



**HAL**  
open science

# Smart product-service systems in interoperable logistics: Design and implementation prospects

Shenle Pan, Ray Zhong, Ting Qu

## ► To cite this version:

Shenle Pan, Ray Zhong, Ting Qu. Smart product-service systems in interoperable logistics: Design and implementation prospects. *Advanced Engineering Informatics*, 2019, 42, pp.100996. 10.1016/j.aei.2019.100996 . hal-02316272

**HAL Id: hal-02316272**

**<https://hal.science/hal-02316272v1>**

Submitted on 20 Jul 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

## Smart Product-Service Systems in interoperable logistics: design and implementation prospects

**Shenle Pan (Corresponding author)**

shenle.pan@mines-paristech.fr

MINES ParisTech, PSL University

Centre de gestion scientifique (CGS), i3 UMR CNRS

60 Bd St Michel 75006 Paris, France

**Ray Y. Zhong**

zhongzry@hku.hk

Department of Industrial and Manufacturing Systems Engineering

The University of Hong Kong

Hong Kong

**Ting Qu**

quting@jnu.edu.cn

School of Intelligent Systems Science and Engineering

Jinan University (Zhuhai Campus)

Zhuhai 519070, China

**ABSTRACT:** To deal with the increasing complexity of customer demands, supply chain (SC) and logistics organisation and management have been constantly moving towards collaboration, intelligence, and service-orientation. The importance of service-oriented design for SC and logistics systems has been stressed, especially with regards to interoperability and sustainability. In this context, the recent intelligent interoperable logistics paradigm has been increasingly studied and the Smart Product-Service System (PSS) concept seems interesting for the paradigm. Smart PSS are characterised by their ability to collect and process information autonomously and subsequently make decisions and self-act/evolve. Interested in the potential for tackling complex logistics systems, this paper investigates how smart PSS could be considered and designed for service-oriented, intelligent interoperable logistics. A recent breakthrough logistics paradigm called the Physical Internet (PI) is taken as a practical example in this research. We present and discuss key design issues and innovative business models associated with smart PSS in PI. The results clearly indicate the promising potential of smart PSS in PI and the need for further research. Consequently, new research avenues leading to a new era of intelligent interoperable logistics are outlined. This paper intends to contribute to two main areas of research: the design and implementation of smart PSS in PI, and functional and conceptual research on PI and intelligent interoperable logistics.

**Keywords:** Smart Product-Service System Design; Physical Internet; Intelligent Interoperable Logistics; Service-orientation; Logistics-as-a-Service, Sustainability.

## **Smart Product-Service Systems in interoperable logistics: design and implementation prospects**

**ABSTRACT:** To deal with the increasing complexity of customer demands, supply chain (SC) and logistics organisation and management have been constantly moving towards collaboration, intelligence, and service-orientation. The importance of service-oriented design for SC and logistics systems has been stressed, especially with regards to interoperability and sustainability. In this context, the recent intelligent interoperable logistics paradigm has been increasingly studied and the Smart Product-Service System (PSS) concept seems interesting for the paradigm. Smart PSS are characterised by their ability to collect and process information autonomously and subsequently make decisions and self-act/evolve. Interested in the potential for tackling complex logistics systems, this paper investigates how smart PSS could be considered and designed for service-oriented, intelligent interoperable logistics. A recent breakthrough logistics paradigm called the Physical Internet (PI) is taken as a practical example in this research. We present and discuss key design issues and innovative business models associated with smart PSS in PI. The results clearly indicate the promising potential of smart PSS in PI and the need for further research. Consequently, new research avenues leading to a new era of intelligent interoperable logistics are outlined. This paper intends to contribute to two main areas of research: the design and implementation of smart PSS in PI, and functional and conceptual research on PI and intelligent interoperable logistics.

**Keywords:** Smart Product-Service System Design; Physical Internet; Intelligent Interoperable Logistics; Service-orientation; Logistics-as-a-Service, **Sustainability**.

