Is Physical Internet a Complex system?

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Abstract—**Industries continuously strive to build new branches across geographies to satisfy their customers' demands and provide essential items at the quickest possible period and a lower cost than their competitors. The achievement of these objectives depends not only on the organisation itself but on all Physical Internet (PI) stakeholders. Similarly, there is a need to manage the whole PI network effectively and efficiently through the collective engagement of all its participants. The PI comprises several suppliers, production companies, retailers, wholesalers, and customers that interchange physical goods, information, and financial flows. The management of these flows is growingly challenging due to supply chain complexities. Therefore, it is crucial to examine this paradigm and consider its features a complex system. The summary of this article thereby demonstrates that the PI is a complex system and emphasizes its most essential aspects.**

Keywords—Physical Internet, Digital Internet, Complex system, Efficiency, Sustainability, Interconnectivity.

I. Introduction

One of the primary problems facing firms is open borders to world commerce. Therefore, companies constantly strive to establish a new subsidiary in other countries to meet the requirements and expectations of their consumers, produce high-quality goods in the quickest possible period, and provide cheaper good and services compared to other competing companies.

The attainment of these objectives is no longer connected to the company's roles, operations, and procedures alone but to all PI partners. As a result, the necessity for effective and prudent management based on strengthening cooperation amongst its players throughout the PI network is urgent.

In this paper, we will introduce and explore the idea of the PI system. This idea is most relevant to the discussions about privacy, data mining techniques, and government surveillance. Utilising concepts from complex systems theory, we can examine how the PI can be understood to reveal its current state in terms of who has access to information, what type of information they are allowed to access, and the potential future changes that could take place considering the technological advances in computing power. Complex Systems theory involves studying how complex systems behave in terms of their patterns and dynamic behaviour. Examples of complex systems that have been studied using this approach include biological ecosystems, traffic flow, and even economies. Complex networks are a specific complex system characterised by having many individual entities interlinked to form a network. Examples of complex networks include social networks, the World Wide Web, and transportation infrastructures (i.e., roads or railways). Within complex networks, there is an attribute that focuses on feedback and a tendency towards self-organisation because of the interlinked nature of the network. However, the idea of self-organisation within a network can be influenced by small perturbations complexity. Within this context, a small change to one element in the network can lead to substantial effects elsewhere in the system, making dealing with the results difficult. Our contribution to Complex System theory resides in the theoretical revelation of this concept, offering an efficient and cautious way to reduce this complexity and steadily improve the performance of the PI.

II. Methodology

No one can refute the rising complexity of the PI; we may even claim that the PI is a complicated system. Our paper's novelty concerning merging these two concepts (i.e., PI and Complex system) to help managers and researchers decrease the complexity of this revolutionary concept and improve its logistic network. We intend to present a practical and sensible approach to reduce this complexity and continuously enhance the PI performance in the light of the complex system theory. By introducing the PI within the Cognitive Info-Communication (CogInfoCom) framework, we are trying to inform about the specificities and properties of the PI as an applicable solution for cooperating between organisations and stakeholders. That could be applied at many communication levels and different sizes of companies. To reach the aim of this paper, we first start by conducting a literature review to better understand the analogical similarity between the Digital

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Internet and the PI by explaining the different factors and their flows to highlight the primary sources of the complexity of the PI concept that prevent its improvement. After that, we have demonstrated the state of the art of the complex system. Finally, we analyse the similarity between the characteristics of a Complex system and the PI. Theoretically, the PI is a complex system because it takes the same features.

III. Physical Internet

PI is an evolutionary concept of Supply Chain Management[1]. [2] introduces this novel concept as the global flow of Physical items in the supply chain network. Various other researchers show interest in this concept, such as [3], [4] and [5]. The PI ensures the movement of goods by using intelligent containers to optimise logistics costs, reduce pollution, and improve social life. "the way in which physical objects are handled, moved, stored, produced, delivered, and used, with a focus on global logistical efficiency and sustainability"[6]. The primary aim of PI is to satisfy consumers' demands by building a strongly interconnected network between organisations. In CogInfoCom terms, there are two types of communication, namely the Intra-cognitive communication and the Inter-cognitive communication. the former focus on transferring information among two or more human beings, meanwhile, the latter is concerned with communication between a human and an artificially cognitive system [7].

