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Physical Internet in city logistics: current practice in the Netherlands

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Abstract

The Physical Internet (PI) is probably the most ambitious and visionary concept towards efficiency and sustainability in transport logistics. PI proposes a full consolidation of logistics flows from independent shippers using vertical and horizontal collaboration. The objective of this paper is to evaluate where the implementation of the Physical Internet concept stands in the practice of city logistics. From our research, it can be concluded that Hubs, Networks, and Extended Inter-networks are developing sufficiently. Access and adoption, as well as the governance of platforms, still seem to be too complex for big steps on the roadmap.

Keywords: Last-mile delivery, Physical Internet, Current Practice, Hubs, Networks

1. Introduction

The Physical Internet (PI) idea of Montreuil et al. (2010) is probably the most ambitious and revolutionary concept in the battle for efficiency and sustainability in transport logistics. It refers to the transformation of freight transport and logistics to enable significantly more efficient use of assets and resources. The PI builds on extensive and systemic consolidation of flows and the network-of-networks concepts. The Physical Internet proposes full consolidation of logistics flows from independent shippers (e.g. extended pooling and shared networks). This means that PI aims to pool resources and assets in open, connected, and shared networks (i.e. connecting existing company networks, capabilities, and resources) so they can be used seamlessly by network users and partners. Fundamental principles of

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City Logistics and the Physical Internet include collaboration, integration, and the distinction between commercial transactions that drive demand on the one hand and the actual execution of freight transport and storage on the other. These concepts complement each other, with City Logistics handling the final and last-mile segments within the hyperconnected logistics and transportation networks enabled by the Physical Internet (Crainic & Montreuil, 2016).

The literature contains a growing number of articles that examine the Physical Internet (PI) concept from a scientific perspective (Matusiewicz, 2024; Crainic & Montreuil, 2016; Pan, 2024). However, only a few studies explore the Physical Internet (PI) concept from a practical implementation perspective (see van Duin et al., 2022 and Plasch et al., 2021 for two exceptions). Neither of these take a normative approach, evaluating progress with a broadly accepted yardstick at hand. We address this gap by taking an innovation roadmap as a reference, broadly agreed upon by researchers, industry representatives and policymakers. In short, this paper aims to assess the current progress of city logistics in achieving key milestones toward the practical implementation of the Physical Internet concept.

The comprehensive roadmap towards the Physical Internet (PI) (Ballot et al., 2020) sketches a path from now to 2040, showing important milestones, required technologies, and first implementation opportunities for the PI. The European Technology Platform ALICE (Alliance for Logistics Innovation through Collaboration in Europe) developed this roadmap (Ballot et al., 2020) to support a comprehensive strategy for research, innovation, and market deployment of logistics and supply chain management innovation in Europe (see Figure 1).

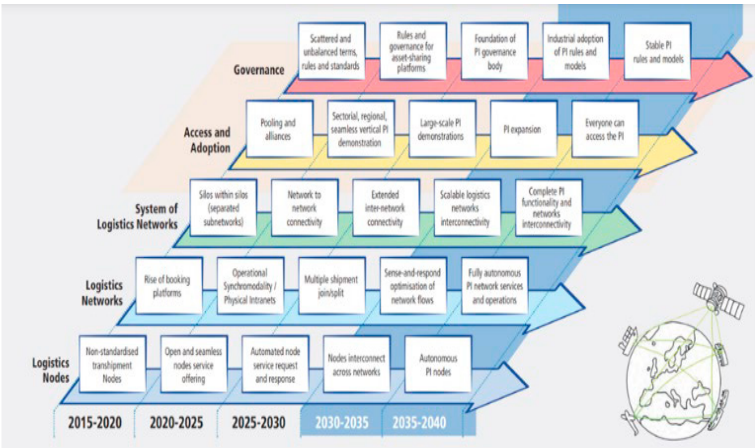

Fig. 1. Roadmap to Physical Internet (Ballot et al., 2020).

The roadmap presents 5 layers in which progress needs to be made: Logistics nodes, Logistics networks, System of logistics networks, Access & adoption and Governance. Here, Access and Adoption relate to the scaling of the concept from the current systems of multilateral pools and alliances towards a fully open network that everyone uses. Governance relates to the introduction and convergence of rules that allow network formation, via electronic platforms, until a stable set of widely accepted rules has been achieved. The more technically oriented areas include Nodes (also known as hubs), Networks (the nodes, interlinked) and the System of Networks, growing from intra-company networks via vertical and horizontal collaboration into a diagonally fully connected network, also called a hyperconnected network. Each of these areas forms a layer in the roadmap, with clear milestones in 5-year intervals, from the 1st Generation PI (2015-2020) until Generation 5 (2035-2040). Despite its stylised and simplistic view of reality, the roadmap has proven to be useful because of its fitness to the PI vision and its ease of communication. It has been used as guidance for several innovation programs by governments in Europe, China, Japan and Australia.

