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Assessing Multimodal Mobility Systems for Benchmarking Rail-Bound Intermodal Pods in ERJU´s FA7-Projekt Pods4Rail

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Abstract

A "Pod" system, defined as a detachable capsule-chassis vehicle concept operating within a seamless, decentralized and autonomous transport system, presents an innovative solution to transportation challenges. ERJU´s FA7 project Pods4Rail aims to explore an intermodal rail-bound autonomous Pod system and its autonomous transshipment onto road and ropeway modes, serving passenger, freight and combined transport needs, using mainly installed infrastructure. This study evaluates several multimodal Pod systems, analyzing their technical, economic and environmental attributes, along with user needs. The findings reveal a lack of a clear benchmark for Pods4Rail, underscoring the project's significance. Nevertheless, features from various concepts hold potential as benchmarks. Additionally, the safety of handling systems in cargo rail-bound detachable systems requires improvement in order to be applied on passenger Pods. The initial economic evaluation shows that the compatibility with existing infrastructure is a critical criterion, as well as its payload and capacity. Environmental criteria align closely with those of economic efficiency, but special attention should be drawn to noise emissions during transshipment. Moreover, exploratory "Future Thinking" interviews revealed potential users' positive attitudes towards Pods, their assumption that this technology would meet their transport needs and could contribute to mitigate the transport sector's negative impact on the environment.

Keywords: seamless, railway, intermodal, capsule, detachable, transshipment, swap body, pods, prospective ergonomics, user research

1 Introduction

Within the scope of Europe´s Rail Joint Undertaking (ERJU's) objectives, as outlined in the Multi-Annual Work Program (MAWP) Flagship Area 7, there is a keen focus on exploring innovative and unconventional flexible guided transport systems [1]. Looking forward, the evolution of railway and guided transport systems is poised to rely heavily on fully automated multimodal and intermodal mobility solutions that prioritize sustainability, collaboration, digitalization, on-demand services, standardization, scalability, and versatility across all transportation modes (Figure 1). Concepts such as dynamic infrastructures and pod-based approaches present numerous advantages and hold significant potential in shaping the future of transportation. As highlighted in the MAWP, the primary intended outcomes of pod-oriented systems are to bolster the role of rail transport in Europe's overall transportation and mobility landscape, particularly by seamlessly integrating lines with low and very low demand. This objective depends on enhancing flexibility and punctuality for both passengers and freight users, achieved through a strong emphasis on compact, demand-responsive units capable of operating across various infrastructures.

Nonetheless, the deployment of these technologies comes with its own set of challenges, including the need to attain technological maturity, which is inherently more complex when compared to incremental improvements to existing systems. Challenges include the design, weight and costs of the interface between carrier and transport unit, as well as the autonomous handling system. Additionally, there might exist substantial gaps related to the introduction and consolidation of legislative frameworks and standardization efforts.

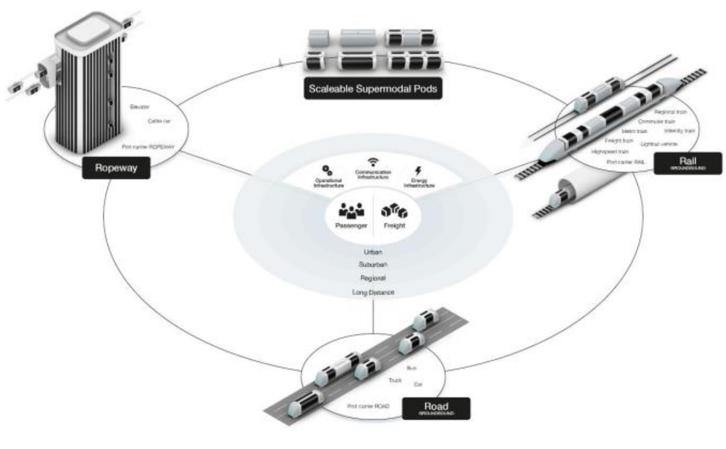

Figure 1: Overview over the Pods4Rail approach (moodley-Siemens, 2022).

