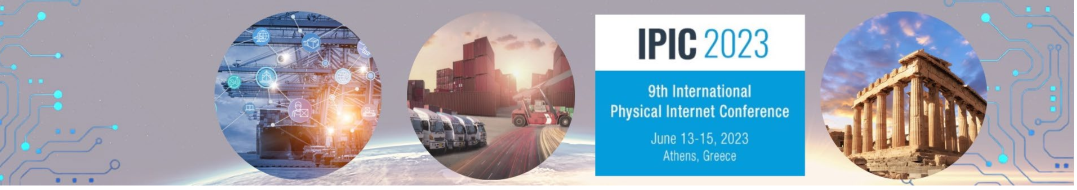

Place your logo here

Can the Physical Internet pave the way to a Mobility of Entities?

Sandra Stein[1] and Matthias Prandtstetter[2]

1. Fraunhofer Austria Research GmbH, Vienna, Austria
2. AIT Austrian Institute of Technology, Vienna, Austria

Corresponding author: sandra.stein@fraunhofer.at

Abstract:

Despite using the same infrastructure, passenger and goods transport are typically perceived as distinct systems and are managed, analyzed, and considered separated from each other, particularly in urban areas. Hence, one of the key approaches of a more efficient and sustainable transportation system is the integration of freight and passenger transport.

In future, the network of mobility systems will be able to orchestrate itself. The IoT network will allow a seamless connection between various transport-related IoT-devices, transport modes, transport means, infrastructure, flows, and information. Assuming this and considering the principles of the Physical Internet (PI) of "physical, digital and operational interconnectivity through encapsulation, interfaces and protocols" (cf. Montreuil et al. 2013), it should not matter if encapsulated goods, or encapsulated passengers are moving. Passenger and freight transport could be orchestrated synergistically if technology was ready and used for a holistic optimization of the system. The concept of the PI could be transferred to individual mobility, and thus evolve to a "Mobility of Entities". Entities are, in that case, understood as objects, or modules, that either move goods or passengers.

Our vision assumes that passengers and goods are encapsulated and move within the same transport system. The capsule, the "PI-box" is, in that case, an autonomous transport module, or unit. Each unit can join and detach with other units – together, they function as a swarm of vehicles. In such units, either passengers or goods can be transported. Hence, the units have physical and digital interfaces, and protocols.

This paper aims at introducing the vision of a "Mobility of Entities" via modular transport units - an integrated freight and passenger transport system.

Keywords: *integrated freight and passenger transport, modular transport units, transferability of the PI*

Conference Topic(s): *autonomous systems and logistics operations (robotic process automation, autonomous transport/drones/AGVs/swarms) business models & use cases; Modularization; PI impacts; vehicles and transshipment technologies*

Physical Internet Roadmap *(Link): Select the most relevant area(s) for your paper:☐ PI Nodes, ☒ PI Networks, ☒ System of Logistics Networks, ☐ Access and Adoption, ☐ Governance.*

1 Introduction

Despite using the same infrastructure, passenger and goods transport are typically perceived as distinct systems and are managed, analyzed, and considered separated from each other, particularly in urban areas. Hence, one of the key approaches of a more efficient and sustainable transportation system is the integration of freight and passenger transport.

A classification of potential solutions for combining passenger and freight transport was suggested by *Trentini and Mahléné* (2010). That classification is comprised of three primary categories: utilization of shared road capacities, utilization of shared public transport services, and utilization of shared consolidation facilities. In 2016, *Arvidsson, N.; Givoni, M.; Woxenius, J.* tackled last mile synergies in passenger and freight transport and provide various examples of sharing resources for transport of passengers and freight. The conclusion drawn is that the integration of passenger and freight transportation in urban areas shows great potential for addressing the last mile problem. *Cavallaro, F. and Nocera, S. (2022)* conducted a broad concept-centric literature review on the integration of passenger and freight transport, focusing on the operational organization of an integrated passenger–freight system. They state that the implementation of this scheme could already be observed for long-distance transport modes, such as airplanes, ferries, ships, and a limited number of trains that permit the joint use of vehicles for both passenger and freight transport. However, an operational integration of passenger and freight transport is less prevalent in short-distance urban transportation and, in terms of transport modes, in road transport (cf. ibid.).

