Holonic Logistics System: 
a novel point of view for Physical Internet

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Abstract. This paper addresses the holonic and isoarchic point of view of logistics systems, applied to Physical Internet. After describing the context of current logistics systems and the resulting difficulties, the Physical Internet paradigm’s basis are recalled. Then, the principles of the structure of the global logistics' problem via a holonic paradigm and isoarchic approach are detailed. The three types of holonic entities and their roles are described and research prospects are outlined.

Keywords: Physical Internet, Holonic Approach, Isoarchic Architecture, Logistics Networks.

1 Proposal’s Context

As the environmental awareness seems to become global, the industrial use of the transport modes, often pollutants and inefficiently used, becomes problematic. In this context, the challenge is considerable: to make the organization of transport in the broad sense and logistics in particular more efficient and sustainable, both as well on the local plans, regional as global.

For this, an overall reconsideration of the logistics sector’s organization was proposed by [1]: the concept of Physical Internet. This concept is based on the metaphor of the Digital Internet: the idea is to learn from the transmission of information in order to imagine the transport of physical objects, while going beyond the original proposal [2], and by ensuring a good quality of service, a satisfactory economic efficiency and the respect of a sustainable development.

The Physical Internet will lead to the development of an open system for connecting the physical objects to the global Internet. This concept suggests significant organizational evolutions. However, we must not lose sight of its deployment’s conditions in terms of safety and respect for confidentiality rules. It will therefore set up a 'governance' that will respect certain principles and values, as in the case of the Digital Internet. The issue is not the transportation of information via communication networks, but the transport of objects via the sharing of logistics resources. We can note that we are therefore talking about 'pooling', 'economy of functionality' and therefore indirectly of 'sustainable development'. That will progressively undermine economic models based on the ownership. The relation to things, to goods and objects is already changing. An object is at the same time 'a communication channel and a stock of information' [3]. The objects are expected to become new actors, autonomous actors of the global economy, and to acquire autonomy and decision-making capacity: the objects become intelligent and autonomous objects. This is referred to as Internet of Things [4, 5]. The organization models of such objects’ transport should therefore be adapted accordingly. Indeed, the existing logistics standards will have to rub shoulders with new approaches considering that the organization of logistics is structured in dynamically manner: it is being set up in real time by the self-organization of logistics stakeholders.

Supply chains involve a large number of logistics actors. That raises the problem of a global control taking into account everyone’s interests: we must come to set up a synchronization as 'perfect' as possible of logistics operations between industrials, distributors, service providers / carriers to avoid chain breaks. This is most often reflected by extensively negotiated supply chains based on a forecast load transport. These supply chains are then frozen and used repeatedly at each transport: each supply chain becomes then a closed system, even isolated in its ecosystem. As a result, the current logistics organizations are shipping a lot of air and packaging, the empty travels are no longer the exception but the rule, the storage facilities are poorly used, the products are not stored in the right places, the products move unnecessarily, and the transportation of products to, in and from the cities is inefficient and unsustainable...
The Physical Internet retains the objective of using good logistics resources at the right time to deliver the right product at the right place on time and with the best cost. For that, it addresses new emerging paradigms: the trivialized access to information and communication, the search of a globalized and pooled use of the logistics resources, and the emergence of a sustainable economic approach. That requires more flexibility, responsiveness, agility, but also opening up to the higher volume flows, the standardization of products’ encapsulations for transport and pooling of transport’s resources: that leads to the design of opened and collaborative logistics systems. For that, it is necessary to pass from handling and storage of goods systems to handling and storage of containers systems. It is referred to as encapsulation of goods in π−containers. The π−containers proposed by [1] are designed to be modular and green, in the ecologically sustainable sense, according to a universal global standard. They are intelligent and networked: that minimizes movement and physical storages by digitally transmitting their data [6].

