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THE PHYSICAL INTERNET: A SYSTEMATIC MAPPING STUDY

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Foreword

While reading through the available dissertation subjects, the words "Physical Internet" immediately caught my attention. Before the selection of my thesis subject, I had never heard of the Physical Internet concept, however, I was always interested in topics related to the Internet of Things. When looking into the subject and reading the first articles, I realised that this subject was way broader than just the Internet of Things. It was an opportunity to help develop a logistics system that deals with many of the present environmental, societal, and economical challenges in the domain of supply chains. Without any doubt, I decided to grab this opportunity and submitted my application.

Before the start of this thesis, I want to express my gratitude towards some of the people who made this work and my education at the University of Ghent possible. First and foremost, I would like to thank my supervisor Prof. dr. Geert Poels for the opportunity as well as his guidance and advice during the course of the last two years. Secondly, I am grateful to my family and friends for their support throughout the five years of my education at Ghent University. This accomplishment would not have been possible without them.

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List of Abbreviations

ALICE	The Alliance for Logistics Innovation through Collaboration in Europe
IJPR	The International Journal of Production Research
IMHRC	International Material Handling Research Colloquium
IoT	Internet of Things
IPIC	International Physical Internet Conference
OLI	Open Logistics Interconnection
PI	Physical Internet
SOHOMA	The international workshop on Service Orientation in Holonic and Multi-Agent Manufacturing
WoS	Web of Science

1 Introduction

The way physical objects are currently transported, stored, and handled is unsustainable from an economic, environmental, and societal perspective. Containers are often shipped half empty, the packaging often is too large for the goods it contains, it takes too long to respond to shocks in demand, the capacity of distribution centers is often poorly utilized, etc. Montreuil [4] states that the world is facing a Global Logistics Sustainability Grand Challenge and that our current logistical models should be replaced by a more efficient and sustainable logistics system.

To meet this Global Logistics Sustainability Grand Challenge, the Physical Internet concept was designed. The Physical Internet (PI) is defined as *"an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. It is a perpetually evolving system driven by technological, infrastructural and business innovation"* [5]. Its name refers to the Digital Internet, which transfers standard data packets in a similar way. However, in the Physical Internet, objects are transported in containers instead of data packets. These containers are smart, green, modular and standardized worldwide in terms of dimensions, functions and fixtures [4]. They are built to easily flow through various transport, handling and storage modes and means.

The term "Physical Internet" was introduced by The Economist as the title of their special report on logistics in June 2006 [6]. The issue contained several articles concerning supply chain and logistics. Although the term Physical Internet was not mentioned in any of the articles, it generated the interest of numerous researchers. In recent years a lot of research has been conducted, covering many topics concerning the Physical Internet. Due to this increase in research, there is a need for a Systematic Mapping Study to collate, describe and catalogue the existing literature related to the Physical Internet.

1.1 Problem statement and research objectives

The literature on the Physical Internet is still in a nascent state. The PI concept concerns various research disciplines including operations research, mechanical design, information technology, and social sciences. This makes it hard for academics to draw overall conclusions related to the concept. Given the rise in the number of Physical Internet related publications and the scope of the topic, there is a need for an overview of the existing literature.

The goal of this systematic mapping study is thus to collect all the published articles on the Physical Internet and to structure them to get a comprehensive overview. Moreover, based on this comprehensive overview, existing research gaps will be identified and recommendations for future research will be proposed in this thesis.

1.2 Structure of the report

To gain a better understanding of the Physical Internet, the second chapter discusses the background of PI and its basic concepts. In chapter three the used systematic mapping method is explained in detail. In chapter four the results of the mapping are discussed and visualised. Finally, in the last chapter a summarizing answer will be provided to each of the research questions and recommendations for future research are suggested.

2 Background

Supply chain practices are often seen as one of the biggest challenges to improve global sustainability. The reasons for this are the scale and complexity of many supply chain systems. In [4], Montreuil states that the way physical objects are currently transported, handled, stored, realized, supplied and used throughout the world is not sustainable economically, environmentally and socially. He presents this global sustainability issue as the Global Logistics Sustainability Grand Challenge. Montreuil exposes this assertion with thirteen key unsustainability symptoms. These thirteen symptoms are all related to economic, environmental and societal sustainability issues. One of the most striking examples indicating environmental unsustainability is the percentage of greenhouse gas emissions related to transport, which has increased from 25% in 1990 to 36% in 2014 [7].

The Physical Internet (PI) has been introduced as a solution to this Global Logistics Sustainability Grand Challenge. Montreuil, Meller and Ballot [5] define the Physical Internet as *"an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols"*. Its name is derived from its analogy with the Digital Internet. The Digital internet transmits standard data packets encapsulating information. The packet header contains all information required for identifying the packet and routing it to its destination. The protocols and interfaces in the Digital Internet are designed to exploit this standard encapsulation [8]. Similarly, the Physical Internet has standardized packets that encapsulate physical objects, termed PI-containers. To achieve efficient and sustainable universal interconnectivity, the use of PI-containers is supported by interfaces and protocols.

2.1 Key Physical Elements

Montreuil, Meller and Ballot [9] introduced three types of key physical elements in the Physical internet: PI-containers, PI-movers and PI-nodes. The PI-containers encapsulate the goods that are to be transported, handled or stored. The PI-movers transport, convey, or handle these containers. Finally, PI-nodes are the facilities and sites of the Physical

Internet.

PI-containers	PI-movers	PI-nodes
Types: • Transport containers • Handling containers • Packaging containers	Types: • PI-transporters • PI-conveyors • PI-handlers	Types: • PI-transit center • PI-hub • PI-distribution center • ...
Properties: • Standardized • Green • Modular • Smart	Properties • Moving PI-containers easily, securely and efficiently • Exchange information	Properties • Optimal design to perform operations on PI-containers • Exchange information

Table 2.1: The Key Physical Elements of PI

2.1.1 PI-containers

Montreuil, Ballot and Tremblay [1] propose a three-tier characterization of PI-containers in transport, handling and packaging containers. This three-tier characterization enables containers to better complement each other and therefore allows a better use of the means of transportation. All three types of containers are to be world-standard, modular, smart, eco-friendly and designed for easing interconnected logistics. Transport containers are designed to cope with tough external conditions and to be easily carried and stacked as usual shipping containers. Handling containers are designed to modularly fit within transport containers, to be easily handled by PI-handlers and to endure rough handling conditions. Considering their interlocking capabilities, the handling containers are able to protect their content without requiring pallets for their consolidated transport, handling and storage. Their modularity is exploited to maximize space utilization within transport containers (see Figure 2.1). Packaging containers directly contain the goods. The authors describe them as the lightest and thinnest amongst Physical Internet containers, designed to be easily inserted, extracted and stacked. The need for privacy is minimal as goods owners want to expose their product to potential buyers.

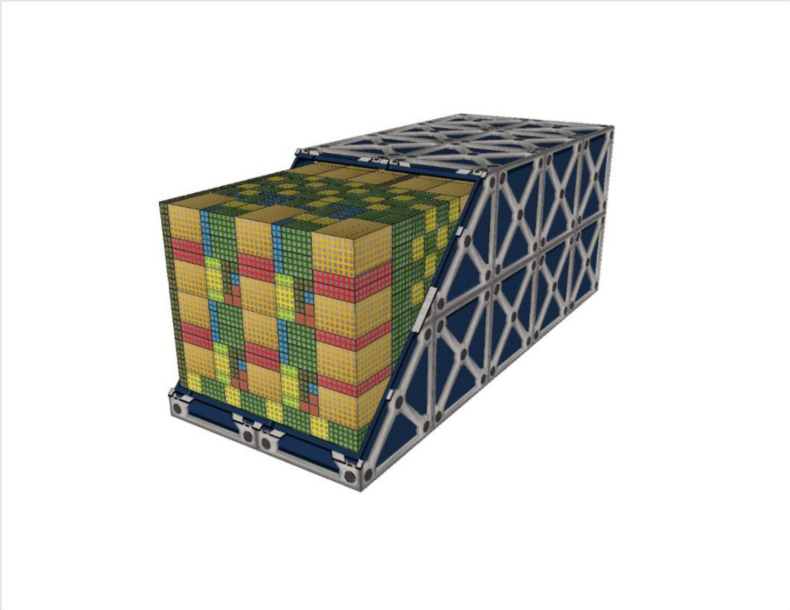

Figure 2.1: Handling containers encapsulated in a transport container [1]

The PI-container is smart, each container has a smart tag to act as its representing agent connected into the Internet of Things (IoT). Tran-Dang and Kim [10] present an information framework based on exploiting the IoT embedded in the physical devices of the Physical Internet and their active interaction. According to the framework, all PI-containers will have basic capabilities such as identification, computation and communication. In order to identify its state and report it, compare its state with the desired one, and send information when certain conditions are met, the containers have the ability to capture their physical status and to accurately transfer all relevant information. Any problem in the logistics process along the supply chain will be recorded in the wireless sensor node memory, this information can be accessed using any device. The authors indicate that the smart tag will operate as a communication channel enabled by wireless communication technologies. It will help ensure the identification, traceability and security of each PI-container and will facilitate the automation of routing.

2.1.2 PI-movers

In the Physical Internet, PI-containers are carried by PI-movers. In [9], Montreuil, Meller and Ballot specify three main types of PI-movers: PI-transporters, PI-conveyors and PI-handlers. The authors describe PI-transporters as vehicles and carriers that are specialized to easily, securely and efficiently move PI-containers. The set of PI-vehicles includes trucks, trains, ships and planes but also smaller types, such as lift trucks. PI-conveyors are conveyors designed for the continuous flowing of PI-containers. These PI-conveyors may differ from current conveyors by not having rollers or belts, as the PI-containers can simply clip themselves to the PI-conveyor gears. Finally, PI-handlers are humans qualified for moving PI-containers. It is key to remark that in the Physical Internet there is no need for pallets, as PI-containers are easily lifted and moved by material handling equipment due to their design.

2.1.3 PI-nodes

The locations specifically designed to perform operations on PI-containers are termed "PI-nodes". Montreuil, Meller and Ballot [9] suggest that the nodes correspond to the sites, facilities and physical systems of the Physical Internet. Even though there are many types of PI-nodes, which vary in terms of mission orientation, scope, scale, capabilities and capacities, they are all tailored to deal with PI-containers at the physical and informational levels.

At the 2012 International Material Handling Research Colloquium (IMHRC), Meller et al. proposed the functional designs of two PI-nodes: a road-based transit center [11] and a road-based crossdocking hub [12]. The three-paper series also includes a functional design for a road-rail hub by Ballot, Montreuil and Thivierge [13]. Each study proposes a feasible conceptual design of the facility. All the essential components of the facilities are presented and simplified models are built. Based on the models, discrete-event simulation is used to evaluate the operations. At the end of the studies, multiple important key performance indicators under various conditions are reported. Despite not being optimal designs, the results already show some possible improvements.

2.2 Key Enablers

The Key Enablers of the Physical Internet facilitate and enhance the use of the previously mentioned Key Physical Elements. The Key Enablers include interconnectivity, innovative business models and innovative technologies. Interconnectivity is the capability of a system to have its components seamlessly interconnected. Interconnection would allow the optimisation of the logistics network as a whole. The development of innovative business models is essential for existing companies, as they need to adapt to the changing business environment, as well as for start-up companies in a Physical Internet context. Lastly, technological innovation enables improved features and designs for the PI-nodes, PI-movers and PI-containers.

Interconnectivity	Innovative business models	Innovative technologies
Types: • Physical interconnectivity • Digital interconnectivity • Operational interconnectivity	Types: • PI-enablers • PI-enabled	Types: • Communication and datasharing technologies • Innovative modes of transportation
Enables: • Optimisation of the PI system as a whole	Enables: • Businesses adjusted to the changing business environment	Enables: • Improved features and designs for the Physical Elements

Table 2.2: The Key Enablers of PI

2.2.1 Interconnectivity

In [5], Montreuil, Meller and Ballot suggest that universal interconnectivity in the Physical Internet is the key to making the Physical Internet an open, global, efficient and sustainable system. They point out that this can be achieved through physical, digital and operational interconnectivity. Physical interconnectivity ensures that physical objects can flow seamlessly through the Physical Internet by making use of the standardized design of PI-containers. Moreover, digital interconnectivity allows the exchange of meaningful information between PI-containers, PI-nodes and PI-movers. Finally, operational interconnectivity ensures that business and operational processes can be efficiently intertwined, so that Physical Internet members, such as logistics service providers and manufacturing companies, can collaborate in optimally serving the users of the Physical Internet.

In [14], Montreuil, Ballot and Fontane propose an Open Logistics Interconnection (OLI) model for the Physical Internet. The goal of this seven-layer OLI model is to structure the interconnected logistics services to ease the conceptualization, the implementation and the deployment of the Physical Internet. The highest layers of the OLI model deal with supply chain, realization, distribution and mobility decisions. The lower layers deal with the interplay of complex handling, storage, transportation and tracking technologies. The OLI model is based on the Open Systems Interconnection (OSI) model of the Digital Internet.

2.2.2 Innovative business models

Multiple publications indicate that the Physical Internet is a key driver for business model innovation. Montreuil et al. [15] suggest that there are two categories of businesses in context of the Physical Internet: the PI-enablers and the PI-enabled. The PI-enablers provide the necessary physical and material infrastructure including: PI-containers, PI-vehicles and software. The PI-enabled companies profit from the potential value creation induced by the Physical Internet. Montreuil et al. state that we face a revolution as radical as the Internet Revolution. Infrastructure and business models will continue to influence one another, leading to radical changes of the current models and opportunities for start-up entrepreneurs to invent new ways to create value through the Physical Internet.

Oktaei, Lehoux and Montreuil discuss the potential business models for PI-Transit Centers, a specific type of PI-nodes, in [16]. The paper presents the business model in a business model canvas [17], a powerful visual and intuitive tool that gives an overview of the company's business. By using the Business Model Canvas of Osterwalder and Pigneur, various aspects of the transit centers have been conceptualized, including their key partners, key activities, key resources, cost structure, revenue streams, value proposition, channels, customer segments and customer relationships. Possible growth strategies were also investigated by the authors.

Furthermore, innovative business models for logistics service providers in a Physical Internet are of similar importance, as they are necessary for the transport between PI-nodes. In [18], Pan, Xu and Ballot propose the First Price Sealed Combinatorial Auction mechanism (FPSCA), in which shippers are the auctioneers and carriers are the bidders. This auction mechanism allows optimal matching between requests and offers and improves the utilization of the logistic network resources. Every transport is auctioned and based on the Winner Determination Program a carrier is chosen. In general, a request bundle will be allocated to the carrier who offers the lowest payment rate. To guarantee that shippers will never pay more than promised, reallocating requests will only take place if a lower payment rate is available.

2.2.3 Innovative technologies

The Physical Internet also drives technological innovation. Essential to the Physical Internet are technologies that enable data sharing and communication between the Key Physical Elements. Technologies that are often mentioned in the literature are RFID, blockchain and artificial intelligence. In [19], for example, Zhong, Huang and Lan propose an RFID-enabled logistics environment and a suitable framework to process the RFID-enabled shopfloor logistics big data.

Besides data sharing technologies, innovative ways of transportation are also necessary to enable the Physical Internet. Kopica, Morales-Alvares and Olaverri-Monreal [20] suggest the use of automated electric vehicles for the transportation of packages or mail. Schönangerer and Tinello [21] on the other hand, present an interesting logistical alternative in which electrically driven transport capsules move PI-containers through underground tubes.

2.3 Readiness and guidelines for Physical Internet implementation

2.3.1 Assessing the potential impact of PI

The ultimate goal of the research on the Physical Internet is its global implementation. Measurements and evaluations of the potential impact of the Physical Internet and its components are critical to support the transition towards a Physical Internet. In the literature, many articles can be found concerning the assessment of physical internet aspects.

In [22], for example, Furtado and Frayret compared the traditional transportation model with the resource sharing transportation model, using the Netlogo platform. The results of the simulations are promising, the total costs of the traditional model are on average 17% higher than the costs of the resource sharing model. The resource sharing model also performs better concerning the social aspects of transportation, the percentage of time spent at home per trucker is on average three times better than for the traditional scenario. Moreover, greenhouse gas emissions and efficiency key performance indicators are influenced positively.

Additionally, Meller, Ellis and Loftis [23] conducted a research project for the Center for Excellence in Logistics and Distribution (CELDI) to measure the impact of the Physical Internet if adopted in the U.S.. The results show that the expected annual benefits of the Physical Internet would be a reduction in costs of over $ 100B, a reduction in CO_2 emissions of over 200 Tg, and a reduction in driver turnover of up to 75%.

2.3.2 Guidelines for PI implementation

To successfully implement the PI concept, there is a need for guidelines regarding all aspects of the Physical Internet. The Alliance for Logistics Innovation through Collaboration in Europe (ALICE) [2] was set-up to develop a comprehensive strategy for research, innovation, and market deployment of logistics and supply chain management innovation in Europe. In July 2013, ALICE was officially recognized as a European Technology Platform by the European Commission. ALICE recognizes the need for a Physical Internet to reach efficient logistics and supply chain operations. They have the vision to increase the efficiency of the EU logistics sector by 10% to 30%. ALICE states that this would mean a €100 - 300 billion cost relief for the European industry. To achieve this, they built a roadmap toward zero-emission logistics and the implementation of the Physical Internet. Figure 2.2 gives an overview of the milestones and goals set by ALICE.

Furthermore, Ehrentraut et al. [24] propose a methodology to create a roadmap for SME. Based on boundary conditions derived from a use case in the automotive sector, and a proposed future standard PI-process, the proposed methodology can be seen as a guide with a practical orientation to map the first promising implementation steps towards a future PI.

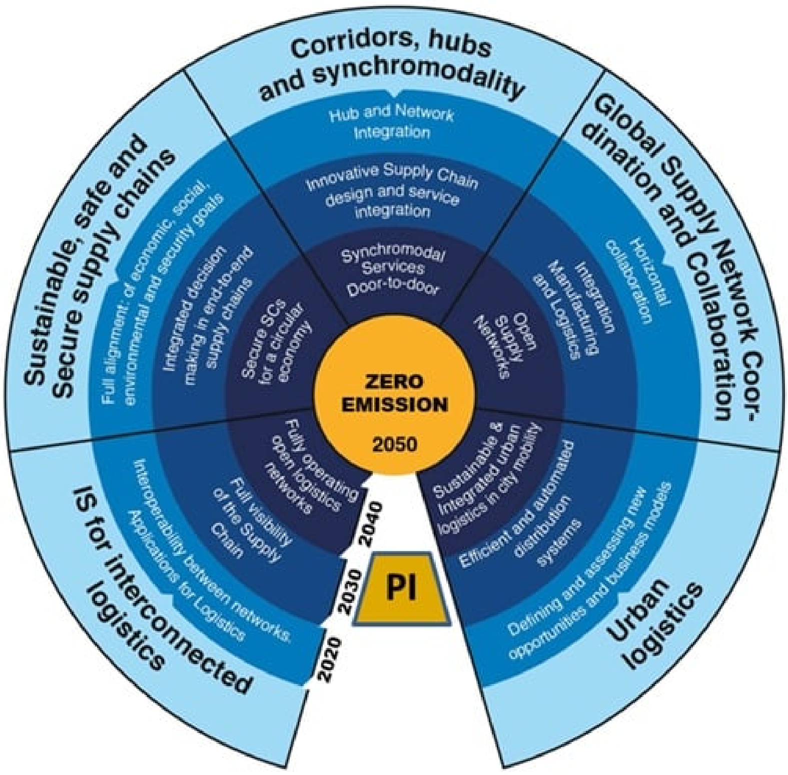

Figure 2.2: Roadmap towards zero emissions logistics by ALICE [2]

2.3.3 Barriers for implementation

Finally, it is important to identify possible barriers that hinder the implementation of the Physical Internet. To identify challenges in the context of horizontal collaboration, Simmer et al. [25] conducted interviews with transport service providers in Austria, to explore their views, experiences, believes, and motivations on collaboration and the physical internet. Their study found that essential factors for successful collaboration are trust between the actors, setting of precise conditions, and shareable IT structures. Simmer et al. state that an EU-wide antitrust regulation would be useful to further support the implementation of future cooperation. Additionally, awareness of the benefits of collaboration should be raised in the companies.

To conclude this chapter, a conceptual framework is created (see Figure 2.3). The conceptual framework provides an overview of the key physical elements, the key enablers, and the ways of assessing readiness and guiding for implementation. It also shows how the concepts are related to each other in the literature. The designs of PI-containers, PI-nodes and PI-movers drive technological and business model innovation, and interconnectivity. In the other way, the innovative technologies, business models and interconnectivity enable the effective use of these key physical elements. Both the research on key physical elements and key enablers are assessed and guided by research concerning the potential impact of PI, guidelines and roadmaps towards a physical internet adoption, and the identification of implementation barriers.

