Framework and Characterization of Physical Internet

Charifa Fergani, Adiba El Bouzekri El Idrissi, Suzanne Marcotte, Abdelowahed Hajjaji

***Abstract*—**Over the last years, a new paradigm known as Physical Internet has been developed, and studied in logistics management. The purpose of this global and open system is to deal with logistics grand challenge by setting up an efficient and sustainable Logistics Web. The purpose of this paper is to review scientific articles dedicated to Physical Internet topic, and to provide a clustering strategy enabling to classify the literature on the Physical Internet, to follow its evolution, as well as to criticize it. The classification is based on three factors: Logistics Web, organization, and resources. Several papers about Physical Internet have been classified and analyzed along the Logistics Web, resources and organization views at a strategic, tactical and operational level, respectively. A developed cluster analysis shows which topics of the Physical Internet that are the less covered actually. Future researches are outlined for these topics.

***Keywords*—**Logistics web, Physical Internet, PI characterization, taxonomy.

I. Introduction

LOGISTICS is the management of the items from the point of origin to the point of consumption in order to meet the needs of customers and companies. It seems to be efficient thanks to the existing equipment, but in reality it represents a big challenge because the way in which physical objects are moved, stored, made, supplied and used around the world is inefficient and unsustainable economically, environmentally and socially [1]. A study on current global logistics has summarized its failures in thirteen symptoms [1], namely: trips are often half empty at the start, with a substantial part of the non-empty filled by the packaging; vehicles and containers often come back empty; truckers have become the modern cowboys; products mostly sit idle, stored where unneeded, yet so often unavailable fast where needed; production and storage facilities are poorly used; so many products are never sold, never used; products do not reach those who need them the most; products unnecessarily move, crisscrossing the world; fast & reliable intermodal transport is still a dream or a joke; getting products in and out of cities is a nightmare; networks are neither secure nor robust; smart automation & technology are hard to justify; innovation is strangled.

In order to improve logistics efficiency and remove this global challenge, Professor Montreuil was inspired from the digital internet, and how millions of computers and servers are interconnected to create a new logistics system [1]. The goal is to move from several inefficient and unsustainable isolated logistics systems to an open, global logistics system that interconnects physical objects across modes and routes in a transparent, easy, fast, reliable, and inexpensive way. Therefore, one could assist to the birth of the Physical Internet which aims to improve the logistics chain economically, environmentally and socially.

The Physical Internet (PI, π) is a new concept aimed at moving from a fragmented organization that is difficult to optimize, to an open and distributed organization. It is defined as a global logistics system based on the interconnection of logistics networks by a standardized set of collaboration protocols, modular containers and smart interfaces for increased efficiency and sustainability [2]. It aims to enable an efficient and sustainable Logistics Web [3].

After the appearance of the PI and its definition, it has attracted several researchers around the world, and several projects have been highlighted. The purpose of this article is to present the state of the art on this future system that is upsetting the global industry, and to provide a taxonomy to: i) present the relevant publications collected about the PI, and classify them according to a specific characterization; ii) facilitate the review of the literature for PI researchers; iii) direct future research by highlighting some gaps in the literature.

This article is organized as follows. In Section II, we give an overview about PI and Logistics Webs. In Section III, we describe the method used to characterize PI problems according to the Logistics Webs in strategic, tactical and operational levels. In Section IV, we provide and discuss a cluster analysis of the selected papers. Finally, we give conclusive remarks and outlines avenues for further research.

II. PI Foundation

A. PI

The concept of PI has been used for the first time in 2006 by the British newspaper "The Economist", but Professor Montreuil [4] was the first one to develop this orphan concept to a large project interesting the whole logisticians in the world. It aims to enable an open market of transportation by deploying an efficient and sustainable Logistics Web, shared by a large worldwide community of industrials, retailers, and points of sale.

The PI has been defined as an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols [3].

Encapsulation: The PI does not treat physical goods directly, but it requires their standardized encapsulation in modular, ecological and intelligent π-containers [3]. These containers are easy to compose and decompose, manipulate, and store. They are also lightweight and equipped with smart

Charifa Fergani, Adiba El Bouzekri El Idrissi, and Abdelowahed Hajjaji are with department of Science of Industrial Technologies (STIN), and Laboratory of Engineering Sciences for Energy (LabSIPE), ENSAJ, Chouaïb Doukkali University, Morocco (e-mail: fergani.charifa@gmail.com).

Suzanne Marcotte is with Department of Management & Technology, UQAM and CIRRELT, Canada.

tags allowing their identification, routing and adequate maintenance [4].

Interfaces: They are the set of container handling and storage systems. They are essential for achieving effective and sustainable universal interconnectivity [3]. Four types of interfaces are very important in the PI: π-fixtures, π- devices, π-nodes, and π-platforms. The π-nodes are related to logistics activities, enabling the deployment and multimodal transport of containers [4].

Protocols: In synergy with the Digital Internet, protocols are standardized regulations necessary to direct logistics services within the PI founded on universal interconnectivity, to have its components seamlessly interconnected in an open, global, efficient and sustainable way.

B. Logistics Web

"In order to achieve its noble ambition, the Physical Internet aims to enable an efficient and sustainable Logistics Web" [3]. The most important in the digital internet are the websites and the applications that we can reach once connected. Similarly, the Logistics Web is what interests' different parts of the supply chain applying the PI. It is the set of actors and, physical, digital, human, organizational and social networks openly interconnected aiming to serve efficiently, and sustainably logistics needs of people, organizations, communities and/or society [3].

The Logistics Web is decomposed into five constituent webs: mobility web, distribution web, realization web, supply web and service web.

1. Mobility Web

Mobility is about moving and handling goods and people from sources to destinations. Mobility Web consists in moving from point-to-point transport to multimodal, distributed, efficient and reliable transport through transit centers and hubs.

Transit centers allow the transfer of π-trailers from one truck to another in order to avoid long paths, although π-hubs allow the multimodal transfer of π-containers between different means of transport to avoid empty trips.

Fig. 1 compares, in a simplified way, the point-to-point transport and the mobility web. As it is shown, the distances traveled are shorter in the second one and the resources are used in a more optimal way.

