential for applications in Pods4Rail, encompassing passenger concepts and well-established combined transport systems, serves as a foundation for WP13 "Concept for the handling, loading/unloading technologies". The overview carried out illustrates the importance of the handling process for pod operation. Given that the Pod will likely operate inside railway stations and considering the project goal of using existing infrastructure with minimal adaptation, the analysis suggests that implementing this Pod system feasibly might necessitate an additional carrier for the operation inside and at railway stations. The analysed Airport Handling Transporters from Gaussin could potentially serve as a benchmark in this context. Cranes were not considered in this analysis, due to their estimated low potential acceptance by passengers, an assumption that was validated by the user research responses.

Other related concepts such as the road-bound ride-pooling by MOIA and the autonomous road shuttles in development that reach speeds up to 70 km/h of VDL, Schaeffler and ZF serve as benchmark for the last mile shared door-to-door operation of the Pod that will be tackled in WP11 "Concept development for traffic coordination of Pods systems". It must be also pointed out, that there is a more pronounced focus on research and development of road-bound Pod systems than for rail-bound solutions, and that there exists a noteworthy research on ropeway-bound Pod systems. Due to this, many parameter estimations were necessary for the task's completion.

In addition, exploratory user research was conducted to gain an initial understanding of the acceptance of this innovative system. Results demonstrate the viability of Future Thinking (FT) as a potent method for investigating potential Pod-systems in low to medium technical readiness scenarios. Successful implementation requires adequate participant preparation and careful consideration when constructing specific future scenarios to avoid bias. The qualitative user research conducted unveiled strong enthusiasm for potential Pod-systems in 2050. Participants consistently praised the environmental friendliness and the seamless mobility experience, which obviated mode transitions. Their concerns primarily revolved around availability and waiting times, particularly among female participants, who worried about safety. However, there was a unanimous desire to share Pods with both passengers and freight due to environmental and efficiency benefits. While safety concerns were generally minimal, the need for safety belts at higher speeds was acknowledged. Aerial handling coupling was universally rejected in favour of a ground-based gliding mechanism with clear audible or tactile feedback to indicate successful linking of the Pods (e.g. natural, mechanical sound or an artificial one similar to a smartphone alert).

This technology vision-induced technology assessment applies a "top-down" assessment and requires to be complemented by the "bottom up" analysis of Use Cases and their SWOT analysis in WP4 "Socio-economical Evaluation and Requirements".

The planned objectives of the task/deliverable have been achieved.

8. List of Figures

9. References

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10. Appendices

Annex 1. Procedure and methodology of the investigation of the user perspective

In order to implement the FT approach proposed by Colin, Martin, Bonneviot and Brangier (2022), a visioning task was administered. For this task, a short future scenario inspired by the on the one for all solution image film[1] was written, which was read to the participants.

It is important to stress that this method is of explorative nature since the Pod technology is still in a very early development phase. The aim of this user research was not to obtain superficial survey responses of a representative sample of potential European users. Instead, it was decided to conduct in-depth interviews with a small group of respondents, in order to uncover relevant themes and motivators related to the usage of Pods in their early development stages. Exploratory, qualitative research provides deeper insights into individuals' motivators and can uncover acceptance barriers, which makes it a powerful tool to gain deep insights into the user perspective, especially at the beginning of technological product development. Research by Nielsen and Landauer (1993) revealed that the optimal cost-benefit ratio for qualitative usability tests is achieved with only five participants. The costs of conducting additional tests exceed their added utility. However, recruiting more participants still increases the probability of detecting potential issues, which is why eight instead of only five participants were recruited for this study. Following a grounded theory approach, interviews were conducted with the goal of inductively building a scientific understanding of Pod use and approaching information saturation (Strauss & Corbin, 1998). Information saturation refers to the point where additional interviews do not add new information to the data. While full information saturation was not achieved, it became evident during later interviews that the themes mentioned by the participants started to converge around a consistent set of topics and the data collection was concluded.

Therefore, participants were recruited through social media networks. In total, the study was conducted with eight volunteers (f = 5, m = 3) and the interviews took 45 to 60 minutes, with a standardised study design (see Fig. 64). In order to maintain anonymity, the age of participants was collected in brackets. Two participants were aged 18 to 29, five participants were aged 30 to 39 and one participant was aged 50 to 59. With regards to the participants' professions, two worked in health care, one in software engineering, two as designers, one as a government clerk and two in user research. All participants were recruited in Germany. Six out of eight participants lived in a city with a population greater than 100,000 inhabitants, one participant was recruited from a city with a population of 20,000 to 100,000 inhabitants and one participant was recruited from a village with less than 5,000 inhabitants.