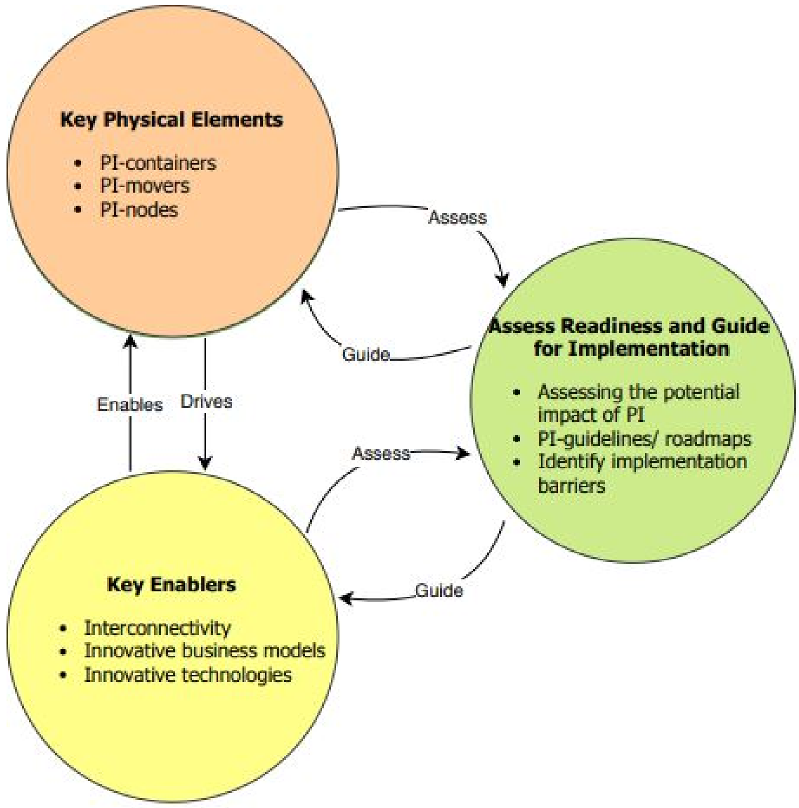

Figure 2.3: Conceptual Framework of Physical Internet Research

3 Method

In the following sections the used Systematic Mapping method is described in detail. The systematic mapping study essentially follows the guidelines provided by Petersen et al. [3]. The systematic mapping process includes the definition of research questions, conducting the search for relevant papers, the screening of the search results using inclusion and exclusion criteria, the creation of a classification scheme, and data extraction and mapping.

3.1 Research questions

The goal of this systematic mapping study is to identify and classify the research concerning the Physical Internet, to identify existing research gaps and to guide future research on the Physical Internet. This leads to the following research questions (RQ):

- *RQ-1: By who were the studies conducted?* This question aims at identifying the most active researchers in the field.
- *RQ-2: When were the studies published?* The answer to this questions shows trends in the number of publications.
- *RQ-3: What are the main publication venues?* This question aims at identifying the most important journals, workshops or conferences for research on the Physical Internet. It also reveals the types of venues in which existing papers are published most frequently.
- *RQ-4: Which topics related to the physical internet are covered in the existing literature?* This question aims to identify the most covered topics and reveals the underrepresented topics and gaps. To answer this research question, a new classification scheme to structure topics related to the Physical Internet is created.
- *RQ-5: To which ALICE roadmaps are the papers related?* This question aims at relating the existing literature to the roadmaps developed by ALICE. Relating the research to these roadmaps helps to identify the current progress on the implementation of the Physical Internet.

- *RQ-6: What types of contributions do the studies constitute?* This question reveals the types of knowledge contributions that are most frequently constituted by the research, it also shows research gaps.
- *RQ-7: What are the most common research methods applied and which were the research types reported?* This question is intended to identify the applied research methods and the research types of the existing research, as well as gaps and under-represented approaches.
- *RQ-8: What are the research gaps that need to be addressed in future studies?* This question aims to identify research gaps and potential future research areas. As an answer to this question, recommendations for future research will be proposed in this work.

3.2 Search Strategy

To find all available research concerning the Physical Internet, multiple search techniques must be applied. The search strategy consists of three steps: automated search, snowballing search and manual search.

Automated search

For the automated search, two databases are selected: Scopus and Web of Science (WoS), as well as one academic search engine: Google Scholar. Every English paper that contains the term "physical internet" in the title, in the abstract or as a keyword, has to be taken under consideration. The papers have to be published after 2005, as the Physical Internet was first mentioned in 2006 by the Economist [6], and before 2020, the year in which this systematic mapping study is conducted. The search string used is "physical internet", no other keywords are added to make sure no research concerning the Physical Internet is left out. Table 3.1 shows the number of search results per database and search engine.

Scopus and WoS are both indexing services that include IEEE, ACM and Elsevier publications. Google Scholar contains documents from most academic publishers, universities, and academic repositories. Consequently, there is a big overlap between the search results of the three databases. Duplicates were eliminated according to the following sequence:

1. Duplicate articles of Scopus and Google Scholar
2. Duplicate articles of WoS and Google Scholar
3. Duplicates of the remaining articles of Scopus and WoS
4. Duplicate articles on Google Scholar

In table 3.2 the number of duplicates and remaining articles, after the removal of duplicates, can be found.

Database	Search results
WoS	142
Scopus	173
Google Scholar	2830
Total	3145

Table 3.1: Automated search results

	WoS	Scopus	Google Scholar
Duplicates	140	165	1854
Remaining articles	2	8	976

Table 3.2: Duplicates and remaining articles

Snowballing

The second applied search technique is snowballing, according to the guidelines suggested by Wohlin [26]. As the automated and manual search technique are also applied in this study, the start set is limited to one article. The most-cited article out of the search results on google scholar, which is [4] by Montreuil, is selected as the seed article. At first, backward snowballing is performed. In this step, papers on the reference list of the seed article are examined. The next step is forward snowballing, this refers to identifying the papers that cite the seed article. Google scholar can be used to easily find all citing papers. Table 3.3 shows the results of the snowballing search after duplicate extraction.

Source	References	Citations
[4]	28	182

Table 3.3: Snowballing search output

Manual search

The last used search technique is manual search. A set of conferences that publish research in the area of interest are chosen to find additional available papers. As their annual proceedings contain many papers on the Physical Internet, the following two conferences are selected:

- The international workshop on Service Orientation in Holonic and Multi-Agent Manufacturing (SOHOMA)
- International Physical Internet Conference (IPIC)

SOHOMA publishes its proceedings in special issues of the Springer Book series "Studies in Computational Intelligence", the editions published after 2010 and before 2020 are examined for relevant articles. The IPIC proceedings contain a wide variety of research papers on the Physical Internet, thus far 6 editions of the conference have been held. All 6 of the published proceedings are examined for articles on the Physical Internet. Table 3.4 shows the remaining results of the manual search, after the extraction of papers that were already found during the automated search and the snowballing search.

Source	Unique papers
SOHOMA	227
IPIC	79

Table 3.4: Manual search output

3.3 Paper selection

After the exclusion of duplicate papers, multiple other exclusion criteria are applied to the search results. As it is necessary to assess the relevance of the paper, non-English papers and papers that are not accessible in full-text are excluded. Ph.D. or Master theses that were conducted before 2018 are also excluded because research covered by the theses would have been published in peer-reviewed journals or conferences, if relevant. It is possible that interesting theses conducted in 2018 and 2019 are not yet published, however, they are not included in the mapping study, as the exclusion of articles based on quality assessment falls out of the scope of this study. In appendix G the identified theses conducted in 2018 and 2019 are listed. Subsequently, the irrelevant articles are first excluded based on title and abstract. If it is still unclear whether to exclude the article or not after reading the abstract, the full text of the article is read.

The following exclusion criteria are applied:

- Exclusion of duplicate papers
- Exclusion of non-English papers
- Exclusion of papers published before June 2006 and after December 2019
- Exclusion of papers that are not accessible in full-text
- Exclusion of old versions of an included paper
- Exclusion of PhD or Master theses
- Exclusion of papers that are unrelated to the Physical Internet

The papers not excluded after the application of the criteria above are selected for Data Extraction. The flowchart (see Figure 3.1) gives an overview of the whole search and selection process.

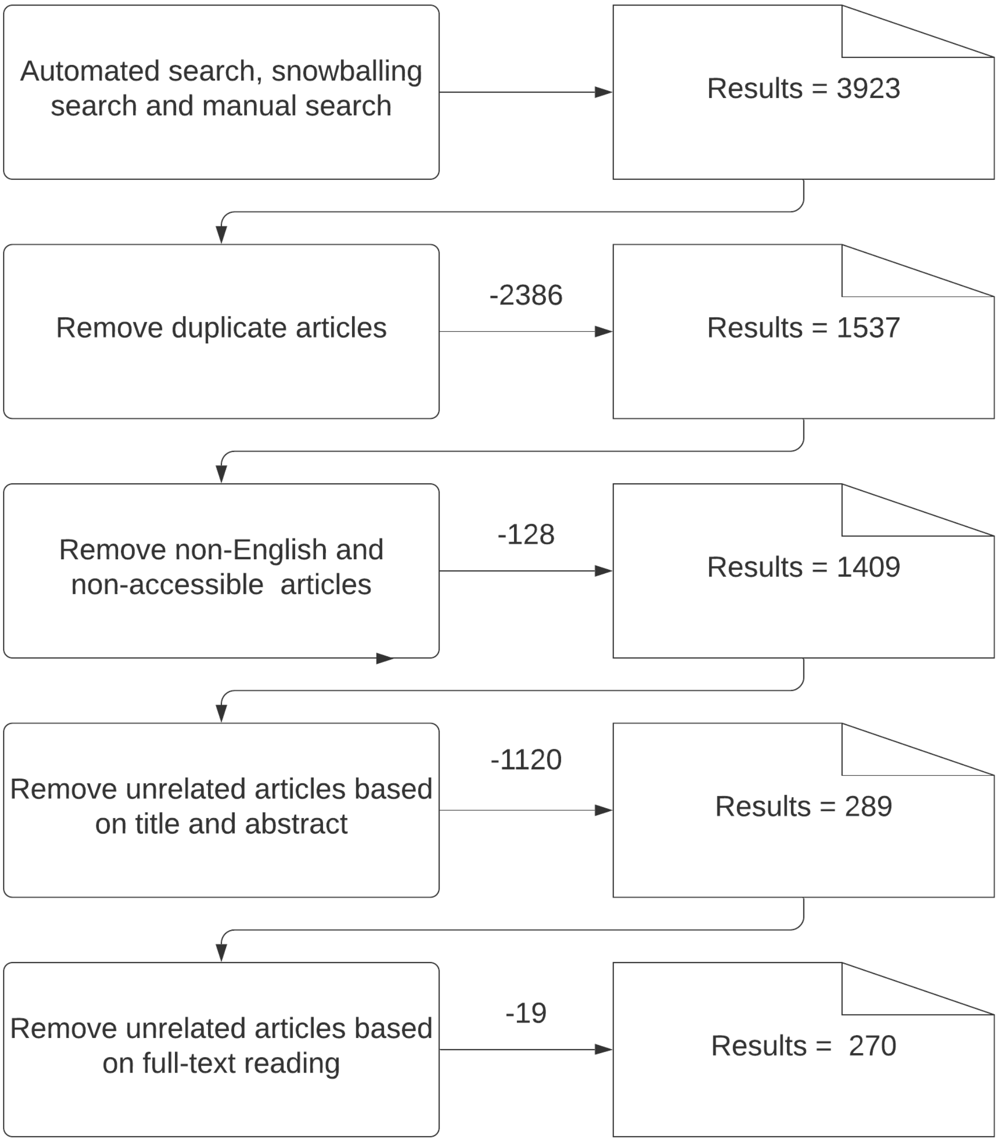

Figure 3.1: Number of included articles during the study selection process

3.4 Data Extraction

In the data extraction phase the full text of each article identified for inclusion is scanned and the pertinent data are extracted. The template shown in table 3.5 was developed to extract data from the identified studies. For each data extraction field a data item, a value and the related research question(s) are given. For each article multiple research topics, types of contribution and research methods can be identified.

Data Item	Value	RQ
Study ID	Integer	-
Article Title	Title of the article	-
Author Name	Set of names of the authors	RQ1
Year of Publication	Calendar year	RQ2
Type of Venue	Workshop, Conference or Journal	RQ3
Venue	Name of publication venue	RQ3
Research Topic	Research Topic(s) of the article	RQ4
ALICE Roadmap	Name of the roadmap proposed by [2]	RQ5
Type of Contribution	Contribution type(s) of the article	RQ6
Type of Research	Research Type Facet by Wieringa et al. [27]	RQ7
Research Method	Used research method(s)	RQ7

Table 3.5: Data extraction form

3.5 Analysis and classification

In this section an overview of the used classifications is presented and all of the possible values are described. The information for each extracted item is tabulated and classified according to these classifications.

3.5.1 Topic

The research on the Physical Internet concerns a wide range of topics. Given the increasing number of studies each year, it is important to have an overview of the existing literature and its subjects. A topic based classification of the literature supports the identification of research gaps within topic areas and facilitates the search process of interested researchers. In [28], Fergani et al. propose a classification of Physical Internet topics. The classification is based on three factors: logistics web, resources, and organization views at a strategic, tactical and operational level. Although their suggested classification is interesting for the identification of some relevant research gaps, a different classification is proposed and used in this thesis.

To create a topic related classification scheme, keywording was used as proposed by Petersen et al. [3]. For a pilot set of articles, mainly the articles mentioned in chapter 2 of this report, frequently recurring keywords and concepts were identified by reading the abstracts. Based on these keywords and concepts, a start set of topic categories was defined. During the classification process of the selected articles, new categories were defined and existing categories were adjusted to better suit the pool of selected articles. Defining or adjusting categories implied an iteration of the classification process. Figure 3.2 depicts the classification scheme building process. Below the name and description of the final set of clusters are presented. Note that some of the topic clusters are related to the Key Enablers or Key Physical Elements presented in the previous chapter.

- **Business model innovation (Key Enabler):** The paper focuses on the potential impact of the Physical Internet on business model innovation. It proposes solutions to improve the current ways of conducting business in a PI-context or describes potential new types of businesses resulting from the Physical Internet.

- **Technological innovations enabling PI (Key Enabler):** The paper describes the innovative technology and its integration into the Physical Internet. The implementation of the technology would solve current PI-barriers and could improve the functioning of PI components.

- **Digital interconnectivity within the Physical Internet (Key Enabler):** The paper proposes information systems that are enabling interconnectivity and interoperability. It describes new ways of information sharing within coopetitive supply chains.

- **Standardized Modular Containers (Key Physical Element):** The paper focuses on the design and implementation of the standardized, smart and modular PI-containers within the logistics system.

- **PI-nodes (Key Physical Element):** The paper focuses on the design and implementation of PI-nodes, which are the essential facilities for the receiving, storing, picking, composing and decomposing PI-containers.

- **Supply chain optimisation within the Physical Internet:** The paper formulates a supply chain optimisation problem within the Physical Internet and solves it by making use of simulation or mathematical optimisation, or proposes new methods and clearly describes how to solve the problem.

- **Adoption of the Physical Internet:** The paper discusses the implementation of the Physical Internet. It contains guidelines for a global Physical Internet adoption or assesses the readiness of a region or a sector for the Physical Internet.
- **Assessment of PI aspects:** The paper compares PI with the conventional logistics systems and assesses the changes.
- **Other:** The paper is not related to any of the topics above.

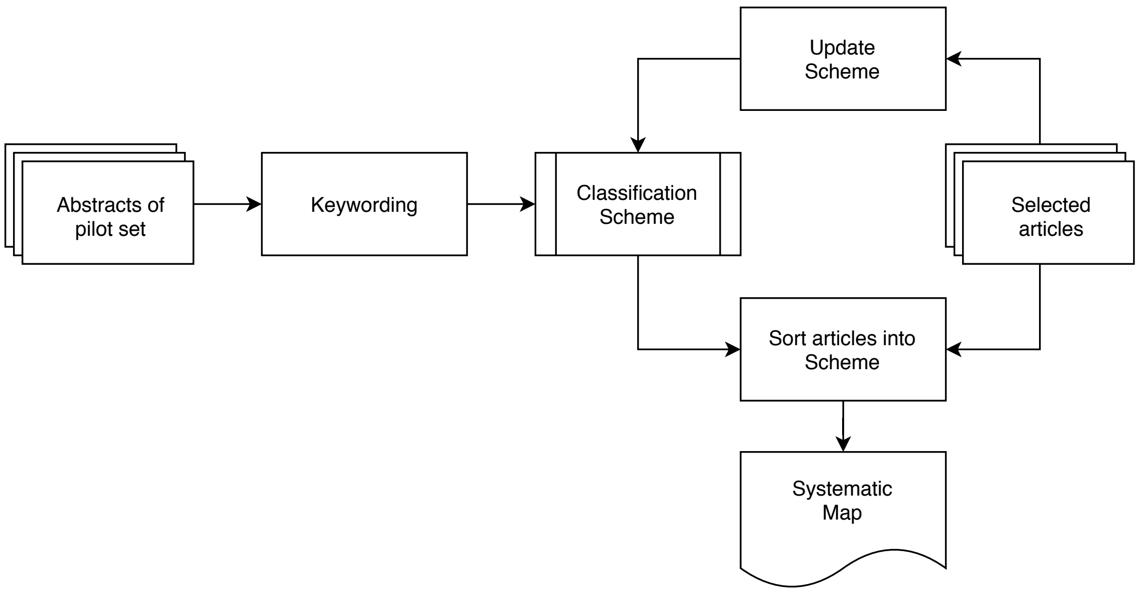

Figure 3.2: Classification scheme building process (Adapted from Petersen et al. [3])

3.5.2 ALICE roadmaps

The European Technology Platform ALICE [2] recognizes the need for an overarching view on logistics and supply chain planning and control, in which shippers and logistics service providers closely collaborate to reach efficient logistics and supply chain operations. To support this goal, ALICE developed 5 different research and innovation roadmaps towards zero emission logistics. These roadmaps are often referred to in the literature and are important guidelines towards a European adoption of the Physical Internet. In this study each of the papers is, if possible, related to one of the roadmaps. This classification provides an overview of the current progress of the research towards a Physical Internet. The roadmaps are listed and described below:

- **Sustainable, safe and secure supply chains:** The paper concerns logistics as a key factor enabling a circular economy, measuring and minimizing emissions, improving load unit standardization and modularization, or improving security.
- **Information Systems for interconnected logistics:** The paper concerns the development of technologies and tools that facilitate the closure of existing gaps in current ICT systems and data sharing capabilities in supply chains.
- **Corridors, hubs and synchromodality:** The paper concerns the synchronization of the full range of services between modes, the exploitation of hub capacity and flexibility, the alignment of equipment and services on corridors and hubs, or the integration of these into resilient networks.
- **Global Supply Network Coordination and Collaboration:** The paper concerns the realization of supply chain networks with full vertical and horizontal collaboration and coordination. This includes sales planning, order management, logistics and transportation planning and strategic network design choices.
- **Urban Logistics:** The paper concerns the full integration of freight flows in cities, operations and activities that efficiently allow citizens to access the goods and the goods to access the citizens they require or sustainable development in cities.
- **Not applicable:** The paper cannot be related to any of the roadmaps above.

3.5.3 Type of Contribution

Given that the Physical Internet is a relatively new concept, the research contains various types of knowledge contributions. In [29], Ulrich describes the different types of knowledge contributions within Information Systems Research. The used classification of research contributions is based on his work. Some of his proposed contribution types were left out or adjusted to better suit the research. The types of contribution are listed and described below:

- **Conceptual framework:** The paper contributes a framework that structures the world we are investigating or designing. It provides the abstractions that serve to conceive or to structure the research subject. A conceptual framework is aimed at guiding problem solving in practice.

- **Conceptual model:** A conceptual model is similar to a conceptual framework, as it also provides an abstraction of a research subject. However, rather than guiding research, a conceptual model is aimed at the construction of artefacts or possible worlds.
- **Evaluation:** The paper contributes a critical examination of a topic. It determines the merit of a subject, using criteria governed by a set of standards.
- **Mathematical model:** The paper contributes the description of a system using mathematical concepts and language.
- **Method:** The paper contributes a technique or mode of procedure, in accordance with a definitive plan. For example, a new way of arranging PI-containers in delivery vehicles.
- **Methodology:** The paper contributes a new way of conducting research. It describes procedures and new manners to gain knowledge.
- **Research agenda:** The paper contributes a plan of action that summarizes issues and ideas in a subset of the field of study.
- **Tool:** The paper contributes a design that can be used to perform an operation in practice. For example, a new platform designed to exchange information between PI-nodes.
- **Other:** The contribution of the paper is not related to any of the contribution types mentioned above.

3.5.4 Type of research

To classify the literature according to research type, we use the classification scheme proposed by Wieringa in [27]. This classification is widely used within systematic mapping studies, as it is valid in most fields of research. The types of research are listed and described below:

- **Evaluation research:** The paper investigates a problem or the implementation of the Physical Internet. The causal properties are studied empirically, such as by case study, field study, field experiment, survey, etc.

- **Proposal of solution:** The paper proposes a solution technique and argues for its relevance, without full blown validation. The technique is novel or a significant improvement of an existing technique.

- **Validation research:** The paper investigates the properties of a solution proposal that has not yet been implemented. The investigation uses a methodologically sound research setup, such as simulation, mathematical analysis, prototyping, etc.

- **Philosophical papers:** The paper sketches a new way of looking at things, a new conceptual framework, etc., or reports secondary studies, such as systematic reviews.

- **Opinion papers:** The paper contains the author's opinion about what is wrong or good about something, how we should do something else, etc.

- **Personal experience papers:** The paper contains a list of lessons learned by the author from his or her experience. The experience is reported without a discussion of the research methods.

3.5.5 Research method

The classification of research methods is the last classification scheme used in this thesis. As many method related schemes have already been applied among researchers, it was decided to base this classification on [30] by Schlichter and Kræmmergaard. However, some categories, such as mathematical optimisation and simulation, were added to better suit the field of research. The types of research methods are listed and described below:

- **Case study:** The paper conducts an in-depth investigation of a situation, group or time period.