### **1. Introduction**

**More and more companies now appreciate how crucial logistics and supply chain management (SCM) is to business success due to its importance for customer services and international competitiveness [1].** Improving resource productivity has been the main goal of logistics and SCM over the last few decades. Recently, companies have also been keen to offer better services to customers to enhance competitiveness, i.e., logistics services with respect to agility, flexibility, sustainability, and resilience. As a result, the organisation of logistics has been constantly evolving, for example, from in-house to outsourced logistics [2], from vertical to horizontal

collaboration [3] then to intelligent interoperable logistics [4], as depicted in Figure 1. Furthermore, this evolution has been concurrent with the emergence of new paradigms and professions in the field. For example, the emergence of 3PL in the 70s that are professional asset-based logistics service providers (LSP), 4PL after 2000 that are asset-free flow orchestrators for multiple mutual SC [5–7], or more recently 5PL that are providers of technical or technological solutions (from operational to strategic level) for logistics performance improvement [8]. These emerging professions rely on innovations in services as well as in business models. Examples include the well-known *Fulfillment By Amazon - FBA* services, as well as other on-demand logistics services (e.g., *cubyn.com*), online freight marketplaces (e.g., *uship.com*, *anyvan.com*), cloud-based warehousing marketplaces (e.g., *stock-booking.com*, *flexe.com*), and many other start-ups proposing big data or Artificial Intelligence services in the field. SC and logistics organisation has been moving towards collaboration (vertical and horizontal), service-orientation, and more recently data-driven intelligence.

Figure 1. Development of supply chain and logistics organisation

Considering the trend towards collaboration and service-orientation in logistics, the Product-Service System (PSS) concept could be of great interest in logistics and SCM. PSS can be seen as a special, concrete business model of *servitization* whose aim is to emphasise asset value and performance (e.g., utilisation and productivity) rather than ownership [9]. The PSS business model suggests that manufacturers should shift to producing and leasing products rather than selling and in turn, customers should exploit products in a shared way rather than individual ownership [10]. In particular, when products are associated with intelligence (generally called smart PSS hereinafter), they are capable of autonomously collecting and processing information to subsequently make decisions and self-act in real time thanks to advanced ICT/IoT technologies and data science [11]. Intelligence may become an effective and efficient means of collaboration and resource sharing in interoperable logistics systems. Consequently, 5PLs that provide technology services will also play an increasingly important role in logistics and SCM for value creation, decision support, and service improvement. Business model reconstruction and innovations are therefore foreseeable. The salient features of smart PSS and 5PL clearly

demonstrate their potential for current and future logistics systems like stages 3 and 4 shown in Figure 1.

Motivated by recent advances, this paper investigates the concept of smart PSS and its potential for seamless intelligent interoperable logistics, which is currently the most advanced logistics organisation model. More specifically, we take a recent breakthrough logistics paradigm called the Physical Internet (PI) as a practical example [12] to discuss the opportunities and prospects for the design and implementation of smart PSS. **PI implies full interconnectivity of independent logistics networks and services based on intelligent interoperability for resource and service sharing. A paradigm like this will probably rely on and encourage the development of smart PSS as well as 5PL business model innovations. By extending the previous study in [13], this paper intends to further investigate the following questions: (i) why are smart PSS and 5PL essential for PI-based data-driven collaboration; (ii) how should smart PSS be applied and designed for PI-enabled interoperability; and (iii) what are the promising future research avenues enabled by smart PSS and PI to move towards open intelligent interoperable logistics.** This work attempts to contribute to two key lines of research: the design and implementation of smart PSS in PI, and functional and conceptual research on PI.

The paper is organised as follows. Section 2 presents a brief literature review on Smart PSS Design, Service-oriented SC and logistics, and the PI concept. Section 3 focuses on the PI paradigm as an example to demonstrate PSS design and implementation issues and opportunities. Section 4 broadens the discussion to encompass intelligent interoperable networks and to indicate further research directions. Finally, Section 5 concludes this work.

## **2. Brief Literature Review**

This section briefly discusses three aspects of the related literature: (i) Smart PSS Design, (ii) collaborative and service-oriented SC and logistics, and (iii) the Physical Internet.