2. Distribution Web

Distribution Web is interested in the deployment and storage of products. It consists of creating open warehouses and distribution centers shared by a multitude of factories to enable seamless, efficient and reliable distributed deployment of encapsulated goods.

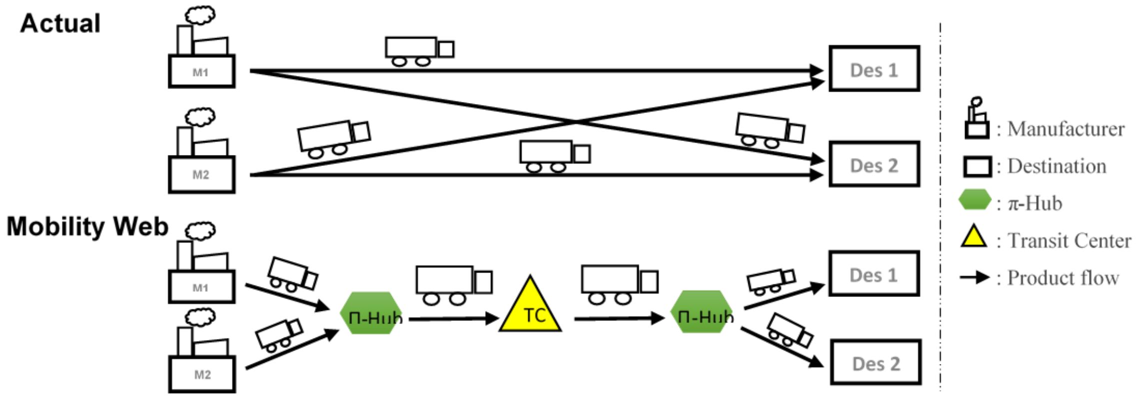

Fig. 1 Interconnected mobility

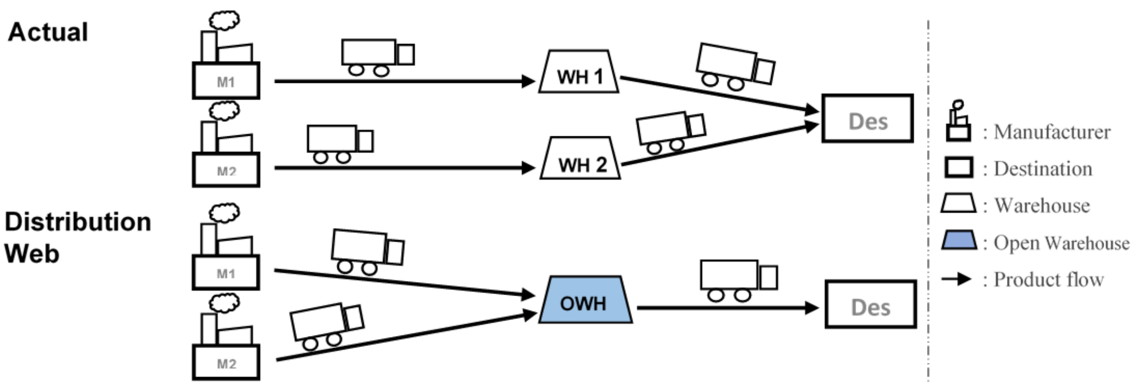

Fig. 2 Interconnected distribution

Fig. 2 illustrates the use of warehouses in Distribution Web. It can be deduced that the sharing of open warehouses by several producers optimizes their uses, and ensures the storage of the products where they are needed. More benefits of the use of transit centers and open warehouses are reported by [1].

3. Realization Web

Realization Web is interested by the production, or in other words, of the realization of products. It enables efficient and agile product realization by the creation of flexible, open, distributed and hyperconnected production centers "open fabs" able to realize on-demand near-point-of-use a wide variety of products based on digital specifications transmitted.

As shown in Fig. 3, the travel distance is reduced and trucks have become smaller after using open and distributed production centers near to costumers. However, this figure does not illustrate very well the flexibility of production centers. A more detailed illustration of open production centers flexibility is presented in Marcotte's papers [5], [6].

4. Supply Web

The supply web is interested in the supply of the goods. It consists in creating an open supply system by exploiting the other webs for supplying physical objects and services worldwide as it is shown in Fig. 4.