1.1 Description of a Pod system

A “Pod” is composed of two main components that can be separated from each other during operation: a carrier and a transport unit (or several transport units). See figures 1 and 2. Further, a coupling system and a handling system are required. This design allows for swift transitions between various transport modes, such as railway, road, or funicular, without the need for system changes or intermediate freight handling.

- Carrier

Multi-purpose mobile underframe construction without the car body. It encompasses the frame, wheelset, the energy storage system, propulsion, most of the auxiliaries, the wheel-axle system and the system for autonomous driving. Different variants for railway, tramway and road modes. The transport units can be coupled and uncoupled to the carrier via the coupling system. The carrier is transport mode specific.

- Transport unit (container, capsule)

Unit that is dedicated for the transport of people or goods with a special design derived for this purpose and provided with the equipment necessary for the application. The transport unit can be coupled to the carrier. It is independent of the transport mode and can be attached to various mode-dependent carriers.

- Coupling system

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

- Handling system

An, preferably, autonomous handling system is required for the transshipment, that is, the automated loading and unloading, ensuring the unhindered transfer of the transport units to the different carrier units, from storages or from one transportation mode (e.g., rail) to another (e.g., road).

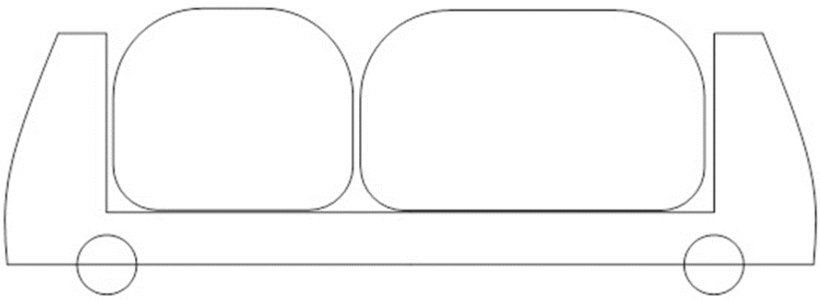

Figure 2: Sketch of a Pod with two different transport units coupled to a carrier (DLR, 2023).

In addition, a highly complex mobility management system (MMS) is required for operation and logistics, which, on the one hand, controls scheduling and operations, ensures the logistics of swap bodies and powered transport units, as well as all aspects of booking and paying for transport, accounting for logistics costs, and security aspects and emergency operations.

1.2 Pods4Rail Consortium

The Pods4Rail project consortium represents a collaborative effort involving Europe's prominent infrastructure managers, key players in the rail industry and research institutions. In response to Europe's evolving mobility demands over the coming decades, the Pods4Rail consortium has taken on the task of leveraging cross-functional expertise to establish the fundamental framework for new mobility solutions that enable the integration of transportation modes, resulting in smaller, faster, and more frequent trains.