### **2.1 Smart PSS design**

The literature shows that the PSS concept originated in the field of manufacturing and production [14], and is being increasingly studied in logistics and SCM. The first and most cited definition of PSS is proposed by [9] who stated, “*PSS is a marketable set of products and services capable of jointly fulfilling a user’s need*”. Since then, the definition has been broadly extended and is

now associated with sustainability, dematerialisation, strategy or business model innovation for competitiveness enhancement, for example (see [15], [16], and [17] for a review).

Most recently and importantly, smart PSS has become an attractive topic in the related production and logistics literature due to the trends in *digitalisation* and *servitization* in the field. This paper adopts the definition of smart PSS suggested by [11]: Smart PSS is “*an IT-driven value co-creation business strategy consisting of various stakeholders as the players, intelligent systems as the infrastructure, smart, connected products as the media and tools, and their generated e-services as the key values delivered that continuously strives to meet individual customer needs in a sustainable manner*”. The definition emphasises the creation of value through tripartite cooperation (players, infrastructures, tools) and regards the e-services generated as new values delivered to users. ICT/IoT techniques and technologies and data science are clearly critical tools necessary for collecting and processing information as well as subsequent real-time decision-making, self-acting or self-evolving. In other words, the connected products/infrastructures, digitalised systems, and data generated will offer opportunities to create new services and values. A number of specific applications can already be observed in the field, e.g., cyber-physical systems and smart PSS for the self-organisation paradigm [18,19], sustainable product or asset lifecycle management [20–22], real-time manufacturing or logistics planning optimisation [10], **and the shared physical asset service system (PASS) at supply hubs in industrial parks [23]**. In addition, some studies offer a systematic design approach for service innovations enabled by smart PSS [11,24].

This paper pays particular attention to the prospects of smart PSS in intelligent interoperable logistics, as it has not yet been sufficiently studied in the literature. Based on the above studies, this paper further investigates the design issues of smart PSS with regards to the efficiency of resource sharing and service enhancement in interoperable logistics networks.

### **2.3 Digitalisation and Service-orientation in SC and Logistics**

This section discusses the current trends in logistics and SCM from two perspectives: digitalisation and service-orientation. *Digitalisation* is often seen as a disruptive innovation in many fields including SC and logistics [25]. This is not only because it may help improve services quality (e.g., more efficient, agile, customised) [26], but also because it offers a fundamentally different way of managing resources and, therefore, improving productivity and

sustainability [27]. Accordingly, a number of paradigms and concepts have been proposed such as Industry 4.0 or Logistics 4.0, Cyber-physical systems, Digital Twin, and holonic systems. Although many theoretical studies have clearly demonstrated the potential and future applications of digitalisation, the transformation still needs substantial support through the development of techniques and technology as well as the related business models [28]. Recent examples include big data analytics and artificial intelligence [18], blockchain and smart contract technologies [29], wearable and Industrial IoT [30], and most recently *Thing'in* the things' graph platform developed by Orange [31]. In fact, digitalisation is disrupting organisation and management in all fields; and this is even more apparent in SC and logistics due to the complexity of and issues relating to the system. Nevertheless, more investigations are still needed to identify clear directions to convert current practices to digitalisation, to propose new services and create value.

*Service-orientation* has been an obvious trend in logistics and SCM in the last few decades [32]. It advocates that the emphasis of logistics and SCM should be placed on service enhancement and value creation to satisfy customer demands by managing the capacity and expertise of the system, which is very different from traditional models that concentrate on maximising asset and system productivity and utilisation [33]. As summarised in Table 1, service level objectives in SC and logistics are very complex. Therefore, it is extremely difficult to comply simultaneously with those objectives while maximising asset productivity and utilisation. In the same vein, service providers prefer to exploit resources to satisfy customer demands rather than own them. One solution is to combine vertical collaboration to better understand and predict customer demands with horizontal collaboration to mutually share resources with other stakeholders. Consequently, the principle of service-orientation has led to an increase in both vertical and horizontal collaboration in SC and logistics [3], and more recently a rise in interoperable logistics. The literature clearly shows that collaboration and interoperability are effective and efficient solutions for service-oriented logistics and SCM. However, the potential and opportunities of smart PSS in such context have received insufficient attention.