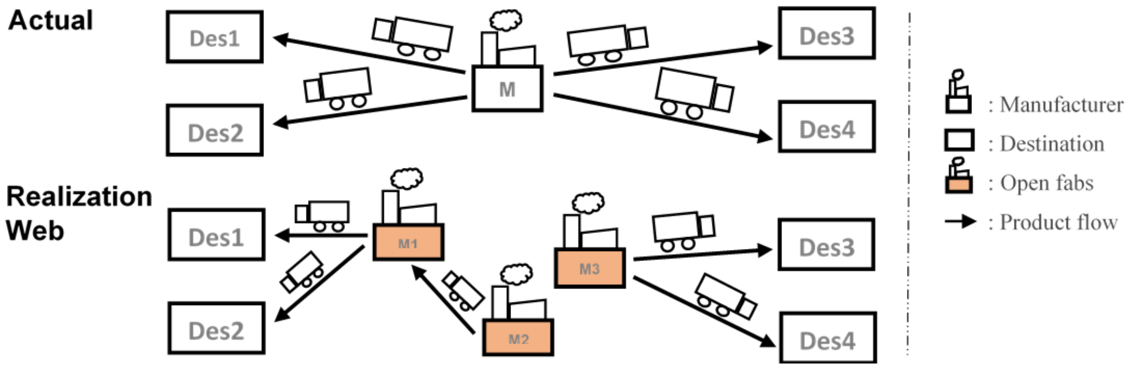

Fig. 3 Mobile hyperconnected production

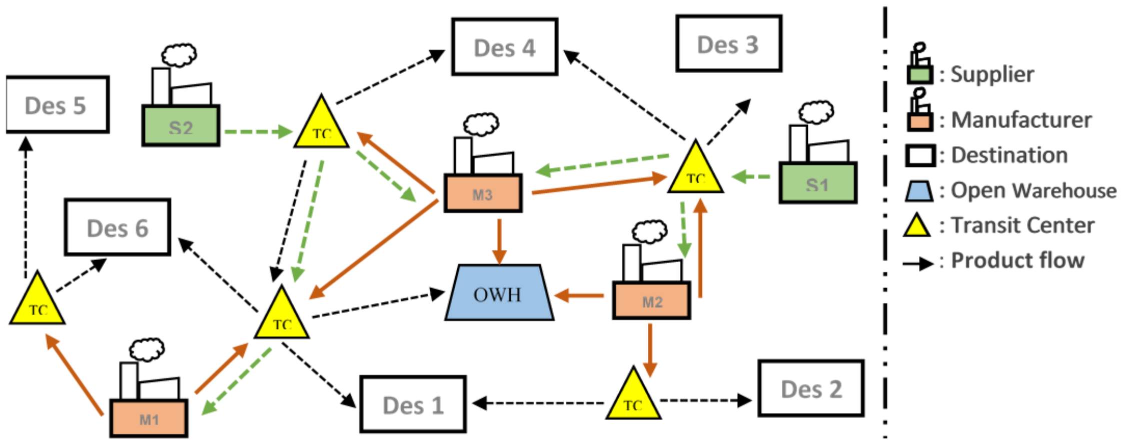

Fig. 4 Logistics Web functions

Figs. 1-4 illustrate how the Logistics Web enables to optimize the use of resources, to reduce traveled distance, and to reduce delivery time, among others.

5. Service Web

The Service Web is to facilitate and share the access and use of services provided by goods and people. It is expected to enable efficient and sustainable collaborative consumption on a worldwide basis.

III. PI Taxonomy

Although the PI is a new discipline, many publications and researches have been published on this topic and there will be even more in the future. In order to facilitate the review of the PI literature, we decided to create a taxonomy because it is an efficient and effective way of consolidating knowledge [7].

First, we started by selecting scientific papers devoted to PI published after 2010, which is when most of the papers on the development and clarification of the PI concept were published. We used academic search engines such as Scopus, Google Scholar and ScienceDirect to find papers having the key word "Physical Internet" in their titles, abstract or key words, and we checked references of publications founded to ensure that no relevant publications are forgotten. As a result, 94 papers were involved.

After, we reduced the number of publications found by keeping only the journal papers and some frequently cited or relevant conference articles and books. Therefore, 49 published papers in different journals and conferences are examined attempting to be as exhaustive as possible. However, we apologize for any unintended omission of some relevant articles.

A. Overview

After a first overview of the articles reviewed, we suggest to classify them according to four major families summarized in Table I. The first family includes papers related to strategic evaluation and organization of the PI. The second family covers studies and analysis carried out on production flow, transport flow, and distribution flow. The third one includes papers on physical elements serving PI. The last one summarizes publications about literature review. In each family, several approaches are used.

TABLE I
PI'S ASPECTS OF RESEARCH

Research interest	Approach	Publications
Strategic and organizational analysis	Protocols & data model	[8], [9]
	Business model	[10]-[13]
	Evaluation	[14]-[18]
Flows analysis	Mathematical modeling	[6], [19], [20]
	Simulation	[21]-[24]
	Modeling & simulation	[25]-[33], [51]
	Conceptual	[34], [5], [35]
	Case study	[36], [37]
Physical elements	Conceptual	[4], [1], [3], [38], [39]
	Design & Simulation	[40]-[44], [50]
PI review	Literature review	[45], [46], [52], [53]
	Special issue	[47]

A large part of the first family papers focuses on the evaluation of the PI and its contribution compared to the current logistics system. The other part of studies is about protocols directing different services of the PI, and the impact of the PI on the innovation of business model. The second family contains the majority of papers on PI, most of the articles are moving towards analyzing, modeling and simulating transport, distribution and fulfillment flows. Articles of the third family bear on designing physical elements of PI, they are limited, and most of them work on π-containers. This classification of the reviewed articles gives a global overview that does not reveal the strengths and weaknesses of the literature. In order to clearly summarize current researches and provide directions for future research, we will establish a taxonomy allowing classifying them according to the logistics webs.

B. Characterization of PI Problems

The PI is defined as a structured approach of decision making at the strategic, tactical and operational levels. Furthermore, the PI may be viewed from three different angles: Logistics Webs, resources, and organization. The PI aims to subdivide the logistics chain into efficient and sustainable webs called Logistics Webs. Resources refer to all means, equipment and personnel needed to operate in the PI. Finally, organization includes all planning and control procedures used to run the system. For each level, the PI problems are placed in perspective using these three angles, which correspond to the three axes in Figs. 5-7.

1. Strategic Level

At the strategic level, we consider decisions that have a long-term impact, mostly decisions that concern high investments. Fig. 5 lists a number of problems addressed at the strategic level, related to the three axes: Logistics Web, resources, and organization. The main decisions at this level concern:

- Evaluating the capacity of the PI to improve performance of a transport operation more than the traditional logistics model
- Studying the impact of the PI on business model innovation in order to push further value creation
- Defining the required webs of Logistics Web, their uses, and the interfaces that they require
- Conception of PI foundations

Each individual decision on this level puts a constraint and additional requirements at decisions on lower levels.

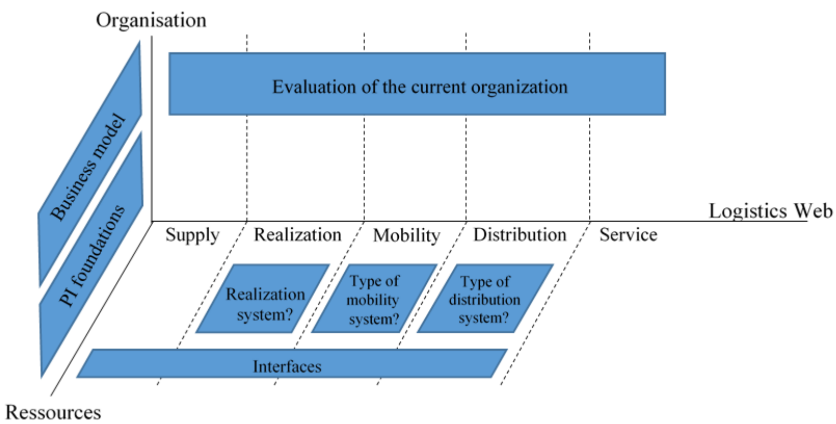

Fig. 1 The Strategic Level

2. Tactical Level

On the tactical design level, a number of medium-term decisions are to be made by relying on the outcomes of the strategic decisions. Tactical decisions require some investment even if they are less decisive than strategic decisions.