Bruzzone, F., Cavallaro, F., Nocera, S. (2021) discussed potential approaches for addressing certain challenges associated with the first-last mile transportation of passengers and freight, that involves promoting greater integration between transport systems. They introduce a tool for performance monitoring of possible passenger/freight transport integrations (cf. ibid., p. 46), that is considered vital for a holistic optimization.

While the Physical Internet (PI) is concentrating on the transport of physical objects, the concept provides principles such as the "physical, digital and operational interconnectivity through encapsulation, interfaces and protocols" (cf. *Montreuil et al. 2013*) that could be merged with individual mobility aspects. *Ouadi et al. (2021)* state that the integration of passenger flows into the concept of the Physical Internet (PI) would be an "innovative idea that could improve the openness and interconnection of universal transportation" (ibid., p. 428). They name numerous challenges and solutions the PI suggests, including the standard PI-elements such as containers, protocols, hubs, standardization, modes, or sensors (ibid., p. 429).

Matusiewicz, M.; Możdżeń, M.; Paprocki, W. (2023) introduced a concept for merging the PI with passenger air transport. While the potential use of the PI concept for passenger air transport has yet to be examined, their demonstration has illustrated that its feasibility is supported by the significant degree of sector integration and the advancement of technologies such as the Internet of Things and Artificial Intelligence.

Overall, literature suggests that integrating passenger and freight transport can lead to significant benefits in terms of efficiency, sustainability, and economic competitiveness. However, successful integration requires careful planning, stakeholder engagement, and the development of appropriate infrastructure and regulatory frameworks.

Considering all such aspects, we go one step further to merging the PI-concept with road-based, short-distance, semi-urban transportation: Our concept builds on the fact that passengers and goods are encapsulated in the same type of capsule and move within the same transport system. The capsule, the “PI-box” is, in that case, an Autonomous Modular Transport Unit (AMTU). Each module can join and detach with other modules – together, they function as a swarm of vehicles. In such modules, either passengers or goods can be transported. Hence, the modules have physical and digital interfaces, and protocols.

2 Vision of the Mobility of Entities

2.1 Basic Assumptions

The integrated freight and passenger transport system, that we call “Mobility of Entities” (MoE), is designed for semi-urban and rural regions and short-distance trips up to 50 km. According to Eurostat, the average distance travelled per day per person in the European Union in the year 2021 was approx. 38 km (cf. Eurostat 2022). This includes different means of transport (bike, car, train, bus, walking). Of course, distances can differ considering countries, regions, purpose of trips, means of transport, and more. The European Commission states that the average length of the last mile in urban areas in the European Union is approx. 4.5 km (cf. European Commission 2019). Obviously, the last mile is depending on aspects such as type of region (urban, rural), country, type of goods, infrastructure, suprastructure, means and mode of transport, and more. However, both average passenger and freight transport distances lie within a 50km radius; hence it can be assumed that most transports in average European areas could be addressed with the concept. Urban regions are not in focus, as in general, cities strive to make urban space accessible to the population again, and not to (individual) traffic (e.g., Vienna, Copenhagen).

Our vision consists of the case-by-case use of:

a) Autonomous modular transport units (modules): Modular transportation systems that enable the efficient and standardized transportation of goods and passengers. The modules could be of different sizes, e.g., for 2, 4, 6, 8, 10, … passengers, or one pallet-size, two pallets side by side, etc. Seats or load securing devices could be set up and dismantled easily, that a unit can either be used for freight or passengers. The modules could be battery-electric-vehicles (BEV) that move autonomously on short runs (< 5km). For longer runs (>5 to < 50 km), they merge with each other such that a train-like construct (swarm, or convoy) is built. In the ideal setting, this train of modules is then mounted on rail tracks and coupled with a pushing/towing device taking over the propulsion of the so-built train. When a module reaches its destination, it uncouples from the train and covers the last mile autonomously again. Recharging of batteries could be realized whilst being pushed.
b) shared-use swarms: Both passengers and freight could be transported in the same swarm, in separate modules. Each module could join and detach with other modules by automatic coupling – together, they function as a swarm of vehicles. This leads to a significant reduction of separate vehicles, improving resource utilization. The swarm could either be pushed or towed by a battery-electric (BEV) or hydrogen fuel-cell (FCV) driven device, or another alternative propulsion system.