Table 1. The most important service level objectives faced by SC and logistics today

### **2.3 The Physical Internet: intelligent interoperable logistics for sustainability**

The Physical Internet is a concrete, pragmatic paradigm of a collaborative and cooperative logistics system. The term was coined in 2010 to emphasise the essence of full interconnectivity (i.e., openness), intelligence, and interoperability for resource sharing and sustainability based on modularisation and standardisation of tools, facilities, and business processes. According to [38] and [12], PI is a metaphor for logistics service networks taken from the digital internet and can be described as “*an interconnected global logistics system enabling seamless asset sharing and flow consolidation, founded on universal physical, digital, operational, business and legal interconnectivity achieved through standard open protocols, “encapsulation”, certification, performance assessment and monitoring*”. The reader can refer to [39–41] for the state-of-the-art reviews.

Moreover, PI is a pragmatic paradigm for sustainable SC and logistics with respect to other objectives. The European Technology Platform *ALICE* ([www.etp-logistics.eu](http://www.etp-logistics.eu)) aims to establish PI in Europe before 2030 in order to reach *zero emission logistics* by 2050. For this goal, academia, practitioners, governments, and authorities together have defined a European PI development roadmap. As shown in Figure 2, five axes have been identified to achieve PI. We can see that the issue of business model innovation is only concerned with the axis of urban logistics. In this paper, we argue that innovations in smart PSS and the associated business models should be considered as a transverse issue for all axes as it concerns both tangible (e.g., assets) and intangible (e.g., information services) products. Moreover, we are particularly interested in studying PSS associated with intelligence and the related business models. To this end, PI serves as a practical example of intelligent interoperable logistics and is studied in this paper as an ecosystem of stakeholders, logistics systems, and products.

Figure 2. European Physical Internet Roadmap (from [www.etp-logistics.eu](http://www.etp-logistics.eu))

### **3. Smart PSS Designing for the Physical Internet**

To discuss the opportunities and prospects of smart PSS in intelligent interoperable logistics, PI was taken as a concrete example in this paper. A conceptual framework depicted in Figure 3 was developed here to tie the PI paradigm and smart PSS together. We discuss the prospects from the



perspective of the three essential components of smart PSS: stakeholders, smart connected products, and intelligent systems, for which PI can be seen as an ecosystem.

Figure 3. Prospects of smart PSS in Physical Internet

### 3.1 PI Stakeholders

PI as a SC and logistics system involves various stakeholders of which the most important are logistics service demanders (shippers and receivers), **service providers (including LSP such as 3PL/4PL and technology service providers 5PL)**, and society, as shown in Figure 4. They collectively design and devise the products and systems, and in return benefit from the services and values generated. Moreover, the data generated by the stakeholders drives the design and creation of new services and values for the system.

Figure 4. Data-driven service innovations within PI eco-system

*Logistics players* such as service demanders and providers are the main users of smart PSS and PI and they play a dual role in data: providers and consumers. Generally, service demanders or shippers (e.g., manufacturers) and receivers (e.g., retailers, consumers) define the service demands and objectives for the system. **In other words, they generate physical demands and related data, called demand-data. LSP (3PL or 4PL) then devise a service network of adequate capacity and expertise to satisfy the demands and objectives. More precisely, asset-based 3PL provides physical services (e.g., transport, inventory) and product-generated data from the assets [11]. Asset-free 4PL, who coordinate flows and plans, optimise the whole system using demand- and product-generated data as well as logistics expertise. 5PL are technology service providers that provide technological or technical solutions and expertise to enhance system performance, for example, manufacturers of smart devices, developers of data tools, or business intelligence providers.** In other words, 3PL can serve as tangible (physical) smart PSS providers, 4PL as intangible (informational) smart PSS providers, and 5PL as both and all of them can be product-data generators.

