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Physical Internet Foundations†

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Abstract. This paper provides insights into the foundations of the Physical Internet that has been introduced as a solution to the Global Logistics Sustainability Grand Challenge [1-2]. The Challenge sets as its goal to improve, by an order of magnitude, the economic, environmental and social efficiency and sustainability of the way physical objects are moved, stored, realized, supplied and used across the world. The paper introduces a formal definition of the Physical Internet 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. In line with the proposed definition, this chapter explains and provides insights into eight foundations of the Physical Internet: a means for logistics efficiency and sustainability, universal interconnectivity, encapsulation, standard smart interfaces, standard coordination protocols, logistics web enabler, an open global logistics system, and driven by innovation.

Keywords. Physical Internet, logistics system, efficiency, sustainability, interconnectivity, encapsulation, protocols, interfaces, business model, innovation.

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1 INTRODUCTION

Logistics has become the backbone of our lifestyle, for example enabling us to eat fruit from across the world all year round at affordable prices. Similarly, in recent decades it has grown to be the backbone of the e-commerce of goods, enabling us to get products purchased on e-retailer web sites and marketspaces, delivered to our home or nearby location at prices and delays competitive with traditional retailing. Globally, it has become the backbone of world trade, notably through the efficiency of container shipping and handling across continents. At face value, current logistics can thus be perceived as achieving great performance. Yet it is the victim of its own success. Indeed, as we will make explicit in section 2 of this chapter, a deeper investigation reveals that, from economic, environmental and societal perspectives, it is facing harsh inefficiency and unsustainability drawbacks..

The Physical Internet (PI, π) concept has been recently introduced as a response to the Global Logistics Sustainability Grand Challenge [1,2]. The Physical Internet has been thus named as such to emphasize (1) its exploitation of the Digital Internet, (2) its tackling of the need for seamless interconnection of logistics services, and (3) the expected magnitude of required change.

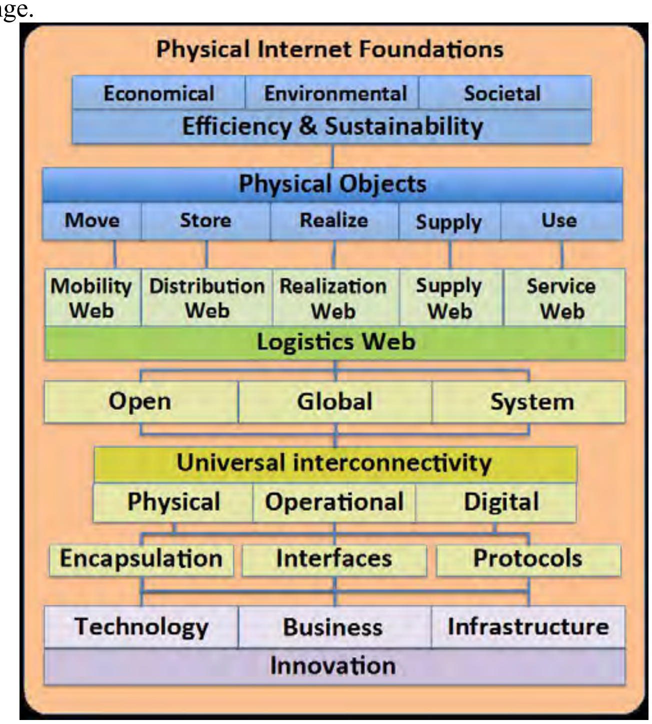

Fig. 1. Physical Internet Foundations Framework

We define the Physical Internet 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. In line with this definition, in this chapter we provide insights into the foundations of the Physical Internet. We use the framework depicted in Figure 1 to structure our discourse.

Section 2 of the chapter focuses on the first foundation on the Physical Internet, being a means for efficiency and sustainability. Then sections 3 to 6 highlight the foundations related to the Physical Internet core: universal interconnectivity, standard encapsulation, standard smart interfaces and standard coordination protocols. Section 7 focuses as another key foundation of the PI, being an enabler for a Logistics Web, similar to how the Digital Internet has enabled the World Wide Web and its world of applications for users. Section 8 highlights the seventh foundation, the fact that the Physical Internet has to be an open global system. Section 9 emphasizes, as the last foundation we present, the fact that the Physical Internet is to be in perpetual evolution driven by technological, business and infrastructural innovation. Finally, section 10 provides concluding remarks.