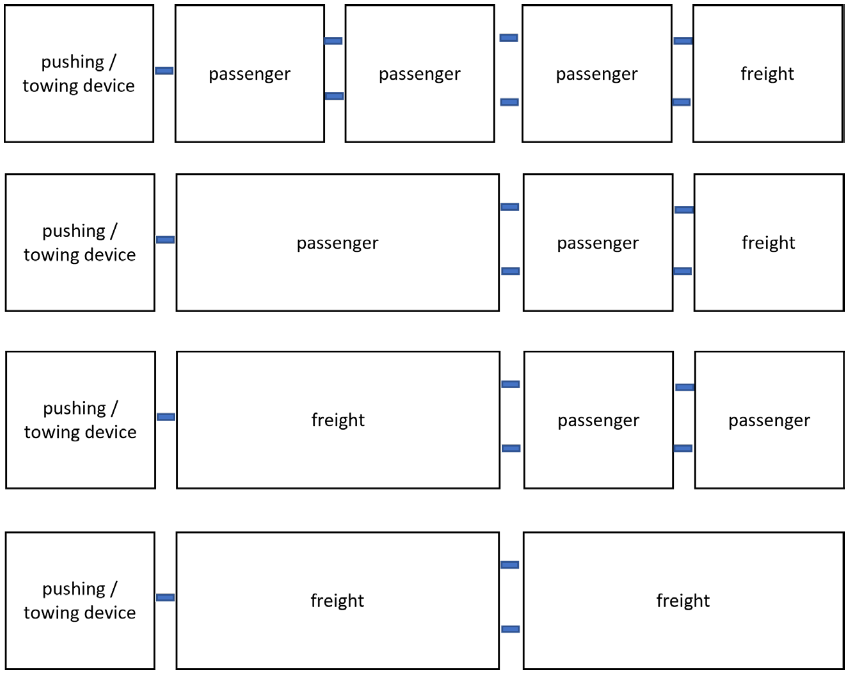

Figure 1: Illustrating different types of transport modules joined in swarms

c) integrated hubs: Integrated hubs could serve as a central location for the exchange of goods and passengers. These hubs could be designed to enable the seamless transfer of goods and people between different modes and means of transportation. This is important for longer transports (>50km), as there is the need to change to (synchromodal) conventional transport means.
d) dynamic ridesharing: Dynamic ridesharing systems could allow freight modules to “hop" on (freight) trains or inland vessels for the main run, or distances >50 km. If a single unit, it might also be transported within a passenger train.

2.2 Autonomous Modular Transport Units (AMTUs)

Autonomous Modular Transport Units (AMTUs) are a type of autonomous vehicle designed for freight transport, mostly. They consist of self-driving cargo modules that can be connected and disconnected as needed, allowing for flexible and efficient transport of goods. AMTUs use a combination of sensors, cameras, and artificial intelligence (AI) to navigate roads and traffic, avoiding obstacles and adapting to changing road conditions. The cargo modules themselves can also be equipped with sensors and monitoring systems to track the status and location of the goods being transported. One of the advantages of AMTUs is their flexibility and scalability. Because the cargo modules can be connected and disconnected as needed, they can be easily customized to meet the specific needs of different types of cargo and delivery routes. They also have the potential to reduce transportation costs and improve efficiency by reducing the need for human drivers and allowing for continuous operation without rest periods.

Ulrich et al. (2019) introduce an on-the-road modular vehicle concept and discuss it on technological level. The MAUDE system (“Modular, Autonomous, Updateable, Disruptive, Electric”) of the German Aerospace Center, Institute of Vehicle Concepts is outlined, including its design, requirements and concepts for the drive system, battery and energy management, and automation of the vehicle concept.

Khan, Z. ; Weili, H.; Menendez, M. (2022) discuss the application of modular vehicle technology to mitigate bus bunching and take NEXT Future Transportation Pods as examples for autonomous modular vehicles (AMVs). The pods "are capable of in-motion transfer, which allows the modular units to couple and decouple while moving on roads, so that passengers can transfer from one unit to another while traveling". The pods can also be used for cargo transport.