In the next sections, each layer is discussed concerning the state of implementation during the current period 2020-2025. Best practice was recorded via the grey literature on city logistics implementation. Also, experts in the field validated the practical findings. This paper ends with a discussion and conclusions about the current state of PI implementation in city logistics.

2. Logistics nodes: open and seamless nodes service offering

2.1. Roadmap

According to the roadmap, in PI Generation 2 (2020-2025), logistics hubs offer services to their users in an open and digitally accessible way. Therefore, these hubs operate on open digital platforms that allow users easy access and interaction with various logistics services. APIs (Application Programming Interfaces) are developed to facilitate integration with other systems. Logistics hubs publish detailed information about their services, capabilities, and performance metrics. This data is readily available to their users, allowing them to make decisions. Services offered by logistics hubs are standardised, meaning they follow common protocols and definitions. This standardisation ensures that services are consistent across different hubs and providers.

Also, logistics hubs adopt interoperable technologies and standards. For instance, the GS1 Scan4Transport (Voorspui, 2020) is a global standard developed by GS1 to enhance the efficiency and accuracy of transport and logistics operations. It enables encoding structured transport-related information within a barcode or QR code, allowing for automated and seamless data capture with other systems and services throughout the supply chain. This reduces complexity and enhances efficiency in the supply chain. Administrative tasks such as booking, invoicing, and compliance are automated through digital platforms. This reduces the time and effort required for manual processing. The hubs provide transparent and standardized pricing models, minimising the need for extensive negotiations. Users can compare services and prices easily, facilitating quicker decision-making. In established business relationships, there is a tendency towards smart contracts and digital agreements to simplify the legal and contractual aspects of logistics operations, making it easier for users to enter business relationships.

Concrete benefits are better information about inbound and outbound flows and capacities; better information quality, e.g., for planning; a decrease in lead times, reduced inefficiencies by using standard boxes (retailers + manufacturers networks), and reduced hurdles for transshipment across modes and nodes.

2.2. Current state

The innovation in city logistics, where the customer comes first, has not always been the main priority of the major players aiming at economic benefits by scaling up their activities. Operational excellence is their main motto. Innovations come mainly from small local players (such as Hubbel, MyPup, CityHub and many others). These companies have a strong local community. Internationally, this list can easily expand to hundreds of promising local start-ups and scale-ups. Although these platform companies operate under the flag of a logistics company, it can be observed many times that the ICT company is legally separated as a private limited company, to spread financial risks. According to Ploos van Amstel (2024), they are the 'local heroes' who innovate in city logistics. They all want to offer a local alternative to the large logistics platforms. They consciously promote a socially just, ecologically sustainable, and economically vital society. These local heroes struggle all with the same issues about managing finance and growth, calculating the proper rates, integrating information systems, developing ICT networks, establishing national coverage, providing cybersecurity, coping with local regulations, managing transport planning, facilitating hub locations, proper vehicle choice, preparing service design, attracting personnel from the labour market, operating in an equal level playing field and organising local lobbists. These issues could be solved by sharing systems, data, facilities, and knowledge. As Ploos van Amstel (2024) stated: these local initiatives are 'identical strangers', i.e. they are equal in their diversity of struggling issues.

Together, these innovative companies have ‘the solution’ in their hands by providing a wonderful product for the 'last mile'. Still, building scale implies that they must work together. Every company has one or more parts of the future 'last mile' solution. Many interconnecting parts need to be developed to cover the full picture. To solve these new parts of the puzzle, financial support is important. Andruetto et al. (2024) also state that the main barriers to city hubs are a need for more trust between Logistics Service Providers (LSPs) and a lack of functioning business models. It requires courage to work with your competitor who operates on the same playing field. To make the next step in competition, 'last-mile nodes' require customer-oriented, sustainable innovations. Together, they can provide a vibrant ecosystem in which new technology, services, and business models can be tested and improved in practice. Scaling up and returns require consortia with a market approach, sharing systems and facilities, collaboration in research, and, finally, investing together. This is the most crucial issue to make the next step in the implementation of PI. Easily accessible, comparable and transparent service offerings can already be obtained. Early experiments in the recent EU project LEAD showed that APIs are available and practice-ready for bilateral cooperation (LEAD, 2023) between complementary services, like parcel locker providers and cycle couriers. The next stage of multi-lateral, open connections is still a bridge too far, however (and only mentioned in PI Generation 4). It will require awareness of business models, higher technological savviness and willingness to harmonize or standardize approaches.