In this paper, the term *society* refers generally to the group of stakeholders and entities on which the impact of logistics activities is significant, for example, government authorities, policymakers, and inhabitants. They are not literally users but value beneficiaries of smart PSS and PI-based logistics and their main concern is reducing negative externalities, for example, emissions, noise, congestion, accidents (see handbook on the estimation of external costs of transport [42]). This can lead to the development of new regulations or charters for urban logistics or urban planning, which generate data (or constraints) for the system, called environment-data in this paper, that should be taken into account for service and value creation. For instance, the circular economy that is crucial to eco-districts seems to bind sustainable logistics and smart PSS together using lifecycle management tools [43]. Other examples include automated distribution and transport systems, sharing economy in logistics, and cargo-bikes. The examples reveal that sustainability might often be seen as a constraint or objective of logistics management, whereas it is a real, significant value for society as well as other stakeholders.

### **3.2 Smart connected products in PI**

This section discusses the design issues of both tangible and intangible smart connected products in PI. According to [38], tangible smart products in PI include physical means and facilities, and intangible products are mostly information system (IS) tools and services.

#### *3.2.1 PI-containers*

Physical means in PI refer to the logistics means designed for the PI paradigm, for example, PI-containers or PI-means for handling, warehousing, inventorying, and transporting PI-containers (trucks, forklifts, AGV, sorters, etc.). Here we take PI-containers as an example for discussing the smart PSS design issue. Generally speaking, PI-containers represent smart logistics units used in PI to encapsulate merchandise. As the discussion here only concerns container intelligence without regard for physical features, we can use the term PI-containers to refer to all kinds of containers and logistics units in PI (see [44] for different types of PI-containers). As illustrated in Figure 5, three levels of intelligence can be associated with PI-containers.

- Class #1 information handling means containers are only used for collecting and carrying data and information that will be sent to the system for decision-making (e.g., GPS data);

- Class #2 problem notification means containers are able to process data, analyse information, and send notifications to the system in the event of a problem (e.g., temperature monitoring and warning);
- Class #3 decision-making means containers are able to make decisions according to real-time information, and are potentially self-acting (e.g., temperature control, routing optimisation).

From a smart PSS perspective, the service and value generated by each class are different even though each container is equipped with an embedded system. It is obvious that Class #3 will provide higher value to users for real-time decentralised and distributed decision-making, i.e., *peer-to-peer processes*, whereas classes #1 and #2 require high-level decisions from the system, i.e., *top-down processes*. However, Class #3 will also generate higher costs and require considerable input of investment and expertise. Over the long-term, we believe that Class #3 has better prospects than the other two classes in PI due to the large-scale interoperability and the need for real-time decentralised and distributed optimisation. Moreover, the development of IoT and data science will help reduce the cost and expertise barriers, as well as improve ROI (return on investment).

Figure 5. Smart PI-container with three levels of intelligence (from [45])

### 3.2.2 PI-hubs

In this paper, the PI facilities primarily involve the physical logistics sites comprising the PI network, namely PI-hubs (others such as roads are public infrastructures rather than PI facilities). The fundamental role is to connect interoperable logistics networks; the flows from different networks are transited to and reconsolidated at PI-hubs so that services can be exchanged and shared. PI-hubs can be used for different purposes such as freight cross-docking or re-routing, warehousing or inventory, or simply to relay drivers. Accordingly, the functional design would be different.

A number of papers have studied the functional design of PI-hubs [46–49], but rarely from the angle of connected products or smart PSS. An authentic example in the fast-moving consumer goods industry is cited here for discussion. *CRC Services* (Collaborative Routing Centre Services,

see *crc-services.com*) is an asset-free 4PL start-up in France inspired by PI. For a given region, they propose local transport and sorting services aiming to reconsolidate multi-supplier and multi-retailer flows to improve transport efficiency and to synchronise deliveries to retailers. Different from traditional LSP, their business model does not rely on long-term contracts but on a *pay-per-use* model in which suppliers/retailers pay for the service per use and per pallet. Conversely, instead of a contract, a *charter* comprising a set of business protocols is co-written and respected by all parties. The advantage is that once a charter becomes a consensus standard used by all stakeholders and all networks, the same service can be run by any company anywhere. This corresponds well to the *plug-and-play* principle for interoperability. This is why the start-up is growing fast and has set up five service centres in France so far, as depicted in Figure 6. There are also other similar start-ups in Europe (see *MixMove.io*, *Stock-booking.com* for example).