- **Content analysis:** The paper evaluates historical documents, newspaper stories, political speeches, interviews, diplomatic messages, and official publications.

- **Descriptive:** The paper solely describes or argues for a phenomenon.

- **Literature review:** The paper enumerates, describes, summarizes, objectively evaluates and clarifies previous work in the field of study.
- **Mathematical optimisation:** The paper uses an optimisation method, such as linear programming, to achieve the best outcome for a problem.
- **Quantitative analysis:** The paper uses statistical models and tests to analyse data.
- **Simulation:** The paper uses an approximate imitation of a process or system to gain insight into its functioning. The simulation model is used to show eventual effects of alternative conditions and courses of action.
- **Survey/qualitative analysis:** The paper gathers data by means of questionnaires and analyses this data based on non-quantifiable information, such as expertise.
- **Other:** The paper's research method is not mentioned above.

3.6 Threats to Validity

This systematic mapping study faces some possible threats to its validity that are common for similar studies. During the automated search, studies could have been missed due to the selected digital libraries. To limit this threat, the search was complemented with backward and forward snowballing and manual search. Another threat to validity is the creation of search queries. However, the mapping study concerns all articles on the Physical Internet, thus the used search query "Physical Internet" should be sufficient to find all relevant studies. The paper selection step is sensitive to researcher biases, as relevant studies might be excluded during the screening phase. This study was conducted by a single author, which is the main threat to validity. To mitigate this threat, the exclusion criteria were clearly defined. No articles were excluded based on quality assessment, which is particularly prone to researcher bias and not essential to systematic mapping studies. Researcher bias is also a threat to the data extraction and classification step. Although the validity of this step is always based on human judgement, biases could be reduced by including other reviewers for the assessment of the extractions.

4 Findings

The application of the exclusion criteria resulted in 270 papers. These 270 papers are mapped according to the classifications described in the previous chapter. In the following sections the mapping results are visualised and described according to the research questions. The full list of selected articles is given in Appendix A.

4.1 Most active researchers in the field (RQ1)

The aim of the first research question was to identify the researchers with the most published research papers on the Physical Internet. In Figure 4.1, the five most active researchers and their amount of publications are shown. Benoit Montreuil has the most published articles related to the Physical Internet. He is a professor in the H. Miltion Stewart School of Industrial and Systems Engineering at Georgia Tech and leads the International Physical Internet Center. Benoit Montreuil introduced a vision for the Physical Internet to meet the Logistics Sustainability Grand Challenge and took part in 56 of the selected studies.

Eric Ballot, professor at Mines ParisTech, contributed 29 articles regarding the Physical Internet. Together with Montreuil, he pioneered research on the Physical Internet by initiating and leading multiple research projects. Ballot is head of the Physical Internet Chair at Mines ParisTech along with Shenle Pan, with whom he conducted many of his Physical Internet related studies. The University of Hong Kong has also launched a Physical Internet Lab under the leadership of Professor George G.Q. Huang. The lab seeks to establish strategic collaborations with industrial associations through collaborative projects. Huang conducted multiple research projects together with Ray Y. Zhong in the field of the Physical Internet, mainly focused on innovative technologies including RFID and the Internet of Things.

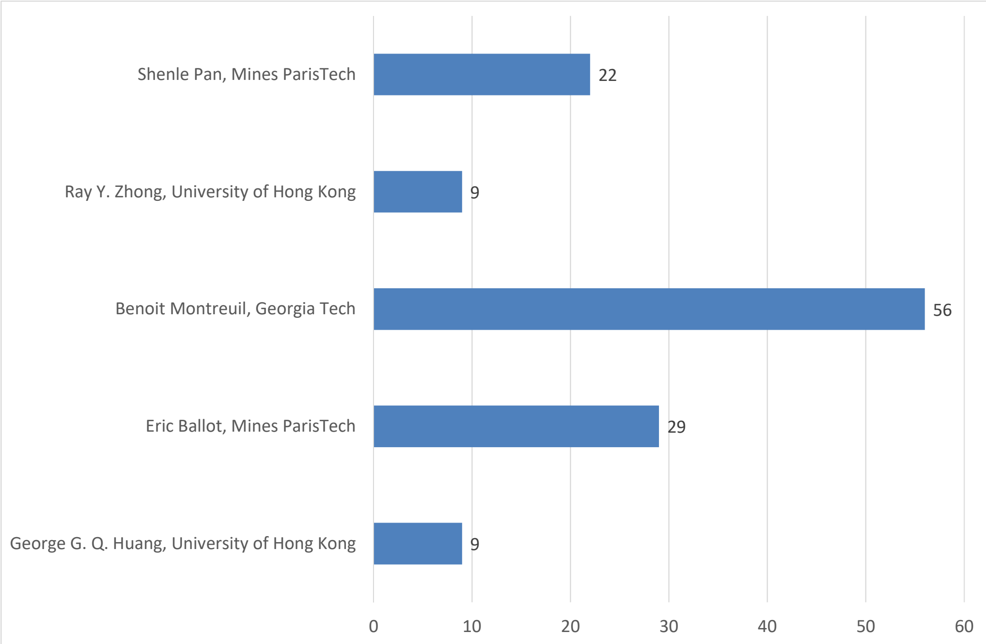

Figure 4.1: The most active researchers

4.2 Number of publications per year (RQ2)

The annual amount of published papers on the Physical Internet is shown in Figure 4.2. This study includes all relevant papers after the year 2005 and before 2020. During the period between 2006 and 2009 no papers were published. The first relevant research was conducted by B. Montreuil, R. Meller and E. Ballot [9] in 2010. This paper titled "Towards a Physical Internet: the Impact on Logistics Facilities and Material Handling Systems Design and Innovation" was published in the proceedings of the 11th IMHRC. Before 2014, most of the research regarding the Physical Internet was conducted by the same groups of researchers. Researchers' interest in the subject increased in 2014, mainly due to the organization of the first International Physical Internet Conference (IPIC), which was held in Quebec, Canada. However, this increase in publications may also be due to the selection of the IPIC for manual search. From then on, the IPIC was held yearly on a different location and multiple new research groups were founded.

Another organization responsible for the attraction of new researchers is ALICE [2]. In 2013 the European Commission recognized ALICE as a European Technology Platform, to support and give advice on the implementation of the EU Horizon 2020 program in the area of logistics. Funded by the European Commission, ALICE was able to set-up a knowledge platform, constructed five different roadmaps to guide the implementation of the Physical Internet, and supported multiple relevant projects. As the need for a more sustainable supply chain system grows and innovative technologies that facilitate and enable the Physical Internet are being developed, the amount of publications is expected to increase on a yearly basis.

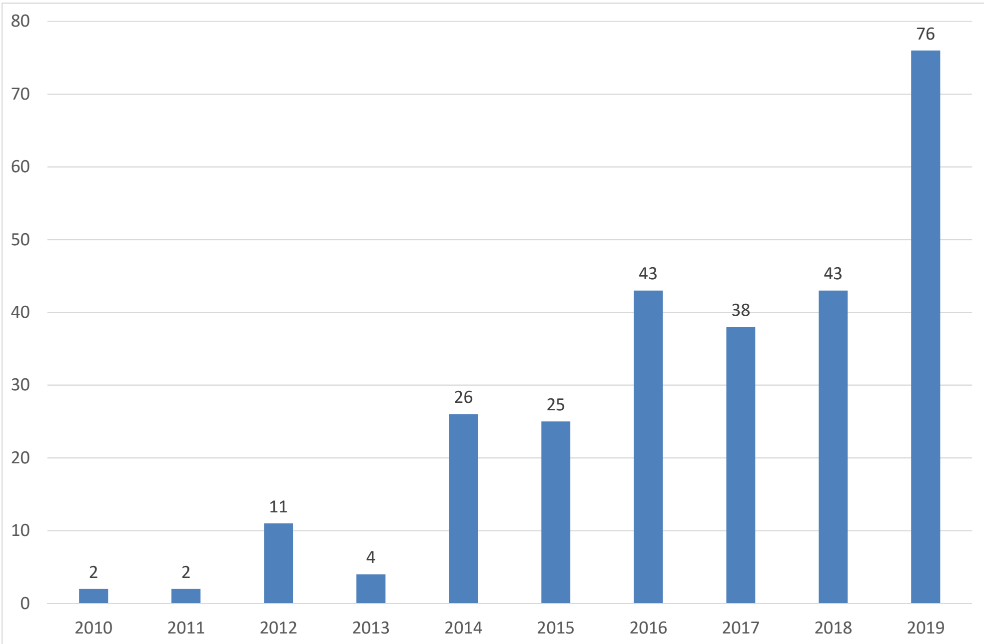

Figure 4.2: Selected publications per year

4.3 Publication venues (RQ3)

Figure 4.3 shows the four venues in which most of the papers are published. As stated in the previous section, it is suspected that the IPIC attracted many new researchers. It currently is the only conference that solely focuses on research related to the Physical Internet. In its six editions, the conference published 110 of the selected papers in its proceedings, which makes the IPIC the highest contributing venue by far. The International Journal of Production Research (IJPR) is another popular research venue for Physical Internet related research. The journal primarily concerns manufacturing strategy, policy formulation and evaluation, and the contribution of technological innovation. The 21 selected papers that were published by IJPR mostly are about supply chain optimisation problems. The third and fourth most popular venues are the International Federation of Automatic Control (IFAC) and the International Material Handlers Research Colloquium (IMHRC) respectively. The IFAC and the IMHRC both published some of the early stage articles on the design of the physical internet concept and its foundations, and cover a wide variety of topics.

Figure 4.4 displays how many articles are published in each type of venue. 181 of the selected papers were published in conference proceedings, mostly in the IPIC. As the Physical Internet concept got more popular among academics, the frequency of publications in journals increased. Only 9 of the selected articles are published in workshop proceedings. However, it is important to note that this may be due to the used search strategy.

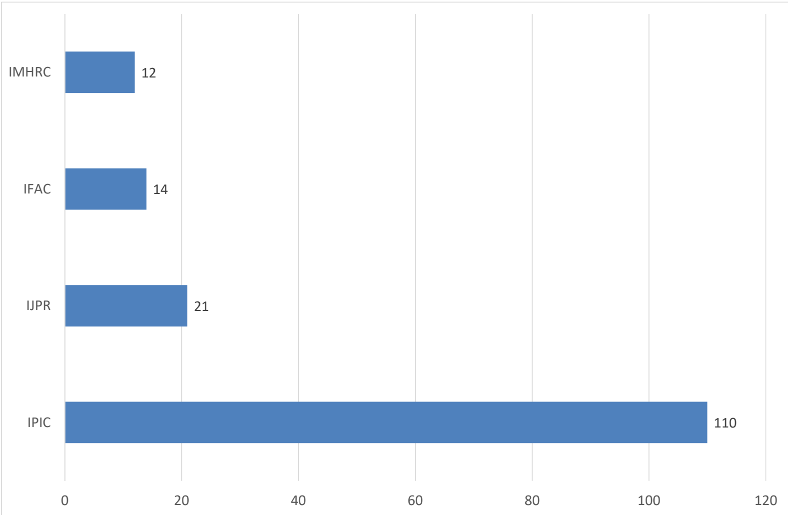

Figure 4.3: Top venues

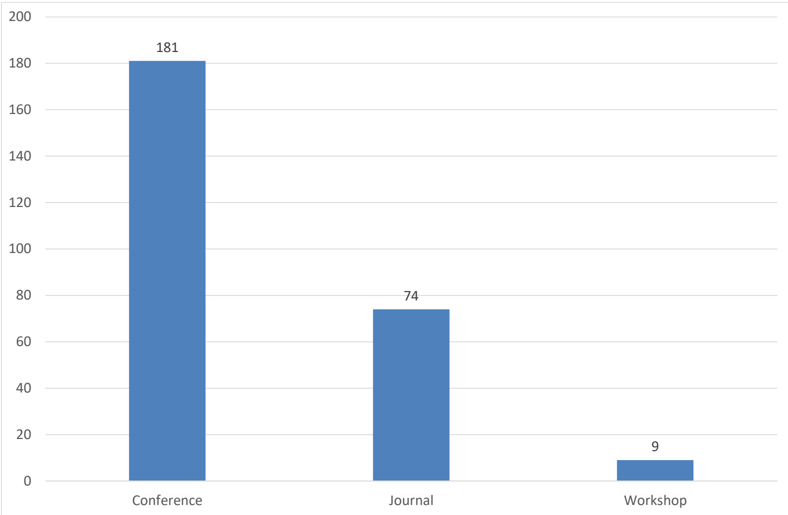

Figure 4.4: Type of venues

4.4 Research Topic (RQ4)

To classify the papers according to their research topic, the classification proposed in Section 3.5.1 was used. As the articles can concern multiple topics, each paper has been classified into one or more topic-related clusters. Figure 4.5 shows the distribution of the topic areas among the articles.

The optimisation of supply chains within the Physical Internet (80 articles) is the most recurring topic in the selected papers, followed by digital interconnectivity within the Physical Internet (54 articles) and PI-nodes (40 articles). The articles on the optimisation of supply chains generally present supply chain problems as mathematical or simulation models and optimise these proposed models by means of operations research methods, such as linear programming (e.g. [A33]), transportation problems (e.g. [A267]) and inventory control problems (e.g. [A174]). Various new heuristics and methods (e.g. [A143]) have also been proposed in these studies.

Most of the papers about digital interconnectivity within the Physical Internet describe models, new technologies or tools that can be used for communication between different Physical Internet systems. Some case studies have also been conducted to assess the implementation of innovative technologies (e.g. [A54]) and communication platforms (e.g. [A22]) within logistics systems. The research on PI-nodes mainly validates, assesses and optimises their functionality. The facility location (e.g. [A58]) and the design of PI-nodes (e.g. [A96], [A97] and [A98]) has also been discussed in several papers.

The number of articles dealing with innovative technologies (27 articles) is smaller than expected. As the physical internet is enabled by and highly dependent on innovative technologies including RFID, IoT, blockchain, AI, automatic vehicles and robotics, it is important to assess and further develop these technologies in a Physical Internet context. Interestingly, the articles mainly concern the application of RFID and IoT technologies, technologies that enable the communication and sharing of information. Although being equally important, hardly any innovative ways of transportation are proposed in the articles. In [A62], the use of drones is evaluated for last mile logistics. Another example is

[A52], in this article an underground network of electric freeways for autonomous trucks is presented.

The proportion of articles on innovative business models is also relatively small (23 articles). Innovative business models are essential to assess the profitability and role of new potential businesses in a PI context. These new business models can also convince or guide existing businesses to adapt to the potential new business environment. Article [A42] is an example of an article that gives future directions for innovative business models based on data sharing. Various business models for PI-nodes (e.g. [A76]), as well as pricing strategies (e.g. [A78]) have been proposed in the existing research. The articles on the adoption of the Physical Internet (25 articles) are mostly studies that assess the readiness of a country (e.g. [A44]) or industry (e.g. [A246]). Additionally, some guidelines and roadmaps towards a Physical Internet implementation are proposed in these articles.

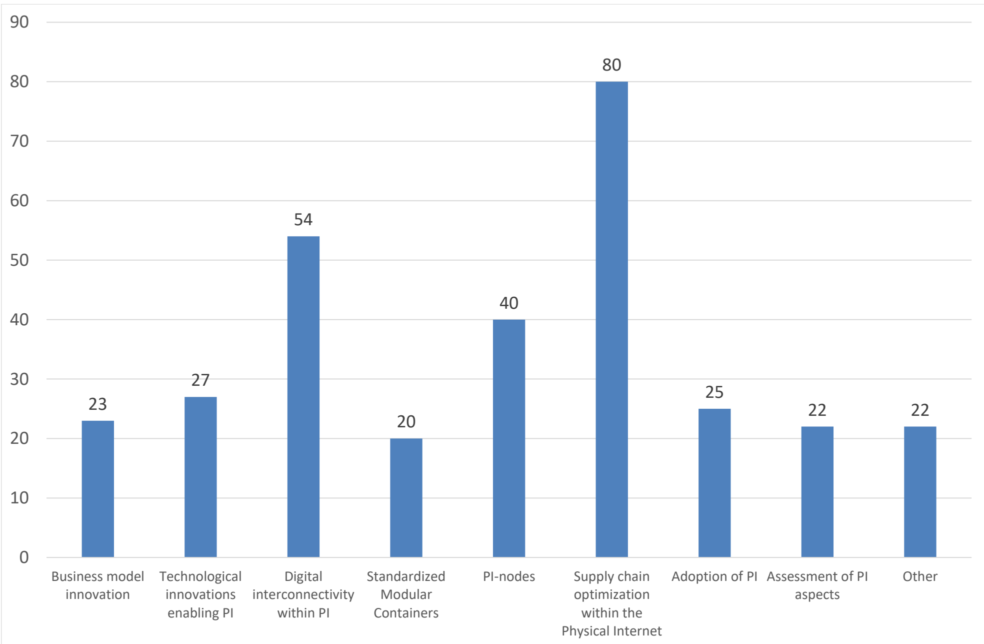

Figure 4.5: Topics covered by the selected papers

Furthermore, 22 of the selected articles assess Physical Internet aspects. Most of these articles use simulation to assess possible scenarios in a Physical Internet context, and present their results by using Key Performance Indicators (KPIs). There are also various articles that discuss and assess the possible outcomes of Physical Internet implementation (e.g. [A198]). Finally, the least amount of articles are focused on standardized modular PI-containers (20 articles). Considering the relatively small amount of research papers, there has been a lot of research progress on this topic. This is mainly due to the MODULUSHCA project [31]. During this project the first physical prototypes of the standardized modular PI-containers have been developed. The other PI-container related papers mainly discuss their implementation (e.g. [A228]) and design (e.g. [A35]). The remaining articles that could not be classified were assigned to the "Other" category. In Appendix B, a list of all the articles per topic-based cluster can be found.

4.5 ALICE roadmaps(RQ5)

In this section, the selected articles are related to the different ALICE roadmaps. Based on its content, each article is assigned to the category to which it relates the most. If it is unclear to which roadmap the article belongs, it was assigned to the "Not applicable" category. The goal of this classification is to track the current research progress on the roadmaps towards a Physical Internet. In section 3.5.2 a detailed description of the five roadmaps can be found. Figure 4.6 depicts the distribution of articles per roadmap.

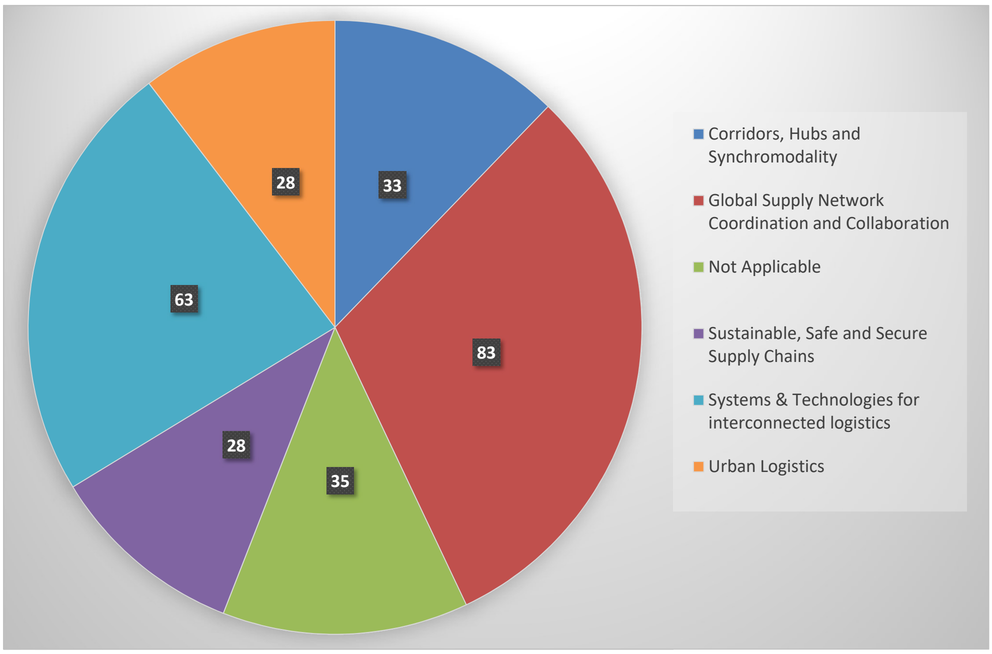

Figure 4.6: Number of articles related to each roadmap

The biggest proportion of the selected papers is related to the Global Supply Network Coordination and Collaboration roadmap (83 articles). The focus of these papers lies on order management, logistics planning, decision making and inventory control in a PI context. The majority concerns horizontal and vertical collaboration and the sharing of assets within a logistics network. In these studies, various ways of collaboration are evaluated and optimised by means of simulation and mathematical optimisation techniques. Only a few of these proposed techniques are subsequently tested with real data (e.g. [A126] and [A156]). The second largest part of articles is related to the Systems and Technologies for Interconnected Logistics roadmap (63 articles). The papers belonging to this category concern the development and implementation of innovative technologies (e.g. [A270]) and the use of ICT systems and data sharing (e.g. [A73]) in supply chains.