To facilitate the CogInfoCom framework efficiently in the PI, there is a strong need for an Intra-cognitive communication at higher levels that depends on the intervention of all stakeholders of the supply chain network. The PI objectives such as efficiency and sustainability are unreachable without the cooperation and strong relationships between businesses. At the same time, the people involved in the inter-cognitive communication, at certain point, will become part of the system and initiate an Inter-cognitive communication. In so doing, the CogInfoCom will facilitate the PI procedures. The PI is a metaphor for the Digital Internet[6]. However, the Digital Internet ensures the movement of information between computers. On the other hand, the PI provides the direction of Physical goods from the supplier to the consumer.

A. The similiarities between the DI and the PI

The components of interconnection between networks varies according to the employed network. Table 1, 2, and 3 provide a synopsis for two types of networks i.e., Digital Internet and Physical Internet.

TABLE I. The interconnection of networks[8]

Network	Digital Internet	Physical Internet
Flow	Datagram	PI-container
Node	Router	Hub
	Host	Supplier/ consumer
Arcs	Cable/wave/wire connection	Transport services

TABLE II. The DI parts and their functionality

The parts of DI	Functions
The router	Connecting neighbouring networks enables the transit of data packets between these neighbouring networks. =>The router role is to dispatch datagrams, indicating upon their arrival the next router along their route to their final destination.
Host	Placing of containerisation or de-containerisation of the Datagram.
Cable/wave/wire connection	They connect two or more devices, enabling electrical signals or power transfer from one device to another.
Data packets or Datagrams	They have standardised characteristics such as size and structure. They are sequentially transmitted via the routers.

In Fig 1, when a datagram reaches a router in the Digital Internet routing process, it is extracted from the frame and placed before processing on a waiting line. The router scans the heading of the data and the section of the target. The data graph is then placed on the appropriate exit portal and sent to the neighbouring router through another frame until its destination is reached [8].

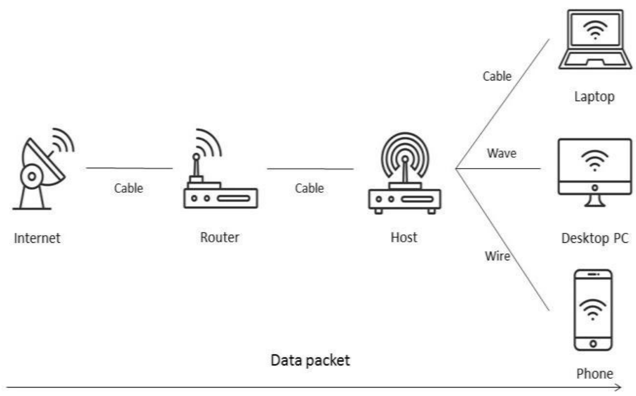

Fig. 1. The routing process of Digital Internet

TABLE III. The PI parts and their functionality

The parts of PI	Functions
Hub	Location of orientation, change of mode, service provider
Supplier or consumer	including distribution centres, warehouses, plants, etc., place of containerisation or de-containerisation of PI-containers
Arcs	To define the transfer of the goods by freight services (road, rail, maritime services, etc.)
PI-containers	The merchandise is encapsulated in the form of standardised packets (standardised, modular, intelligent and eco-friendly containers)

As we can see in Fig 2. the routing mechanism of PI would be comprised of container nodes which may then sort and recompose the containers for optimising transit in each segment (e.g., filling, or refilling containers with a set of sub-containers). The collection of the received containers is then moved toward the next node depending on the destination [8].

In terms of tangible aspects, the PI confronts a more complicated reality [9]. The PI seeks to link all these logistic service networks by transposing the principles of the Internet and by ensuring that all logistic networks are interconnected universally.