Tactical decisions typically concern the design of resources and a number of organizational issues. The first one defines the design of each web interfaces and determine the required resources. For example, open fabs enabling to realize locally a wide variety of products must be designed according to the defined strategic objectives (flexible, open and distributed).

The organizational issues concern decisions of control procedures used to run the Logistics Web. It includes:

- Defining the model of management of production demand
- Optimizing the uses of production modules
- Developing transport management in transit centers and π-hubs
- Determining storage standards in open distribution centers and warehouses concerning stock and space management
- Illustrating the rules of access to the PI services as well as ensuring the conditions of security
- Defining the protocols that direct PI multilayer services
- Conception and sizing of π-containers of encapsulation
- Assessing the impact of PI on supply chain management

The decisions on the tactical level and their interaction are visualized in Fig. 6. Obviously, the outcomes of the decisions made here have a strong impact on the remaining problems to be solved at the operational level.

3. Operational Level

At the operational level, webs have to be performed within the constraints set by the strategic and tactical decisions made. The main decisions at this level concern assignment and control problems of people and equipment:

- Providing formations and trainings on PI
- Preparing schedules of tasks and their assignment to personnel in production centers
- Assignment of transport in transit centers and π-hubs
- Allocation of incoming products to free storage locations, according to the storage concept determined at the tactical level.
- Exploring the possibility of adapting the PI to regions around the world
- Use of PI in real cases

Fig. 7 resumes a number of decisions to be taken at the operational level. These decisions are made in a limited scope and in the short term.

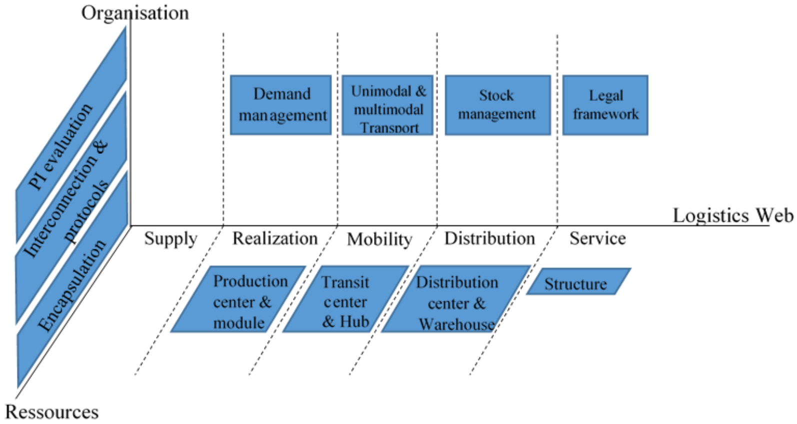

Fig. 2 The Tactical Level

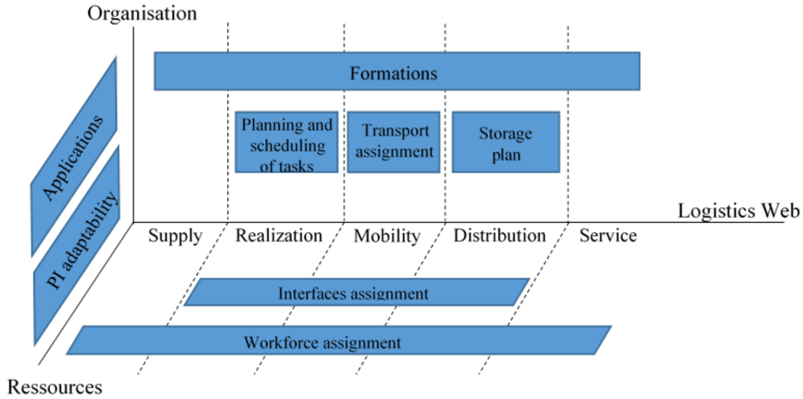

Fig. 3 The Operational Level

IV. Clustering According to Logistics Web

The developed characterization allows classifying PI literature and following the development of this concept. Therefore, the reviewed articles may be classified according to the established characterization of PI at a strategic, tactical and operational level.

A. PI Organization

Several works evaluated the capacity of the PI to improve efficiency of logistics. A study [1] compared the integration of the intermodal distributed transport with the point-to-point transport of a trailer entirely charged from Quebec to Los Angeles. Distributed transport induced a reduction of the time travelled to the half, in addition to the better working conditions. Similarly, a modeling of supply networks of two fast moving customer goods (FMCG) retailers in France showed that the combination of a network of π-hubs and modular containers makes the difference compared to the current logistics, and allows an increase of almost 17% in the filling rate of transport means and a reduction of 60% in CO_2 emissions [15]. Reference [14] confirmed that the resource sharing transportation improves the financial, operational, social and environmental performance of a transport operation, more than the traditional model.

Some studies were drawn up to study the potential impact of the PI on business model and how it is generating an intense wave of innovative changes in business models [8], [11]. Reference [34] studied the links of synergy between city logistics and PI. They introduce the concept of Hyperconnected City Logistic, and its nine fundamental concepts constituting a rich framework for designing an efficient and sustainable urban logistics systems.

Under the European project MODULUSHCA (2012/2015) developing π-containers of encapsulation, [48] presented a relevant work in the definition of their sizes. Its results helped to design prototypes of the modular boxes of encapsulation and to propose a technical sight on their loading [43].