2 MEANS FOR LOGISTICS EFFICIENCY AND SUSTAINABILITY

A first foundation is that the Physical Internet is a means to an end, not an end by itself.

It has indeed been introduced as a response to the Global Logistics Sustainability Grand Challenge to improve, by an order of magnitude, the economic, environmental and social efficiency and sustainability of the way physical objects are moved, stored, realized, supplied and used across the world, indeed of logistics in its broadest sense [1,2].

Logistics is efficient when it serves the needs for moving, storing, realizing, supplying and using physical objects with minimal economical, environmental and societal resources overall. It is sustainable when it is capable of maintaining high economical, environmental and societal performance over the long run, capable of facing the risks and challenges associated with a dynamic, changing and fast-evolving context, contributing to a better world for future generations.

From an economic perspective, logistics is a high percentage of the gross domestic product of most countries so gains in reducing logistics-induced wastes would have significant impact on the productivity and competitiveness of companies and countries. From an environmental perspective, the huge negative contribution of logistics to greenhouse gas emission, non-renewable fuel-based energy consumption, pollution and materials waste must be reduced drastically if we are to meet environmental goals towards a greener planet. From a societal perspective, the precarious work conditions and high turnover rates in logistics can be drastically improved. Society at large would greatly benefit form reducing the congestion inflated by logistics-induced freight transportation and by enabling easier, cheaper and more reliable accessibility and mobility of physical objects across the world. Encompassing these three perspectives, thirteen broad symptoms for the overall inefficiency and unsustainability of the current logistics system have been revealed in [1,2].

Figure 2 illustrates the challenge of required changes using the emblematic CO_2 emissions as an example. The data are provided in [3-5]. Using Europe as an example, it highlights the significant growth in both tons-kilometers travelled and CO_2 emissions form 1990 to 2010, showing that current emission levels are way above the European goals for 2050 [3].

This example goes to the heart of what is meant by saying that the Physical Internet means to affect by an order of magnitude the performance of the logistics system. That is, key economic, environmental and societal efficiency and sustainability performance indices will be reduced from their initial value of P to P/N, where N is an integer aimed to be at least equal to 2 (and hopefully higher). As displayed in Figure 2, the European goal for freight transportation induced greenhouse gas emissions is a reduction to 1/3 the 2010 level by 2050 (i.e., N=3).

Clearly, multiple avenues have to be explored to address the overall grand challenge. More energy-efficient and greener transportation means and the reliance on smart grids for providing as cheap as possible renewable energy usable for logistics purposes are two well known avenues. The Physical Internet, with its systemic focus on the organization of logistics, opens a promising complementary new avenue.