Figure 2: Next pods (cf. https://www.next-future-mobility.com/)

Further examples for (prototype) Autonomous Modular Transport Units are:

Producer	Name of unit	Passenger / cargo	Type of unit	Type of usage
Volvo	Vera	cargo	tractor unit	Short haul in logistics centers, ports, and other industrial settings
Einride	Einride Pod	cargo	modular cargo u nit	medium distance transport
EasyMile	EZ10	passenger	modular unit	Urban areas
EasyMile	TractEasy	cargo	tractor unit	Short haul in logistics centers, ports, and other industrial settings
Lohr	Cristalya	passenger and cargo	can be operated in convoys or solo	Urban areas, geared to municipal mobility needs

2.3 Shared-use swarms

Autonomous Modular Transport Units (AMTUs) could be integrated into swarms, or train-like constructs, using v2v-communication, similar to platooning systems. To integrate AMTUs into a swarm, each vehicle must be equipped with sensors and communication systems that allow it to share information with other vehicles in the swarm. This information must include location, speed, and passenger/cargo factor/capacity, as well as data about road conditions, traffic, and other environmental factors.

Using this information, the modules in the swarm can coordinate their movements to optimize their routes, avoid congestion, and reduce energy consumption. They can also work together to handle unexpected events, such as road closures or accidents, by rerouting cargo and adjusting their routes in real time.

In addition, AMTUs may also be designed to be modular and scalable, allowing them to be quickly reconfigured to meet the changing needs of a swarm. This might include adding or removing cargo modules, adjusting the number of vehicles in the swarm, or changing the distribution of cargo among the vehicles.

2.4 Potential process

Whenever a person wants to, e.g., commute, s/he enters the autonomous module which is either parked at home (self-owned) or is brought by from a depot (mobility-as-a-service). Then, the module drives to a connection point where it is joined with other modules. Here, either a dynamic determination of connection points could be applied, or a train-station like equivalent can be used. This new built train then automatically continues its ride towards the destination, or according to a predetermined route. At some location (e.g., at the connection point), a pushing (or towing) device is connected to the train of modules. This pushing device can also connect to overhead lines, or other means of energy supply, that individual modules can be recharged during the trip. The individual modules, however, leave the train again as soon as they reached their destination (or destination station). The same concept applies for modules transporting freight.