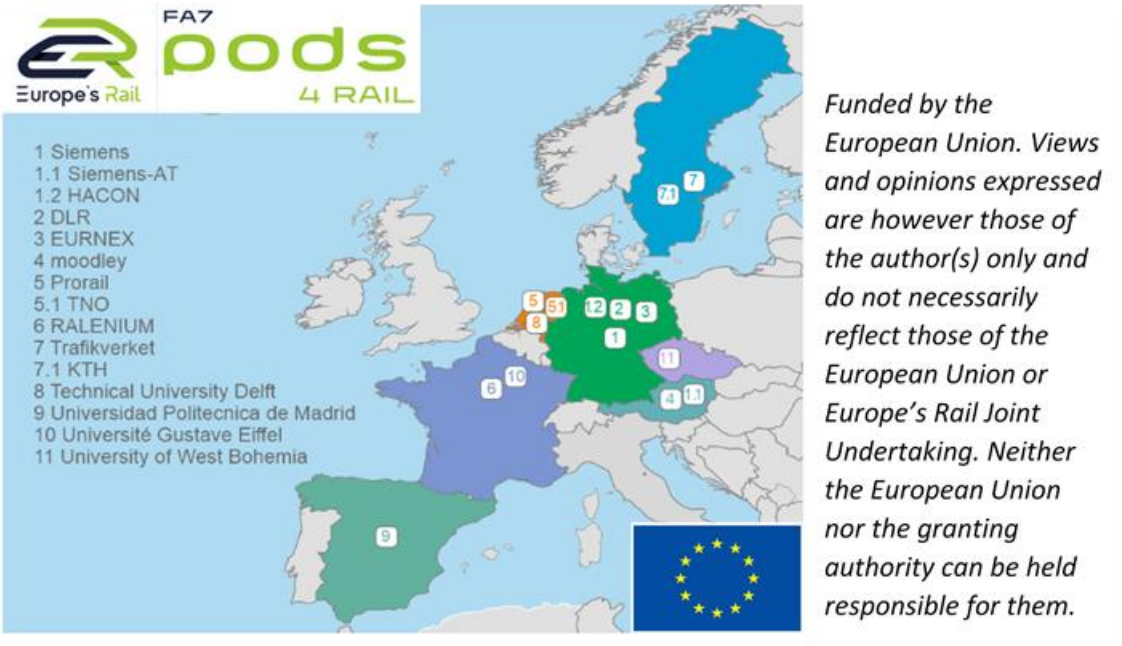

Figure 3: List of Pods4Rail project partners (EURNEX, 2022).

1.4 Timelines of Pod development and Pods4Rail-Project

The development of such a disruptive transport system, which represents connectivity and thus a stronger connection between all modes of transport and enables real intermodal transport from door to door, is an extremely complex undertaking. A key aim of the project is to clarify the technical and economic constraints before the actual technical development begins. The focus of the project is not on the purely technical solution, but also on clarifying whether such a system makes sense and has an economic basis. Only when this becomes apparent can technical development begin. For this reason, the time frame for possible implementation is generously set at a range from 2025 to 2050.

The forecasted milestones for the Pod system are as follows:

- 2025 – 2050: Comprehensive development phase (with simultaneous rollout)
- 2030 – 1:1 demonstration
- 2040 – Sequential rollout for branch lines or tram systems
- 2050 – Sequential rollout for entire railway networks

In terms of technology development, the retrospective analysis of technologies began in 2018. The Pods4Rail project was launched in September 2023 and over the 30 months of its duration is committed to laying the concrete foundation for such a system. The following specific objectives are to be achieved in Pods4Rail:

- Investigation and analysis of the usefulness and economic viability of such a system, considering technical, normative, and legal framework conditions.
- Development of a technical concept for pods, and their operating and logistic network system.
- Development of a technical concept for transport vehicles, standardized coupling systems, and concepts for handling, loading/unloading, and storage technologies.

It is planned to build a demonstrator after the successful Pods4Rail project duration phase.

2 Methods

In the context of the project, comprehensive data on multimodal mobility systems were gathered, vehicle concepts were characterized and evaluated across a spectrum of relevant technical, economic, environmental and societal parameters, with a focus on road and rail vehicles, but not excluding other relevant modes of transport like ropeways. This assessment extends to both passenger, freight and combined applications.