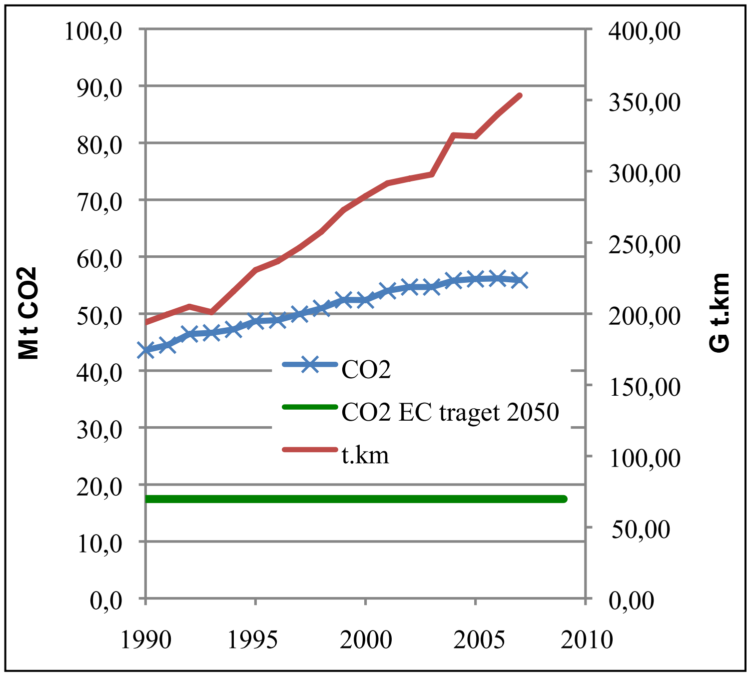

Fig. 2. European CO2 target for 2050 freight transportation emissions compared to actual emissions: the required magnitude of change

3 UNIVERSAL INTERCONNECTIVITY

Interconnectivity refers to the quality of a system to have its components seamlessly interconnected. From a logistics perspective, it means easing the movement of physical entities from one component to another, their storage or treatment within any of its capable constituents, as well as responsibility sharing and contracting between actors.

The Digital Internet was designed and implemented for interconnectivity. Its interconnected digital service architecture, initially conceptualized using the seven-layer open systems interconnection (OSI) model has been simplified in practice to a four-layer TCP/IP model due to the interconnection inefficiencies created by the management of interfaces and protocols between too many layers. There is indeed perpetual argumentation aimed towards ever efficient and sustainable interconnectivity, as exemplified by network working group request for comments 3439 outlining philosophical guidelines for Digital Internet backbone network architecture and design [6].

Similarly, a second foundation of the Physical Internet is universal interconnectivity. It is the key to making the Physical Internet open, global, efficient and sustainable system.

The aim when conceptualizing and implementing the Physical Internet is towards universal interconnectivity so as to permit a high degree of co-operation. This co-operation is not meant to necessarily be part of a formal, rigid collaboration agreement, but rather developed on the fly from a detailed set of exchange and coordination protocols.

As depicted in Figure 1, this universal interconnectivity is to be achieved through interlaced physical, digital and operational interconnectivity.

Physical interconnectivity is about making sure that any physical entity can flow seamlessly through the Physical Internet. As will be made more explicit in section 4, in order to achieve this physical interconnectivity, physical objects are encapsulated in standard modular Physical Internet containers. This enables physical objects to be be moved, handled and stored ubiquitously, provided that are respected constraints due to factors such as size, weight, security and conditioning. They can also be physically transferred from one means or mode to another seamlessly.

Digital interconnectivity ensures that physical entities, constituents and actors can seamlessly exchange meaningful information across the Physical Internet, fast knowledge and fact-based decision-making and action. This includes tracking of objects within the Physical Internet, message passing among virtual agents and human actors within the Physical Internet, visibility about the state of demand, offer and flow, and so on. The Internet of Things [7] is to be a major enabling technology towards that goal.

Operational interconnectivity is about ensuring that in-the-field operational processes as well as the business processes are seamlessly interlaced so that it is easy and efficient for users to exploit Physical Internet for fulfilling their logistics needs and for Physical Internet constituents to seamlessly collaborate in serving the logistics users of Physical Internet users. This includes designing and using standardized business contracts and incoterm-type modalities as well as implementing and respecting operational protocols.

Universal interconnectivity in the Physical Internet is to be enabled through the integrated exploitation of encapsulation, interfaces and protocols.

4 ENCAPSULATION

The Digital Internet deals only with information that is encapsulated in standard data packets whose format and structure are equipment independent. All protocols and interfaces in the Digital Internet are designed so as to exploit this standard encapsulation. In this way, data packets can be processed by different systems and through various networks: modems, copper wires, fiber optic wires, routers, etc.; local area networks, wide area networks, etc.; Intranets, Extranets, Virtual Private Networks, etc. [8,9].

On the large side, physical logistics systems today exploit the world-standard 20- and 40-foot cargo container for transport, handling and storage [10]. On the small side, parcel standardization is deployed and exploited by logistics giants such as DHL, FedEx, Purolator and UPS.