Reference [38] introduced the concept of "Smart π-container (SPIC)" which exploits the idea of informational interaction of the container to take part in the decision-making processes related to it or to another π-container. Reference [44] showed that besides the intelligence of the π-container, its activity is very important because it allows to identify its state, to compare it with another, to send information and more. Also, they have proved its interest with an application of consolidation of π-containers in a π-hub. Evaluation studies judged the relevance of the use of π-containers for the establishment of PI principles [16], [18].

Reference [8] presented the OLI model (Open Logistics interconnection) with seven layers allowing the interconnection of services, and they described each proposed layer and the way in which logistics services are organized inside and between these layers. Reference [9] described an approach of data processing on the modular boxes within the framework of the PI, based on the definition of a common data model to have a single and shared format of all messages to exchange between the participants. Reference [20] presented and described two systems of optimization of the transport of the containers by the PI: Optimization network, and System multi-agent.

In an operational level, [36] studied the architecture of prefabricated construction based on PI which allows to improve this type of construction by integrating logistic scales. Besides, [13] studied the prospects for the development of PI in an emerging country such as Morocco, through a diagnosis of the current situation of the logistics sector.

B. Mobility Web

The Mobility Web consists in moving from point-to-point transport to distributed transportation through interfaces to avoid long paths. We distinguish two types of multi-segment transportation: unimodal and multimodal transport.

To enable the transfer of π-containers from their inbound to outbound destinations, unimodal transport consists of transporting the π-containers from one carrier to another of the same type. Multimodal transport enables to transfer π-containers between the different means of transport. Recently, a new concept in transport has been developed that is synchromodal transport which extends the multimodal transport by adding new features. Despite the synergy between PI and synchromodal transport, no well-established interconnection has been denoted in the literature between these two concepts [52], which points out a problem that would benefit from being addressed in future researches.

Reference [19] proposed a dynamic pricing model for incomplete loading based on an auction mechanism to optimize the price of the carrier's bid. This article presents the first searches on the problem of the transport price in the PI.

References [40]-[42] proposed functional designs of three types of π-facilities: unimodal transit centers to transfer π-trailers from one truck to another, crossdocking π-hubs allowing the transshipment of π-containers from the incoming truck to the outgoing one, and rail-road π-hubs allowing the multimodal transfer of π-containers. They offered a detailed description of their components.

Reference [25] presented a hybrid approach of controlling the containers routing in a rail-road π-hub, and demonstrated its ability to cope with strong external disturbances such as train swapping as well as local disturbances such as the failure of the unit of transport. Reference [35] studied another approach of control of rail-road π-hubs able to cope with local disturbances affecting the transport network. In other side, [23] showed the robustness of cross-docking π-hubs by comparing the performance of a classic cross-dock and a π-hub one under the same product flow and under the same conditions.

References [27], [28] dealt with the assignment of the π-containers unloaded from the train to the available trucks, in two papers. In the first one, two methods (Heuristics and Metaheuristic) are implemented, tested and compared by using generated instances. The second one defined a multi-agent system taking into account disturbances for the allocating of π-containers. Reference [24] have studied the Road-Rail assignment problem as well. They proposed a mixed integer linear programming (MILP) mathematical model with the objective to minimize both the number of used wagons and the internal travel distance by the PI-containers from the PI-docks to the wagons. Moreover, they used heuristic and meta-heuristic methods to find better solutions.

Reference [37] introduced microzoning, a method that generates small compact areas, called microzones, which can be used as building blocks to design efficient service zones. They carried out a case study based on data of a parcel's delivery company. This study proved the effectiveness of this method in the daily route planning.

C. Distribution Web

Distribution Web is interested at creating open warehouses and distribution centers shared by a multitude of factories.

Reference [17] studied the gain in economic performances by exploiting the hyperconnected distribution system instead of a dedicated one. The results of the survey demonstrate a very significant financial gain by exploiting the hyperconnected distribution system.

Reference [21] measured the impact of PI on inventory levels and costs. They defined and tested several inventory control models called Physical Internet-based Inventory Control Models (PIICM) to explore the management of inventory routing in the PI context. The results showed that PI operations could reduce the system inventory level as well as the total logistics costs if the appropriate inventory control models are used.

Reference [26] studied the problems of inventory control for fast moving consumer goods, and proposed a control model for the π-inventories with four selection strategies of the sources of supplying. Continuing along this path, in 2017, they examined how inventory models apply PI address disturbances in hubs and factories, and they proposed an optimization model based on simulation to determine the inventory control decisions [30]. In addition, they studied the resilience of the PI facing the hubs disruption [22]. To achieve this, a multi-agent simulation model is developed, and two protocols of planning of transport are proposed and studied to cope with various profiles of disturbance: the avoidance of the risks and the taking risks. Reference [32] addressed the inventory management in the classical supply chain and the PI supply chain networks while considering possible perturbations during the delivery of goods between the hubs.

At an operational level, [29] proposed a generic model for solving the problem of resources location/allocation in the real supply chains in order to minimize the costs of ownership, transportation costs and handling costs. This model was verified by a real case study in the supply chain.

D. Realization Web

It consists of materializing products as locally as possible through the use of modular production in a hyperconnected framework via open and distributed production centers. Production is the most important node in the supply chain; however, there is very few publications in the Realization Web compare to the two previous ones presented.

Reference [6] presented interconnected modular production that consists in having open factories able of exploit modules of production to create products close to the markets. They gave two optimization models (for two production modes: make-to-order and make-to -stock) of decision-making related to the acquisition and deployment of modules as well as the realization, storage and delivery to the markets. In 2016, they introduced the notion of hyperconnected mobile production that allows companies to dynamically increase their production capacity in regions around the world. It is based on the convergence of eight production threads: distributed, outsourced, on-demand, modular, additive, mobile, containerized and hyperconnected production [5].

Reference [33] introduced the problem of planning the logistics of a multi-location production-inventory system with transportable production capacity and they propose well-performing heuristic methodologies to effectively manage its response to uncertainty. Also, they generalized this framework to allow the additional option of inventory relocation between locations and to capture non-stationary Markov-modulated demands with a partially observed modulation process.