33 of the selected articles are related to the Corridors, Hubs and synchromodality roadmap. These articles mainly concern the design of PI-facilities (e.g. [A96]) and the processes within the different types of PI-hubs (e.g. [A11]). Furthermore, to both the Urban Logistics, and the Sustainable, Safe and Secure Supply Chains roadmap 28 articles are related. The articles belonging to the Urban Logistics roadmap discuss the implementation of the Physical Internet in cities. Numerous new ways of parcel delivery to reduce urban congestion (e.g. [A29]) and greenhouse gas emissions are proposed in these articles. The articles related to the Sustainable, Safe and Secure supply chains roadmap are articles that assess the sustainability (e.g. [A233]) and safety (e.g. [A68]) of the proposed logistic web, as well as articles on the standardization and modularization of load units. Lastly, 35 of the articles could not be categorized and were assigned to the "Not applicable" category. In Appendix C, the articles are listed per roadmap.

4.6 Research contributions (RQ6)

The analysis regarding RQ6 reveals a wide set of research contributions (see Figure 4.7). As mentioned in the description of the data extraction phase, a single article can present multiple types of contributions. The different types of contributions are described in Section 3.5.3. Out of the 270 selected articles, 99 proposed a mathematical model, 89 contributed an evaluation and 39 proposed a conceptual framework. Furthermore, 32 of the articles designed a method, 14 designed a methodology and 16 designed a tool. Finally, 28 conceptual models were proposed and 11 research agendas were created. In Appendix D the articles are listed per type of contribution.

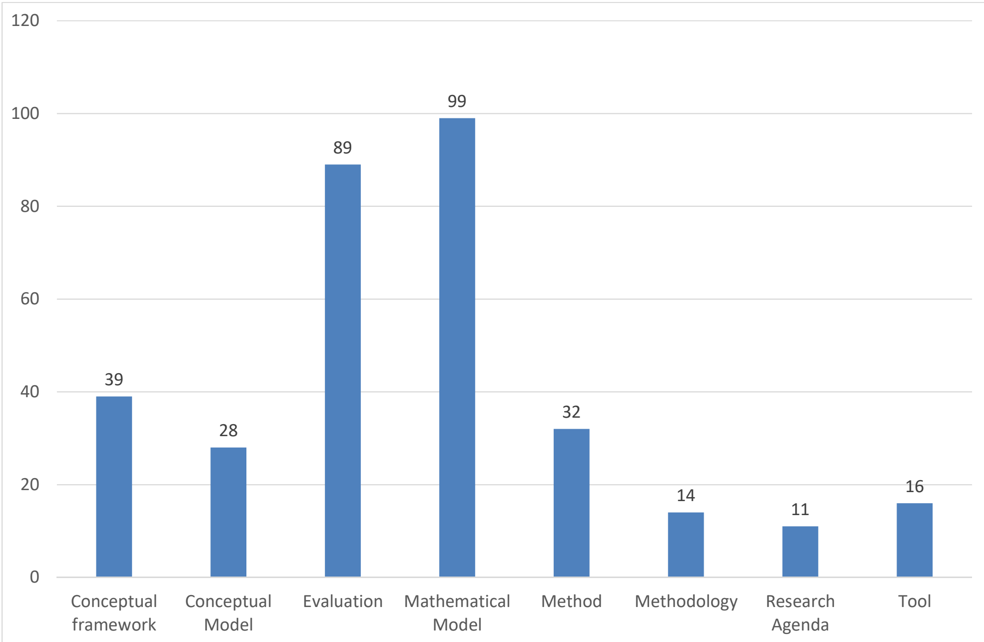

Figure 4.7: Number of articles per type of research contribution

The research on the Physical Internet takes a wide variety of topics into account. Since the importance of the type of contributions differs depending on the topic, few conclusions can be drawn from the global overview of research contributions (Figure 4.7). It seemed more interesting to present the amount of articles per type of contribution according to each research topic. The bubble chart in Figure 4.8 discloses all possible combinations of contribution types with research topics.

Most of the studies with regard to Technological Innovations that enable the Physical Internet contribute an evaluation (19 articles) or a conceptual framework (13 articles). The articles that provide an evaluation of the innovative technologies are mostly descriptive assessments of a single or multiple innovative technologies. Only a few of the studies provide an in depth evaluation of a use case scenario (e.g. [A48] and [A194]). The conceptual frameworks provide an abstraction to structure the “possible world” in which the innovative technologies are implemented in the logistics system. Its aim is at guiding problem solving in practice. Examples of articles on Technological Innovations proposing a conceptual framework are [A50] and [A31].

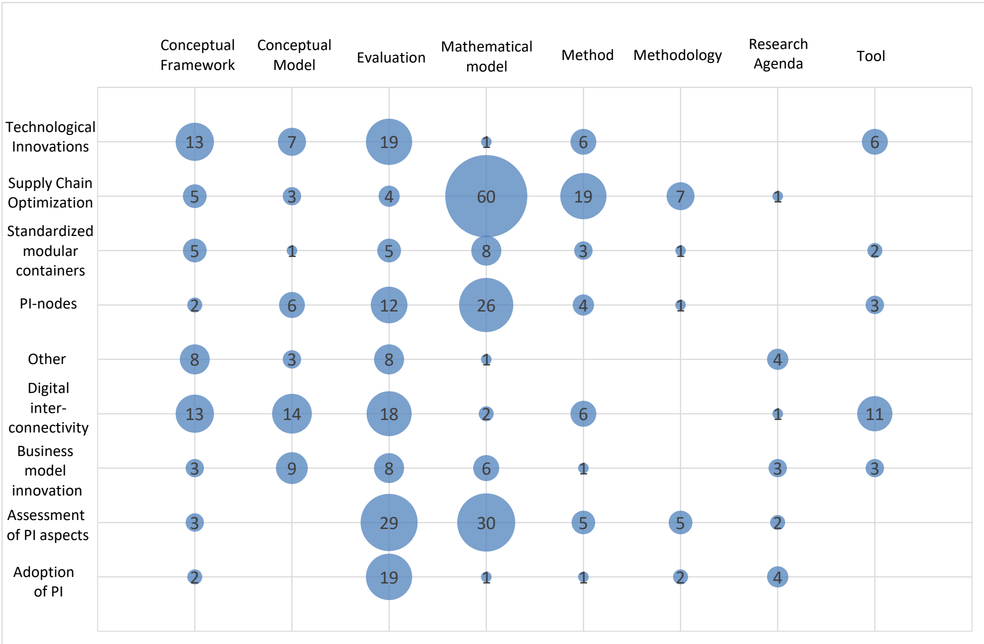

Figure 4.8: Number of articles per type of research contribution combined with research topic

The contributions by articles on Supply Chain Optimisation within the Physical Internet consist mostly of new mathematical models (60 articles), used to optimise or simulate essential processes including inventory management (e.g. [A15]), production scheduling ([A30] and [A33]), and distribution (e.g. [A37] and [A159]). Furthermore, numerous articles propose new methods and research methodologies to optimise certain supply chain optimisation problems (resp. 19 and 7 articles). A big part of these optimisation problems take place in PI-nodes and consider the use of standardized modular containers. This explains the large number of articles on both supply chain optimisation and PI-nodes or modular containers and the frequent contribution of mathematical models by articles on these topics.

The number of articles on PI-nodes and on standard modular containers proposing a mathematical model is 26 and 8 respectively. The majority of the other articles on Standardized Modular Containers contribute an evaluation (5 articles) or a conceptual framework (5 articles). For instance, an article that evaluates the impact of standardized containers on the shipping volume is [A242]. Article [A89] is one of the articles contributing a conceptual framework for smart containers. The remaining articles on PI-nodes primarily contribute evaluations (12 articles) and conceptual models (6 articles). In article [A113] for example, alternative designs of hyperconnected smart pickup-and-delivery locker bank networks are evaluated. Examples of articles that present a conceptual model of a PI-node are [A96], [A97] and [A98], these three articles describe the functional design of three different types of Physical Internet facilities.

The articles on business model innovation contributed 9 conceptual models and 8 evaluations. Although most of the contributions by articles on business model innovation are conceptual models, a bigger number was expected. Only a few articles made use of the business model canvas [17] or any other tool to present business models (e.g. [A17]). In addition to the articles on business model innovation, the biggest contributors of conceptual models are the articles on Digital Interconnectivity (14 articles). These articles propose the architecture and main concepts of various information systems (e.g. [A22]). Besides conceptual models, the articles on digital interconnectivity propose 13 conceptual frameworks, 18 evaluations and 11 tools.

As expected, the articles on the assessment of PI aspects contribute the biggest proportion of the evaluations (29 articles). Moreover, numerous articles also propose a mathematical model (30 articles) that is used to assess PI aspects. Finally, the articles on the adoption of the physical internet contribute 19 evaluations. For the most part, these papers assess the readiness and evaluate ways on how to implement the Physical Internet. One of the articles [A3] also proposes a methodology to create a roadmap towards a Physical Internet for SME. It is noticed that only a few guidelines for Physical Internet implementation are introduced in the articles (e.g. [A103] and [A107]).

4.7 Research methods and research types (RQ7)

To answer RQ7, first the type of research of the articles was analysed. The articles were classified according to the Research Type Facet proposed by Wieringa et al.[27]. The different types of research are described in section 3.5.4. Figure 4.9 shows the number of papers per research type. In appendix E a list of articles per type of research can be found. Out of the 270 selected articles, 110 are Validation Research. Almost all of these articles use mathematical optimisation and simulation to investigate the properties of a proposed solution. In only four of the validation studies quantitative analysis techniques are used, including variance analysis and regression ([A40], [A230], [A79] and [A237]).

Furthermore, there are 79 Philosophical papers. These papers sketch a new way of looking at things, a new conceptual framework or conceptual model, or contribute a critical examination of the existing research on a topic. An example of a philosophical paper is [A89], which provides a conceptual framework for smart PI-containers. 62 of the selected articles are solution proposals. In these articles solutions are described and some examples of their possible use are given. As these articles don't provide a full-blown validation, most of them are descriptive. Surprisingly, there are only 19 Evaluation Research papers. This indicates a lack of empirical studies, in which the properties of the Physical Internet are tested.

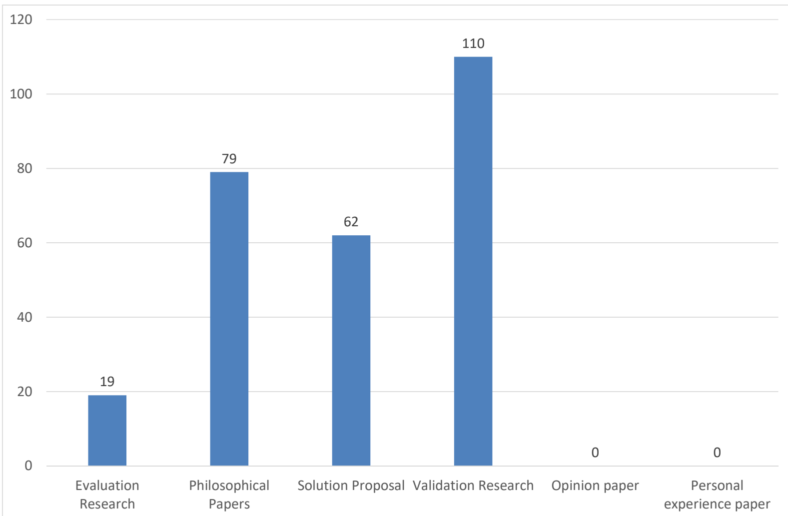

Figure 4.9: Number of articles per Research Type

To complete the analysis regarding RQ7, the applied research methods according to the topic of the study are investigated. The bubble chart (see Figure 4.10) gives an overview of the applied methods for the studies on each topic. In section 3.5.5 the applied research methods are described. It should be noted that for each study multiple methods can be identified.

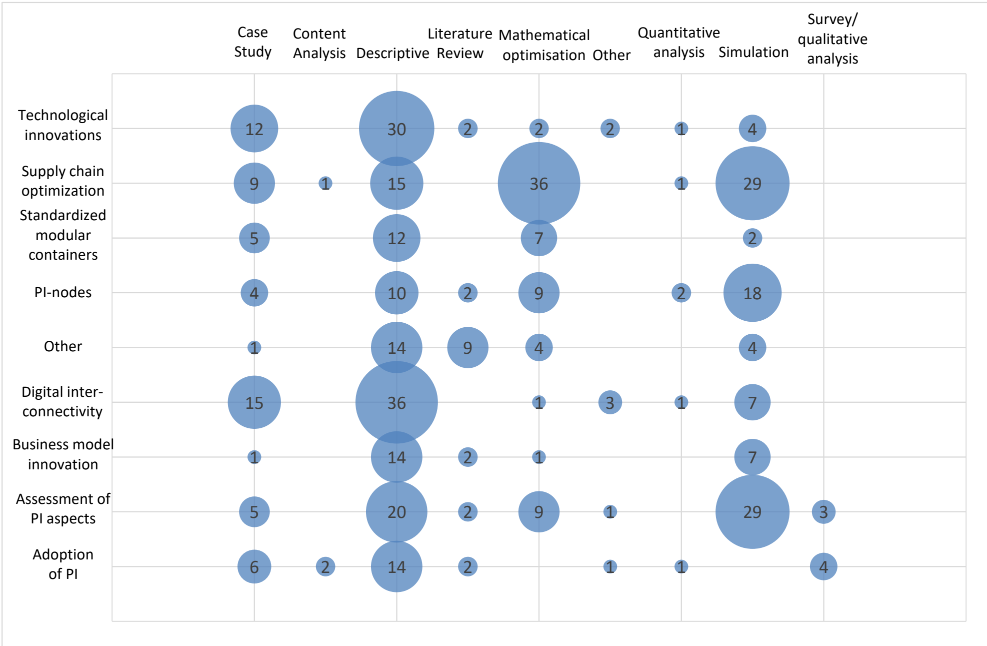

Figure 4.10: Applied methods for the research on each topic

More than half of the articles on the adoption of the Physical Internet are descriptive (14 articles), they propose guidelines (e.g. [A103] and [A107]) or examine potential roadblocks to a PI implementation (e.g. [A100] and [A120]). Some descriptive case studies (6 articles) have also been conducted, for example to analyse the readiness of Brazil ([A51]) and Hungary ([A19]). To assess the readiness of Africa, two studies applied content analysis ([A44] and [A189]). Furthermore, two literature reviews ([A100] and [A106]) were conducted in which various ways to overcome challenges when implementing the Physical Internet are identified.

To assess the aspects of the Physical Internet, numerous scenarios in a PI context are simulated (29 articles) or optimised using mathematical techniques (9 articles). [A221] for example assesses the service capabilities of a hyperconnected mixing center, a specific type of PI-nodes. Multiple simulations also compare the conventional transportation model with the Physical Internet model (e.g. [A61] and [A118]). In many of these simulation studies NetLogo is used to develop simulation models in a multi-agent environment. The other articles on the assessment of PI aspects are mostly descriptive (20 articles). Interestingly, only three surveys have been conducted to obtain the opinion of managers on the sharing of resources in supply chains ([A214] and [A55]) and to gather the shippers' perspectives on the realization of the Physical Internet ([A247]).

Mathematical optimisation methods are most frequently used for the optimisation of supply chains within the Physical Internet (36 articles). These studies first formulate an optimisation problem as a mathematical model and subsequently find the best possible solution by using an optimiser such as the IBM ILOG CPLEX optimisation studio. Besides mathematical optimisation, 29 simulation studies have been conducted to find the optimal conditions for Supply Chains within a Physical Internet. 9 of these optimisation articles are case studies that used real input data of companies (e.g. [A156]) or regions (e.g. [A108]). To analyse the functionality of PI-nodes researchers also mainly used simulation (18 articles) and mathematical optimisation techniques (9 articles). These studies focus on processes that take place within PI-nodes. Examples are articles [A199] and [A206] that investigate the routing in a Physical Internet cross-docking hub and [A11] that proposes a storage and transfer system for containers in a rail-to-rail hub.

A big part of the articles on digital interconnectivity also concern innovative technologies, this explains why their distributions of used methods are similar. The articles on technological innovations and digital interconnectivity are mostly descriptive (resp. 30 and 36 articles). Furthermore, there have been multiple case studies (resp. 12 and 15 articles) that test the implementation of innovative technologies related to digital interconnectivity within a Physical Internet, including [A27], [A48] and [A53].

The articles on standardized modular containers mostly describe their implementation or design (12 articles). To validate their impact on the shipping volume or to solve container loading problems, mathematical optimisation techniques (7 articles) are used. Furthermore, 5 case studies have been conducted. For example, in [A181] a modularized furniture container has been designed and implemented in a leading customized furniture company in China. Another example is article [A263], in which the use of PI-containers is proposed for the transportation of blood by the French Blood Establishment.

Finally, most of the research on business model innovation is descriptive (14 articles). Besides the descriptive methods, simulation techniques are used to validate the performance of the proposed business models (7 articles). An example of an article that simulates a new business model using realistic data is [A17]. The articles that used none of the methods mentioned above were classified in the "Other" category.

5 Discussion

In this chapter, a concise answer will be provided to each of the research questions. Furthermore, recommendations for future research are proposed based on the identified research gaps (RQ8).

5.1 Summary of study findings

RQ-1: By who were the studies conducted?

To answer this research question, the number of publications per researcher was counted. Five researchers stood out in terms of publication frequency. Benoit Montreuil, professor at Georgia Tech, and Eric Ballot, professor at Mines ParisTech, are often considered to be the pioneers of Physical Internet research, they are respectively the first and second biggest contributors of research. The third most active researcher in the field is Shenle Pan, associate professor at Mines ParisTech, a lot of his work was conducted together with Eric Ballot. Finally, both George G.Q. Huang and Ray Y. Zhong, professors at Hong Kong University, contributed nine of the selected articles and are the fourth biggest contributors of research articles.

RQ-2: When were the studies published?

In response to this research question, the annual amount of published articles on the Physical Internet after 2005 and before 2020 was counted. Interestingly, none of the selected articles were published during the period between 2006 and 2009. In 2010 the first relevant article ([9]) was published in the proceedings of the 11th IMHRC. Until 2013, the yearly number of published articles remained low. From 2014 on a conference focused on Physical Internet research was held every year, namely the International Physical Internet Conference. This conference attracted many new researchers, which possibly explains the sudden increase in publications. Furthermore, multiple Physical Internet focused research groups have been founded since then. As people are becoming more aware of the need for a more sustainable logistics system, the number of publications is expected to increase on a yearly basis.

RQ-3: What are the main publication venues?

First, the four most popular publication venues in terms of published articles on the Physical Internet were identified. The IPIC published by far the most articles on the Physical Internet. However, it should be noted that this may be due to the selection of the IPIC proceedings for manual search. Besides the IPIC, the top four publication venues included two more conferences: IMHRC and IFAC. The second most popular publication venue was a journal, namely the IJPR. When considering the types of venues, most of the articles were published in conference proceedings. This is mainly due to the high amount of publications by the IPIC. Most of the other articles were published in journals, and only a few workshop articles were selected. Although, it is possible that this is the case because of the used search strategy.

RQ-4: Which topics related to the physical internet are covered in the existing literature?

To categorize articles based on their topic, a classification scheme was created using the keywording technique. The results of the topic based classification indicated that the most recurring topic in the selected articles was optimisation of supply chains within the Physical Internet, followed by digital interconnectivity. Furthermore, multiple research gaps were identified. It was noted that only a few articles concerned innovative ways of transportation, such as drones and automated vehicles. Moreover, a relatively small number of articles on business model innovation and standardized modular containers were identified.

RQ-5: To which ALICE roadmaps are the papers related?

To answer this research question, the selected articles are classified based on the five roadmaps created by ALICE. The biggest proportion of selected papers is related to the Global Supply Network Coordination and Collaboration roadmap, followed by the number of articles related to the Systems & Technologies for Interconnected Logistics roadmap. The topics related to the other three roadmaps, Corridors, Hubs and Synchromodality, Sustainable, Safe and Secure Supply Chains, and Urban Logistics, were almost equally discussed in the literature. No glaring research gaps were identified by the classification of articles based on the roadmaps.

RQ-6: What type of contributions do the studies constitute?

The used classification of knowledge contributions is based on the different types of research contributions proposed by Ulrich [29]. First, the frequency of each type of contribution was counted. The results showed that most of the articles contributed a mathematical model or an evaluation. However, the importance of the type of contribution depends on the topic. Thus, to identify research gaps, the number of articles per type of contribution was counted for each topic category. Regarding the contributions of articles on technological innovation, only a few studies provided an in-depth evaluation of a use case scenario. Finally, when considering business model innovation, a low amount of conceptual models was identified. This indicates a lack of new business models that are presented by a canvas model or any other tool to visualize business models.

RQ-7: What are the most common research methods applied and which were the research types reported?

To answer this question, the articles were first classified according to the research type facet by Wieringa et al [27]. The biggest proportion of articles was categorized as validation research, followed by philosophical papers and solution proposals respectively. Interestingly, only 19 of the selected articles were evaluation research papers, indicating a lack of empirical research. After the classification according to research type, the applied research methods were investigated according to the topic of the study. For most of the topic categories, a big part of the articles was descriptive. As expected, the studies regarding supply chain optimisation mainly used mathematical optimisation or simulation methods. However, simulation methods were also frequently used to assess PI aspects or to analyze PI-nodes. Finally, only a few case studies that use real data of companies or regions were identified, as well as a lack of surveys to collect relevant data.