The Physical Internet generalizes and significantly extends this practice by encapsulating physical objects in physical packets or containers, hereafter termed π-containers so as to differentiate them from current containers, packets, boxes and so on. These π-containers are world-standard, smart, ecofriendly and modular. They are modularized and standardized worldwide in terms of dimensions, functions and fixtures. They are designed to be easy to load, unload, handle, store, transport, seal, snap and interlock with each other. They are made of light, ecofriendly materials, and have a small footprint when off service. The Physical Internet deals directly with the π-containers, not with the freight, merchandises, products and materials that are encapsulated within them. This allows all transportation, handling and storage devices, means and systems to be designed and engineered to exploit this standard, modular encapsulation.

Thus, in the Physical Internet, there are no generic, all-purpose material handling and storage systems. There are only π-container material handling and storage systems, embedding innovative technologies and processes exploiting the characteristics of π-containers to enable their fast, cheap, easy and reliable input, storage, composing, decomposing, monitoring, protection and output through smart, sustainable and seamless automation and human handling [1,11].

The Physical Internet drives product design for encapsulation. Indeed any product having to flow through the Physical Internet contributes to logistics efficiency and sustainability by being designed and engineered so as to minimize the load it generates on the Physical Internet, with dimensions adapted to standard container dimensions.

The Physical Internet also relies heavily on informational and communicational encapsulation. It interacts with the smart π-containers, not with the products they embed. If desired by the user, π-containers can communicate with their embedded physical objects when these are smart and have communications capabilities using the concepts of the Internet of Things. Then the π-containers relay any information pertinent.

In fact, the π-container creates a private space within its envelope, wherever it is currently located, drastically reducing the need for dedicated or proprietary facilities and networks.

5 STANDARD SMART INTERFACES

Interfaces are critical for achieving efficient and sustainable universal interconnectivity. Four types of interfaces have paramount importance in the Physical Internet: fixtures, devices, nodes, and platforms.

At the basic physical level, functionally standard and modular physical fixtures are necessary for ensuring that π-containers can flow smoothly through the Physical Internet. Each π-container is equipped with such fixtures that allow them to interlock with each other, to be snapped to a storage structure, to be secured on a carrier, to be conveyed easily, and so on. Each physical constituent of the Physical Internet, such as a π-carrier, π-store or a π-conveyor, is similarly equipped with complementary fixtures.

At the basic information and communication level, devices are critical interfaces. Each smart π-container has a smart tag to act as its representing agent connected into the Internet of Things. The smart tag provides the correct codification of information that helps ensure the identification, integrity, routing, conditioning, monitoring, traceability and security of each π-container. It also enables distributed handling, storage and routing automation [11].

At a higher operational level, critical interfaces are the logistics π-nodes. For example, π-gateways enable efficient and controlled entry of π-containers into the Physical Internet as well as their exit from the Physical Internet. As another example, π-transits allow the smooth unimodal and multimodal transfer of π-carriers between π-vehicles. As a final example, π-hubs enable the smooth unimodal or multimodal transfer of π-containers from carriers to carriers along their route through the Physical Internet. The logistics π-nodes, through their standardized operational interfacing, are key to the scalability of the Physical Internet, ensuring that wherever one is around the planet, the interaction with such nodes is to be the same.

At a higher information and communication level, digital middleware platforms are pivotal interfaces in enabling the open market for logistics services in the Physical Internet as well as the smooth systemic operation of the interacting π-constituents and routing of π-containers from source to destination through the Physical Internet. These π-platforms are enabling human-human, human-agent and agent-agent interfacing.

6 STANDARD COORDINATION PROTOCOLS

Protocols are at the core of the Digital Internet, as illustrated by the central role played by the TCP/IP communications protocol suite. Similarly, such a suite of world-standard protocols is a fifth foundation of the Physical Internet.

The main idea behind the protocols is enabling concurrent global coordinated networks without entering in one-to-one, or even more complex many-to-many, collaborative agreements. The coordination is ensured through adherence to the protocols, thus not imposing special collaboration contracts.

Basic protocols validate the physical integrity of π-containers and other physical π-constituents flowing through the Physical Internet. They guide the transfer of π-containers from one π-constituent to another. In line with Internet-of-Things guidelines, a universal protocol assigns a unique identification number to each π-container and each π-constituent.