E. Service Web

Reference [12] described a space of solution for omnichannel business-to-consumer supply chain facilitating and sharing access and use of services. The omnichannel business aims to allow customers to order anytime from anywhere, in person or via digital and mobile devices, and to be filled at their convenience, delivered or picked up on time and at any time where they prefer.

Reference [39] presented modular smart locker banks for pickup and delivery in the context of omnichannel business-to-consumer supply chains. They gave the conceptualization of hyperconnected smart lockers network designs as an alternative to home delivery for fast and convenient business-to-consumer pickups and deliveries. Reference [31] proposed a conceptual decision framework for dynamic capacity deployment of smart lockers, and they depicted the induced design and operational challenges, highlighting the potential benefits and trade-offs through an illustrative case.

F. Cluster Analysis & Future Research Directions

Cluster analysis deals with separating data into groups whose identities are not known in advance [49]. Considering the selected papers, we observe that half of the reviewed articles are about PI organization, and the other half about Logistics Web. This first observation shows that research encompasses different aspects of PI. However, we note that there is a lack of publications in some webs compared to others. For instance, from the 22 papers about Logistics Web, ten of them are about the Mobility Web. Therefore, further researches should be conducted in the other webs.

To provide relevant directions for future research about PI, we chose to concentrate on gaps in Logistics Web publications. We looked out for major topics to be treated in each web and compared them to the reviewed articles to look for additional research opportunities.

Under each of the logistics web, some attributes should be addressed in the literature. Table II resumes the major components of the Logistics Webs, as addressed by the literature.

In Fig. 8 the number of papers addressing different attributes of each Logistics Web is mentioned according to the decision level.

TABLE II
LOGISTICS WEB ATTRIBUTES

	Logistics Web
1	Mobility Web
1.1	Unimodal transport
1.2	Multimodal transport
1.3	Transport management
1.4	Innovation
2	Distribution Web
2.1	Distribution Center
2.2	Warehouse
2.3	Inventory control
2.4	Innovation
3	Realization Web
3.1	Production center (open fabs)
3.2	Production module
3.3	Demand management
3.4	Innovation
4	Service Web
4.1	Legal framework
4.2	Access rules & structure
4.3	Security

In the Mobility Web cluster, multimodal transport is more addressed in the literature compared to the unimodal one. For the transport management concerning route planning and cost determination, publications are very limited and may require more deep studies.

In the Distribution Web cluster, all papers except [17] are devoted to inventory control. There could be more studies for the conception and the handling of distribution centers and warehouses under the PI.

Publications in the Realization Web cluster are very limited, and just two relevant articles are found in the literature. References [5], [6] about hyperconnected mobile production are the major publications about the problem of goods production towards the PI. Studies showing significant improvement from the Realization Web need to be elaborated in the light of these articles, and more interest ought to be addressed for the conception and the treatment of production centers and modules.

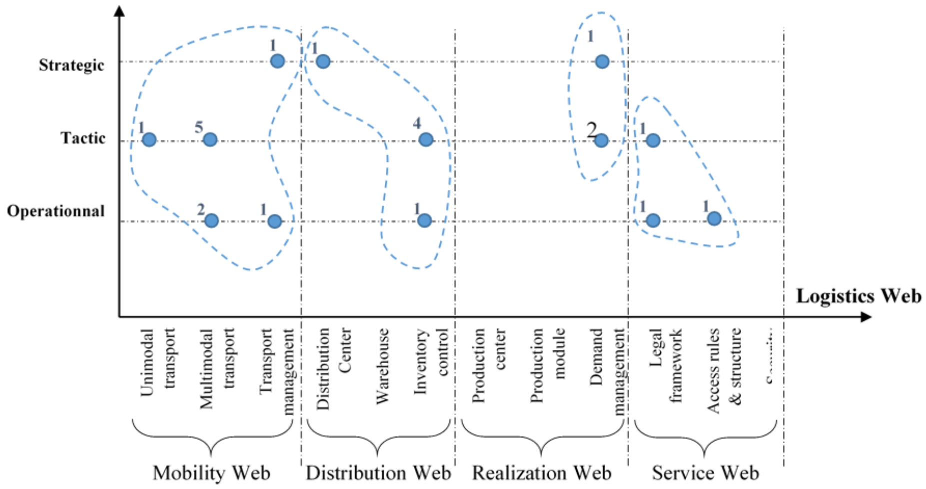

Fig. 4 Cluster Analysis

TABLE III
FUTURE RESEARCHES RELATED TO THE LOGISTICS WEB

Research topic	Future Studies
Mobility Web	• Improve suggested designs of: π-transit centers, π-hubs and π-crossdocking to be smarter; • Improve the robustness of reactive routing approach and further study external disturbances and uncertainties for unimodal and multimodal transport; • Address the coordination of the allocation problem with the routing problem in the π-hub; • Extend [19] to encompass the three characteristics of PI auction time: the demand path, the carrier, and the size of the demand; • Carry out more optimization studies of the allocation in the railroad π-hub;
Distribution Web	• Study the potential effect of PI on the famous Bullwhip effect; • Conduct more studies on the performance of inventory control policies; • Improve control approaches to distribution centers and inventories for PI; • Study decision-making methods for inventory management face to supply chain disruptions; • Analyze the environmental and social aspects of the exploitation of hyperconnected distribution and transport;
Realization Web	• Develop and simulate hyperconnected mobile production (HMP) process; • Expand researches on modular production to focus on Plug-and-Play capability and standardized encapsulation of containerized production modules; • Develop optimization models of HMP and study the impact of demand disturbances; • Conduct pilot tests in the industry to assess HMP potentialities and discover all the hidden obstacles;
Service Web	• Study the security of goods transportation in the world through the PI system; • Develop standards to ensure access and use of PI services in all transparency; • Design an open network of worldwide services;

Recently, interest in to the Service Web increased and some studies were established concerning legal framework and service structures; however, more research is required to ensure access and use of PI services in all transparency.

Moreover, it is undeniable to ensure the safety and security of goods transportation in the world through this system, and try to maintain peace in our tumultuous societies including individuals from different racial, cultural and ideological backgrounds. Security at the PI system requires more documentation and research to create an efficient and sustainable secure system.