Figure 6. CRC Services Network in France in 2019 (from *www.crc-services.com*)

These real examples highlight considerable prospects for smart PSS. Firstly, PI-hubs can be seen as smart connected products or services. Each PI-hub, although independent, is connected to the PI system and to others for logistics planning and synchronisation. Secondly, PI-hubs generate product-data whereby they gather and offer precise local information to the PI system. The information is certainly valuable for new services and value creation. Thirdly, asset-free service providers (4PL or 5PL) may be more interested in the *pay-per-use* model rather than long-term contract model, especially for intangible services. The discussion also reveals that the PI paradigm will stimulate business model innovations with regard to smart PSS.

### *3.2.3 PI-Information tools and services*

Intangible smart products in PI refer primarily to information tools and services for data management, e.g., databases, platforms, Blockchain services, or APIs. These tools and services can be investigated from different perspectives as they can be seen as products or systems. They are discussed as intangible products in this paper. Two main issues relating to interoperability in PI should be discussed here: object monitoring and data sharing. Although the two issues are correlated, different perspectives can be discussed with regard to smart PSS.

Object monitoring concerns tracking and tracing objects from one network (or party) to another. Taking a PI-container as an example, Figure 7 illustrates the route of a PI-container through interoperable networks in which it is managed by different actors and operators. At each stage, the smart PI-container generates product-data and sends it to the system or coordinators (i.e. network operators, data platforms, or other smart products). As such, the containers can always be tracked and traced. Innovative services are required to manage the information and *EPCIS* (Electronic Product Code Information Services) proposed by *GSI* is a good example [50]. The service ensures that all objects and their travel history through the network are recorded, then converted to product-data by a set of consensus standards (what, when, where, why). It can be regarded as an intangible smart PSS used in PI to track and trace the PI-containers (as well as the merchandise inside). Once data are generated via standards, data sharing is the next issue of interoperability. Many technologies have been developed for this purpose, e.g., blockchain and smart contract technologies, or smart API. The common objective of these technologies is to connect databases and platforms of different SC or logistics networks to enable interoperability.

Figure 7. Illustration of a PI-container journey through interoperable networks (from [45])

### **3.3 Intelligent systems**

The role of intelligent systems is to group and (inter)connect stakeholders and smart products, and to optimally coordinate the activities inside. More specifically, PI can be defined as an intelligent logistics system integrating various systems, e.g., interoperable SC or logistics systems, infrastructure systems, and information systems. Its main goal is to optimally coordinate logistics activities and control the objects involved by harmonising all stakeholder demands, system objectives, and infrastructure supports and constraints. This definition implies that PI is an intelligent system with a much wider scope than traditional examples in the manufacturing field [11], especially when considering smart PSS. Knowing that PI is a complex system interconnecting interoperable networks and smart PSS, services and value should be of both individual and global interest. A system-based global vision is particularly important to service and value creation. One of the key issues is how to integrate the three sets of data into the design and creation of new services and value (i.e., user, product, and environment, as explained in Figure 4).

## 4. Future Prospects and Avenues of Research

Section 3 shows that PI is a complex logistics ecosystem involving various stakeholders, intelligent management systems, and smart PSS for service and value creation. This part aims to broaden the scope of the discussion to outline prospects and avenues of research leading to a more advanced era of intelligent interoperable logistics. **We are especially interested in the logistics scenarios or models subsequent to the implementation of smart PSS, and the avenues of research working to achieve these scenarios.** According to the recent relevant literature, four promising research directions should be discussed: (i) Connected objects and the network effect; (ii) Plug-and-play principle for sharing economies; (iii) Supply Chain Digital Twin; and (iv) a Logistics-as-a-Service business model.