[1] Siemens One for All concept, video credit: Moodley Industrial Design

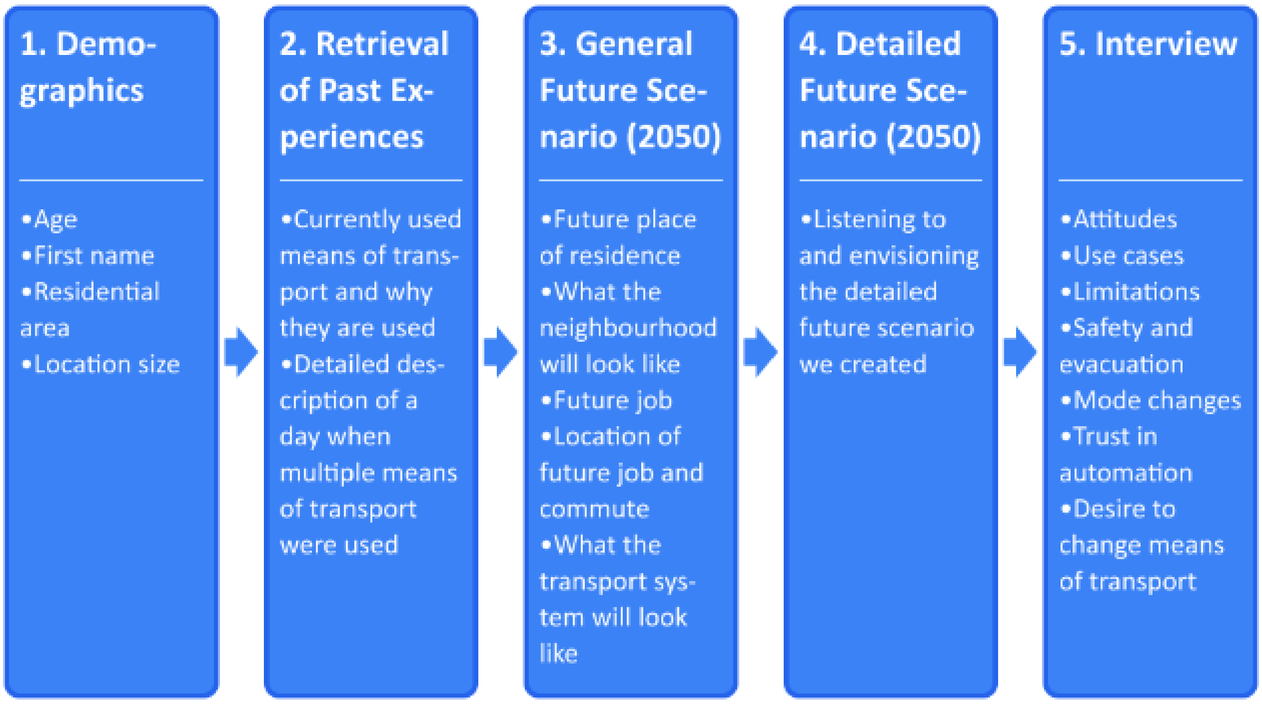

Figure 69: *Overview of the Study Design*

Before the FT-session was started, participants were shown two images of the DLR U-Shift prototype[2, 3] and a 3D-render of the upBUS concept[4]. In parallel, the function of the drive-board, the interchangeable containers and the aspect of inter-modality were explained.

First, the following demographic information of the participants were collected: age, first name, residential area and location size. After that, recollections of past use of mobility systems were elicited. As revealed by Ernst and Manning (2016), memories form the basis for participants to engage in FT. It was hence crucial to elicit recollections of past uses of mobility systems, so that these episodes could be recombined to form visions of the future. Therefore, interviewing was commenced by first asking participants which means of transport they usually take and why. After that, participants were asked to think about a day when they used several different modes of transport. In addition, they were asked what they liked and disliked about switching means of transport and what could have made the transitioning easier.

Following the semantic scaffolding hypothesis suggested by Colin, Martin, Bonneviot and Brangier (2022), participants were asked to imagine their lives in the year 2050. This way, a frame of reference for the subsequent detailed future scenario was generated. Therefore, this warm-up exercise was implemented, in order to collect richer answers during the interview.
After prompting participants to vision themselves in the year 2050, they were asked the following questions:

[2] U-Shift drive board, image credit: DLR
[3] U-Shift with passenger capsule, image credit: DLR
[4] upBUS 3D-render, image credit: RWTH Aachen

- In which city or area will you live?
- How densely populated will your neighbourhood be? I.e. urban city centre, suburbs or rural area. Can you describe your neighbourhood? Will there be cafés, parks, landmarks, specific activities to do, etc.?
- What will be your job?
- Where will be your job and how will you get there?
- How will the transportation system more broadly look like? Are there certain trends and developments you would expect to come to fruition?