In the context of these approaches, it is necessary to model the dynamics of the concerned logistics systems by focusing on the control rules to set up in order to control the transport of the π-containers. Indeed, the control should aim to constantly ensure outcome targets, e.g. in terms of quality of service or of operating account or assessment carbon. These future logistics systems will necessarily be more complex and therefore more complex to control. Thus, the forecast organization and global optimization will have no place. It is therefore essential to set up systems: (i) with intelligible behaviors, (ii) that can interact face reality and with the environment, relying on ad hoc information systems. For this, the coupling between the Physical Internet, the Internet of Thinks and the Digital Internet provides a wide range of possibilities. The goal is to facilitate the interaction between the physical (real) and informational (virtual) worlds. The virtual world can actually impact the real world, since it can influence the evolution of the real world by taking decisions from the observation of the real world and from decision rules used in an ad hoc manner. A virtual entity will be able to control a physical object (with which it will have been associated) according to operational events.

In this context, the Physical Internet is a paradigm that allow to implement a control holonic system of a global logistics system based on self-organization of the autonomous and intelligent entities. This paper aims to establish the theoretical bases and the fundamental principles of this logistics’ approach within the overall framework of the Physical Internet paradigm. After a presentation of the scientific context of this work, the scientific proposal of a Holonic Logistics System (HLS) is set out and described in detail. Then, the research prospects are outlined.

2 Proposal’s Background

For a few years, the proposed control solutions for complex manufacturing and logistics systems, based on self-organization of actors, provides promising prospects [7, 8, 9, 10]. Indeed, the centralized control solutions (based on the search of an optimum from the aggregation of data previously collected in the field or defined with a provisional manner) do not allow inherently to be robust against disturbances due to the own operation of the system and against changes in demands from the dynamics of customer needs. The prepared centralized optimal solution is generally no longer applicable because it no longer reflects the actual operating conditions, which are regulated under the appearance of numerous random disturbances: the state of the situation in the field is constantly evolving. Consequently, decision-making architectures where the control is organized as close to the field must be favored. The self-organized logistics approach is precisely based on the increasing of the autonomy of the ‘actors’ involved in the organization of this logistics activity. The term ‘actor’ is defined as an identifiable entity with a role or an interest in the operation of the logistics system. An actor has thus a capacity to intelligibly decide on actions they should take. For that, capabilities of communication and of collaboration between actors allow each actor to coordinate, so that it can take into account the state of its environment when taking its decisions. The objective is to develop responsiveness’ qualities, which is possible if the decisions are based on the real state of each actor. For that, each actor has a real time decision center time allowing him to participate in a negotiation by call for proposals on the basis of its own performance obtained using a multicriteria analysis. Each type of actor uses the same multicriteria decision-making mechanism. However, each actor is described by its own setting and by state variables that describe its own state at the current time. This setting allows to differentiate each actor in relation to a set of criteria. Each actor can thus participate in the negotiation by highlighting the call for proposals for which it is the most efficient and/or that are potentially most profitable to it. The multicriteria decision-
making allows the integration of different points of view, even antagonistic, all contributing to the establishment of the control solution.

We applied these principles in the logistics sector. We therefore proposed an isochronic1 control system of the relationship between each partner and a self-organization of the suppliers/subcontractors to meet the customer requirements as well as possible. To increase the dynamic operation of the supply chain in a formal and collaborative framework, this organization concept was called a partnership logistics network. Gradually, as the needs are expressed (in real time within a logistics system), the load is complemented and effective solutions related to the real capacity are sought: at the appearance of each new supply need (purchase or subcontracting) expressed by one of the customers, then a supplier/subcontractor will be defined to meet this need. For this, a call for proposal is launched in the network. The responses (established by each actor, potentially able to respond) are established through a multicriteria analysis: various aspects of the response are integrated, such as the real capacity of the actor to address the need, its usual level of quality of service (assessed by synthesis of its previous services), its quality/cost ... The different responses issued by actors are managed through an auction mechanism. The best answer shows the assignment of the corresponding task to the associated actor. This self-organized approach promotes responsiveness, smoothing loads and high quality service.