### 4.1 Connected objects and the network effect

The literature predominantly concerns issues regarding the intelligence and connectivity of smart and connected objects, but the network effect of these objects has received much less attention, especially in logistics and SCM. The network effect (or network externality) can be described as *“the utility that a user derives from consumption of the good increases with the number of other agents consuming the good”* [51]. In other words, the value of the product or service increases when the consumption increases. A good example of this is the rise in smartphone and application platforms [52]. Beyond physical products, the effect also involves intangible products such as data standards, blockchain technologies [53].

The PI paradigm intensifies the network effect of smart connected products due to the fact that PI is based on the standardisation and modularisation of physical material, data and information systems, and business processes. However, product design should be carefully investigated from an intelligent system perspective to achieve the broadest network effects and value maximisation. The intelligence of PI-containers is a concrete example. On the one hand, the lack of IoT infrastructure may halt the widespread use of smart containers and on the other hand, the different levels of intelligence associated may be a hindrance to their value as well as the data generated. The issue is even more significant with large-scale interoperable networks, which could cover more than one country or continent. We believe that further research investigating the network effect of smart PSS will be of great value for PI and general intelligent interoperable logistics networks.

## **4.2 Plug-and-play principle and sharing economies**

According to [54], there could be two kinds of sharing economies in SC and logistics. The first is called *collaborative consumption* that refers to *peer-to-peer* (P2P) product or service sharing based on a consumer-to-consumer (C2C) network. Examples include car-sharing systems such as *Uber* or the crowdshipping concept (e.g., *piggybee.com*). The second is called *collaborative business* that consists in sharing logistics assets or services among competitors based on a business-to-business (B2B) network. The latter clearly reflects the idea of horizontal cooperation, which is particularly interesting for interoperable logistics networks as it combines vertical collaboration and horizontal collaboration (sometimes called cooperation). Knowing that PI advocates resource sharing among shippers, LSP, or receivers, it is indeed a form of collaborative business and horizontal cooperation to maximise asset value.

From the perspective of smart PSS, integrating the *plug-and-play* principle into collaborative business sharing seems to offer even better opportunities and prospects. Within interoperable logistics networks, each smart PSS can be used in a B2B shared way. Moreover, when a plug-and-play principle applies, every smart PSS can be seen as a modular building block [55], so the number of blocks can be adjusted according to the actual demands and constraints. On the one hand, this will considerably enhance the flexibility and resilience of the system, and on the other hand provide opportunities for LSP to innovate their business models. The aforementioned real example, *CRC Services*, is a good illustration of such prospects. Furthermore, from a system point of view, interoperable networks can be regarded as holonic systems in which every plug-and-play component is a holon [56]. Holons are usually defined as autonomous, cooperating, and potentially recursive decisional entities which can simultaneously be a part or sub-whole of the system [57]. A vision of a holonic system will help stakeholders understand better the issues of the whole network, and to control its components and activities better. Further research by academia and practitioners is still needed on this topic.

## **4.3 Supply Chain Digital Twin**

Smart PSS is a solution for the digital transformation of SC and logistics. It focuses mainly on data-driven design and data analytics for service innovation using demand-data and product-data [11], as well as environment-data. Digital Twin (DT) is a similar concept but it pays more attention to mirroring the life of physical objects. It comprises three components: physical

product, virtual product (avatar), and connected data that link the physical and virtual product [58]. In other words, DT emphasises online and real-time monitoring and control, whereas smart PSS is more concerned with offline modelling, data exploitation and business model innovation.

Supply Chain Digital Twin (SCDT) is the application of DT in logistics and SCM. The concept was recently proposed in [59] to enhance SC resilience. The authors argue that SCDT will provide real-time data from logistics assets and activities (demands, capacity, disruptions, etc.) that can be used for data-driven planning and real-time control decisions using simulation and optimisation tools. In this context, smart PSS may play a dual, central role: data generator and data consumer (decision-maker or decision-executor depending on the level of intelligence). One of the next research topics could be the design and implementation of smart PSS in SCDT, especially regarding the question about how to gather and exploit the data for offline data-driven service innovation and online data-driven planning and control. Furthermore, lifecycle management of the shared products in interoperable SC and logistics networks will also be a critical subject, especially under the SCDT concept.