The analysis of the reviewed publications reveals that the Logistics Web requires more research in order to build a solid foundation for the PI system. Table III resumes some PI questions to be answered by future studies related to the major components of the logistics webs, as addressed by the literature.

V. Conclusion

In this paper, a general taxonomy for the PI has been proposed. Several papers have been classified and analyzed along the Logistics Web, resources and organization views at a strategic, tactical and operational level, respectively. In addition, we presented an extensive review of the literature that allows concluding that the majority of papers primarily deal with the problems of transportation and storage.

Our review further shows that many Logistics Web problems were treated in the literature, but at the same time, publications are limited in some Webs. Even though this review may not be exhaustive, it highlights some gaps in the literature and helps researchers finding relevant topics.

Clearly, the state of the art of the PI has more enriched since 2014. It attracted more attention from researchers; and PI will benefit from future researches that will cover the gaps identified in the paper.

Acknowledgment

The authors are grateful to the LABSIP laboratory and to CED of Chouaïb Doukkali University for their involvement in the project.

References

[1] B. Montreuil, "Toward a Physical Internet: meeting the global logistics sustainability grand challenge," Logistics Research, vol. 3, pp. 71-87, 2011.

[2] E. Ballot, B. Montreuil, and R. D. Meller, "The physical internet: The network of logistics networks," (English language adaptation of Ballot & Montreuil (2014)), La Documentation Française, Paris, France, 205p, 2014.

[3] B. Montreuil, R. D. Meller, and E. Ballot, "Physical Internet foundations," in Service orientation in holonic and multi agent manufacturing and robotics, ed: Springer, pp. 151-166, 2013a.

[4] B. Montreuil, R. D. Meller, and E. Ballot, "Towards a Physical Internet: the impact on logistics facilities and material handling systems design and innovation," in Progress in Material Handling Research 2010, Edited by K. Gue et al., Material Handling Industry of America, p. 305-328, 2010.

[5] S. Marcotte and B. Montreuil, "Introducing the concept of hyperconnected mobile production," Progress in Material Handling Research, 2016.

[6] S. Marcotte, B. Montreuil, and L. Coelho, "Modeling of Physical Internet Enabled Interconnected Modular Production," in 2nd International Physical Internet Conference, Paris, France, 2015.

[7] A. Reisman, Management science knowledge: its creation, generalization, and consolidation: Quorum Books, 1992.

[8] B. Montreuil, E. Ballot, and F. Fontane, "An open logistics interconnection model for the Physical Internet," IFAC Proceedings Volumes, vol. 45, pp. 327-332, 2012a.

[9] G. Tretola, V. Verdino, and D. Biggi, "A Common Data Model for the Physical Internet," in 2nd International Physical Internet Conference. Paris, France, 2015, pp. 1–16.

[10] B. Montreuil, J.-F. Rougès, Y. Cimon, and D. Poulin, "The Physical Internet and business model innovation," Technology Innovation Management Review, vol. 2, 2012b.

[11] P. Oktaei, D. Hakimi, N. Lehoux, B. Montreuil, and C. Cloutier, "Impact of Geographic Locations on the Business Model of Physical Internet Enabled Transit Centers," in 2nd International Physical Internet Conference. Paris, France, 2015, pp. 6-8.

[12] B. Montreuil, "Omnichannel Business-to-Consumer Logistics and Supply Chains: Towards Hyperconnected Networks and Facilities," Progress in Material Handling Research, vol. 14, Ed. K. Ellis et al., MHI, Charlotte, NC, USA. 2016.

[13] S. Rhafir, D. Riopel, and B. Benbba, "Internet physique au Maroc: vers une logistique efficiente et durable," Revue Marocaine de recherche en management et marketing, 2015.

[14] P. Furtado and J.-M. Frayret, "Impact of resource sharing of freight transportation," in First International Physical Internet Conference. Québec City, Canada, May, 2014, pp. 28-30.

[15] R. Sarraj, E. Ballot, S. Pan, D. Hakimi, and B. Montreuil, "Interconnected logistic networks and protocols: simulation-based efficiency assessment," International Journal of Production Research, vol. 52, pp. 3185-3208, 2014.

[16] Y.-H. Lin, R. D. Meller, K. P. Ellis, L. M. Thomas, and B. J. Lombardi, "A decomposition-based approach for the selection of standardized modular containers," International Journal of Production Research, vol. 52, pp. 4660-4672, 2014.

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

[18] E. Ballot and B. Montreuil, "Transport Items and Physical Internet Handling Boxes: a Comparison Framework Across Supply Chains," 2016.

[19] B. Qiao, S. Pan, and E. Ballot, "Dynamic pricing model for less-than-truckload carriers in the Physical Internet," Journal of Intelligent Manufacturing, pp. 1-13, 2016.

[20] V. A. Hauder, E. Pitzer, and M. Affenzeller, "Optimization Approaches for the Physical Internet," in OTM Confederated International Conferences" On the Move to Meaningful Internet Systems", pp. 236-245, 2017.

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

[22] Y. Yang, S. Pan, and E. Ballot, "Freight Transportation Resilience Enabled by Physical Internet," IFAC-PapersOnLine, vol. 50, pp. 2278-2283, 2017b.

[23] T. Chargui, A. Bekrar, M. Reghioui, and D. Trentesaux, "Simulation for PI-Hub Cross-Docking Robustness," in Service Orientation in Holonic and Multi-Agent Manufacturing, ed: Springer, pp. 317-328, 2018a.

[24] T. Chargui, A. Bekrar, M. Reghioui, and D. Trentesaux, "Road-Rail Assignment Problem: Mathematical Formulation, Heuristic and Tabu Search," Proceedings of the 5th International Physical Internet Conference, Groningen, Netherland, 2018b.

[25] Y. Sallez, T. Berger, T. Bonte, and D. Trentesaux, "Proposition of a hybrid control architecture for the routing in a Physical Internet cross-docking hub," IFAC-PapersOnLine, vol. 48, pp. 1978-1983, 2015.

[26] Y. Yang, S. Pan, and E. Ballot, "A model to take advantage of Physical Internet for vendor inventory management," IFAC-PapersOnLine, vol. 48, pp. 1990-1995, 2015.