The traditional distribution network between suppliers and retailers is primarily separate from other networks, and each player operates independently. Here the two types of communication provided by the CogInfoCom framework can act as a threshold of moving from the traditional distribution networks towards more active and dynamic PI network.

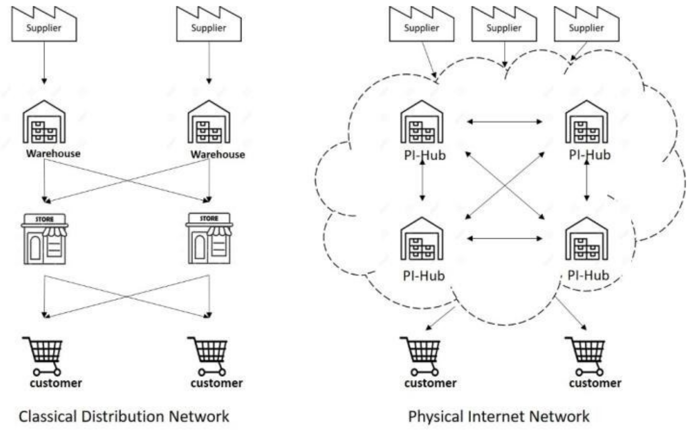

Fig. 2. Comparison between Classical distribution network and PI network

B. *The complexity of PI*

There are several physical items in the core flow of the PI, which might vary based on the aim of employing it. In contrast, Digital data, electronic 0s and 1s are the fundamental units carried by DI.

The boundaries that PI acts within can be stretched to include different features of any PI network. Among these meaningful features: cost, time, schedule, emissions, capacity, resources, and distance succinctly discussed in table IV below.

TABLE IV. THE MOST CRITICAL CHARACTERISTICS THAT DIFFER PI FROM THE DI

Categories	The various variables of the PI
Cost	In the PI, we mean the cost of logistics services and the external cost, such as accidents, noise, pollution, and congestion[10]. The distribution of goods involves non-fixed costs such as modes of transport, composition and decomposition of smart containers, loading and unloading at distribution hubs. We only need electronic devices and the electricity cost to send an e-mail compared to the Digital Internet. The Internet also uses a packet retransmission concept that permits retransmissions after a certain amount of packets are lost or rejected due to congestion on a router. The return of tangible things is an expensive process, which no PI user would welcome.
Time	There is approximately no delay in most situations of moving datagrams while the digital signals move so fast. But for the PI users, the flow speed and arrival time of goods to the consumers is critically considered[11]. However, the transit time is highly significant, and the routing network decisions are considered different from the DI.
Schedule	Digital information transfer is almost immediate. However, there are sometimes delays due to network traffic and server time response. The PI flow schedule is a dynamic and possibly troublesome procedure that depends on the network's real-time condition[12]. For example, new route routings that lead to late delivery might be required if congestion occurs or the vehicle breaks down. Such delays affect shipping companies, consumers and service providers, leading to fines and the loss of revenue and other supplementary costs.
Emission	The PI emissions are "variable" and proportional to the products supplied[6]. But DI emissions may be viewed as a 'fixed cost. That is because the PI emissions are mainly due to the physical movements of the elements. Also, DI electronic equipment needs quite a bit of power, and the consumption of e-mails is almost nothing.
Capacity	The capacity in the PI is limited for every stakeholder's participant in the PI network[13]. For instance, after fully loading the truck, goods should wait for the next available truck. It's impossible and costly to change to another transportation mode. In the DI, it is possible to send a Datagram to test the congestion of routes and routers. The router can easily use another pathway if the first choice is congested. It is flexible in allocating each route's capacity and is essential to have enough data transfers throughout the network.
Resources	In the PI, the flow consists of various physical objects that may differ from each other. The number of international exchange platforms is minimal such as international airports, ports and train stations. Also, it's costly to implement these platforms[14]. Further, every country has its transport means and its specific laws and regulations on the good movements. That's why it's very recommended to standardise all transport means and all transport regulations globally.
Distance	The distance in the PI is a priority for logistics providers. However, managers always find the shortest pathway to transport goods to the consumers[15]. The geographic interconnection between countries is very complex and needs many models and simulations to make it possible. That is not the case for the DI in which the distance is not a problem