Higher-level protocols focus on the integrity and performance of the π-networks, the routing of π-containers through these π-networks, the management of shipments and deployments of π-containers through the Physical Internet. There are π-contracting protocols exploiting standard π-contract formats for logistics services within the Physical Internet. This set of protocols can be seen as an extension of current International Commercial Terms, usually named INCOTERMS.

A key protocol set ensures that the Physical Internet relies on live open monitoring of achieved and foreseeable performance of all its actors and constituents, focusing on key performance indices of critical facets such as speed, service level, reliability, safety and security. This protocol set brings about the required transparency ensuring that logistics decisions are backed by fact-based evidence.

A highest-level protocol is used for multi-level Physical Internet capability readiness certification of containers, handling systems, vehicles, devices, platforms, ports, hubs, roads, cities, regions, protocols, processes and so on.

The Physical Internet network of networks has to warrant its own reliability and resilience, and that of its containers and shipments through its intrinsic nature, its protocols and its structure. The webbing of the networks and the multiplication of nodes should allow the Physical Internet to ensure its own robustness and resilience [12] to unforeseen events. For example, if a node or part of a network fails, protocols have to ensure that the traffic of π-containers is easily re-routable as automatically as possible.

7 LOGISTICS WEB ENABLER

As reported in the Wikipedia page devoted to the World Wide Web [13], the World Wide Web is a system of interlinked hypertext documents accessed via the Internet. With a web browser, one can view web pages that may contain text, images, videos, and other multimedia, and navigate between them via hyperlinks. In the information and communications technology world, the terms (Digital) Internet and World Wide Web are often used in everyday speech without much distinction. However, the Digital Internet and the World Wide Web are not one and the same. The Digital Internet is a global system of interconnected computer networks while the World Wide Web is one of the services that run on the Internet. It is a collection of text documents and other resources, linked by hyperlinks and URLs, usually accessed by web browsers from web servers. In short, the Web can be thought of as an application "running" on the Internet [13].

The World Wide Web and its applications, as well as its mobile variants, are the nexus of Internet usage for most people, indeed taking the underlying Digital Internet as a given, as long as it does not break down or gets too slow.

In order to achieve its noble ambition, the Physical Internet aims to en-able an efficient and sustainable Logistics Web. As this Logistics Web is to involve a more complex setting than the interplay between a user and software, we hereafter enrich the semantic underlying a Logistics Web.

In general, a web can be defined as a set of interconnected actors (entities) and networks, or a network of networks, offering services to each other and/or to external users. In the Physical Internet context, the types of actors and networks can be characterized, leading to define a web as a set of inter-connected physical, digital, human, organizational and social agents and networks.

A Web (with capital W) is here differentiated from any web by the fact that a Web is both open and global. Globalism here infers both a universal worldwide scope and a multi-scale microscopic-to-macroscopic scope. Openness is here referring to the accessibility, willingness and availability of actors and networks to deal with any actor or network. There may exist webs that are not open to everyone, and may be limited to some geographical territory and/or domain.

A logistics web is defined as a web aiming to serve logistics needs of people, organizations, communities and/or society. A Logistics Web is a logistics web that is both open and global.

As logistics is a broad loaded concept, it is useful to decompose a logistics web into five constituent webs: a mobility web focused on moving physical entities, a distribution web focused on storing and deploying objects, a realization web focused on realizing (making, assembling, personalizing, etc.) objects, a supply web focused on supplying and acquiring access to and/or property of objects, and a service web focused on using objects, on gaining access to the functionality provided by objects.

7.1 Mobility Web

A mobility web is aiming to serve the needs for the mobility of physical entities, encompassing people and other living beings as well as physical objects such as goods and materials. Mobility is about moving (transport, handle) these entities from sources to destinations. The Mobility Web is expected to enable seamless, efficient and reliable multimodal, multi-segment transportation and handling of beings and goods within facilities and sites, across cities and regions, and around the world.