5.2 Recommendations for future research (RQ-8)

5.2.1 Topics

Standardized and modularized containers are essential to the Physical Internet. These containers have to be easily handled, stored, loaded, and transported within the PI system. To optimize the Physical Internet, all transportation, handling, and storage devices, means and systems have to be designed to exploit the properties of the containers. In other words, the design of the different PI-nodes and the modes of transportation highly depends on the design of the PI-containers. Moreover, it drives product design for encapsulation. Considering the importance of standardized and modularized containers, the number of articles on the topic is very low. Although multiple prototypes have already been proposed, there is a need for a general conclusion on the optimal design of the containers. To reach a general conclusion more research on new designs of PI-containers is required, as well as studies in which the functionality of the already proposed container designs is tested.

When looking at the current research on innovative technologies enabling a Physical Internet, another research gap was identified. Since articles could be categorized into multiple topic clusters, it was noticed that most of the articles on innovative technologies concern new ways of communication and data sharing that enable digital interconnectivity. Only a few articles consider innovative modes of transportation. In recent years, many new modes of transport have been introduced, including automated vehicles, drones, as well as underground tubes for parcel deliveries in urban areas. These new modes were merely described in the literature. More research on these new modes of transportation in a Physical Internet context and their impact on the sustainability and efficiency of logistics systems is recommended.

Furthermore, a lack of articles on business model innovation was observed. The physical Internet is reliant on horizontal and vertical collaboration. All stakeholders are expected to share their resources and infrastructure to enable a more efficient and sustainable logistics system. The conventional logistics system is very different, companies hardly share any resources as these are seen as a competitive advantage. Since the way of doing business is expected to radically change, not only existing companies will be influenced, also new businesses will be founded upon innovative ways of creating value. To evaluate new business ideas and to prepare companies for the new business environment, more research should be conducted on innovative business models.

Finally, it is important to note that almost no articles mention the importance of a legal framework, which is necessary for PI adoption on a bigger scale. This lack of research on the legal aspects of the Physical Internet is most likely due to the interests of the researchers, most of whom have an operations management background. To further develop this aspect, more legal research on the Physical Internet is required.

5.2.2 Research Contributions and Methods

The results of the classification based on applied research methods indicate that descriptive research methods are most frequently used in the literature. Besides the descriptive methods, numerous articles use simulation and mathematical optimisation techniques. Only a few of these techniques were applied to real company or regional data, these studies were also classified as case studies. To validate the proposed simulation and mathematical models in a real life environment, it is recommended to conduct more studies with data from existing logistics companies or regional data provided by government institutions. Furthermore, a lack of empirical studies is identified. In the existing research, only a few case studies have been conducted in which aspects of the physical internet are implemented in practice and its effects are evaluated. A small number of survey studies have also been conducted to gather the opinions of stakeholders of the logistics system. To demonstrate the potential benefits of the Physical Internet it is recommended to conduct more research in which the already described methods, tools, and systems are implemented in practice.

As mentioned in the previous section, hardly any new business models have been proposed in the literature. To present new business models, it is recommended to make use of the business model canvas. The business model canvas is used to give a clear overview of a business and its key building blocks. Moreover, the method is frequently used by academics and in practice. A business model canvas helps to communicate new business ideas in an easily understandable way to people who are new to the Physical Internet concept. In other words, it could be a crucial way to create more awareness amongst potential stakeholders and to facilitate the adoption of the Physical Internet.

Finally, the existing literature suggests that the complete package of benefits of a Physical Internet can only be achieved when all the foundations of the Physical Internet concept are exploited in an integrated manner. Taking this under consideration, the analysis of a single company and pilot studies that only consider horizontal or vertical collaboration are not sufficient. Essential to a transition towards a Physical Internet are pilot studies that involve multiple companies covering the whole value chain in the same region, as these pilot studies would uncover the real benefits of a Physical Internet.

6 Conclusion

The systematic mapping study presented in this thesis analysed the existing research on the Physical Internet. To allow a systematic and reproducible mapping of the research, the guidelines by Petersen et al [3] were followed throughout this study. Out of the initial 3923 search results, 270 articles, published after 2005 and before 2020, were selected for data extraction. First, multiple classifications were developed, to categorize these selected articles. The classifications for research type, methods and contributions were based on existing classifications. For the categorization according to the topic, first a start set of topic categories was identified. During the mapping process, this topic based classification was frequently adjusted and updated to better suit the research. Furthermore, the articles were also related to the roadmaps proposed by ALICE.

Based on the results of the mapping, eight research questions were answered. First, the most active researchers, trends in the number of publications and the main publication venues were identified. Secondly, the research questions concerning the content of the articles were answered. Multiple research gaps were identified based on the frequencies of the applied methods, the research types, the topics and the contributions in the articles. The most interesting findings were the lack of studies on innovative ways of transportation, as well as the relatively small number of articles on business model innovation and standardized modular containers. Moreover, a big proportion of the applied research methods were descriptive and only a few empirical studies were found.

Finally, recommendations for future research were suggested based on the identified research gaps. Main implications for future research include a need for more work on standardized modular containers, as the designs of PI-nodes and the modes of transportation highly depend on the final design of the PI-containers. Secondly, more research on innovative ways of transportation and business model innovation in a Physical Internet context is recommended. Furthermore, a legal framework is also necessary to make PI adoption possible on a bigger scale. At last, it is recommended to conduct more research in which the already described methods, tools, and systems are implemented in practice.

References

[1] Benoit Montreuil, Eric Ballot, and William Tremblay. Modular design of physical internet transport, handling and packaging containers. In *13th IMHRC Proceedings*, 2015.

[2] ALICE. Alliance for logistics innovation through collaboration in europe, 2017. Retrieved from: `http://www.etp-logistics.eu/`.

[3] Kai Petersen, Robert Feldt, Shahid Mujtaba, and Michael Mattsson. Systematic mapping studies in software engineering. In *12th International Conference on Evaluation and Assessment in Software Engineering (EASE) 12*, pages 1–10, 2008.

[4] Benoit Montreuil. Toward a physical internet: meeting the global logistics sustainability grand challenge. *Logistics Research*, 3(2-3):71–87, 2011.

[5] Benoit Montreuil, Russell D Meller, and Eric Ballot. Physical internet foundations. In *Service orientation in holonic and multi agent manufacturing and robotics*, pages 151–166. Springer, 2013.

[6] The Economist. *The physical internet: A survey of logistics*, London, England, June 2006. The Economist Newspaper Limited.

[7] ALICE. Sustainable,safe and secure supply chains: Research & innovation roadmap, 2014. Retrieved from: `http://www.etp-logistics.eu/`.

[8] James F Kurose. *Computer networking: A top-down approach featuring the internet, 3/E.* Pearson Education India, 2005.

[9] Benoit Montreuil, Russell D Meller, and Eric Ballot. Towards a physical internet: the impact on logistics facilities and material handling systems design and innovation. In *11th IMHRC Proceedings*, 2010.

[10] Hoa Tran-Dang and Dong-Seong Kim. An information framework for internet of things services in physical internet. *IEEE Access*, 6:43967–43977, 2018.

[11] Russell D Meller, Benoit Montreuil, Collin Thivierge, and Zachary Montreuil. Functional design of physical internet facilities: a road-based transit center. In *12th IMHRC Proceedings*, 2012.

[12] Russell D Meller, Benoit Montreuil, Collin Thivierge, and Zachary Montreuil. Functional design of physical internet facilities: A road-based crossdocking hub. In *12th IMHRC Proceedings*, 2012.

[13] Eric Ballot, Benoit Montreuil, and Collin Thivierge. Functional design of physical internet facilities: a road-rail hub. In *12th IMHRC Proceedings*, 2012.

[14] Benoit Montreuil, Eric Ballot, and Frédéric Fontane. An open logistics interconnection model for the physical internet. *IFAC Proceedings Volumes*, 45(6):327–332, 2012.

[15] Benoit Montreuil, Jean-François Rougès, Yan Cimon, and Diane Poulin. The physical internet and business model innovation. *Technology Innovation Management Review*, 2(6), 2012.

[16] Parnian Oktaei, Nadia Lehoux, and Benoit Montreuil. Designing business models for physical internet transit centers. In *Proceedings of 1st International Physical Internet Conference, Québec City, Canada*, 2014.

[17] Alexander Osterwalder and Yves Pigneur. *Business model generation: a handbook for visionaries, game changers, and challengers.* John Wiley & Sons, 2010.

[18] Shenle Pan, Xiaozhou Xu, Eric Ballot, et al. Auction based transport services allocation in physical internet: a simulation framework. In *1st International Physcial Internet Conference*, 2014.

[19] Ray Y Zhong, George Q Huang, and SL Lan. Shopfloor logistics management using rfid-enabled big data under physical internet. In *Proceeding of 1st International Physical Internet Conference*, pages 1–14, 2014.

[20] Franz Kopica, Walter Morales-Alvarez, and Cristina Olaverri-Monreal. Automated delivery of shipments in urban areas. In *6th International Physical Internet Conference*, 2019.

[21] Balthasar Schönangerer and Daniel Tinello. Logipipe: A vision to close the physical internet's last-mile gap. In *6th International Physical Internet Conference*, 2019.

[22] Pedro Furtado and Jean-Marc Frayret. Impact of resource sharing of freight transportation. In *First International Physical Internet Conference*, pages 28–30, 2014.

[23] Russell D Meller, KP Ellis, and Bill Loftis. From horizontal collaboration to the physical internet: Quantifying the effects on sustainability and profits when shifting to interconnected logistics systems. *Center for Excellence in Logistics and Distribution, University of Arkansas*, 2012.

[24] Florian Ehrentraut, Christian Landschützer, Dirk Jodin, Hans-Christian Graf, and Andreas Gasperlmair. A case study derived methodology to create a roadmap to realize the physical internet for sme. In *3rd International Physical Internet Conference*, 2016.

[25] L Simmer, S Pfoser, M Grabner, O Schauer, and LM Putz. From horizontal collaboration to the physical internet–a case study from austria. *International Journal of Transport Development and Integration*, 1(2):129–136, 2017.

[26] Claes Wohlin. Guidelines for snowballing in systematic literature studies and a replication in software engineering. In *Proceedings of the 18th international conference on evaluation and assessment in software engineering*, pages 1–10, 2014.

[27] Roel Wieringa, Neil Maiden, Nancy Mead, and Colette Rolland. Requirements engineering paper classification and evaluation criteria: a proposal and a discussion. *Requirements engineering*, 11(1):102–107, 2006.

[28] Charifa Fergani, Adiba El Bouzekri El Idrissi, Suzanne Marcotte, and Abdelowahed Hajjaji. Framework and characterization of physical internet. *International Journal of Computer and Information Engineering*, 13(11):599–608, 2019.

[29] Ulrich Frank. Towards a pluralistic conception of research methods in information systems research. ICB-research report No. 7, Universität Duisburg-Essen, Institut für Informatik und Wirtschaftsinformatik (ICB), Essen, 2006.

[30] Bjarnet Schlichter and Pernille Kræmmergaard. V. *Journal of Enterprise Information Management*, 23(4):486–520, 2010.

[31] MODULUSHCA. Modulushca – modular logistic units in shared co-modal networks, 2016. Retrieved from: https://cordis.europa.eu/project/id/314468/reporting.

Appendix A: Selected Articles

[A1] Graf, H. C., Ehrentraut, F., & Piekarz, B. (2019, July). “protoPI”-Development of a prototypical Gateway to the Physical Internet. In *6th International Physical Internet Conference 2019.*

[A2] Tetouani, S., Chouar, A., Lmariouh, J., Soulhi, A., & Elalami, J. (2019). A “Push-Pull” rearrangement while routing for a driverless delivery vehicle. *Cogent Engineering*, 6(1), 1567662.

[A3] Ehrentraut, F., Landschützer, C., Jodin, D., Graf, H. C., & Gasperlmair, A. (2016, July). A case study derived methodology to create a roadmap to realize the Physical Internet for SME. In *3rd International Physical Internet conference.*

[A4] Maslarić, M., Nikoličić, S., & Mirčetić, D. (2016). Logistics response to the industry 4.0: the physical internet. *Open engineering, 1* (open-issue).

[A5] Krommenacker, N., Charpentier, P., & Bron, J. (2017). A Collective Intelligence Approach for the Composite PI-Containers Management. In *4th International Physical Internet conference.*

[A6] Tretola, G., Verdino, V., & Biggi, D. (2015, July). A common data model for the physical internet. In *Proceedings of the 2nd international physics international conference, Paris, France* (pp. 160-176).

[A7] Pan, S., Chen, C., & Zhong, R. Y. (2015). A crowdsourcing solution to collect e-commerce reverse flows in metropolitan areas. *IFAC-PapersOnLine*, 48(3), 1984-1989.

[A8] Lin, Y. H., Meller, R. D., Ellis, K. P., Thomas, L. M., & Lombardi, B. J. (2014). A decomposition-based approach for the selection of standardized modular containers. *International Journal of Production Research*, 52(15), 4660-4672.

[A9] Darvish, M., Larrain, H., & Coelho, L. C. (2016). A dynamic multi-plant lot-sizing and distribution problem. *International Journal of Production Research*, 54(22), 6707-6717.

[A10] Pal, A., & Kant, K. (2017). A food transportation framework for an efficient and worker-friendly fresh food physical internet. *Logistics*, 1(2), 10.

[A11] Gue, K. (2016). A High-Density, Puzzle-Based System for Rail-Rail Container Transfers. *14th IMHRC Proceedings, Karlsruhe, Germany* 14.`https://digitalcommons.georgiasouthern.edu/pmhr_2016/14`.

[A12] Zhong, R. Y., & Xu, C. (2015, August). A Job-Shop Scheduling Model with Real-Time Feedback for Physical Internet-Based Manufacturing Shopfloor. In *2015 IEEE 12th Intl Conf on Ubiquitous Intelligence and Computing and 2015 IEEE 12th Intl Conf on Autonomic and Trusted Computing and 2015 IEEE 15th Intl Conf on Scalable Computing and Communications and Its Associated Workshops (UIC-ATC-ScalCom)* (pp. 638-641). IEEE.

[A13] Chargui, T., Bekrar, A., Reghioui, M., & Trentesaux, D. (2018). A Mathematical Formulation and Tabu Search Approach for the Road-Rail Assignment Problem. In *5th International Physical Internet Conference, Groningen, Netherlands.* ⟨hal-0186866⟩.

[A14] Deplano, I., Lersteau, C., & Nguyen, T. T. (2019). A mixed-integer linear model for the multiple heterogeneous knapsack problem with realistic container loading constraints and bins' priority. *International Transactions in Operational Research.*

[A15] Yang, Y., Pan, S., & Ballot, E. (2015). A model to take advantage of Physical Internet for vendor inventory management. *IFAC-PapersOnLine*, 48(3), 1990-1995.

[A16] Pan, S., Nigrelli, M., Ballot, E., Sarraj, R., & Yang, Y. (2015). Perspectives of inventory control models in the Physical Internet: A simulation study. *Computers & Industrial Engineering*, 84, 122-132.

[A17] Vargas, A., Traill, A., Fuster, C., & Corne, D. (2019). A New 'Gain-Sharing' Business Model to facilitate the Physical Internet via a Competitive, Collaborative Logistics Platform. In *6th International Physical Internet Conference.*

[A18] Le Roch, Y., Ballot, E., & Perraudin, X. (2015). A New Framework for the Management of Returnable "Containers" Within Open Supply Networks. *In Service*

Orientation in Holonic and Multi-agent Manufacturing (pp. 293-305). Springer, Cham.

[A19] Ehrentraut, F., Landschützer, C., Telek, P., & Bánya, T. (2018). A new network concept for Logistic Centres in Hungary–regional segmentation in line with the PI vision. In *5th International Physical Internet Conference* (pp. 129-141).

[A20] Chen, K., Xu, G., Xue, F., Zhong, R. Y., Liu, D., & Lu, W. (2018). A physical internet-enabled building information modelling system for prefabricated construction. *International Journal of Computer Integrated Manufacturing*, 31(4-5), 349-361.

[A21] Klabi, H., Rekik, M., & Mellouli, S. (2014). A PI Allocation of Shipping Contracts Using Reliability-Based Auctions. In *Proceedings of 1st International Physical Internet Conference* (pp. 28-30).

[A22] Oger, R., Benaben, F., & Lauras, M. (2016). A Platform to Support Collaboration and Agility in Logistics Web. In *3rd International Physical Internet Conference, Atlanta, USA*.

[A23] Colin, J. Y., Mathieu, H., & Nakechbandi, M. (2016, May). A proposal for an open logistics interconnection reference model for a Physical Internet. In *3rd International Conference on Logistics Operations Management (GOL)* (pp. 1-6). IEEE.

[A24] Walha, F., Bekrar, A., Chaabane, S., & Loukil, T. M. (2016). A rail-road PI-hub allocation problem: Active and reactive approaches. *Computers in Industry*, 81, 138-151.

[A25] Chargui, T., Reghioui, M., Bekrar, A., & Trentesaux, D. (2016) A simulation model to migrate from cross-docks to pi-hubs. In *3rd International Physical Internet Conference* (pp. 1-11).

[A26] Chargui, T., Bekrar, A., Reghioui, M., & Trentesaux, D. (2019). A Simulation-Optimization Approach for Two-Way Scheduling/Grouping in a Road-Rail Physical Internet Hub. *IFAC-PapersOnLine*, 52(13), 1644-1649.

[A27] Karampatzakis, D., Avramidis, G., Kiratsa, P., Tseklidis, I., & Oikonomidis, C. (2019, November). A Smart Cargo Bike for the Physical Internet enabled by RFID and LoRaWAN. In *2019 Panhellenic Conference on Electronics & Telecommunications (PACET)* (pp. 1-4). IEEE.

[A28] Gözaçan, N., & Kabadurmuş, Ö. A Sustainability Comparison of Traditional Supply Chains and Physical Internet Supply Chains Using Simulation. *Celal Bayar Üniversitesi Fen Bilimleri Dergisi*, 15(4), 385-392.

[A29] Biggi, D., & Tretola, G. (2015, October). Addressing urban congestion with modular logistics and collaborative networks. In *URban freight and BEhavior change (URBE) conference, Roma Tre University, Rome* (pp. 1-2).

[A30] Nouiri, M., Bekrar, A., & Trentesaux, D. (2019). An energy-efficient scheduling and rescheduling method for production and logistics systems. *International Journal of Production Research*, 1-21.

[A31] Tran-Dang, H., & Kim, D. S. (2018). An information framework for internet of things services in physical internet. *IEEE Access*, 6, 43967-43977.

[A32] Gruber, M., Hübl, A., & Staberhofer, F. (2016). An Initial Approach of Monitoring the Effects on Logistics Performance Initiated by the PracticalRealization of Physical Internet in a Specific Region. *Forschungsformum der Österreichischen Fachhochschulen*.

[A33] Ji, S. F., Peng, X. S., & Luo, R. J. (2019). An integrated model for the production-inventory-distribution problem in the Physical Internet. *International Journal of Production Research*, 57(4), 1000-1017.

[A34] Ji, S. F., Peng, X. S., & Luo, R. J. (2019). An integrated model for the production-inventory-distribution problem in the Physical Internet. *International Journal of Production Research*, 57(4), 1000-1017.

[A35] Ha, C. T., Nguyen, T. T., Bui, L. T., & Wang, R. (2017, April). An online packing heuristic for the three-dimensional container loading problem in dynamic environments and the Physical Internet. In *European Conference on the Applications of Evolutionary Computation* (pp. 140-155). Springer, Cham.

[A36] Montreuil, B., Ballot, E., & Fontane, F. (2012). An open logistics interconnection model for the Physical Internet. *IFAC Proceedings Volumes*, 45(6), 327-332.

[A37] Sohrabi, H., Montreuil, B., & Klibi, W.(2015). An Optimization-based Investigation of Exploiting Physical Internet-enabled Interconnected Distribution System. In *2nd International Physical Internet Conference.*

[A38] Aroca, J., & Prunonosa, S. (2018). Analogies across Hubs and Routers in the Physical and Digital Internet. In *5th Internation Physical Internet Conference.*

[A39] Sarraj, R., Ballot, E., Pan, S., & Montreuil, B. (2014). Analogies between Internet network and logistics service networks: challenges involved in the interconnection. *Journal of Intelligent Manufacturing*, 25(6), 1207-1219.

[A40] Shin, N., & Treiblmaier, H. (2016). Antecedents of the Physical Internet: A Cross-Country Analysis of Transportation Volume Change. In *3rd International Physical Internet Conference, Atlanta, USA.*

[A41] Hofman, W. J., Spek, J. C., & Brewster, C. (2017). Applying blockchain technology for hyperconnected logistics. In *4th International Physical Internet Conference, Graz, Austria.*

[A42] Djurica, M., & Hofman, W. (2019). Applying concepts of telecom networks to logistic networks–towards new business roles and-models for the Physical Internet. In *6th International Physical Internet Conference.*

[A43] Kantasa-ard, A., Bekrar, A., & Sallez, Y. (2019). Artificial intelligence for forecasting in supply chain management: a case study of White Sugar consumption rate in Thailand. *IFAC-PapersOnLine*, 52(13), 725-730.

[A44] Abodohoui, A., Aïhounhin, S. P., Mayuto, R., Marif, A., & Montreuil, B. (2014). Assessing the readiness of africa for the physical internet. In *First International Physical Internet Conference. Québec City, Canada* (pp. 28-30).

[A45] Zheng, L., Beem, P., & Bae, K. H. G. (2019). Assessment of the physical internet enabled urban logistics using agent-based simulation. *International Journal of Logistics Systems and Management*, 33(4), 441-466.

[A46] Pawlewski, P. (2015). Asynchronous multimodal process approach to cross-docking hub optimization. *IFAC-PapersOnLine*, 48(3), 2127-2132.