IV. COMPLEX SYSTEM

A complex system is a unique system type with exceptional complexity. In other words, it consists of many modules, which interact with the whole device in a nonlinear networked manner [16]. For a complex structure, there is no agreed description, but there are some common examples. For example, according to [17], "A system comprised of a (usually large) number of (usually strongly) interacting entities, processes, or agents, the understanding of which requires the development, or the use of, new scientific tools, nonlinear models, out-of-equilibrium descriptions and computer simulations.".

[18] provides another conceptualisation of the complex system stating that it is "a system that can be analysed into many components having relatively many relations among them so that the behaviour of each component depends on the behaviour of others." Finally, [19] mentions that a complex system is "a system that involves numerous interacting agents whose aggregate behaviours are to be understood. Such aggregate activity is nonlinear; hence it cannot simply be derived from a summation of individual components behaviour."

A. The Physical Internet as a Complex Systems

An excellent example of a complex system is the PI. Nowadays, the PI is receiving the attention of a lot of practitioners and academics. [20] define PI as "a global logistical system based on the interconnection of logistical networks through a standardised set of collaboration protocols, modular containers, and smart interfaces for increased efficiency and sustainability." However, we define PI as a solution and response to the global logistics sustainability grand challenge founded on physical, digital, and operational interconnectivity, composed of PI hubs operated by different services interconnected through encapsulation interfaces protocols. The model of PI is made up of components and interactions on many different scales.

B. The Parts of a complex system: The parts of the Physical Internet:

Perhaps the only property found in all descriptions of a complex system is that many parts interact on several levels. With the emergence of PI, an entirely new structure stage appears and then begins to communicate with other processes in its environment. The result is that new hierarchical tendencies evolve, and we develop the level of another organisation, etc.

People are part of social groups that comprise a more prominent, human-made society, which provides a hierarchical structure for these systems. It is a universal global phenomenon. Elements are nested in subsystems and are part of larger structures, etc. This multidimensional property exists in all complex systems. They are made up of several components at different stages, all of which influence each other. For example, a company is part of a local economy, a national economy, and a global economy. They are linked and interdependent with each other. We cannot isolate a variable entirely or reduce it to a single level, which is the primary source of the difficulty. However, you can get a clear idea of what they are calling complicated as you can put yourself in a structure where all the pieces communicate on several different levels. That is the first property of a complex system that works in several different ways, with many other components.

The PI is based on standard containers easily transported by different PI hubs through several operators' transport means (planes, trucks, and cars). Hence, all users, including suppliers, shippers, and consignees, can share this same logistic system, which needs a complete horizontal and vertical coordination in logistics by universal interconnectivity, standard encapsulation, standard smart inter-faces, and standard coordination protocols to optimise the loading and unloading of containers. Furthermore, open hubs and open logistics materials are part of the network, enabling a global logistics web.