As a simple example, ultimately a shipper would encapsulate its to-be-shipped goods in a set of π-containers. He would either bring these to the nearest Physical Internet gateway or request a transporter to come and pick them up. He would inform each π-container of its destination, its target arrival time window and its assigned budget, and would tell it to inform him of its arrival or of any event leading it to assess that it could not get to the destination in time on budget. For this shipper, the actual paths followed by the π-containers across the Physical Internet would not be of interest to him, except for monitoring and exception management purposes. The Mobility Web would ease the work for this shipper and take care in a distributed manner of all transport and handling services involved in delivering the requested mobility service. The actual transport and handling activities would be performed by the Physical Internet actors and constituents, with the π-containers being moved from source to final destination through a series of logistics nodes acting as relays, being efficiently consolidated by next destination at each relay and assigned to the best fitting transport mode for its next segment.

7.2 Distribution Web

A distribution web aims to serve the needs for distributing physical objects. In a Physical Internet context, these objects are embedded in modular, green, smart, world standard π-containers. Distribution is here about dynamically deploying objects through a territory to serve a market, a set of clients for these objects. Deployment focuses on where to store objects at any given time. As a physical transposition of digital cloud storage, the Distribution Web is expected to enable seamless, efficient and reliable distributed streaming deployment of encapsulated goods within myriads of open distribution centers across the world. Ultimately most distribution centers and warehouses across the world would accept to be certified for the Distribution Web, as they would have gradually be adapted to receive, store and ship generic π-containers.

As a simple example, contrast the current case of a small or medium size Canadian manufacturer whose products are sold on the Internet to consumers across North America through a number of e-retailers, with its equivalent exploiting a Distribution Web. Bounded by his financial capacity, the manufacturer currently has three distribution centers: one in Canada, one in the U.S.A. and one in Mexico. In these distribution centers, the manufacturer stores its inventory of products, for example, with an average stock of two-months of demand, with some high demand products having just a few weeks of demand while long tail products could have many months worth of demand. Each e-retailer has a partnering third-part logistics provider (3PL) responsible to move products from the hub where it is brought by a manufacturer to the consumer shipping location. Each day the manufacturer has to analyze its received orders from consumers, to decide from which hub the each order is to be fulfilled, to consolidate these orders by nearest 3PL hub and to request a transporter to move the π-containers to these hubs, most often at least a truck to each hub or nearby hubs. Through this current setting, some consumers would get their products within a day after shipment while others might have to wait more than ten days.

With a Physical Internet enabled Distribution Web, the manufacturer would alternatively deploy in a dynamic fashion its products through a wide set of distribution centers, located for example within a day of all significantly active markets in North America. He would shuffle product-encapsulating π-containers around as demand materializes, higher than expected in some markets, lower than expected in other markets. He would ship its products from the nearest-to-consumer distribution center exploiting the Mobility Web. The manufacturer is in a much better service position, capable of fast delivery all across North America. Expansion to other markets around the world is facilitated as the manufacturer can exploit the Mobility and Distribution Webs in targeted international markets.

7.3 Realization Web

A realization web is similarly aimed to serve the needs for realizing physical objects, extending widely the current contract manufacturing capabilities and scope. Realization is a generic term used to encompass manufacturing, production, assembly, finishing, personalization, retrofitting, recycling and other such activities. Realization is about making and dismantling physical objects, from materials to components and modules all the way to products and systems. In the spirit of digital cloud computing, the Realization Web is expected to enable realizing physical products in a distributed way using open realization centers from all around the world. Such open centers are capable of locally realizing for clients a wide variety of products from combinations of digitally transmitted specifications, local physical objects and, if necessary, critical physical objects brought in from faraway sources through the Mobility and Distribution Webs. Relative to the Physical Internet, it is important to note that the Realization Web goes beyond moving and storing π-containers, requiring to actually dealing with the products themselves as well as their constituents. It notably involves for contract manufacturers and their clients to develop open realization and certification capabilities.