For the development of seamless booking systems, implementing smart contracts is the next step of innovation. Automated contractual agreements require educating legal, technical, and executive stakeholders, developing intuitive interfaces, formalising standards, and pioneering cross-industry use cases that demonstrate exponential value (Blockchain Today, 2023). In essence, these initiatives remain in an experimental phase. Legal support for these contractual agreements is lacking.

3. Logistics networks: operational synchromodality/physical intranets

3.1. Roadmap

The principle of consolidation is a key focus point in logistics network development. As seen in the former section, digital platforms are being developed for service management. Logistics service providers and forwarders organise multi-modal delivery networks, which combine various transportation modes, such as bikes, drones, and electric vehicles, depending on specific criteria including delivery urgency, geographical constraints, and package size. This integration allows for more efficient use of resources and faster delivery times, especially in densely populated urban areas where traditional delivery vehicles may face accessibility challenges in the urban landscape and delivery requirements. Andrei et al. (2024) presented a setup for a cohesive network (see Figure 2).

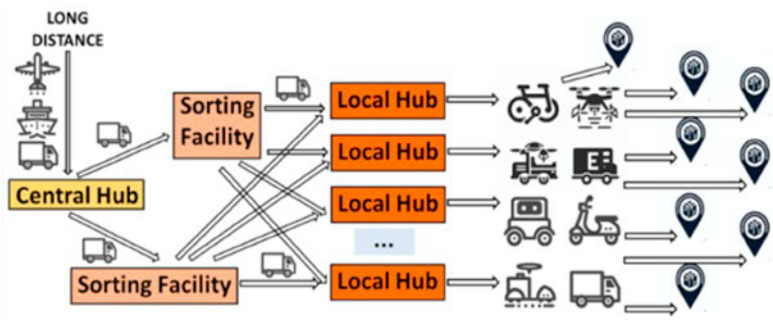

Fig. 2. Multi-modal delivery network (Andrei et al., 2024).

Figure 2 contains many local hubs that provide opportunities for sharing warehouse capacity as a service proposition. Such a multimodal delivery network can optimise efficiency and adaptability. To manage these transport and logistics (autonomous) operations, they develop systems to create full visibility and allow access to resources (owned or contracted) seamlessly integrated into so-called ‘physical intranets’ (Ballot et al., 2020). These allow for managing flows and services more seamlessly by shifting freight quickly between modes of transport.

3.2. Current state

The following city logistics trends are playing an important role in the formation of logistics networks: Zero emission zones (Greendeal C-173, 2018); changes of policies to create more priority for walking and cycling in inner cities (Verkeersplan, 2024); different freight needs of five different types of districts (historical centre, old city district, high-rise, suburbia, and car-free districts) in a city (Quak et al., 2024);

These trends all require a thorough rethink of the appropriate transport modes. The need to select an appropriate vehicle to deliver goods efficiently is becoming more difficult, but critical for current hubs. The above trends are pushing the system to consider synchronized intermodal solutions more seriously, despite higher costs in the short term. According to Kou et al. (2022), multimodal delivery is a must-have for last-mile delivery since there are many challenges such as traffic congestion, environmental and noise pollution, and high distribution costs that can be overcome by including multimodal options like trains, cars, trucks, drones, bikes, and walking. A special case must be mentioned here where Renault Trucks has proposed a vehicle for multimodal delivery in last-mile delivery by combining three types of electric vehicles: (1) it is an e-Van for delivering pallets and large parcels, (2) it is a cargo bike in case of traffic congestion or narrow streets, and (3) it contains drones in case of urgent deliveries that are difficult to reach by road (Randall, 2022). At the same time, one can observe that crowd shipping – leveraging individuals to deliver packages during their regular routes – is gaining traction as a flexible and sustainable delivery method. The company Shopopop has expanded internationally across offices in the Benelux countries, Italy, and Spain. The platform has facilitated over 10 million deliveries in France, partnering with around 7,000 stores, including major retailers such as Auchan, Carrefour, and E. Leclerc.