2.1 Formulation of evaluation criteria

The values in technical action described and hierarchized in VDI 3780 [2], were applied to the objectives of the Pod development within the Pods4Rail project resulting in the formulation of the following evaluation criteria and their prioritization:

i. Functionality: rail-bound, autonomous and intermodal

- A rail-bound and autonomous Pod is at the core of the functionality. Therefore, these three criteria - rail-bound, grade of automation [3, 4] 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 range without charging have been identified as significant for achieving a flexible Pod functionality.

ii. Safety

- It was identified that safety, both technically and perceived, is particularly relevant in three Pod-processes: safety of swap handling, coupling of additional modules (e.g. virtual coupling) and of the charging of the energy storage system (e.g. battery).

iii. Operational efficiency

- The criteria of operational efficiency have a strong impact on the economic efficiency of the system. The following were identified for the project considering that a key objective of Pods4Rail is making use of existing infrastructure with only very minor modifications: suitability for the existing infrastructure, payload efficiency, i.e. the estimated ratio between payload and tara weight, and the (estimated) maximum capacity of the vehicle in terms of persons or tons to be transported.

iv. Environmental quality

- The identified evaluation criteria for environmental quality are similar to the operational efficiency ones. Additionally, noise emissions should be taken into consideration.

v. Health, personal development, and societal quality

- 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.

2.2 Future thinking (FT) interviews

In order to supplement the hitherto described technical analysis with the user perspective, the authors conducted exploratory, qualitative user research, based on the FT method, see Colin et. al. [5]. This approach was aimed as a methodological proof of concept for the investigation of a Pod system with a prospective ergonomics research method. Hence, the sample size was kept small. According to [5], FT methods leverage the human capacity to envision the future by recombining information from episodic (i.e., recollections of past events) and semantic (i.e., concepts, facts and ideas) memory into new episodes. Therefore, FT was applied in order for participants to imagine a future scenario in which Pod systems have become a widely available means of transport. Subsequently, interviews with the participants were conducted to collect their attitudes, opinions and preferences towards this prospective system.

A total of eight participants (f = 5, m = 3) were recruited. All respondents live in Germany, six in a city with a population of greater than 100,000 inhabitants, one lives in a city with 20,000 to 100,000 inhabitants and one lives in a small town with less than 5,000 inhabitants. With regards to the age distribution, two participants were aged 20 to 29, five participants were aged 30 to 39 and one participant was aged 50 to 59.

The study materials were comprised of a short, written future scenario and an interview guide. To apply the FT method, the authors read the scenario to the participants and conducted a short interview. The scenario depicted a commuting use case and described how the participants might travel from the suburbs to the city centre of a metropolis using a Pod system. Several key aspects of the system were highlighted: on-demand service, possibility for users to complete non-driving related tasks during the ride, intermodal and seamless travel, a crane as the handling system to facilitate the mode-switch and combined passenger and freight transport. The subsequently facilitated interview inquired participants' attitudes and preferences towards the system, as described in the scenario.

The study procedure consisted of three tasks, as recommended by [5], to counter the negative effects of cognitive biases and difficulties to extrapolate from the present to the future: retrieval of past experiences, building a general vision of the future and building a detailed vision of the future. After a short general introduction about the functionality of Pod systems and the collection of demographic information, participants were asked to verbally report experiences pertaining to past travel episodes. As revealed by Nielsen [6], past memories form the building-blocks for participants to generate future scenarios in their minds. Next, participants were asked general questions about how they envisioned their lives in the year 2050, such as "in which city will you live?" or "what will be your job?". This task served to prime respondents for thinking about the future and according to [5], such warm-up exercises aid to yield richer answers during the subsequent interview. For building a detailed vision of the future, a short scenario was read to the participants. It took around 10 minutes to read out loud. The participants were asked to close their eyes while listening so that they could envision the scenario in as much detail as possible. Afterwards, the questionnaire was administered for data collection (with questions like e.g., "for which applications could you see yourself using it [the Pod system]?" or "would you prefer the mode change to be executed through the air with a crane or via a sliding mechanism on the ground?").