C. The Nonlinearity in the Physical Internet

The term nonlinearity is used in nearly all well-formulated descriptions of complex systems. It's an ongoing and omnipresent problem. Nonlinearity defines the degree to which a system's input and output are not proportional in the most intuitive and straightforward sense [21]. Nonlinearity stems from the fact that the outcome cannot simply add the individual properties in isolation as we bring two or more items together. On the opposite, we can obtain a cumulative result of more or less than each part's primary number [22]. For example, two waves of sound, totally out of alignment, cancelling one another by noise interference or division of labour, as found in many cultures of humans and birds, can lead to synergies that mean that the performance of the individuals can be much more excellent than what the individuals would do in isolation. Because of what is known as feedback loops, nonlinear systems will exponentially expand or decay. These rapidly evolving phases are known as phase transitions. Complex systems are also considered to be able to transition into new regimes in brief periods. Feedback loops may cause an overall structural effect with few slight changes in input value to the device. For example, we make a simple change on containers in the PI and significantly impact logistics performance [23]. The benefits of these intelligent modular boxes involve more efficient transport and handling of PI-containers very easily, lower logistics costs, and improved distribution by combining several goods from several companies in shared packages (higher utilisation with a minimum number of transportations means). Besides, recyclable green, bright containers reduce the total cost, minimise the required resources, and reduce CO2 emissions. Thanks to Radio-Frequency Identification (RFID) support, smart boxes enhance the visibility and control of the entire supply chain system by ensuring traceability and exchange of information. Moreover, the active role of PI-containers is in grouping several transportation containers into one composite transportation container in PI hubs [24].

D. Connectivity

Many complex systems are designed to have high or dense component interconnectivity [25]. When we determine the degree of connectivity, it becomes the essence and structure of these networks. The elements of how objects are related and what is linked to what is the critical concern. The system stops being a collection of components at any primary degree of connectivity and becomes a connectivity network. Connectivity takes us to the complex universe because of the exponential growth of the interactions between elements. If we take a few pieces, thousands or even millions of separate forms can be linked. The principle of the PI is to ensure interconnectivity [26]. The PI allows the interconnection of its elements (the logistic networks and the whole stakeholders) and enables the mobility and accessibility of physical objects efficiently and sustainably.

E. Adaptation

There is no overarching top-down structure for organising the environment within complex systems in our global economy. Instead, elements have a degree of control due to their ability to react according to their directions and local environment. The power of features to organise themselves comes without centralised coordination and with a degree of autonomy. They will either synchronise or collaborate, which contributes to the bottom-up creation of organisational trends. The ability to react differently to a given phenomenon, with autonomy and adaptation, often means that complex systems with high diversity can often be heterogeneous. The example of PI-nodes in the PI is an excellent example in this case.

However, as their name indicates, the nodes are the global network nodes; they ensure the operations are carried out on the PI-containers such as loading, unloading, composition, decomposition, shipping, moving, and traceability PI-containers. PI-nodes allow PI-containers to be transmitted efficiently and safely. Note that the general location of PI-nodes should be interconnected to the logistics activities to facilitate collaboration and information sharing between the different actors and companies and to ensure the adaptation to market or other changes such as demand variations without creating a new network (Option of dynamically changing inventory locations). However, they all have in common that they are explicitly specialised to treat PI-containers at the physical and informational levels.

F. Evolution

Complex systems evolve on the macro level without centralised coordination in an evolution process. Elements within diverse adaptive systems are subject to the evolutionary intensity of selection as they are chosen and replicated when some are not appropriate to this environment. The PI is a global and systemic vision that a region or a group of companies should not be thinking about. Still, it touches the whole planet for a lasting improvement. Thus, the entire macro-scale structure can conform to its context without centralising coordination and higher distinction and integration levels. The more independent and adaptive the elements are, the more complicated the system we face.

V. Conclusion

It was tough to globalise the market, open borders and control its distribution network. Therefore, companies have been concerned with excellent management of distribution network complexity to remain competitive in marketplaces and increase customers satisfaction.

In that respect, the novelty of our paper aims to merge the two scientific disciplines: Complex Systems and PI. We started with a literature review to understand the similarity between the Digital Internet and PI by describing their flows to the different players to highlight critical sources of the complexity and solutions to improve the idea and functioning of the PI. Then, we have shown the state of the art of complex systems while simultaneously analysing the resemblance between the features of a complex system and the PI. Here we highlight the importance of A CogInfoCom application in seizing the already existing systems and logistics but with alternations and better utilizations. In theory, we conclude that the PI is a complex system because it has the same complex system features as discussed earlier.

Our next contribution lies in modelling the complexity of the PI and proposing more practical solutions to minimise its complex features.

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