Due to the different logistical needs that arise from the different districts, it can be observed that current hubs are also extending their services by sharing warehouse space, providing moving services, collecting packaging materials (other recycling materials), and providing facilities for new freight flows like (conditioned) foods and facility goods. We note that a standardized service range for all hubs would fit with the Generation 2 (2020 - 2025) status of the PI for Nodes. An example of such a company is Cityhub located in the cities of Utrecht, Roermond, Groningen, Leiden, Maastricht, and Amsterdam. From the hub located at the edge of the city, they deliver the goods to the customers in small portions every day. In their selection of transport, they make use of cargo bikes, e-vans, or e-trucks provided by their partner companies. Due to efficient routes with a high drop density, they can keep the costs of additional delivery at a low level. For their customers, they provide 24-hour insight into where their goods are located. They also provide storage and inventory management for pallet storage to small units, for ambient products to cool & freezing options, and additional shared spaces or closed spaces for rent (Hoeben, 2024).

By developing these services, the hubs become more centroids of the networks by consolidating these new freight flows with the traditional ones (see also the next session). This supports the formation of new networks around open city hubs. Although it is too early to call these physical internets due to the absence of one hyperconnected open network, it would be fair to say that these form physical intranets for city logistics. Still, barriers exist to developing vertical and horizontal hyperconnectivity. Vertically, service chains are still often disconnected, and exchangeability throughout (of shipments, data, accountability, service guarantees, and social responsibility) is poor. Horizontally, many service providers remain small-scale and fail to grow, maintaining an unhealthy level of fragmentation in the market. The next generation of platforms and protocols could help to create connections that can leverage network effects.

4. System of logistics networks: extended inter-network connectivity

4.1. Roadmap

The roadmap (Ballot et al. 2020) mentions that the protocols and operational systems will be enhanced and prepared for implementation in inter-company network operations. During this phase, groupage, pallet, and other types of logistics service networks will begin operating based on fully interconnected digital protocols and procedures. This will include tools and solutions designed to plan and execute multiple customer shipments within a pooled logistics network system. The protocols and attendant operational systems will be improved and made ready for use in inter-company network operations. Platforms of platforms help to consolidate flows in the back office, while competition for clients can continue in the front office.

4.2. Current state

Although it can be observed in practice that the development of inter-company network operations is lagging due to competition, legal, and trust issues, there are some promising developments. As many logistics hub providers already operate in several Dutch cities, they have organised themselves in a cooperative called the Green City Hubs Network (Netwerk van Groene Stadshubs (NGS)). Participants offer services as a national network of independent, local city hubs for bundled and emission-free transport. Most of these companies cannot provide national services on their own. For this reason, they have joined forces with parties in parts of the Netherlands where the individual companies are not located yet. This initiative can help customers throughout the Netherlands and ensure a more efficient and greener last mile (Nieuwenbroek, 2024).

A tempting initiative, "SMART BRICK", has started in the construction sector. Digital-twin data is linked to a brick and shared with the supplier, transporter, and recipient. Based on these data streams, the brick can theoretically make a more sustainable journey. By providing real-time tracking of goods and linking them to real-time information about the waterway, bridges, and available capacity on ships, the carrier can follow the entire process live (i.e. the Internet of cargo). This way, a carrier can choose the most sustainable journey (by road or water) at the most favourable time. This data allows planners to bundle loads and plan a better trip. The first practical experiments of smart bricks were carried out. The Metropolitan Hub System was set up as a conceptual extension continuation of the Smart Brick (Circlelinelogistics, 2024). Such product- or shipment-focused data management systems will not need fixed contracts with carriers, but as intelligent cargo, they will be able to find their way across companies, transport chains and even multi-company networks, switching when useful or needed. This will promote the connection of networks into networks-of-networks and constitute an interesting demand-side or pull factor for the 3rd Generation of PI.

5. System of logistics networks: extended inter-network connectivity

5.1. Roadmap

One of the main changes in Generation 2 (2020 – 2025) PI is that companies start to experiment within their current business settings, realising that cooperation, even with their competitors in logistics, is beneficial but also easy to execute and implement, either directly or through logistics service providers. It is also crucial to assist companies in taking initial steps toward this goal. There are new methods for sharing assets, services, and resources between stakeholders in vertically integrated supply chains and horizontally collaborative networks. The value of cooperation is widely acknowledged within the sector and demonstrated to intrinsically motivated managers working on closer collaboration within the specific supply chain setting. The value of cooperation is widely acknowledged, as evidenced by the increasing intrinsic motivation among managers to work towards closer collaboration within specific supply chain settings.

5.2. Current state

Besides the above-mentioned unique and novel initiatives, "SMART BRICK" and "NGS", the practice of Access and Adoption is hard to establish. Although the motivation of managers is exceptionally strong to cooperate with other companies in practice, there remains a lack of trust and activation to allow vertical integration in supply chains. Therefore, more attention should be paid to smart contracts for collaborative planning and asset sharing. Moreover, the concepts of tokenisation will be explored for new governance models and incentive mechanisms of PI systems for logistics collaboration (Pan, 2024).