[A47] Pan, S., Xu, X., & Ballot, E. (2014, August). Auction based transport services allocation in Physical Internet: a simulation framework. In *1st International Physcial Internet Conference.*

[A48] Kopica, F., Morales-Alvarez, W., & Olaverri-Monreal, C. (2019). Automated delivery of Shipments in Urban Areas. In *6th International Physical Internet Conference.*

[A49] Zhong, R. Y., Xu, C., Chen, C., & Huang, G. Q. (2017). Big data analytics for physical internet-based intelligent manufacturing shop floors. *International journal of production research*, 55(9), 2610-2621.

[A50] Meyer, T., Kuhn, M., & Hartmann, E. (2019). Blockchain technology enabling the Physical Internet: A synergetic application framework. *Computers & Industrial Engineering*, 136, 5-17.

[A51] Defina, D., & Montreuil, B. (2017). Brazilian Logistics Unsustainability: a Conceptual Revision applying Physical Internet. In *4th International Physical Internet Conference.*

[A52] DeDomenico, R. (2014). Cargofish: a Network Utility for Parcel Exchange. In *1st International Physical Internet Conference.*

[A53] Lin, I. C., & Cheng, C. Y. (2018). Case study of physical internet for improving efficiency in solar cell industry. *Journal of Ambient Intelligence and Humanized Computing*, 9(2), 285-294.

[A54] Wang, X., Kong, X. T., Huang, G. Q., & Luo, H. (2018). Cellular Warehousing for Omnichannel Retailing: Internet of Things and Physical Internet Perspectives. In *5th International Physical Internet Conference.*

[A55] Adamczak, M., Hadaś, Ł., Stachowiak, A., Domański, R., & Cyplik, P. (2019). Characteristics of Resources as a Determinant of Implementation of the Physical Internet Concept in Supply Chains. In *Advances in Manufacturing II* (pp. 72-91). Springer, Cham.

[A56] Papagiannakopoulou, E., Lioudakis, G. V., Kalaboukas, K., Jermol, M., Zacharias, M., Koukovini, M., & Quattropani, S. (2019, April). The COG-LO Framework:

IoT-based COGnitive Logistic Operations for next generation logistics. In *2019 IEEE 5th World Forum on Internet of Things (WF-IoT)* (pp. 117-121). IEEE.

[A57] Frindik, R., & Prudon, M. (2017). Collaborative City Logistics in Hyperconnected Delivery Networks. In *4th International Physical Internet COnference.*

[A58] Habibi, M. K., Allaoui, H., & Goncalves, G. (2018). Collaborative hub location problem under cost uncertainty. *Computers & Industrial Engineering*, 124, 393-410.

[A59] Treiblmaier, H. (2019). Combining Blockchain technology and the Physical Internet to achieve triple bottom line Sustainability: A comprehensive research agenda for modern logistics and supply chain management. *Logistics*, 3(1), 10.

[A60] Lafkihi, M., Ballot, E., & Pan, S. (2019, October). Comparison of Centralization and Decentralization of Physical Internet Through Gamification. In *6th International Physical Internet Conference.*

[A61] Fazili, M., Venkatadri, U., Cyrus, P., & Tajbakhsh, M. (2017). Physical Internet, conventional and hybrid logistic systems: a routing optimisation-based comparison using the Eastern Canada road network case study. *International Journal of Production Research*, 55(9), 2703-2730.

[A62] López-Molina, L., de Miguel Rodrıguez, J., Cornejo, V. R., Paz, Á. C., del Rıo, M. Á. M., & Garcıa, R. G. (2018). Complex Systems as a model for implementing Physical Internet standards:" Using Drones for last mile logistics". In *5th International Physical Internet Conference.*

[A63] Puskás, E., & Bohács, G. (2019). CONCEPTING FREIGHT HOLDING PROBLEMS FOR PLATOONS IN PHYSICAL INTERNET SYSTEMS. *Acta Logistica*, 6(1), 19-27.

[A64] Schett, G., Brunnthaller, G., Hess, C., & Kritzinger, S. (2019). Conceptual Model of a Decentralized Transport Organization in the Increasingly Uncertain Environment of the Physical Internet. *6th International Physical Internet Conference.*

[A65] Treiblmaier, H., Mirkovski, K., & Lowry, P. B. (2016, May). Conceptualizing the physical internet: Literature review, implications and directions for future research. In *11th CSCMP Annual European Research Seminar, Vienna, Austria.*

[A66] Landschützer, C., Ehrentraut, F., & Jodin, D. (2015). Containers for the Physical Internet: requirements and engineering design related to FMCG logistics. *Logistics Research*, 8(1), 8.

[A67] Tran-Dang, H., Krommenacker, N., & Charpentier, P. (2017). Containers monitoring through the Physical Internet: a spatial 3D model based on wireless sensor networks. *International Journal of Production Research*, 55(9), 2650-2663.

[A68] Yang, Y., Ballot, E., & Cedillo-Campos, M. G. (2018). Contribution of Physical Internet Containers to Mitigate the Risk of Cargo Theft. In *15th IMHRC Proceedings, Savannah, USA*. 22. `https://digitalcommons.georgiasouthern.edu/pmhr_2018/22`

[A69] Vo, N. V., Berger, T., Bonte, T., & Sallez, Y. (2018). Control of Rail-Road PI-Hub: The ORCA Hybrid Control Architecture. In *Service Orientation in Holonic and Multi-Agent Manufacturing* (pp. 291-302). Springer, Cham.

[A70] Raviv, T., & Tenzer, E. Z. (2018). Crowd-shipping of small parcels in a physical internet. *Industrial Engineering Department, Tel Aviv University.*

[A71] Rougès, J. F., & Montreuil, B. (2014, May). Crowdsourcing delivery: New interconnected business models to reinvent delivery. In *1st international physical internet conference* (pp. 1-19).

[A72] Pujo, P., & Ounnar, F. (2018). Cyber-Physical Logistics System for Physical Internet. In *Service Orientation in Holonic and Multi-Agent Manufacturing* (pp. 303-316). Springer, Cham.

[A73] Hofman, W., & Dalmolen, S. (2019). Data sharing in supply and logistics networks–development and implementation of extendable, standardized platform services for the Physical Internet in an open dynamic ecosystem of organizations. In *International Physical Internet Conference, London.*

[A74] Ortega del Vecchyo, M. R., Phillipson, F., & Sangers, A. (2019). Decision making in a Dynamic Transportation Network: a Multi-Objective Approach. In *6th International Physical Internet Conference.*

[A75] Zhong, R. Y. (2016). Design and development of a physical internet-enabled smart factory for discrete manufacturing. In *Proceedings of the 22nd International Conference on Industrial Engineering and Engineering Management 2015* (pp. 549-556). Atlantis Press, Paris.

[A76] Oktaei, P., Lehoux, N., & Montreuil, B. (2014, May). Designing business models for Physical Internet transit centers. In *Proceedings of 1st International Physical Internet Conference, Québec City, Canada.*

[A77] Ambra, T., Caris, A., & Macharis, C. (2018). Do You See What I See? A Simulation Analysis of Order Bundling within a Transparent User Network in Geographic Space. *Journal of Business Logistics.*

[A78] Qiao, B., Pan, S., & Ballot, E. (2019). Dynamic Pricing for Carriers in Physical Internet with Peak Demand Forecasting. *IFAC-PapersOnLine*, 52(13), 1663-1668.

[A79] Van der Heide, G., Buijs, P., Roodbergen, K. J., & Vis, I. F. A. (2018). Dynamic shipments of inventories in shared warehouse and transportation networks. *Transportation Research Part E: Logistics and Transportation Review*, 118, 240-257.

[A80] Oger, R., Lauras, M., Montreuil, B., & Benaben, F. (2017, July). Enabling Supply Chain Agility and Resilience Improvement: Toward a Methodology and Platform. In *IFAC 2017 World Congress.*

[A81] Brandtner, P., Kalt, M., Plasch, M., & Schauer, O. (2018). Establishing a Physical Internet Test Region - Learnings from ATROPINE. In *5th International Physical Internet Conference.*

[A82] (2016).Evaluating five typologies on costs and requirements for hyperconnected logistics networks. In *3rd International Physical Internet Conference.*

[A83] Faure, L., Montreuil, B., Burlat, P., & Marquès, G. (2014, May). Ex ante sustainability improvement assessment of city logistics solutions: learning from a simple interlinked pooling case. In *Proceedings of 1st International Physical Internet Conference, Québec, Canada.*

[A84] Fatnassi, E., Klibi, W., Deschamps, J. C., & Labarthe34, O. (2016). Exploring mobility networks inter-connectivity for an on-demand transshipment of goods in urban areas. In *6th ILS*.

[A85] L'Hermitte, C., Wang, W., & Deakins, E. (2018). Exploring the Physical Internet Concept to Improve Disaster Relief Operations. In *Proceedings of ISCRAM Asia Pacific*.

[A86] Herrmann, E., & Kunze, O. (2019). Facility Location Problems in City Crowd Logistics. *Transportation Research Procedia*, 41, 117-134.

[A87] Hofman, W. (2015). Federated platforms for seamless interoperability in the Physical Internet. In *Proceedings of the 2nd International Physical Internet Conference.*

[A88] Fergani, C., El Idrissi, A. E. B., Marcotte, S., & Hajjaji, A. (2019). Framework and characterization of Physical Internet. *International Journal of Computer and Information Engineering*, 13(11), 599-608.

[A89] Rahimi, A., Sallez, Y., & Berger, T. (2016). Framework for Smart Containers in the Physical Internet. In *Service Orientation in Holonic and Multi-Agent Manufacturing* (pp. 71-79). Springer, Cham.

[A90] Yang, Y., Pan, S., & Ballot, E. (2017). Freight transportation resilience enabled by physical internet. *IFAC-PapersOnLine*, 50(1), 2278-2283.

[A91] Larioui, S., Reghioui, M., Elfallahi, A., & Elkadiri, K. E. From a classical Cross dock to a PI cross dock: Latest Advances and New Challenges. *Revue Marocaine de Management, Logistique et Transport*, (2).

[A92] Naccache, S., Montreuil, B., Sohrabi, H., & Barriault, F. (2014). From an integrated to interconnected B2CE-commerce distribution an agent-basedsimulation assessment. In *1st International Physical Internet Conference.*

[A93] Simmer, L., Pfoser, S., Grabner, M., Schauer, O., & Putz, L. M. (2017). From horizontal collaboration to the Physical Internet–a case study from Austria. *International Journal of Transport Development and Integration*, 1(2), 129-136.

[A94] Sohrabi, H., & Montreuil, B. (2011, October). From private supply networks and shared supply webs to Physical Internet enabled open supply webs. In *Working Conference on Virtual Enterprises* (pp. 235-244). Springer, Berlin, Heidelberg.

[A95] Dong, C., & Franklin, R. (2018). From the Digital Internet to the Physical Internet: A conceptual framework with a simple network model. In *5th International Physical Internet Conference.*

[A96] Meller, R. D., Montreuil, B., Thivierge, C., & Montreuil, Z. (2012). Functional design of physical internet facilities: A Road-based Crossdocking Hub. In *12th IMHRC Proceedings Gardanne, France.* 26.https://digitalcommons.georgiasouthern.edu/pmhr_2012/2.

[A97] Meller, R. D., Montreuil, B., Thivierge, C., & Montreuil, Z. (2012). Functional design of physical internet facilities: a road-based transit center. In *12th IMHRC Proceedings Gardanne, France.* 26.https://digitalcommons.georgiasouthern.edu/pmhr_2012/2.

[A98] Ballot, E., Montreuil, B., Thivierge, C. (2012). Functional design of physical internet facilities: a road-rail Hub. In *12th IMHRC Proceedings Gardanne, France.* 26.https://digitalcommons.georgiasouthern.edu/pmhr_2012/2.

[A99] Zuchowski, W. (2018). Future Hubs on the Background of the Physical Internet Implementation. *Logistics and Transport* .4(40).

[A100] Zijm, H., & Klumpp, M. (2017). Future Logistics: What to expect, how to adapt. In*Dynamics in logistics* (pp. 365-379). Springer, Cham.

[A101] Caminada, S. (2019). Game and Choice Based Simulation: The design of a methodological framework using the case of the Physical Internet inspired "Freight Transportation Game". *Faculty of Technology, Policy and Management, Delft University of Technology.*

[A102] Zdziarska, M. (2017). GLN standard as a facilitator of physical location identification within hyperconnected logistics. In *4th International Physical Internet Conference.*

[A103] Gasperlmair, A., Graf, H., & Hörtenhuber, S. (2016). Go2PI – Practically proved steps to implement the Physical Internet. In *3rd Internation Physical Internet Conference.*

[A104] Tretola, G., & Verdino, V. (2015, July). High Level ICT Architecture for Modular Logistics. In *2nd International Physical Internet Conference, Paris, France* (pp. 6-8).

[A105] Ounnar, F., & Pujo, P. (2016, June). Holonic Logistics System: a novel point of view for Physical Internet. In *Proceedings of International Conference on Information Systems, Logistics and Supply Chain (ILS 2016)* (pp. 1-4).

[A106] Pan, S., Trentesaux, D., Ballot, E., & Huang, G. Q. (2019). Horizontal collaborative transport: survey of solutions and practical implementation issues. *International Journal of Production Research*, 57(15-16), 5340-5361.

[A107] Erboz, G., Bohács, G., & Szegedi, Z. (2018). How to Achieve Physical Internet through Lean Principles and Industry 4.0?.

[A108] Hu, Z., Askin, R. G., & Hu, G. (2019). Hub relay network design for daily driver routes. *International Journal of Production Research*, 57(19), 6130-6145.

[A109] Chakroun, A., Abbar, H., & Elaraki, M. T.(2016). Hyperconnected City Logistics and Last Mile Delivery in Casablanca City. In *3rd International Physical Internet Conference.*

[A110] Goyal, M., Cook, J., Montreuil, B., Kim, N., & Lafrance, C. (2016). Hyperconnected city logistics for furniture and large appliance industry: Simulation-based exploratory investigation. In *3rd International Physical Internet Conference.*

[A111] Tu, D., & Montreuil, B. (2019). Hyper-connected Megacity Logistics: Multi-Tier Territory Clustering and Multi-plane Meshed Hub Network Design. In *6th International Physical Internet Conference.*

[A112] Liu, C., Marcotte, S., Lynch, G., & Spulick, S. (2017). Hyper-connected Modular Renewable Energy Production. In *4th International Physical Internet Conference.*

[A113] Faugere, L., & Montreuil, B. (2017). Hyperconnected pickup & delivery locker networks. In *Proceedings of the 4th International Physical Internet Conference.*

[A114] Park, J., Montreuil, B., & Dayarian, I. (2019). Hyperconnected Showcasing-Based Retail and Distribution of High-Value Products. In *6th International Physical Internet Conference.*

[A115] Colin, J. Y., Nakechbandi, M., & Mathieu, H. (2019, June). Ideas on reference models, formal languages and communication design patterns in a physical internet. *7th IEEE International Conference on Advanced Logistics & Transport (ICALT 2019), Marrakech, Morocco.*

[A116] Kim, N., & Montreuil, B. (2016). Assessing the Impact of Inventory Deployment and Sharing Policies on Hyperconnected Last-Mile Furniture Logistics. In *3rd International Physical Internet Conference.*

[A117] Buckley, S., & Montreuil, B. (2018). Impact of Modular Containerization and Continuous Consolidation on Hyperconnected Parcel Logistics Hub Design and Performance. In *5th International Physical Internet Conference.*

[A118] Furtado, P., & Frayret, J. M. (2014, May). Impact of resource sharing of freight transportation. In First International Physical Internet Conference (pp. 28-30).

[A119] Othmane, I. B., Rekik, M., & Mellouli, S. (2014). Impact of shipper collaboration on carriers selection in reputation-based transportation auctions. In *Proceedings of 1st International Physical Internet Conference (IPIC 2014), Quebec, Canada.(cpfr) state of the art. Journal of Enterprise Information Management* (Vol. 28, No. 6, pp. 838-871).

[A120] Cimon, Y. (2014). Implementing the Physical Internet real-world interface: Beyond business models, the devil is in the details. In *Proceedings of 1st International Physical Internet Conference, Québec City, Canada.*

[A121] Betti, Q., Khoury, R., Hallé, S., & Montreuil, B. (2019). Improving Hyperconnected Logistics With Blockchains and Smart Contracts. *IT Professional*, 21(4), 25-32.

[A122] Schoen, Q., Fontanili, F., Lauras, M., & Truptil, S. (2019, April). Improving parcels transportation performance by introducing a hitchhiker parcel model. In *2019 IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA)* (pp. 420-429). IEEE.

[A123] Ambra, T., Meers, D., Caris, A., & Macharis, C. (2017, July). Inducing a new paradigm shift: A different take on synchromodal transport modelling. In *Proceedings of the 4th International Physical Internet Conference, Graz, Austria* (pp. 4-6).

[A124] Yang, Y., Pan, S., & Ballot, E. (2017). Innovative vendor-managed inventory strategy exploiting interconnected logistics services in the Physical Internet. *International Journal of Production Research*, 55(9), 2685-2702.

[A125] Marcucci, E., Gatta, V., Nigro, M., Le Pira, M., & Simoni, M. (2019). Integrating passenger and freight transport via public transport-based crowdshipping for sustainable last-mile deliveries. In *6th International Physical Internet Conference.*

[A126] Sarraj, R., Ballot, E., Pan, S., Hakimi, D., & Montreuil, B. (2014). Interconnected logistic networks and protocols: simulation-based efficiency assessment. International Journal of Production Research, 52(11), 3185-3208.

[A127] Wickramage, N., & Ferrell, B. (2016). Intermodal Hubs in the Physical Internet. In *4th IMHRC Proceedings Karlsruhe, Germany.* 33. https://digitalcommons.georgiasouthern.edu/pmhr_2016/33

[A128] Pal, A., & Kant, K. (2019). Internet of perishable logistics: Building smart fresh food supply chain networks. *IEEE Access*, 7, 17675-17695.

[A129] Mohammadi, M., Hofman, W., & Tan, Y. H. (2019). Interoperability in Logistics: An Ontology Alignment Approach. In *6th International Physical Internet Conference.*

[A130] Arnäs, P. O., Holmström, J., & Kalantari, J. (2013). In-transit services and hybrid shipment control: The use of smart goods in transportation networks. *Transportation Research Part C: Emerging Technologies*, 36, 231-244.

[A131] Marcotte, S., & Montreuil, B. (2016). Introducing the concept of hyperconnected mobile production. In *14th IMHRC Proceedings Karlsruhe, Germany.* 16.https://digitalcommons.georgiasouthern.edu/pmhr_2016/16.

[A132] Ekren, B. Y., Akpunar, A., & Sağol, G. (2018). Inventory Control Models towards

Physical Internet: Lateral Transshipment Policy Determination by Simulation. In *6th International Physical Internet Conference.*

[A133] Nouiri, M., Bekrar, A., & Trentesaux, D. (2018, June). Inventory Control under Possible Delivery Perturbations in Physical Internet Supply Chain Network. In *5th International Physical Internet Conference, Groningen, Netherlands.*

[A134] Marino, F., Seitanidis, I., Dao, P. V., Bocchino, S., Castoldi, P., & Salvadori, C. (2019). IoT enabling PI: towards hyperconnected and interoperable smart containers. In *Proceedings of 6th International Physical Internet Conference* (pp. 349-362).

[A135] Stein, S., Prandtstetter, M., Starkl, F., & Reiner, G. (2019). Is Collaboration Necessary? Or: Might the Physical Internet be implemented by Internalization?. In *6th International Physical Internet Conference.*

[A136] Garcia, R., Lopez-Molina, L., Rodriguez Cornejo, V., Cervera Paz, A., Perez-Fernandez, V., & Angel Montanez, M. (2019). Is social capital relevant to the Physical Internet?. In *6th International Physical Internet Conference.*

[A137] Schönangerer, B., & Tinello, D.(2019). LogiPipe: A vision to close the Physical Internet's last-mile gap. In *6th International Physical Internet Conference.*

[A138] Klumpp, M., & Zijm, H. (2019). Logistics innovation and social sustainability: How to prevent an artificial divide in Human–Computer Interaction. *Journal of Business Logistics*, 40(3), 265-278.

[A139] Maslarić, M., Nikoličić, S., & Mirčetić, D. (2016). Logistics response to the industry 4.0: the physical internet. *Open engineering, 1* (open-issue).

[A140] HAO, Y., OUNNAR, F., & PACHÉ, G. (2019, July). LSP Selection in the Context of Physical Internet: A Comprehensive Analysis of the Literature. *In Symposium on Logistics* (p. 316).

[A141] Dalmolen, S., Bastiaansen, H., Somers, E., Djafari, S., Kollenstart, M., & Punter, M. (2019). Maintaining control over sensitive data in the Physical Internet: Towards an open, service oriented, network-model for infrastructural data sovereignty. In *6th International Physical Internet Conference.*

[A142] Colin, J. Y., Nakechbandi, M., & Mathieu, H. (2015, May). Management of mobile resources in Physical Internet logistic models. In *4th International Conference on Advanced Logistics and Transport (ICALT)* (pp. 323-326). IEEE.

[A143] MSc, B. S., & Cruijssen, F. (2017). Microzoning: A grid based approach to facilitate last-mile delivery. In *4th International Physical Internet Conference.*

[A144] Yang, Y., Pan, S., & Ballot, E. (2017). Mitigating supply chain disruptions through interconnected logistics services in the Physical Internet. *International Journal of Production Research*, 55(14), 3970-3983.