Continuing the manufacturer example used for illustrating the Distribution Web, here the focus is not on where to deploy manufactured products. It is rather on where to manufacture products. Let us say that the manufacturer currently offers ready-to-assemble products to his e-clientele that he makes in three factories located in Canada, Mexico and the U.S.A., nearby its three distribution centers. Access to a realization web with open assembly centers certified for assembly of the manufacturer's products and spread across North America would enable him to extend his e-commerce offering to assembled products (1) without the high cost of transporting lower-density assembled products across vast distances and (2) with a fast-delivery capability. Similarly, he can exploit the realization web for extending and/or virtualizing its ready-to-assemble product manufacturing capacity and flexibility through distributed, open and certified manufacturing centers.

7.4 Supply Web

A supply web aims to serve the needs for supplying physical objects. It is about sourcing, acquiring, buying and securing access to materials, parts, assemblies, products, as well as systems. Whereas the Distribution Web basically takes the overall inventory as a higher-level decision, such decisions as order/reorder quantities from suppliers are central in a supply web context. Key actors in any supply webs are suppliers, contractors and providers connected through an open platform and exploiting the Mobility, Distribution and Realization Webs for supplying physical objects and services worldwide, expectedly enabling fast, efficient, reliable and resilient supply chains and networks. The Physical Internet indirectly enables high levels of supply web performance by enabling suppliers to offer their products much faster, cheaper and more reliably in vast territories.

In the manufacturer example, we showed that product assembly could be realized through a set of geographically distributed open realization centers. Yet assembly requires a set of components available for assembly. When these components come from numerous suppliers, with some near the current factories and others from around the world, their supply to a large set of realization centers with time variable assembly assignments may well be deterrent to get going with exploiting the realization web for product assembly. Assume now that many current and potential suppliers (1) are connected to the Supply Web and (2) are fully competent and capable in exploiting the Physical Internet enabled Mobility, Distribution and Realization Webs. In such a context, then the potentiality of the supply network becomes an attractor rather than a deterrent for the manufacturer. He will have to pay less to get his components delivered where he needs them, he will have to maintain much less inventory of components to insure the required service level, and so on.

7.5 Service Web

A service web aims to serve the needs for physical object usage. It is focusing on the accessibility of the services provided by, through, and with physical goods and beings. The Service Web is expected to enable efficient and sustainable cooperative consumption on a worldwide basis, such as peer-to-peer lending and sharing of goods and facilities. Also, instead of bringing specialists into locations that are time-consuming, costly and risky to reach, the Service Web is expected to enable them to be virtually present, interacting just-in-time with field personnel through mobile telepresence, access to sensor-fed information, and physical (testing) equipment brought through the Mobility Web and handled by the field personnel.

Let us assume that the illustrative manufacturer makes products that are long lasting yet used sporadically by users (such as circular saws). Provided a Service Web, each person acquiring a product could decide to make it available to others for a fee in the periods when he is not using it. The Service Web actors would make his offer known to all, deal with setting the transactions, offer post-use cleaning and maintenance services, offer insurances to protect both parties in case the product gets broken or fails to operate properly, locate the product in an appropriate location in the Distribution Web when not needed by the owner, and get the product moved to/from the contracting user when needed. Such a Service Web, focused on making the product functionality widely and fluidly available, has the potential to reduce significantly the number of products needed to serve a given community or territory, with highly significant positive sustainability impacts. The manufacturer may select to evolve his business model and become a key actor in this service web or let third-party actors take the lead.

7.6 Back to the Logistics Web

A Logistics Web is expected to enable a shift from private to open sup-ply chains and logistics networks. It does so through the worldwide exploitation of its open actors and networks populating its mobility, distribution, realization, supply and service webs. This increases drastically the number and quality of logistics options available to each enterprise and person in the world.

A Logistics Web is efficient when it serves the logistics needs with minimal resources overall. It is sustainable when it is capable of maintaining high economical, environmental and societal performance of logistics over the long run, capable of facing the risks and challenges associated with a dynamic, changing and fast-evolving context, contributing to a better world for the future generations. The Physical Internet aims to enable such an efficient and sustainable Logistics Web.

8 OPEN GLOBAL LOGISTICS SYSTEM

On one hand, the Logistics Web to be enabled by the Physical Internet is to be open and global. On the other end it has to be efficient and sustainable. The combination of these four demanding adjectives leads to a complexity that can be harnessed by having the Physical Internet be an open global logistics system, as depicted in Figure 1.