This approach can be extended to the transport field. Let us consider a product ‘p’, that must getting from point ‘A’ (Company A) to point ‘B’ (Company B) (see Figure 1), on a long-distance transport. This product will first be packed (output inventory of A ‘OI_A’) in a carton ‘Ca_1’, that will be sent by road ‘Transport_Tr1’ to a point ‘C’. ‘Ca_1’ will in turn be stored or packaged within a container ‘Co_1’ which will be sent by sea ‘Transport_Tr2’ to a point ‘D’. At this level, the different packaging are sorted or repackaged for distribution to customers. The carton ‘Ca_1’ comprising the product ‘p’ will therefore be routed to the point ‘B’ through a truck ‘Transport_Tr3’ to the B input inventory (‘II_B’).

Figure 1: Transportation of the product ‘p’, from ‘A’ to ‘B’

In order to implement product the transport of the product ‘p’ from point A to point B in satisfactory economic conditions and to follow its progress, it is necessary to establish, throughout each supply chain as part of a logistics network, a consolidation/ unbundling system of different transport orders, concerning different products and require different resources of various types. A holonic approach provides a formal framework to structure such a multi-actors problem, at different levels of granularity.

3 Holonic Logistics System

The holonic and isochronic approach can thus be applied to the Physical Internet concept. Originally, [11] proposed to revisit the notion of systems’ hierarchical decomposition to open it on different architectures: it’s the Open Hierarchical Systems Theory. Thus, any system can be seen as a multi-level hierarchy of semi-autonomous subsets forming vertical trees and horizontal networks. The basic element of this approach is called ‘holon’ (a neologism established from the Greek ‘holos’, the whole, and the suffix ‘on’, indicating an elementary particle). A ‘holon is an identifiable part of a system having a single identity, but which nevertheless consists of subordinate parties and which is also part of a larger whole [11]. These two aspects of the holon are fundamental, because it shows the fundamental duality, at the functional and behavioral levels, of a holon related to a simple system. The first of these aspects gives the holon the identity of a whole autonomous. Furthermore, the holon is a part integrated in

1 The composition of the term ‘isochronic’ comes from the combination of two Greek radicals: the prefix iso (equal) and the suffix archy (power), which therefore means a single authority and thus a total absence of hierarchy. In a decision system composed of several decision-making centers, a decisional architecture can be described as isochronic when each decision center has the same capacity of decision.
a whole. On this second aspect, the intelligence associated with holon should enable it to contribute, for a part, to the global operation of the system. In manufacturing, different holonic architectures are proposed in the literature for HMS control [12]. The best known is PROSA (Product, Resource, Order, Staff Architecture) [13]. Numerous holonic architectures are extremely close [14]. These architectures are generally based on three basic types of holons that describe a holarchy:

- A type of holon allowing to define the purpose of the work (In this case: what must we transport?);
- A type of holon to describe the mission (In this case: how the transport is going to be achieved? (departure points/destinations and departure/arrival dates));
- A type of holon to define the necessary means to achieve the mission (In this case: what are the necessary resources to achieve the different transports?).

PROSIS [15] is a proposed architecture that also respects these principles, but complement them with two additional assumptions. First, all holons have the same level of decision. We then talk about an isoarchic decision-making architecture, according to a 'Flat Holonic Form'[16]. Then, a holon is thus a dual entity composed of a material part (called M_holon) and an informational part (I_holon). The I_holon has an information system containing data relative to the M_holon, and a decisional intelligence that help controlling the M_holon. Therefore, with this decisional intelligence, the holon can act on its own behavior, but can also act on the system’s behavior to which it belongs. In other words, a holon has sufficient autonomy to create and control the execution of its own plans. It can cooperate with other holons to develop mutually acceptable plans in order to respect the global objective of the whole logistics system. The concept of holon allows thus to associate to each actor of a logistics system the intelligence that allows the system to self-organize. Typically, a holarchy in a HLS could therefore be modeled from the three following types of holons:

- The Holons of Product type (PH), which give a description of the transported products;
- The Holons of Order type (OH, which are associated to each transported product, and that will allow to describe how each product will be transported and to monitor the real progress of each transport;
- The Holons of Resource type (RH), which represent the different modes of used transport.