[A145] Saoud, A., & Bellabdaoui, A. (2017, April). Model of distributed hierarchical framework for carrier collaboration. In *2017 International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA)* (pp. 160-165). IEEE.

[A146] Jiang, H., Ballot, E., & Pan, S. (2019). Modeling and analysis of alternative distribution and Physical Internet schemes in urban area. *CoRR.*

[A147] Sohrabi, H., Klibi, W., & Montreuil, B. (2012). Modeling scenario-based distribution network design in a Physical Internet-enabled open Logistics Web. In *International conference on information systems, logistics and supply chain.*

[A148] Karakostas, B. (2019). Modelling and Simulation of a Physical Internet of Transportation Hubs. *Procedia Computer Science*, 151, 17-22.

[A149] Ben Mohamed, I., Klibi, W., Labarthe, O., Deschamps, J. C., & Babai, M. Z. (2017). Modelling and solution approaches for the interconnected city logistics. *International Journal of Production Research*, 55(9), 2664-2684.

[A150] Montreuil, B., Ballot, E., & Tremblay, W. (2015). Modular design of physical internet transport, handling and packaging containers. In *Progress in Material Handling Research: 2014, 13, MHI, 2015, International Material Handling Research Colloquium*, 978-1-882780-18-3.

[A151] Zdziarska, M. (2019). Modular logistics: effective distribution. *Autobusy: technika, eksploatacja, systemy transportowe*, 20.

[A152] Gerschberger, M., Treiblmaier, H., & Montreuil, B. (2015). More Than Commerce: Harnessing the Power of the Physical Internet to Create Resilient Regions. In *Proceedings of the 2nd Physical Internet Conference.*

[A153] Quak, H., van Kempen, E., & Hopman, M. Moving towards practical implementation of self-organizing logistics–making small steps in realizing the PI vision by raising awareness. In *6th International Physical Internet Conference.*

[A154] Sun, Y., Zhang, C., Dong, K., & Lang, M. (2018). Multiagent modelling and simulation of a physical internet enabled rail-road intermodal transport system. *Urban Rail Transit*, 4(3), 141-154.

[A155] Chargui, T., Bekrar, A., Reghioui, M., & Trentesaux, D. (2019). Multi-Objective Sustainable Truck Scheduling in a Rail–Road Physical Internet Cross-Docking Hub Considering Energy Consumption. *Sustainability*, 11(11), 3127.

[A156] Raggl, S., Affenzeller, M., Lengauer, E., & Hübl, A. (2016). Network on demand planning of Supply Chains towards Physical Internet. *Forschungsformum der Österreichischen Fachhochschulen.*

[A157] Pal, A., & Kant, K. (2016). Networking in the real world: Unified modeling of information and perishable commodity distribution networks. In *Proceedings of the IEEE International Physical Internet Conference (IPIC), Atlanta, GA, USA* (Vol. 29).

[A158] Montreuil, B. (2016). Omnichannel Business–to–Consumer Logistics and Supply Chains: Towards Hyper-connected Networks and Facilities. In *14th IMHRC Proceedings Karlsruhe, Germany.* 19.

[A159] Sohrabi, H., Montreuil, B., & Klibi, W. (2016). On comparing dedicated and hyperconnected distribution systems: an optimization-based approach. In *International Conference on Information Systems, Logistics and Supply Chain (ILS2016). Bordeaux, France.*

[A160] Di Febbraro, A., Giglio, D., & Sacco, N. (2018, November). On exploiting ridesharing and crowd-shipping schemes within the physical internet framework. In *2018 21st International Conference on Intelligent Transportation Systems (ITSC)* (pp. 1493-1500). IEEE.

[A161] Hoa, T. D., & Kim, D. S. (2018, January). On exploiting wireless sensor networks for enhancing the logistics operation efficiency in the Physical Internet. In *2018 2nd International Conference on Recent Advances in Signal Processing, Telecommunications & Computing (SigTelCom)* (pp. 236-240). IEEE.

[A162] Venkatadri, U., Krishna, K. S., & Ülkü, M. A. (2016). On Physical Internet logistics: modeling the impact of consolidation on transportation and inventory costs. *IEEE Transactions on Automation Science and Engineering*, 13(4), 1517-1527.

[A163] Sallez, Y., Pan, S., Montreuil, B., Berger, T., & Ballot, E. (2016). On the activeness of intelligent Physical Internet containers. *Computers in Industry*, 81, 96-104.

[A164] Prandtstetter, M., Biesinger, B., Hu, B., Nolz, P., Reinthaler, M., Zajicek, J., Angelini, A., Hauger, G., Steinbauer, M., Braith, J., Schodl, R., & Eitler, S. (2019). On the Potentials and Dilemmas of Cooperative/White-Label Deliveries based on Selected Austrian Demonstration Cases. In *6th International Physical Internet Conference*.

[A165] Krommenacker, N., Charpentier, P., Berger, T., & Sallez, Y. (2016). On the Usage of Wireless Sensor Networks to Facilitate Composition/Decomposition of Physical Internet Containers. In *Service Orientation in Holonic and Multi-Agent Manufacturing* (pp. 81-90). Springer, Cham.

[A166] Pan, S. (2019). Opportunities of Product-Service System in Physical Internet. *Procedia CIRP*, 83, 473-478.

[A167] Yao, J. (2017). Optimisation of one-stop delivery scheduling in online shopping based on the physical Internet. *International Journal of Production Research*, 55(2), 358-376.

[A168] Hauder, V. A., Pitzer, E., & Affenzeller, M. (2017, October). Optimization Approaches for the Physical Internet. In *OTM Confederated International Conferences" On the Move to Meaningful Internet Systems"* (pp. 236-245). Springer, Cham.

[A169] Qiao, B., Pan, S., & Ballot, E. (2017, October). OPTIMIZATION OF LESS-THAN-TRUCKLOAD REQUEST PRICING AND SELECTION FOR CARRIER

IN PHYSICAL INTERNET.In *the 47th International Conference on Computers & Industrial Engineering (CIE47). Lisbon, Portugal.*

[A170] Yim, J., Derhami, S., Montreuil, B. (2019). Optimizing High-Value Product Availability in Hyperconnected Retail Networks. In *6th International Physical Internet Conference.*

[A171] Thompson, R., Zhang, L., Stokoe, M., & Ghaderi, H.(2019). Parcel Lockers for B2B Distribution in Central Business Districts.In *6th International Physical Internet Conference.*

[A172] Guo, C., Thompson, R., & Foliente, G. (2019). Parcel lockers for the pickup and delivery problem with transshipment in Hyper-connected City logistics. In *6th International Physical Internet Conference.*

[A173] Pan, S., Nigrelli, M., Ballot, E., & Sarraj, R. (2013, October). Performance assessment of distributed inventory in physical internet. In *43rd International Conference on Computers and Industrial Engineering (CIE43). Hong Kong, SAR, China* (pp. 1-15).

[A174] Pan, S., Nigrelli, M., Ballot, E., Sarraj, R., & Yang, Y. (2015). Perspectives of inventory control models in the Physical Internet: A simulation study. *Computers & Industrial Engineering*, 84, 122-132.

[A175] Puskás, E., & Bohács, G. (2019). Physical Internet–a novel application area for Industry 4.0. *Műszaki és Menedzsment Tudományi Közlemények*, 4(1), 152-161.

[A176] Domański, R., Adamczak, M., & Cyplik, P. (2018). Physical internet (PI): a systematic literature review. *LogForum*, 14.

[A177] Pan, S., Ballot, E., Huang, G. Q., & Montreuil, B. (2017). Physical Internet and interconnected logistics services: research and applications. *International Journal of Production Research*, 55:9, 2603-2609.

[A178] Ehrler, V. C. (2017). Physical Internet and its impact on the emission calculation standardization of transport chains-are we there yet?. In *IPIC 2017, 4th INTERNATIONAL PHYSICAL INTERNET CONFERENCE* (pp. 116-128). Verlag der Technischen Universität Graz.

[A179] Fergani, C., El Idrissi, A. E. B., Marcotte, S., & Hajjaji, A. (2019). Physical Internet characterization. *International Journal of Computer and Information Engineering*, 13(11), 599-608.

[A180] Luo, H., Tian, S., Yang, X., & Kong, X. (2019). Physical Internet enabled bulky goods delivery and pick up solution in city logistics. In *6th International Physical Internet Conference.*

[A181] Luo, H., Tian, S., & Kong, X.(2018)Physical Internet enabled bulky goods urban delivery system: a case study in customized furniture industry. In *5th International Physical Internet Conference.*

[A182] Crainic, T. G., & Montreuil, B. (2016). Physical internet enabled hyperconnected city logistics. *Transportation Research Procedia*, 12, 383-398.

[A183] Kim, N., Montreuil, B., & Klibi, W. (2019). Physical Internet Enabled HyperConnected Fulfillment of Delivery Time Sensitive E-Commerce Orders. In *6th International Physical Internet Conference*

[A184] Ballot, E., Gobet, O., & Montreuil, B. (2012). Physical internet enabled open hub network design for distributed networked operations. In *Service orientation in holonic and multi-agent manufacturing control* (pp. 279-292). Springer, Berlin, Heidelberg.

[A185] Tran-Dang, H., & Kim, D. S. (2019, October). Physical Internet for Military Logistics: Perspectives. In *2019 International Conference on Information and Communication Technology Convergence (ICTC)* (pp. 755-757). IEEE.

[A186] Montreuil, B., Meller, R. D., & Ballot, E. (2013). Physical internet foundations. In *Service orientation in holonic and multi agent manufacturing and robotics* (pp. 151-166). Springer, Berlin, Heidelberg.

[A187] Żuchowski, W. (2016). Physical Internet in Warehouse on the Background of GHG Emissions. *Research in Logistics & Production*, 6.

[A188] Mourhrib, W., Validi, S., & Dani, S. (2018). Physical Internet: Stakeholder Mapping. In *5th International Physical Internet Conference.*

[A189] Mayuto, R., Aïhounhin, S. P., Abodohoui, A., & Chrysostome, E. (2017). Physical Internet, Africa's Transport Infrastructure and Capacity Building. *Journal of Comparative International Management*, 20(1).

[A190] Fazili, M., Venkatadri, U., Cyrus, P., & Tajbakhsh, M. (2017). Physical Internet, conventional and hybrid logistic systems: a routing optimisation-based comparison using the Eastern Canada road network case study. *International Journal of Production Research*, 55(9), 2703-2730.

[A191] Fazili, M., Venkatadri, U., Cyrus, P., & Tajbakhsh, M. (2017). Physical Internet, conventional and hybrid logistic systems: a routing optimisation-based comparison using the Eastern Canada road network case study. *International Journal of Production Research*, 55(9), 2703-2730.

[A192] Zhong, R., Gong, H., Xu, C., & Lu, S. (2016). Physical internet-enabled manufacturing execution system for intelligent workshop production. *International Journal of Signal Processing, Image Processing and Pattern Recognition*(pp. 121 - 132). 9 (6).

[A193] Kong, X., Huang, G. Q., Luo, H., & Yen, B. P. (2018). Physical-internet-enabled auction logistics in perishable supply chain trading. *Industrial Management & Data Systems.*

[A194] Schoen, Q., Fontanili, F., Lauras, M., Truptil, S., & Anquetil, A. (2016). PI-Based Automated Diagnosis: The Blood Supply Chain Perspective. In *3rd International Physical Internet Conference.*

[A195] Crainic, T. G., Gendreau, M., & Jemai, L. (2019). Planning hyperconnected, urban logistics systems. *Transportation Research Procedia*, 47, 35-42.

[A196] Peng, X. S., Ji, S. F., & Ji, T. T. (2019). Promoting sustainability of the integrated production-inventory-distribution system through the Physical Internet. *International Journal of Production Research*, 1-20.

[A197] Chargui, T., Bekrar, A., Reghioui, M., & Trentesaux, D. (2019). Proposal of a multi-agent model for the sustainable truck scheduling and containers grouping problem in a Road-Rail physical internet hub. *International Journal of Production Research*, 1-25.

[A198] Furtado, P., & Frayret, J. M. (2015). Proposal sustainability assessment of resource sharing in intermodal freight transport with agent-based simulation. *IFAC-PapersOnLine*, 48(3), 436-441.

[A199] Sallez, Y., Berger, T., Bonte, T., & Trentesaux, D. (2015). Proposition of a hybrid control architecture for the routing in a Physical Internet cross-docking hub. *IFAC-PapersOnLine*, 48(3), 1978-1983.

[A200] Pach, C., Berger, T., Adam, E., Bonte, T., & Sallez, Y. (2014, May). Proposition of a potential fields approach to solve routing in a rail-road PI-hub. In *1st International Physical Internet Conference (IPIC).*

[A201] Kalicharan, K., Phillipson, F., Sangers, A., & Juncker, M. D. (2019). Reduction of Variables for Solving Logistic Flow Problems. In *6th International Physical Internet Conference (IPIC).*

[A202] Wang, J. Q., Fan, G. Q., Yan, F. Y., Zhang, Y. F., & Sun, S. D. (2016). Research on initiative scheduling mode for a physical internet-based manufacturing system. *The International Journal of Advanced Manufacturing Technology*, 84(1-4), 47-58.

[A203] Schildorfer, W., Neubauer, M., Schauer, O., Kuhn, A., & Aigner, W. (2019). Revealing mutual Relationships between Truck Platooning and Smart Hyperconnected Physical Internet Systems. In *6th International Physical Internet Conference.*

[A204] Qiao, B., Pan, S., & Ballot, E. (2018). Revenue optimization for less-than-truckload carriers in the Physical Internet: dynamic pricing and request selection. *Computers & Industrial Engineering*, 105563.

[A205] Simhandl, G., Tausig, M., & Treiblmaier, H. (2016). Root of Trust in the Physical Internet. In *3rd International Physical Internet Conference.*

[A206] Pach, C., Sallez, Y., Berger, T., Bonte, T., Trentesaux, D., & Montreuil, B. (2014, September). Routing management in physical internet crossdocking hubs: Study of grouping strategies for truck loading. In *IFIP International Conference on Advances in Production Management Systems* (pp. 483-490). Springer, Berlin, Heidelberg.

[A207] Gontara, S., Boufaied, A., & Korbaa, O. (2018, October). Routing the PI-Containers in the Physical Internet using the PI-BGP Protocol. In *2018 IEEE/ACS 15th International Conference on Computer Systems and Applications (AICCSA)* (pp. 1-8). IEEE.

[A208] Pagano, P., Tardo, A., Lattuca, D., Sessler, A., Cardone, R., Stroppolo, L., Puleri, M., & Pepe, T. (2019). RTPORT: the 5G-based Model-Driven real Time Module for General Cargo Management. In *6th International Physical Internet Conference.*

[A209] Lafkihi, M., Pan, S., & Ballot, E. (2019). Rule-based incentive mechanism design for a decentralised collaborative transport network. *International Journal of Production Research*, 1-17.

[A210] Kong, X. T., Chen, J., Luo, H., & Huang, G. Q. (2016). Scheduling at an auction logistics centre with physical internet. *International Journal of Production Research*, 54(9), 2670-2690.

[A211] Bodner, A. (2016). Securing Supply Chains from Counterfeiting Threats in a Transformed Open and Collaborative Enterprise. In *3rd International Physical Internet Conference.*

[A212] Quak, H. J., van Kempen, E. A., Dijk, B., & Phillipson, F. (2019). Self-organization in parcel distribution-SOLiD's first results. In *IPIC 2019 6th International Physical Internet Conference, London.*

[A213] Hofman, W., Punter, M., Bastiaansen, H., Cornelisse, E., & Dalmolen, S. (2016). Semantic technology for enabling logistics innovations–towards Intelligent Cargo in the Physical Internet. *International Journal of Advanced Logistics*, 5(2), 58-69.

[A214] Adamczak, M., Domański, R., & Cyplik, P. (2017). SHARING LOGISTICS RESOURCES AS A WAY TO PHYSICAL INTERNET—RESULTS OF SURVEY STUDIES. *DEStech Transactions on Engineering and Technology Research*, (icpr).

[A215] Lopez-Molina, L., Paz, A. C., & Rodriguez Cornejo, V. M. (2018). SHIFTING FOUNDATIONS IN LOGISTICS: THE PHYSICAL INTERNET. *DYNA*, 93(4).

[A216] Zhong, R. Y., Huang, G. Q., & Lan, S. L. (2014, May). Shopfloor logistics management using RFID-enabled big data under physical internet. In *Proceeding of 1st International Physical Internet Conference* (pp. 1-14).

[A217] Hakimi, D., Montreuil, B., Sarraj, R., Ballot, E., & Pan, S. (2012, June). Simulating a physical internet enabled mobility web: the case of mass distribution in France. In *9th International Conference on Modeling, Optimization & SIMulation - MOSIM'12, Bordeaux, France*. 10 p.

[A218] Buckley, S., Montreuil, B., & Montreuil, Z. (2017). Simulation Based Study of the Effect of Competition on the Operations of Hyperconnected Crossdocking Hubs. In *4th International Physical Internet Conference.*

[A219] Chargui, T., Bekrar, A., Reghioui, M., & Trentesaux, D. (2018). Simulation for Pi-hub cross-docking robustness. In *Service Orientation in Holonic and Multi-Agent Manufacturing* (pp. 317-328). Springer, Cham.

[A220] Furtado, P., Fakhfakh, R., Frayret, J. M., & Biard, P. (2013, October). Simulation of a Physical Internet—Based transportation network. In *Proceedings of 2013 International Conference on Industrial Engineering and Systems Management (IESM)* (pp. 1-8). IEEE.

[A221] Kim, N., & Montreuil, B. (2017). Simulation-based Assessment of Hyperconnected Mixing Center Capacity Requirements and Service Capabilities. In *proceeding of IPIC 2017-4th International Physical Internet Conference. Graz, Austria* (pp. 71-86).

[A222] Haider, C., Kinast, A., Kritzinger, S., Pitzer, E., & Affenzeller, M. (2018). Simulation-based optimization approach for IP networks. In *5th International Physical Internet Conference.*

[A223] Haider, C., Pitzer, E., & Affenzeller, M. (2017). Simulation-Based Optimization in the Field of Physical Internet. In *4th International Physical Internet Conference.*

[A224] Zhang, Y., Liu, S., Liu, Y., & Li, R. (2016). Smart box-enabled product–service system for cloud logistics. *International Journal of Production Research*, 54(22), 6693-6706.

[A225] Faugère, L., & Montreuil, B. (2018). Smart locker bank design optimization for urban omnichannel logistics: Assessing monolithic vs. modular configurations. *Computers & Industrial Engineering*, 105544.

[A226] Faugère, L., Malladi, S. S., White, D. C., & Montreuil, B. (2018). Smart Locker Based Access Hub Network Capacity Deployment in Hyperconnected Parcel Logistics. In *the Fifth International Physical Internet Conference.*

[A227] Pan, S., Zhong, R. Y., & Qu, T. (2019). Smart product-service systems in interoperable logistics: Design and implementation prospects. *Advanced Engineering Informatics*, 42, 100996.

[A228] Harald, K., Graf, H., Hoertenhuber, S., Widmann, R., & Stadlmann, B. (2016). SmartBox–An Austrian PI solution leading to small loads mobility 4.0. In *3rd international physical internet conference.*

[A229] Graf, H. C., & Harald, K. (2015). "smartBOX"-A BUSINESS CONCEPT TOWARDS THE PHYSICAL INTERNET. *Business Logistics in Modern Management*, 15, 253-262.

[A230] OKTAEI, P., HAKIMI, D., LEHOUX, N., MONTREUIL, B., & CLOUTIER, C. (2015). Studying the Effect of Locational Factors on the Profitability of Physical Internet Enabled Transit Centers. *11e CONGRES INTERNATIONAL DE GENIE INDUSTRIEL – CIGI2015. Québec, Canada.*

[A231] Neubauer, M., & Krenn, F. (2017, March). Subject-oriented design of smart hyper-connected logistics systems. In *Proceedings of the 9th Conference on Subject-oriented Business Process Management* (pp. 1-8).

[A232] Hofman, W., Dalmolen, S., & Spek, J. (2019). Supply Chain Visibility Ledger. In *6th International Physical Internet Conference.*

[A233] Zdziarska, M. (2017). Sustainability—Indispensable Part of the Logistics Development. In *Efficiency in Sustainable Supply Chain* (pp. 53-62). Springer, Cham.

[A234] Nikolopoulou, A., Amditis, A., Tsimiklis, G., Tsertou, A., Latsa, E., Krikigianni, E., ... & Hinkka, V. (2019, July). Sustainable port development: towards the Physical Internet concept. In *6th International Physical Internet Conference.*

[A235] Lemmens, N., Gijsbrechts, J., & Boute, R. (2019). Synchromodality in the Physical Internet–dual sourcing and real-time switching between transport modes. *European Transport Research Review*, 11(1), 19.

[A236] Yee, H., Gijsbrecht, J., & Boute, R. (2019). Synchromodality in the Physical Internet: Real-time Switching in a Multimodal Network with Stochastic Transit Times. In *6th International Physical Internet Conference.*

[A237] Chargui, T., Bekrar, A., Reghioui, M., & Trentesaux, D. (2018, June). Tabu Search Robustness for Cross-Dock and PI-Hub Scheduling Under Possible Internal Transportation Breakdowns. In *International Workshop on Service Orientation in Holonic and Multi-Agent Manufacturing* (pp. 295-307). Springer, Cham.