6. Rules and governance for asset-sharing platforms

6.1. Roadmap

The period from 2020 to 2025 marks a significant evolution in the governance of asset-sharing platforms. Asset-sharing becomes more straightforward, secure, and efficient with the introduction of new specific rules and standards. Initial steps towards a shared governance framework for interconnected networks set the stage for future developments by comprehensive rules and tools that address the key aspects of asset-sharing, from liability to gains redistribution. This is made possible by rules and standards for asset-sharing, supported or driven by the government.

6.2. Current state

According to Matusiewicz (2024), further research is needed to understand the legal implications, potential barriers, and necessary legal restructuring required to adopt the Physical Internet principles and practices. The EU is issuing various workable regulations for the European platform economy. While the laws are made in Brussels, national authorities are responsible for implementation, regulations and enforcement. Evaluation and dialogues among stakeholders are important, especially in a rapidly changing digital landscape. The biggest concern here is the importance of a fair level playing field. According to EU Commissioner for Competition Teresa Ribera, good legislation and regulations promote innovation. If one company is too powerful, it is not attractive for other entrepreneurs to invest. That is a bad situation for both the market and consumers. They generally pay higher prices and innovation lags (Arrets, 2024). This is the case in the tech world, as Big Tech companies (Apple, Google and Amazon) are market leaders in an entire ecosystem. They own the devices, the operating systems, the app stores, and the payment systems. They are both market leaders and participants in their market. That makes it easy for these types of parties to abuse their power. They learn from the innovation of entrepreneurs on their platform, copy services or products, and give their services a higher place in the search results. They work as gatekeepers and decide who gets access to the marketplace and under what conditions.

Independent agencies working for the government should continuously check these access rules on fair market principles. This is now also happening at the European level by launching the new Digital Markets Act (DMA). For complete implementation of PI, it is important that the market also remains accessible to newcomers, making exemptions for SMEs (fewer regulations for Small and Medium Enterprises).

7. Conclusions

The comprehensive roadmap towards the Physical Internet (PI) (Ballot et al., 2020) sketches a path from now to 2040, showing important milestones, required technologies, and first implementation opportunities for the PI. In this paper, our mission was to evaluate the current state of city logistics in practice. It showed the current milestones in implementing the Physical Internet concept in Dutch practice. Experts in the field were consulted to validate the findings in practice.

For the nodes (hubs), the market is full of innovative companies having ‘the solution’ in their hands by providing a wonderful product/service for the 'last mile'. Every company has one or more parts of the future 'last mile' solutions. Joint investments are crucial for advancing the last-mile sector in Physical Internet (PI) implementation. However, many companies hesitate to invest due to uncertainty about their return on assets and a lack of clarity on equity. The core challenge underlying this reluctance appears to be a lack of trust. Future research can help build trust by developing innovative business models (Brehmer et al., 2018) that enhance transparency, shared values, and risk mitigation in last-mile logistics.

In city logistics networks, multimodal delivery is a must-have for last-mile delivery since there are many challenges like traffic congestion, environmental and noise pollution, and high distribution costs. Logistics networks are extending, because current hubs are also extending their services by sharing warehouse space, providing moving services, collecting packaging materials (other recycling materials), and providing facilities for new freight flows like (conditioned) foods and facility goods. This leads to the basic principle of PI that the hubs become more centroids of networks by consolidating these new freight flows with the traditional ones. Future research on AI could support these developments by providing better estimates of arrival times, (peak) demands and available capacities.

The development of inter-company network operations is lagging due to competition, legal, and trust issues. At the same time, promising new developments like Smart Stone and the Green City Hubs Network exemplify the planned state in the Roadmap of Physical Internet. Access and Adoption Rules and Governance for asset-sharing platforms appear to be too complex to make big steps toward implementation in the short term. The legal aspects are at all levels (EU, National) of the playing field. They represent a juridical complexity as PI has many legal issues: the privacy implications of data sharing, data governance issues, competition law issues, liability issues, and contractual issues. Because these issues are all strongly intertwined in the Physical Internet, it is quite a fundamental challenge to tackle and allow next steps to be taken. Integration of government at all levels is needed to make next steps.

As a recommendation for further work, we argue that further formalising the approach presented here into the Physical Internet Maturity Index for city logistics is feasible and critical to guide progress. Only with sufficient awareness about the speed of changes in the landscape will government and industry be motivated to innovate for a more sustainable future.

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