3 Results

The technological evaluation of existing Pod systems considers the aforementioned criteria under the categories of functionality, safety, and societal quality, as well as an estimation of their technology readiness level (TRL) [7]. For the purpose of the technological evaluation, ranking scales from 1 (poor) to 5 (very good) were adopted for each of the specific parameters and were rated by the interdisciplinary expert team from the project. The evaluation is organized 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

3.1 Technological evaluation of existing pod systems with interfaces to railway

Table 1 and the polygonal illustration in Figure 4 represent the performance of each rail-related Pod-system across the different technological parameters. The concepts of Siemens-moodley "one for all" [8], Parallel Systems [9], Aachen Rail Shuttle (ARS) [10], CargoMover [11], Minimodal [12] and Nevomo Cargo MagRail [13] were considered in this analysis. Based on this graphic, it seems that most of the technological criteria are completely fulfilled, so that the analyzed concepts could serve as partial benchmarks [14].

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"
 Aachen Rail Shuttle ARS	2 - TRL 2 - 4	5 - Yes	4 - Driverless, with attendant. GoA3-SAE4	1 - No	1 - No	3 - Estimated 50 - 150 km	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 by combustion engine	1 - Crane or non-detachable "on the road"
 Minimodal Boxes	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 1: Abstract of the technological evaluation of rail-related pod systems.

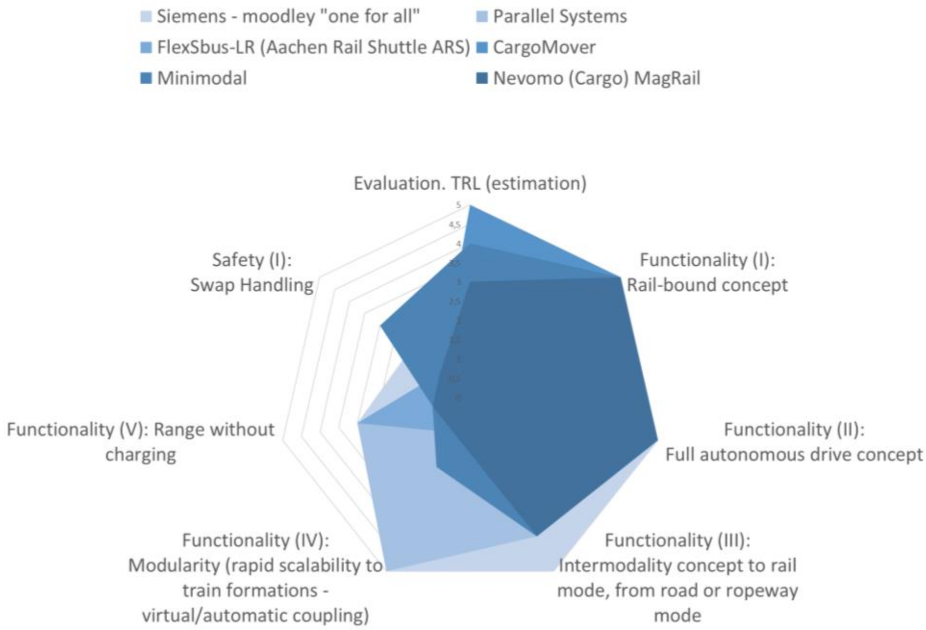

Figure 4: Illustration of the technological evaluation of rail-related Pod systems. Ranking scales 1 (poor) to 5 (very good).

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 for these concepts 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.

3.2 Technological evaluation of existing pod systems and those under development, in other transport modes

Table 2 and the polygonal illustration in Figure 5 represent the performance of each Pod system of other transport modes (non-rail-bound) across the different technological parameters.

The concepts of the DLR U-Shift [15], LEITNER ConnX® [16], upBUS [17], Rinspeed Metrosnap [18], Snap [19] and Microsnap [20], Citroën Autonomous Mobility Vision [21], Toyota e-Palette [22], Schäffler Mover 1.0 [23] and Tesla´s travel pod system of Fábio Martins [24] were considered in this analysis. Based on this graphic, it seems that some of the technological criteria are completely fulfilled, so that the analyzed 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 numerous 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.

The two polygons from Figure 4 and Figure 5, when examined closely, demonstrate a complementary relationship of the technological capabilities of rail-related Pod systems and Pod systems in other transport modes.