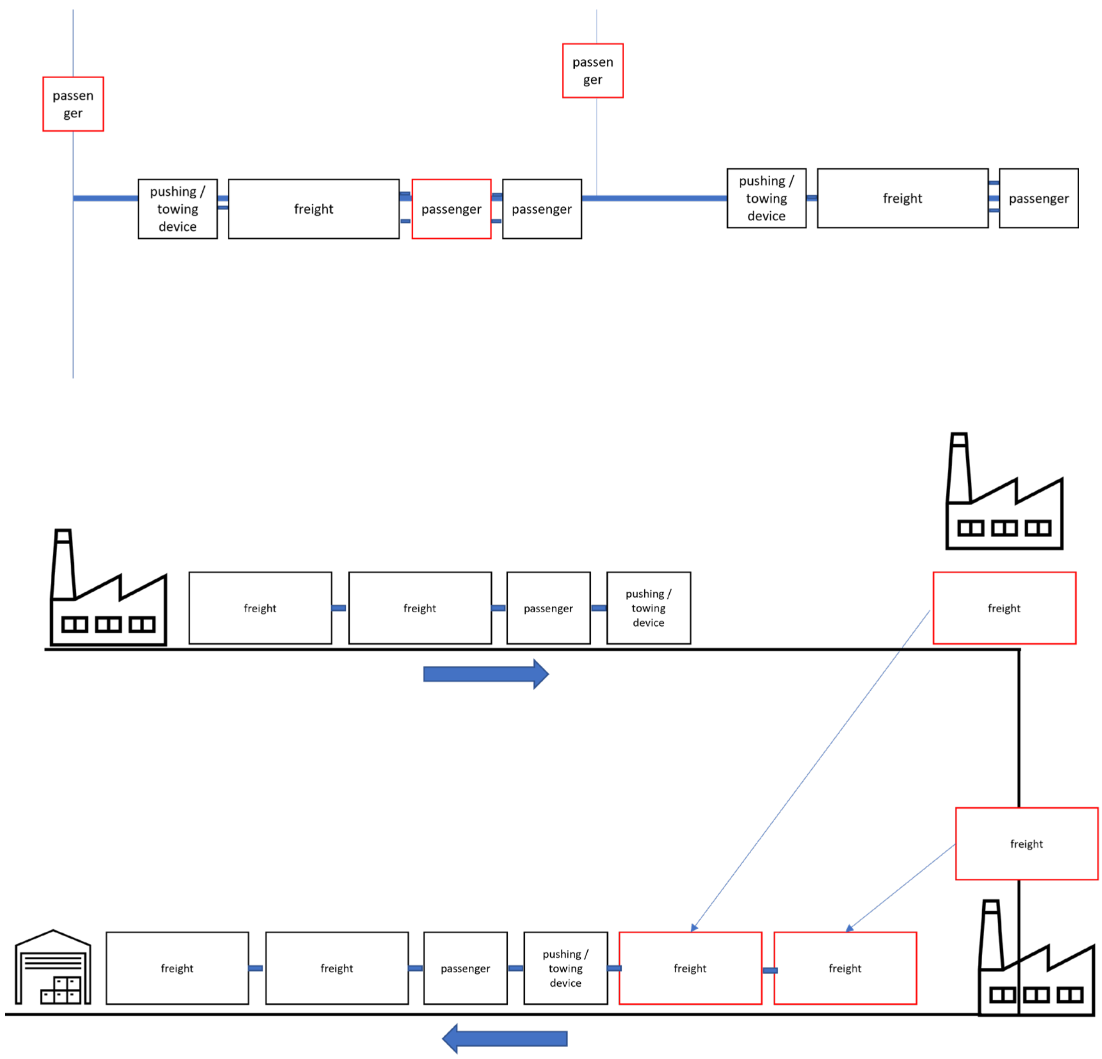

Figure 3: Rough sketches of the potential process

3 Benefits for stakeholders

We assume the following benefits for the stakeholders:

a) For individual passengers, this kind of mobility allows for an individual experience (like in a private car) with the benefits of mass transportation (i.e., the possibility to work, read, sleep, etc.). Moreover, a significant reduction in transport time due to fully automated transport chain can be expected. Due to e-drive and module concept, a significant reduction in breakdown probability and downtime is possible. Furthermore, the investment requirement could be reduced, up to the complete offer of a mobility-as-a-service principle. All in all, it would be a smooth transition to fully autonomous driving via linkable front module.

b) For shippers (or other stakeholders involved in the freight transport sector), the main benefits are that instead of classical transport logistics, on-demand ad-hoc transportation could be realized as each palette/set of palettes could be put in its own module and forwarded into "the system". As the building of trains or swarms would be self-organizing, shippers would not need to look for potential partners to cooperate with. Contrary, they would even be requested to not influence the transport system at all.

c) Municipalities/state/cities/society: As the transport system would be a self-organizing swarm instead of a conventional structured transport network, traffic management would become more dynamic and plannable, as measures can be easily set. E.g., closing of a lane on the highway for construction work only needs to be communicated to the modules. They would then reorganize in other set of trains on the remaining tracks. In cases there would be traffic congestion, detours can be chosen. As trains are modular, it is even possible that some of the modules would take a detour, while others stay on track. It is, however, a necessity that the appropriate information (traffic situation, road/rail network, travel demand of others, etc.) is available in real-time. Moreover, the vision delivers a response to solve the problem of rapid wear and tear of our transport infrastructure. A flexible implementation of legal requirements regarding energy consumption and emissions would be possible, as well as its permanent control. Considering different applicable propulsion technologies, the system would be flexible and adaptable with regards to energy supply.

4 Need for research

As this vision is still a conceptual approach, we highlight that there is significant need for research until such a system could be realized. We think, however, that from a technological perspective, the main work is related to implementation than rather development, or even research.