[A238] Meyer, T., & Hartmann, E. (2019). The bumpy road to the adoption of the Physical Internet - Overcomming barriers from stakeholder perspective. In *6th International Physical Internet Conference.*

[A239] Walha, F., Chaabane, S., Bekrar, A., & Loukil, T. (2014, May). The cross docking under uncertainty: State of the art. In *2014 International Conference on Advanced Logistics and Transport (ICALT)* (pp. 330-335). IEEE.

[A240] Ambra, T., Caris, A., & Macharis, C. (2019). The Digital Twin concept and its role in reducing uncertainty in synchromodal transport. In *6th International Physical Internet Conference.*

[A241] Zhang, J., Onal, S., & Das, S. (2019). The dynamic stocking location problem–Dispersing inventory in fulfillment warehouses with explosive storage. *International Journal of Production Economics*, 107550.

[A242] Meller, R. D., Lin, Y. H., & Ellis, K. P. (2012). The impact of standardized metric Physical Internet containers on the shipping volume of manufacturers. *IFAC Proceedings Volumes*, 45(6), 364-371.

[A243] Prandtstetter, M. (2018). The Meaning and Importance of True Intermodal Route Planning in the Context Of the Physical Internet. In *6th International Physical Internet Conference.*

[A244] Sternberg, H., & Norrman, A. (2017). The Physical Internet–review, analysis and future research agenda. *International Journal of Physical Distribution & Logistics Management.*

[A245] Montreuil, B., Rougès, J. F., Cimon, Y., & Poulin, D. (2012). The physical internet and business model innovation. *Technology Innovation Management Review*, 2(6).

[A246] Roodbergen, K. J., Montreuil, B., & Vis, I. F. (2014). The Physical Internet concept for libraries: a first set of ideas. In *First International Physical Internet Conference. Québec City, Canada* (pp. 28-30).

[A247] Ciprés, C., & de la Cruz, M. T. (2019). The Physical Internet from Shippers Perspective. In *Towards User-Centric Transport in Europe* (pp. 203-221). Springer, Cham.

[A248] Klibi, W., Labarthe, O., Deschamps, J. C., & Babai, Z. (2014). The Role of Peri-Urban Networks in Building Efficient and Sustainable Distribution Systems. In *Proceedings of 1st International Physical Internet Conference, Québec, Canada.*

[A249] Ballot, E., Montreuil, B., & Fontane, F. (2011). Topology of logistic networks and the potential of a physical internet. In *International Conference on Industrial Engineering and Systems Management IESM* (pp. 585-594).

[A250] Grest, M., Lauras, M., & Montreuil, B. (2019, September). Toward Humanitarian Supply Chains Enhancement by using Physical Internet Principles. In *International Conference on Industrial Engineering and Systems Management IESM* (pp. 1-6). IEEE.

[A251] Hofman, W. (2015, October). Towards a federated infrastructure for the global data pipeline. *In Conference on e-Business, e-Services and e-Society* (pp. 479-490). Springer, Cham.

[A252] Montreuil, B. (2011). Toward a Physical Internet: meeting the global logistics sustainability grand challenge. *Logistics Research*, 3(2-3), 71-87.

[A253] Montreuil, B., Meller, R. D., & Ballot, E. (2010). Towards a Physical Internet: the impact on logistics facilities and material handling systems design and innovation. In *11th IMHRC Proceedings. Milwaukee, Wisconsin. USA*. 40. https://digitalcommons.georgiasouthern.edu/pmhr_2010/40

[A254] Sohrabi, H., & Montreuil, B. (2014, May). Towards an interconnected distribution planning framework. In *1st International Physical Internet Conference*.

[A255] Ambra, T., Caris, A., & Macharis, C. (2019). Towards freight transport system unification: reviewing and combining the advancements in the physical internet and synchromodal transport research. *International Journal of Production Research*, 57(6), 1606-1623.

[A256] Oger, R., Lauras, M., Montreuil, B., Benaben, F., & Salatge, N. (2017, July). Towards Hyperconnected Resource Requirements Planning. In *4th International Physical Internet Conference*.

[A257] Oger, R., Montreuil, B., Lauras, M., & Benaben, F. (2018, June). Towards Hyperconnected Supply Chain Capability Planning: Conceptual Framework Proposal. In *5th International Physical Internet Conference*.

[A258] Strzelczak, S. (2015). Towards intelligent and sustainable economy-from incas, through eScop, to the seven internets. In *Proceedings of the Int'l Conference on "Technology• Intelligence• Future". Boao Edu Forum Asia, Chengdu (PR China)* (pp. 324-336).

[A259] Abdoulkadre, A., Intissar, B. O., Marian, M., & Benoit, M. (2014). Towards Physical Internet enabled interconnected humanitarian logistics. In *First International Physical Internet Conference. Québec City, Canada* (pp. 28-30).

[A260] Zhong, R. Y., Peng, Y., Fang, J., Xu, G., Xue, F., Zou, W., & Huang, G. Q. (2015). Towards Physical Internet-enabled prefabricated housing construction in Hong Kong. *IFAC-PapersOnLine*, 48(3), 1079-1086.

[A261] Caballini, C., Paolucci, M., Sacone, S., & Ursavas, E. (2017, October). Towards the physical internet paradigm: a model for transportation planning in complex road networks with empty return optimization. In *International Conference on Computational Logistics* (pp. 452-467). Springer, Cham.

[A262] Di Febbraro, A., Giglio, D., & Sacco, N. (2017). Towards the Physical Internet with Coloured Petri Nets. In *4th International Physical Internet Conference*.

[A263] Schoen, Q., Fontanili, F., Anquetil, A. G., Truptil, S., & Lauras, M. (2017, May). Tracking in real time the blood products transportations to make good decisions. In *14th International Conference on Information Systems for Crisis Response and Management*.

[A264] Ballot, E., & Montreuil, B. (2016). Transport Items and Physical Internet Handling Boxes: a Comparison Framework Across Supply Chains. In *14th IMHRC Proceedings. Karlsruhe, Germany.* 4. https://digitalcommons.georgiasouthern.edu/pmhr_2016/4.

[A265] Kim, N., Kholgade, N., & Montreuil, B. (2018). Urban Large-item logistics Hyperconnected Fulfillment and Transportation. In *5th International Physical Internet Conference*.

[A266] Montreuil, B., Buckley, S., Faugere, L., Khir, R., & Derhami, S. (2018). Urban parcel logistics hub and network design: The impact of modularity and hyperconnectivity. In *15th IMHRC Proceedings. Savannah, Georgia. USA*. 19. https://digitalcommons.georgiasouthern.edu/pmhr_2018/19.

[A267] Bruijns, L. A. M., Phillipson, F., & Sangers, A. (2019). User Equilibrium in a Transportation Space-Time Network. In *6th International Physical Internet Conference*.

[A268] Darvish, M., El Boukili, M., Kerekou, S., & Montreuil, B. (2014). Using Cloud computing as a Model to Design the Service Web. In *1st International Physical Internet Conference*.

[A269] Osmólski, W., Voronina, R., & Koliński, A. (2019). Verification of the possibilities of applying the principles of the Physical Internet in economic practice. *LogForum*, 15.

[A270] Poenicke, O., Kirch, M., Richter, K., Schmid, F., & Telek, P. (2017). Wearable solutions for efficient manual logistics processes-RFID wristband and smart-glasses. In *4th International Physical Internet Conference, Graz* (pp. 160-169).

Appendix B: List of articles per topic

Topic	Article IDs
Adoption of the Physical Internet	[A3,A19,A40,A44,A51,A55,A81,A85,A93,A100,A103,A106, A107,A109,A112,A120,A135,A153,A189,A238, A246,A247,A250,A259,A269]
Assessment of Physical Internet Aspects	[A16,A25,A28,A32,A39,A45,A55,A58,A60,A61,A62,A77, A83,A84,A85,A90,A92,A94,A101,A110,A116,A118,A125, A126,A132,A133,A135,A136,A138,A144,A146,A147,A152, A159,A164,A170,A171,A173,A174,A178,A183,A187,A188, A196,A198,A214,A217,A218,A219,A220,A221,A233,A235, A240,A242,A247,A250,A258,A259,A265,A269]
Business Model Innovation	[A1,A7,A17,A29,A42,A70,A71,A76,A78,A81,A96,A97,A98, A112,A120,A125,A137,A166,A193,A211,A227,A229,A245]
Digital Interconnectivity within the Physical Internet	[A87,A82,A75,A73,A72,A6,A57,A54,A4,A268,A263,A260, A251,A240,A232,A231,A227,A22,A213,A207,A205,A203, A20,A192,A191,A18,A141,A134,A129,A115,A104,A102,A1, A12,A27,A31,A41,A43,A48,A49,A53,A56,A59,A63,A121, A130,A161,A163,A165,A194,A208,A216,A228,A270]
PI-nodes	[A11,A13,A24,A25,A26,A38,A58,A69,A91,A96,A97,A98,A99, A108,A113,A127,A148,A197,A199,A200,A206,A218,A219, A225,A226,A230,A237,A239,A262,A46,A54,A76,A86,A111, A117,A155,A172,A181,A234,A241]
Standardized Modular Containers	[A5,A8,A14,A35,A66,A67,A68,A89,A117,A150,A151,A163, A165,A181,A224,A228,A229,A242,A263,A264]

Supply Chain Optimization within the Physical Internet	[A7,A9,A10,A15,A21,A30,A33,A37,A45,A46,A47,A63,A64, A70,A74,A77,A79,A80,A84,A86,A95,A111,A114,A116,A119, A122,A123,A124,A126,A128,A140,A142,A143,A144,A146, A149,A154,A155,A156,A157,A159,A160,A162,A167,A168, A169,A170,A172,A173,A174,A180,A184,A190,A195,A201, A202,A204,A209,A210,A220,A222,A223,A236,A241,A243, A248,A254,A256,A257,A261,A267,A13,A24,A26,A92,A94, A108,A196,A197,A225]
Technological Innovations enabling the Physical Internet	[A2,A12,A27,A31,A41,A43,A48,A49,A50,A52,A53,A56,A59, A62,A121,A130,A137,A138,A161,A175,A185,A194,A208, A212,A216,A234,A270,A75,A73,A72,A29,A6,A4,A260,A100, A232,A213,A205,A20,A192,A191,A18,A134,A104]
Other	[A23,A34,A36,A65,A88,A105,A131,A139,A145,A158,A176, A177,A179,A182,A186,A215,A244,A249,A252,A253,A255, A266]

Appendix C: List of articles per roadmap

Roadmap	Article IDs
Corridors, Hubs and Synchromodality	[A11,A13,A19,A24,25,A26,A38,A46,A69,A76,A86,A91,A96, A97,A98,A99,A108,A117,A123,A127,A148,A154,A197,A199, A200,A206,218,A219,A230,A236,A237,A239,A262]
Global Supply Network Coordination and Collaboration	[A9,A10,A15,A17,A21,A33,A37,A47,A55,A58,A60,A61,A64, A74,A77,A78,A79,A80,A92,A93,A94,A95,A101,A106,A110, A114,A118,A119,A122,A124,A126,A128,A131,132,A133, A135,140,A142,A144,A145,A147,A155,A156,A157,A158, A159,A160,A162,A164,A167,168,A169,A170,A173,A174, 177,A184,A190,A193,A195,A201,202,A204,A203,A209, A210,A211,A214,A217,A220,A221,A222,A223,A225,A226, A241,A243,A254,A255,A256,A257,A261,A267]
Sustainable, Safe and Secure Supply Chains	[A5,A8,A14,A28,A30,A35,A39,A66,A67,A68,A85,A89,A90, A150,A151,A152,A178,A187,A196,A198,A224,A229,A233, A235,A242,A252,A253,A264]
Systems and Technologies for interconnected logistics	[A1,A2,A87,A82,A12,A75,A73,A72,A27,A31,A41,A43,A49, A50,A51,A52,A53,A6,A56,A59,A63,A54,A4,A268,A263, A260,A100,A251,240,A232,A121,A231,130,A227,A138, A139,A22,A143,A161,A163,A165,A175,A185,213,A207, A194,A205,A20,A208,A212,A192,216,A191,A228,A18, A141,A234,134,A129,A115,A104,A102,A270]
Urban Logistics	[A7,A29,A34,A45,A48,57,A62,A70,A71,A83,A84,A109,A111, A113,116,A125,A137,A146,A149,171,A172,A180,A181,A182, 183,A248,A265,A266]
Not applicable	[A3,A16,A23,A32,36,A40,A42,A44,A65,A81,A88,103,A105, A107,A112,120,A136,A153,A166,A176,A179,186,A188,A189, A215,A238,244,A245,A246,A247,249,A250,A258,A259,A269]

Appendix D: Articles per type of contribution

Type of Contribution	Article IDs
Conceptual Framework	[A1,A5,16,A31,A49,A50,A52,53,A56,A89,A95,A123,131, A137,A138,A145,A150,A158,163,A182,A186,A213,A207, A226,A228,A141,A234,A245,248,A252,A253,A254,A257, A259,104,A266,A189,A191]
Conceptual Model	[A87,A17,A75,A73,A72,A23,A34,A36,A38,A6,A63,A64,A71, A54,A4,A268,A76,A260,A251,A227,A22,A229,A96,A97, A98,A128,A20,A211]
Evaluation	[A82,A19,A29,A41,A42,A44,A51,A55,A62,A65,A81,A263, A83,A85,A88,A91,A93,A99,100,A240,A106,A107,A112, A113,A232,A120,A125,A135,A136,A151,A152,164,A166, A172,A175,A176,A177,178,A179,A185,A187,A188,189, A193,A194,A199,A203,A208,A212,A214,A215,A18,A238, A239,A134,A244,A246,A247,A250,A255,A258,A115,A264, A265,A102,A269,A270,A2,A43,A53,A69,A260,A101,A133, A138,A144,A154,A181,A183,A198,A200,A206,A192,A218, A219,A220,A242,A129]
Mathematical Model	[A7,A8,A9,A12,A13,A14,A15,A24,A25,A26,A28,A33,A35, A37,A39,A40,A45,A46,A58,A61,A67,A68,69,A70,A74,A78, A79,A84,A86,A90,A92,A94,A96,A97,A98,A108,A110,A114, A118,A122,A124,A126,A127,A128,A132,A133,A142,144, A146,A147,A148,A149,A154,A155,156,A157,A159,160, A162,A165,A167,A169,A170,A173,A174,A180,183,A184, A190,A195,A196,A197,A198,A200,A201,A204,A206,A209, A210,A218,A219,220,A224,A225,A230,A235,A236,A241, A242,A249,A261,A10,A21,A30,A47,A111,A199,A262,A267]

Method	[A2,A21,A30,A43,47,A77,A116,A117,A119,121,A130,A140, A153,161,A168,A171,A181,A202,A216,A222,223,A237, A243,A267,A35,A70,A74,95,A240,A149,A172,A210]
Methodology	[A3,A60,A66,A80,A101,A109,A111,A143,A217,221,A256, A146,A209,A257]
Research Agenda	[A59,A103,A139,A65,A80,A112,A227,A193,244,A247,A250, A255]
Tool	[A1,A17,A117,A264,A102,A11,A27,A48,A57,A231,A205, A20,A211,A192,A191,A129,A262]

Appendix E: List of Articles per type of research

Research Type	Article IDs
Evaluation Research	[A19,A44,A55,A81,A260,A93,A153,A189,A194,A20,A192,A214, A216,A191,A18,A238,A247,A129,A270]
Philosophical Papers	[A5,A82,A16,A23,A31,A34,A36,A38,A41,A42,A49,A50,A51, A52,A53,A6,A56,A59,A65,A71,A4,A268,A76,A88,A89,A91, A99,A100,A105,A106,A113,A120,A131,A227,A135,A136, A137,A138,A139,A150,A151,A152,A158,A163,A164,A166, A175,A176,A177,A178,A179,A182,A185,A186,A187,A188, A213,A193,A215,A226,A228,A229,A141,A233,A234,A239, A244,A245,A248,A250,A252,A253,A254,A255,A257,A258, A259,A104,A266]
Solution Proposal	[A3,A87,A12,A13,A75,A73,A72,A29,A32,A43,A57,A60,A62, A63,A64,A66,A54,A74,A80,A263,A83,A84,A85,A95,A251, A103,A107,A109,A112,A232,A117,A123,A125,A127,A231, A140,A22,A142,A143,A145,A147,A165,A168,A171,A172, A181,A202,A205,A203,A208,A211,A222,A223,A134,A243, A246,A256,A115,A262,A264,A102,A269]

Validation Research	[A1,A2,A7,A8,A9,A10,A11,A14,A15,A17,A21,A24,A25, A26,A27,A28,A30,A33,A35,A37,A39,A40,A45,A46,A47, A48,A58,A61,A67,A68,A69,A70,A77,A78,A79,A86,A90, A92,A94,A96,A97,A98,A101,A240,A108,A110,A111,A114, A116,A118,A119,A121,A122,A124,A126,A128,A130,A132, A133,A144,A146,A148,A149,A154,A155,A156,A157,A159, A160,A161,A162,A167,A169,A170,A173,A174,A180,A183, A184,190,A207,A195,A196,197,A198,A199,A200,A201, A204,A206,A209,A210,A212,217,A218,A219,A220,A221, A224,A225,A230,A235,236,A237,A241,A242,249,A261, A265,A267]

Appendix F: Articles per Research Method

Research Method	Article IDs
Simulation	[A1,A7,A11,A15,A17,A24,A25,A26,A28,A30,A45,A46,A61, A69,A70,A77,A90,A92,A96,A97,A98,A240,A110,A116, A117,A118,A121,A124,A126,A128,A130,A132,A133, A144,A148,A154,A155,A156,A157,A161,A165,A170, A173,A174,A183,A184,A190,A207,A198,A199,A200, A206,A209,A210,A212,A217,A218,A219,A220,A221, A235,A236,A241,A265,A101,A16]
Case Study	[A75,A27,A48,A50,A51,A53,A263,A260,A22,A143,A181, A20,A192,A191,A18,A237,A238,A19,A68,A54,A81,A108, A109,A126,A128,A146,A154,A156,A170,A180,A183,A207, A194,A208,A221,A224, A264,A3]
Content Analysis	[A44,A189,A140]
Descriptive	[A87,A5,A82,A73,A72,A23,A29,A31,A32,A34,A36,A38,A41, A42,A49,A52,A6,A56,A57,A59,A62,A63,A64,A66,A71,A54, A4,A268,A80,A81,A83,A85,A89,A99,A251,A103,A105, A107,A109,A112,A113,A232,A120,A123,A125,A127,A231, A131,A227,A135,A136,A137,A138,A140,A145,A150,A151, A152,A158,A163,A164,A166,A168,A171,A175,A178,A182, A185,A186,A187,A213,A202,A203,A208,A211,A216,A222, A223,A226,A228,A229,A141,A233,A234,A134,A243,A245, A246,A248,A250,A252,A253,A254,A256,A257,A258,A259, A115,104,A264,A266,A102,A269,A75,A50,A53,A260, A100,A117,A153,A165,A172,A181,A188,A18,A76]
Literature Review	[A65,A88,A91,A100,A106,A139,A176,A177,A179,A188, A193,A215,A239,A244,A255,A125,A175]
Other	[A60,A153,A194,A129,A270]

Mathematical Modeling	[A2,A8,A9,A10,A12,A13,A14,A21,A33,A35,A37,A39,A47, A58,A67,A68,A74,A78,A79,A84,A86,A94,A95,A108,A111, A114,A119,A122,A142,A146,A147,A149,A159,A160,A162, A167,A169,A172,A180,A195,A196,A197,A201,A204,A224, A225,A242,A249,A261,A262,A267]
Quantitative analysis	[A40,A43,A230,A79,A237]
Survey	[A19,A55,A93,A214,A247]

Appendix G: Theses 2018-2019

[T1] Chadha, S. S. (2019). An Applied Optimization Model for Freight Delivery in a Physical Internet Supply Chain (Master's thesis, Dalhouse University, Nova Scotia, Canada). Retrieved from http://hdl.handle.net/10222/76844

[T2] Arnau Ortega, Q. (2018). Applications of Metaheuristics to the Physical Internet (Bachelor's thesis, Universitat Politècnica de Catalunya).Retrieved from: http://hdl.handle.net/2117/117965

[T3] Brustia, A. (2018). Internet of Things (IoT) applications in the Physical Internet (PI) framework Can IoT be an accelerator for the PI roadmap? (Master's thesis, Vrije Universiteit Brussel, Brussels, Belgium). Retrieved from: https://www.macnil.it/tesi_laurea/Brustia_Andrea_Thesis.pdf

[T4] Qiao, B. (2018). Revenue Management for transport service providers in Physical Internet: freight carriers as case (Doctoral thesis, Mines ParisTech, Paris, France). Retrieved from: https://hal.archives-ouvertes.fr/tel-02129336/

[T5] Zheng, L. (2019) Simulation and optimization of a multi-agent system on physical internet enabled interconnected urban logistics (Doctoral thesis, University of Louisville, Kentucky, U.S.). Retrieved from: https://ir.library.louisville.edu/etd/3324/

[T6] Martinez De Ubago Alvarez De Sotomayor, M. (2019). The future of ports in the Physical Internet: Developing future scenarios of the PI and their influence on maritime ports(Master's thesis, TU Delft, Delft, Netherlands). Retrieved from: https://repository.tudelft.nl/islandora/object/uuid:9ffd28f4-2cb8-4bac-a418-40414cf15aa0