Afterwards, a detailed vision of the participants' future was created (see Annex 2. Description of the visioning exercise). The scenario contained certain assumptions about the future. That is, because no depiction of the future is value-free and assumptions regarding certain aspects of the technology were tested. Hence, these features had to be incorporated into the scenario. By generating a positive vision of the future, it became possible to gauge participants' responses for a prospective best-case scenario. Notwithstanding, the wording of the scenario should be carefully chosen, in order to minimise bias.

After the participants completed the future visioning exercise, a semi-structured interview was conducted. While the interview manual was closely followed, liberty was taken to pursue any interesting and unexpected aspects that came up.

The participants were asked the following questions during the interview:
- Now that you have heard a detailed description of the concept and have envisioned it, how do you like the concept and why?
- For which purposes could you see yourself using the Pod?
- Does the concept of intermodality provide benefits for your mobility? I.e. because you need to switch modes of transport regularly.
- Where do you see limitations or issues with the concept?
- Which features or aspects would you like to see added?
- Would you generally feel safe in the Pod?
- Would you feel safe during the change of modes?
    - Would you like to be belted?
    - Do you want to hear a sound when the coupling is happening or do you not want to hear anything?
- Would you prefer the mode change to be executed through the air with a crane or via a sliding mechanism on the ground?
- Is it OK for you when freight is added during you trip? Why not, why yes?
- How comfortable would you feel with such an intelligent, autonomous system?
- Would you be ready to share the Pod with others?
    - If so, with how many?
    - Why yes, why not?
    - Or would you prefer to use it alone?

- Would you prefer to remain in the Pod for the whole journey to change modes less often or would you prefer to be able to stretch your legs while transferring to another Pod?
- Now imagine an emergency occurred: How would you like to evacuate from the vehicle?
- Is there anything else you would like to add?

Annex 2. Description of the visioning exercise

For the visioning exercise, the following excerpt was read to the participants:
Please, close your eyes and picture this: You are at home in a rural area. You are living in a green and quiet village outside one of the large megacities. The flat you live in is modern, pretty and homely. It is surrounded by large trees and lush, green grass. You really enjoy relaxing here, far away from the megacity. As the megacity is perfectly accessible through the modern and very comfortable multimodal Pod mobility system, you are able to do whatever you plan to do in the city, at the exact time you want to do it. Just like this morning: You are ready to go to work and leave your house at 7:30 am. You therefore ordered a Pod with your smartphone, for precisely this time. Moments later, a road-Pod loaded with a passenger capsule arrives. The capsule is approximately ten meters long, three meters wide and three meters tall. It is surrounded by large glass windows and there are panoramic windows in its roof. After you have entered it, it starts travelling towards the megacity. You sit down on a comfortable seat.

First, you enjoy the nature outside of the capsule, since you can be sure the Pod will do all the driving for you. Now it is time to relax. The Pod is spacious enough for you to walk in it. It is fall and you can see the bright colours of the leaves on the trees. After some minutes you decide to read the newspaper. While you read a very interesting article, the road-Pod arrives on the outskirts of the megacity. Your surroundings change and you look outside again. You see that the streets come to an end here and that they give way to a railway network. Barely any car is allowed inside the megacity since the latest transport reforms by the local government. Nowadays, mainly railroads lead into the city centre, where your workplace is located.

The Pod changes its mode by sliding smoothly from the road drive board to the rail drive board. The drive board is literally just that: An empty, driverless chassis with four wheels. All sensors, processing units, the gear train and the motor are contained within it. You then hear the satisfying locking sound of the coupling mechanism, when the Pod safely locks to the rail drive board. You think how great it is, that you do not have to change modes but that the Pod does all the work. In contrast to the road-Pod, the roof is not transparent. That is, because sometimes another cargo-Pod is stacked on top of the passenger-Pod. After your Pod was successfully transferred to the new drive board, the vehicle then starts its way to bring you into the city centre.

After you arrived at your workplace, you leave the Pod and it drives away. You know that empty Pods are used for freight transport at night, which seems very efficient. This is very different to owning a car many years ago, when the car just stood around most of the time.

After a day full of work, you want to drive home. Again, you order a rail-Pod and drive outside the city. This time you can see that your travel time is five minutes longer because a freight capsule will be added to your Pod during the ride. Just before the end of the city, the Pod suddenly but very smoothly decelerates. You take a short look at the information pad on one of the walls of the capsule and see that the freight capsule will be added to your Pod now. A countdown of five minutes appears, so you know how much longer the process will take.

You can see a little crane, lifting a large box from another drive board onto your capsule. You can hear the satisfying coupling sound again, this time from above your head and the Pod starts driving again. After the change from rail to road, you arrive in front of your home. You leave the Pod and see that it continuous its way to the closest supermarket to load off its freight.