The concept of holon allows to take into account the encapsulation of Products, Orders and Resources in the logistics network. This is particularly interesting in the context of a self-organized approach of Physical Internet: the logistics choices’ issues ultimately correspond to manage, at each node (hub) of the supply chain belonging to the global logistics network, on the one hand the convergence of flow at the input of this node and the divergence of flow at the output of this on the other (see Figure 2). This is achieved by integrating the notion of scaling (change of scale) in the used transport mode (from volume to retail or from retail to volume). Whatever the granularity level of the hub in the logistics network (urban hub, regional, national, international or intercontinental), products, resources and orders will be to manage. Indeed, ongoing/outgoing flows of a node can be of different kind (small and/or large flows), requiring different types of resources (vans, trucks, trains, boats, planes ...) and must response to specific missions (transportation of a product from point A to point B, with or without specific delivery date ...).

This level of granularity should be viewed from the perspective of the concept of recursion of a holon. A holon belonging to a holarchy can be itself a holarchy, but it will behaves as an autonomous and cooperative unit in the first holarchy (see Figure 3). Let us take the previous modeling of the ‘p_x’ product’s transport shown in Figure 1. This product will be modeled by a PH, composed of its informational part (I_PH) and its physical (material) part (M_PH). A
transport order OH₁ will be associated with PH. Finally, a RH₁ will be assigned to the PH to response to the OH₁. Throughout the supply chain, each type of holon XHᵢ will be encapsulated in a XHᵢ₊₁ (‘X’ representing the product ‘P’ or the order ‘O’ or the resource ‘R’) (see Figure 3). Therefore, the associations of products on pallets, then on the containers, associated with elementary transports resulting from the PH-OH interaction, will be managed.

In the context of this modeling, it is necessary to manage the complexity of data access. For that, isoarchic architecture allows at each decision-making stage, to highlight only the entities concerned by the decision. Therefore, all the self-organization capacity lies in the intelligence of the redirection/aggregation/disaggregation of flows within a node (see Figure 4).

The goal is to address the whole chain (B to B/B to C/C to C) with decisional methods and homogeneous functional criteria within each of the nodes (hubs) constituting the HLS of the Physical Internet.

4 Conclusion and research prospects

The finding currently done by the logistics actors is that it is becoming increasingly unsustainable with economic, social and environmental plans. Indeed, logistics’ costs increase while nobody would like to pay them. It becomes difficult to quickly and effectively respond to people's and industrials’ needs. Finally, logistics does not correspond to an assertion of durability. It is therefore urgent to set up an efficient and sustainable logistics on all geographic levels. From the opened and distributed transmission information network which is Internet, the transposition of the concept to the objects’ transport and therefore to the logistics’ activities allows to offer a real logistics revolution. This latter is articulated within a global and open logistics system, exploiting transport and supply networks interconnected via
intermodal hubs, using collaborative protocols and standardized modular containers and addressable via smart standard interfaces. The Physical Internet (implement logistics flows from the management of information flows) advocates to a certain extent the control by the flows, but must aim to optimize these flows: the transport of material goods is much more expensive than the transport of information.

The proposal allows to provide a generic approach for determining the product transport logistics chain since the first kilometer until the last kilometer by exploiting the concept of Physical Internet. The approach is generalized to address the choices’ issues related to the transcontinental mass transportation to those of the pooling of the last kilometer in urban logistics. Therefore, the exploitation of the concept of Physical Internet has important implications on the evolution of different types of logistics (urban, regional ...). The proposed self-organized approach promotes responsiveness, smoothing loads and high quality service. A first research axis consists in the establishment of complex decision-making structures, integrating a set of strategic, tactical and operational considerations. These structures will be implemented on each hub by involved holons, to establish local optimization scenarios allowing the efficiency of the Physical Internet. The multicriteria decision aid can provide good solutions, and potential solutions can be developed from [17], but any other solution can be considered.

Simultaneously, the authors are confident that these approaches based on self-organization of smart logistics entities must rely for their implementation on infotronics technologies such as RFID (Radio Frequency IDentification) or the WCN (Wireless Control Network) in relation to the Internet of Things. For that, a research axis considers the design of I_holons as embedded systems with low energy consumption [18] ...

References