First, the Physical Internet is a system. It has a myriad of components that do not have the capability to independently enable an efficient and sustainable Logistics Web. It is through their well-designed relationships and interdependencies that the system as a whole can achieve its purpose completely.

Second, the Physical Internet is a global system, being both worldwide and multi-scale. It has to be based on the same conceptual framework whatever the scale of the involved networks. Networks will be embedded in wider networks, each operating according to Physical Internet principles, protocols and standards. This extends from networks at the facility level to networks at the city, state, country, continental and inter-continental levels, whatever their mobility, distribution, realization, supply and/or service mission.

Third, the Physical Internet is an open system. Thus, it is not a private, closed, member-only system. This implies that all its constituents, its enablers and its operators have to think and act in terms of openness. The actors have to design, implement and exploit their Physical Internet components in an open way, making it is easy for any other actor or user of the Physical Internet to access and use its services. It also implies that new constituents, enablers, operators and users can be added to the Physical Internet at any time under anybody's leadership, as long as they are certified to be respecting its principles, protocols and interfaces.

The Physical Internet is to be thriving through its worldwide co-operative sharing of resources. Organizations are no longer limited by resources that they own and control or have pre-specified long-term contracts with. The Physical Internet allows organizations to examine Physical Internet-certified networks to determine which network best meets the needs of the organization at the time needed.

9 DRIVEN BY INNOVATION

In its quest for ever-better logistics efficiency and sustainability, the Physical Internet will relentlessly evolve, subject to pressures for change from an interlaced flux of open business, technological and infrastructural innovation from its myriad of stakeholders, shaped by the current experiences of its users and their evolving needs and expectations.

Technological innovation stems from every type of constituent of the Physical Internet. For example, technologies currently available for enabling the smart tags of π-containers currently include RFID and GPS. Yet, there are numerous alternative technologies currently being researched and incubated that are challenging RFID and GPS. So, as is true with all other elements of the Physical Internet, the implementation of smart tags will evolve with technological innovations.

Myriads of businesses will concurrently be using the Physical Internet, such as retailers, distributers and manufacturers, or enabling its operation, such as logistics service providers and solutions providers. All of them, in their quest for competitiveness, will be adapting their business models [1,14-16] so as to best exploit the Physical Internet to offer and deliver high-value propositions to their clients. Innovative revenue and risk-sharing models for the various stakeholders are to be developed. Furthermore, as business innovation has lead to Digital Internet pure-bred giants such as Amazon, eBay, Facebook and Google, business innovation is bound to enable the birth and rise of Physical Internet pure-bred stars that will transform the Physical Internet business landscape [14].

Infrastructure innovation is stimulated by the open systemic coherence and the universal interconnectivity. Standardizations, rationalizations and automations are to be exploited to conceive, engineer and implement π-capable logistics infrastructures that are themselves going to alter the shape of the Physical Internet. For example, electromobile highway networks, subterranean container pipelines and cargo subways are currently being promoted.

10 CONCLUSION

The Physical Internet is a breakthrough departure from the paradigm currently dominating transportation, logistics and supply chain theory and practice. It exploits the Digital Internet metaphor as an inspiration for reshaping the real world where physical objects are currently being moved, stored, realized, supplied and used in inefficient and unsustainable ways. It is a comprehensive logistics system based on a set of eight foundations that have been presented and discussed in this chapter. These foundations have to be well understood by researchers and practitioners engaging in Physical Internet exploration, investigation, instrumentation, implementation or operation.

As a means to an end, the Physical Internet aims to contribute to enabling order-of-magnitude improvements in logistics efficiency and sustainability. Achieving such order-of-magnitude improvements requires a comprehensive Physical Internet implementation enabling a Logistics Web capable of sustaining highly significant improvements, not just relative to the movement of physical objects, but also to the storage, realization, supply and usage of physical objects. Current Physical Internet research results [12-22] are quite encouraging with their assessment of highly significant potential improvements. Yet these initial studies clearly demonstrate the need for exploiting all the foundations of the Physical Internet in an integrated manner.

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