Firstly, this result confirms the reason why these different modes of transportation coexist in the market, since they pose their respective different and complementary advantages and disadvantages. Moreover, this is also a call for further implementation of multimodal and intermodal mobility systems, in order to make use of the advantages of both modes. Conversely, this shows that a mobility strategy based on only road or only railway would not be optimal and that combining both modes can also bring about challenges in every direction.

The robust performance of handling systems and electric range for road-bound transport could serve as a benchmark to enhance and complete the attributes portrayed in the initial polygon chart for rail-bound Pod-systems.

Conversely, this evaluation shows that road concepts lay behind rail concepts in the scalability to vehicle formations, underscoring the importance of the development of the platooning technology for road transport.

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 autonomous 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 pod - 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 2: Abstract of the technological evaluation of Pod systems in other transport modes. Ranking scales 1 (poor) to 5 (very good).

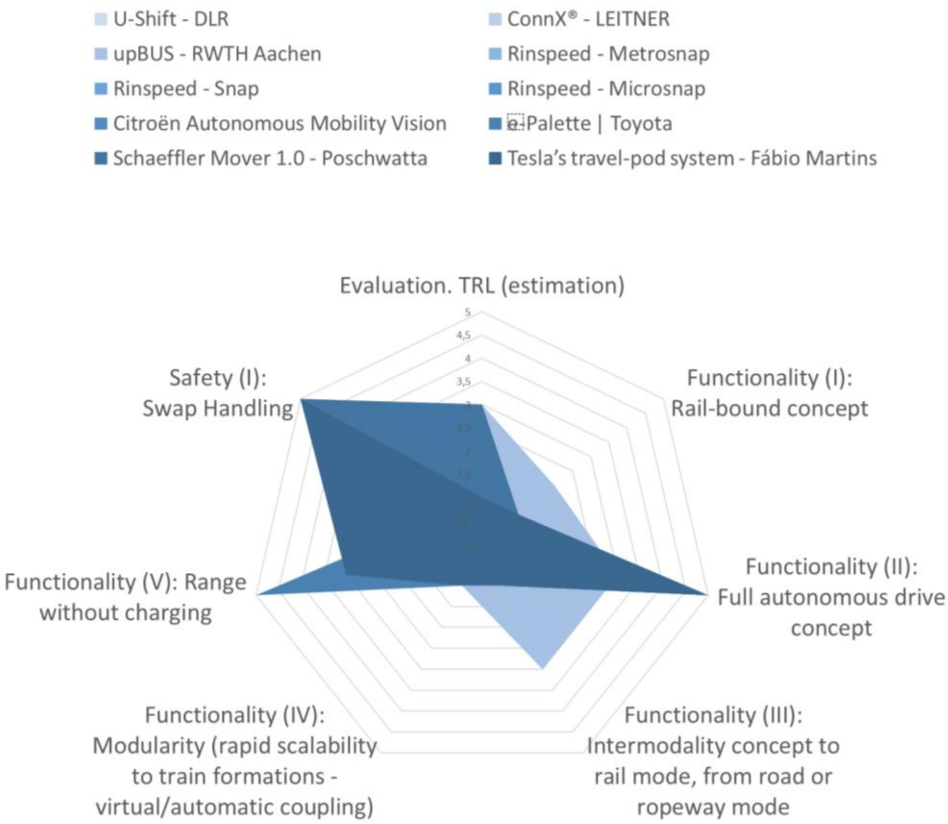

Figure 5: Illustration of the technological evaluation of Pod systems in other transport modes. Ranking scales 1 (poor) to 5 (very good).