[27] F. Walha, S. Chaabane, A. Bekrar, and T. M. Loukil, "A Simulated Annealing Metaheuristic for a Rail-Road PI-Hub Allocation Problem," in Service Orientation in Holonic and Multi-agent Manufacturing, ed: Springe, pp. 307-314 r, 2015.

[28] F. Walha, A. Bekrar, S. Chaabane, and T. M. Loukil, "A rail-road PI-hub allocation problem: Active and reactive approaches," Computers in Industry, vol. 81, pp. 138-151, 2016.

[29] S. Raggl, M. Affenzeller, E. Lengauer, and A. Hübl, "Network on Demand Planning of Supply Chains Towards Physical Internet," in FFH Forum, pp. 1-6, 2016.

[30] Y. Yang, S. Pan, and E. Ballot, "Mitigating supply chain disruptions through interconnected logistics services in the Physical Internet,"

International Journal of Production Research, vol. 55, pp. 3970-3983, 2017a.

[31] L. Faugere, S. S. Malladi, D. C. White III, and B. Montreuil, "Smart Locker Based Access Hub Network Capacity Deployment in Hyperconnected Parcel Logistics," Proceedings of the 5th International Physical Internet Conference, Groningen, Netherland, 2018.

[32] M. Nouiri, A. Bekrar, and D. Trentesaux, "Inventory Control under Possible Delivery Perturbations in Physical Internet Supply Chain Network," Proceedings of the 5th International Physical Internet Conference, Groningen, Netherland, 2018.

[33] S. S. Malladi, "Data-Driven Reconfigurable Supply Chain Design and Inventory Control," Doctoral dissertation, Georgia Institute of Technology, 2018.

[34] T. G. Crainic and B. Montreuil, "Physical internet enabled Hyperconnected City logistics," Transportation Research Procedia, vol. 12, pp. 383-398, 2016.

[35] N.-V. Vo, T. Berger, T. Bonte, and Y. Sallez, "Control of Rail-Road PI-Hub: The ORCA Hybrid Control Architecture," in Service Orientation in Holonic and Multi-Agent Manufacturing, ed: Springer, pp. 291-302, 2018.

[36] R. Y. Zhong, Y. Peng, J. Fang, G. Xu, F. Xue, W. Zou, et al., "Towards Physical Internet-enabled prefabricated housing construction in Hong Kong," IFAC-PapersOnLine, vol. 48, pp. 1079-1086, 2015.

[37] B. Schellens MSc and F. Cruijssen, "Microzoning: A grid based approach to facilitate last-mile delivery," Proceedings of the 4th International Physical Internet Conference, Graz, Austria, 2017.

[38] A. Rahimi, Y. Sallez, and T. Berger, "Framework for Smart Containers in the Physical Internet," in Service Orientation in Holonic and Multi-Agent Manufacturing, ed: Springer, pp. 71-79, 2016.

[39] L. Faugere and B. Montreuil, "Hyperconnected Pickup & Delivery Locker Networks," Proceedings of the 4th International Physical Internet Conference, Graz, Austria, 2017.

[40] B. Montreuil, R. D. Meller, C. Thivierge, and Z. Montreuil, Functional design of Physical Internet facilities: a unimodal road-based crossdocking hub: CIRRELT, Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport= Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation, 2013b.

[41] E. Ballot, B. Montreuil, and C. Thivierge, "Functional design of Physical Internet facilities: a road-rail hub," in Progress in Material Handling Research Vol. 12, Ed. B. Montreuil, A. Carrano, K. Gue, R. de Koster, M. Ogle & J. Smith, MHI, Charlotte, NC, USA, pp. 28-61, 2014.

[42] R. D. Meller, B. Montreuil, C. Thivierge, and Z. Montreuil, "Functional design of physical internet facilities: a road-based transit center," in Progress in Material Handling Research, vol. 12, Ed. B. Montreuil, A. Carrano, K. Gue, R. de Koster, M. Ogle & J. Smith, MHI, Charlotte, NC, USA, pp. 347-378, 2014.

[43] C. Landschützer, F. Ehrentraut, and D. Jodin, "Containers for the Physical Internet: requirements and engineering design related to FMCG logistics," Logistics Research, vol. 8, p. 8, 2015.

[44] Y. Sallez, S. Pan, B. Montreuil, T. Berger, and E. Ballot, "On the activeness of intelligent Physical Internet containers," Computers in Industry, vol. 81, pp. 96-104, 2016.

[45] H. Treiblmaier, K. Mirkovski, and P. Lowry, "Conceptualizing the physical internet: Literature review, implications and directions for future research," in 11th CSCMP Annual European Research Seminar, Vienna, Austria, May, 2016.

[46] H. Sternberg and A. Norrman, "The Physical Internet–review, analysis and future research agenda," International Journal of Physical Distribution & Logistics Management, vol. 47, pp. 736-762, 2017.

[47] S. Pan, E. Ballot, G. Q. Huang, and B. Montreuil, "Physical Internet and interconnected logistics services: research and applications," International Journal of Production Research , pp. 2603-2609, 2017.

[48] R. D. Meller, Y. Lin, and K. Ellis, "The impact of standardized Physical Internet containers on shipping volume," Proceedings of ILS, vol. 2012, p. 4, 2012.

[49] D. S. Wilks, "Cluster analysis," in International geophysics. vol. 100, ed: Elsevier, pp. 603-616, 2011.

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

[51] C. T. Ha, T. T. Nguyen, L. T. Bui, and R. Wang, "An online packing heuristic for the three-dimensional container loading problem in dynamic environments and the Physical Internet." European Conference on the Applications of Evolutionary Computation. Springer, Cham, 2017.

[52] T. Ambra, A. Caris, and C. Macharis. "Towards freight transport system unification: reviewing and combining the advancements in the physical internet and synchromodal transport research." International Journal of Production Research, pp. 1606-1623, 2019.

[53] M. Maslarić, S. Nikoličić, and D. Mirčetić. "Logistics response to the industry 4.0: the physical internet." Open engineering 6.1, 2016.