Research is, however, important with respect to the usage of such a system. For example, it needs to be evaluated whether such a dynamic system has a positive or negative impact with respect to sustainability. On the one hand, the individual movements of persons and freight directly relates to the basic PI idea (which is assumed to be positive). On the other hand, if each palette is transported by its own device, overheads (in terms of needed hardware) are significant and will most probably reduce the positive (financial) impacts. Even more, if modules are owned by individuals, it is basically just a replacement of conventional cars with some newly designed modules. They still need parking spaces and will most probably not moving for about 23 hours per day (as it is with cars today). If they are, however, shared among different users, they need to be moved from the last location the previous customer stepped out towards the next location where the next customer wants to enter. In this case, an empty module is driving around. It can then be expected that the average number of persons per module is less than 1 (which is a major reduction compared to the even now bad value of something close above 1).

Furthermore, it needs to be investigated whether persons are even willing to accept this kind of mobility. Safety issues might be considered if self-driving modules are extensively used. Therefore, we think that research should be done in these directions. It needs, however, to be critical and not “in love with technology”.

5 Conclusion

Within this paper, a thought experiment has been presented which introduces autonomous modular transport vehicles for individual use by passengers and freight. Positive effects might be the easy combination of freight and passenger mobility, the integration of individuals “taking their car” into trains, and the easiness for traffic management and congestion avoidance. Negative effects might be empty moving modules, heavy overheads (hardware-wise) compared to current technologies, and safety issues with other road users. Especially rebound effects (e.g., more energy consumption than current systems, less public transport users in the future) need to be considered. Many research questions are still open – although they are more focusing on the “soft” measures than on “hard” measures linked to the development of technologies.

References

- Arvidsson, N.,; Givoni, M.,; Woxenius, J. (2016): Exploring Last Mile Synergies in Passenger and Freight Transport. Built Environment, Volume 42, Number 4, Winter 2016, pp. 523-538(16). https://doi.org/10.2148/benv.42.4.523
- Bruzzone, F., Cavallaro, F., Nocera, S. (2021): The integration of passenger and freight transport for first-last mile operations, Transport Policy, Volume 100, Pages 31-48, ISSN 0967-070X, https://doi.org/10.1016/j.tranpol.2020.10.009.
- Cavallaro, F., Nocera, S. (2022) : Integration of passenger and freight transport: A concept-centric literature review, Research in Transportation Business & Management, Volume 43, 100718, ISSN 2210-5395, https://doi.org/10.1016/j.rtbm.2021.100718.
- European Commission (2019) : Smart and Innovative Urban Freight Solutions - State of Play and Future Prospects. https://op.europa.eu/en/publication-detail/-/publication/e8b35c84-3a3e-11e9-9d01-01aa75ed71a1/language-en., 10.04.2023
- Eurostat (2022) : Transport statistics - Data extracted in March 2021. https://ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en., 10.04.2023.
- Khan, Z., Weili, H. ; Menendez, M. (2022): Application of Modular Vehicle Technology to Mitigate Bus Bunching. https://www.researchgate.net/publication/358603692, 11.04.2023.
- Matusiewicz, M.; Możdżeń, M.; Paprocki, W. (2023): Physical Internet in passenger air transport to decrease emissions – A concept. In: Sustainable Materials and Technologies, Volume 36, e00589, ISSN 2214-9937, https://doi.org/10.1016/j.susmat.2023.e00589.
- Montreuil B. (2013): Physical Internet Manifesto, v1.10, (Original v1.0, 2009), www.physicalinternetinitiative.org, 2014/02/20.
- NextFutureMobility (2023): Website. https://www.next-future-mobility.com/, 12.04.2023
- Ouadi, J., Malhene, N., Benhadou, S., Medromi, H. : Shared public transport within a physical internet framework: Reviews, conceptualization and expected challenges under COVID-19 pandemic. In : IATSS Research, Volume 45, Issue 4,2021, Pages 417-439.
- Ulrich et al. (2019): Technologies for a modular vehicle concept used in passenger and goods transport. https://elib.dlr.de/127001/1/2019-03_ISS19_Full-Paper_Ulrich-et-al.pdf., 12.04.2023.