3.3 Initial economic evaluation

Overall, the economic efficiency of the analyzed Pod systems varies based on a combination of factors. A first rough economic evaluation of multiple Pod systems highlights varying significative parameters for the economic efficiency of Pods:

- Infrastructure utilization: Systems that can utilize existing road or rail infrastructure score better, since they avoid high upfront investment costs.
- Capacity: Systems with higher capacity for passenger or cargo offer improved economic efficiency, as they can potentially replace multiple vehicles.
- Weight: Lightweight construction designs contribute positively to economic efficiency by reducing energy consumption and infrastructure requirements.
- Adaptability: Systems that can adapt to various transport modes, like road and ropeways, offer unique advantages in urban settings but may require balancing infrastructure costs with benefits.

3.4 Initial environmental evaluation

The initial 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.

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 transshipment is highly recommended.

3.5 Results of the user research

For the qualitative analysis of the FT interviews, three participants from cities with more than 100,000 inhabitants were dropped, as to reduce the bias towards city dwellers. While this sample size may appear small, it is sufficient for qualitative ergonomics research, as revealed by Nielsen [25]. A thematic analysis was conducted with the remaining data for each questionnaire item. Contents were sorted into themes until stable clusters emerged. From these clusters, the following key insights were derived:

- Participants generally expressed positive attitudes towards Pod systems.
- One of the most positive aspects was that Pods can serve multiple purposes simultaneously (i.e., combined transport).
- Combined transport was perceived as beneficial for the environment, due to expected efficiency gains in transport.
- Seamless travel, without the need to change mode of transport, was generally envisioned as comfortable.
- Participants expressed that they would prefer using Pods over owning a car.
- With regards to the handling system, almost all participants preferred a sliding mechanism over a crane, since being lifted in the air by a crane was deemed anxiety-inducing.
- Similarly, cargo should be stored below the passenger capsule rather than on top of it, since most participants expressed unease with such a solution.
- Willingness to share the Pod with other passengers was generally very high.
- One caveat is that women might feel unsafe due to other passengers aboard and adequate safety measures would need to be taken to address this issue.
- Pods should be less crowded than current means of public transport.
- Participants would also like to sometimes enjoy quietness and private sphere in a premium Pod (e.g., after work).

One methodological caveat is that FT interviews construct the future as much as they measure it. For instance, some respondents reported that they would prefer using Pods over using their car. However, this is contrary to previous research findings, which indicate greater preference for car usage over public transport usage [26] and a reluctance to quit car usage even among environmentally conscious individuals [27]. Given that a seamless commuting scenario without any disturbances was described in the FT scenario, it is likely that the study participants formed an idealized image of the system in their minds. Nonetheless, the method proved valuable for early-stage concept testing.

4 Conclusions

One of the main results of this analysis is that no single existing system or new approach offers a comprehensive benchmark for the Pod, highlighting the need for Pods4Rail research. Nonetheless, a primary objective was also to pinpoint systems or system-components that can serve as benchmarks for the technological development of the Pod system. Several analyzed systems stand out as potential benchmarks:

- Siemens-moodley “one for all” intermodal seamless mobility concept.
- Lightweight design by the Aachen Rail Shuttle and its detachable concept.
- Chassis concept of Nevomo Cargo MagRail with its integrated front and back structures for sensors.
- Minimodal freight wagon bundling up to six small containers.
- DLR U-Shift's modular multipurpose carrier and its docking system.
- The innovative gondola designs of upBUS and ConneX® ropeways.
- Rinspeed's road vehicle concepts that allow transshipment 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 in this regard, 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. In the initial economic and environmental analysis, it becomes evident that compatibility with pre-existing infrastructure, alongside payload and capacity, emerges as pivotal criteria. Environmental considerations should make a notable emphasis on minimizing noise emissions during transshipment.

Challenges encountered include the limited data availability, a literature bias toward road-bound Pods, and the necessity of conducting a bottom-up analysis to better understand user needs.

Taken together the user research revealed two main results. From a methodological perspective, the FT method proved a valuable tool for applying prospective ergonomics research to future Pod systems. From a content perspective, it can be concluded that the respondents of the study were open to using future Pod systems, given the perceived benefits of the technology. Particularly the technology’s potential to mitigate the negative impact of the transport system on the environment by increasing its efficiency was perceived as favourable. Moreover, Pods may effectuate a change in urbanites’ choice of place of residence by reducing the value of travel time. The desirability of suburban neighbourhoods may thus be increased.

References

[1] ERJU, "Europe’s Rail Joint Undertaking - Multi-Annual Work Programme", https://rail-research.europa.eu/wp-content/, March 2022.

[2] Verein Deutscher Ingenieure (VDI), “VDI 3780, Technology Assessment Concepts and Foundations”, Beuth Verlag, 2000.
[3] International Electrotechnical Commission (IEC), "IEC 62290-1:2014: Railway applications - Urban guided transport management and command/control systems - Part 1: System principles and fundamental concepts", 2014.
[4] Society of Automotive Engineers (SAE), "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles", 2021.
[5] C. Colin, A. Martin, F. Bonneviot, E. Brangier, “Unravelling Future Thinking: A Valuable Concept for Prospective Ergonomics”, 2022.
[6] A. Ernst, & L. Manning, “The Impact of Multiple Sclerosis on Future-Oriented Mental Time Travel: Neuropsychological and Neuroimagining Approaches”, in “Seeing the Future: Theoretical Perspectives on Future-Oriented Mental Time Travel”, Oxford, United Kingdom: Oxford University Press, 2016.
[7] HORIZON 2020, "Work Programme 2014-2015”, General Annexes, Extract from Part 19), §§ G. Technology readiness levels (TRL), 2015.
[8] moodley-Siemens, https://moodley.com/work/siemens-one4all, 2022.
[9] Parallel Systems, https://moveparallel.com/, 2023.
[10] RWTH Aachen, https://www.isatec-aachen.de/de/news/artikel/flexsbus-mobilitaet-der-neuen-art, 2022.
[11] Die Bahnseiten dybas, https://www.dybas.de/dybas/index/c/cargo_mover, 2003
[12] Minimodal freight system of Rail Freight Limited, https://www.railwatch.org.uk/backtrack.php?issue=094&page=rw094p04.pdf, 2002.
[13] Nevomo, https://www.nevomo.tech/en/magrail/, 2023.
[14] R.C. Camp, “Benchmarking: The Search for Industry Best Practices That Lead to Superior Performance”, Quality Press, 1989.
[15] DLR Verkehr, https://verkehrsforschung.dlr.de/en/projects/u-shift, 2020.
[16] LEITNER AG, https://www.leitner.com/produkte/seilbahnsysteme/, 2023.
[17] RWTH Aachen, https://www.upbus.de/, 2019.
[18] Rinspeed AG, https://www.rinspeed.com/de/Concept-Cars, 2020.
[19] Rinspeed AG, https://www.rinspeed.com/de/Concept-Cars, 2018.
[20] Rinspeed AG, https://www.rinspeed.com/de/Concept-Cars ,2019.
[21] Citroen, https://www.media.stellantis.com/em-en/citroen, 2023.
[22] Toyota, https://www.toyota.de/startyourimpossible/e-palette, 2018.
[23] Poschwatta, https://www.poschwatta.de/projects/schaeffler-mover/, 2018.
[24] Fábio Martins, https://www.yankodesign.com/2019/01/22/teslas-interchangeable-travel-pod-system-shows-modularity-in-transportation/, 2019.
[25] J. Nielsen, T. K. Landauer, “A mathematical model of the finding of usability problems”, in “Proceedings of the SIGCHI conference on Human factors in computing systems”, ACM Press, 1993.
[26] J. de Vos, “Do people travel with their preferred travel mode? Analysing the extent of travel mode dissonance and its effect on travel satisfaction”, in “Transportation Research Part A”, Volume 117, 2018.
[27] J. Geng, R. Long, H. Chen, W. Li, “Exploring the motivation-behaviour gap in urban residents’ green travel behaviour: A theoretical and empirical study”, in “Resources, Conservation and Recycling”, Volume 125, 2017.