#### **4.4 Logistics-as-a-Service business model**

The *servitization* business model has been seen in many sectors including *Mobility-as-a-Service* (MaaS) or *Software-as-a-Service* (SaaS). It has also been studied in SC and logistics and some concepts have been proposed: Cloud Logistics [60], Logistics- or Supply Chain-as-a-Service [61]. Even under different names, the principle is similar, which is to “*provide the right commodity or service, in the right quality and quantity, at the right location and time, to the right customer, at the right price for resources*” [60]. It is generally called *Logistics-as-a-Service* (LaaS) in this paper. The principle of LaaS can also be applied to interoperable logistics, considering that the latter concentrates on collaboration and cooperation for resources and services sharing. In particular, it is plausible that the LaaS business model will become even more widespread thanks to the interoperability and connectivity of logistics systems. **From this perspective, the design and potential value of smart PSS should be reviewed differently, for example, from a product-leasing model to a *pay-per-use* model. The aforementioned start-ups in transport (e.g., *crc-services.com*) or in warehousing (e.g., *stock-booking.com*, *flexe.com*) clearly illustrate the ongoing changes in mindset. However, most of the current service innovations are aimed at niche markets of basic logistics operations (transport, warehousing, etc.). The LaaS model in the future**



should be based on a higher level and more comprehensive vision to provide smart integrated solutions and service design and innovation. This could be of particular interest for city logistics, for example passenger/freight shared autonomous vehicles [62]. The new trend will come up with new research topics such as more smart and sustainable services, the development of effective procurement mechanisms taking the interests of all stakeholders into consideration, or innovations in business models.

## **5. Conclusion**

This paper discusses design and implementation issues of smart PSS for intelligent interoperable logistics. A recent breakthrough logistics paradigm, the Physical Internet (PI), an illustration of intelligent interoperable logistics, is studied. The prospects and perspectives of smart PSS are then investigated under such a paradigm. The results clearly indicate the crucial role played by smart PSS for PI implementation. In light of some recent logistics start-ups inspired by PI, logistics innovation opportunities under this paradigm have been highlighted. However, the results also demonstrate that the aforementioned start-ups chiefly follow bottom-up innovation and concern basic logistics operations. Cases following top-down innovation with a more comprehensive vision are still rare. PI-inspired top-down best practices are particularly appealing for smart PSS design. This paper also calls for research on smart PSS design for PI and for intelligent interoperable logistics.

The findings also show some future research opportunities. Firstly, PI and intelligent interoperable logistics are still in their infancy and the theoretical and fundamental research is inadequate to support the design and implementation of smart PSS in this context. In particular, a service-oriented conceptual framework would be necessary for the next step. Secondly, sustainability merits more research attention. As shown in recent research [21], smart PSS is of particular interest in sustainable SC and logistics. Asset lifecycle management is one of the most popular ongoing research topics. Some other related topics can also be recommended, such as industrial symbiosis, smart city and smart PSS for sustainable logistics, and the social impacts of smart PSS.

## References

- [1] R. Wilding, B. Wagner, D.M. Gligor, M.C. Holcomb, Understanding the role of logistics capabilities in achieving supply chain agility: a systematic literature review, *Supply Chain Management: An International Journal*. 17 (2012) 438–453.
- [2] R. Wilding, R. Juriado, Customer perceptions on logistics outsourcing in the European consumer goods industry, *International Journal of Physical Distribution & Logistics Management*. 34 (2004) 628–644. doi:10.1108/09600030410557767.
- [3] R. Mason, C. Lalwani, R. Boughton, Combining vertical and horizontal collaboration for transport optimisation, *Supply Chain Management: An International Journal*. 12 (2007) 187–199.
- [4] S. Pan, D. Trentesaux, E. Ballot, G.Q. Huang, Horizontal collaborative transport: survey of solutions and practical implementation issues, *International Journal of Production Research*. 0 (2019) 1–22. doi:10.1080/00207543.2019.1574040.
- [5] Z.G. Zacharia, N.R. Sanders, N.W. Nix, The Emerging Role of the Third-Party Logistics Provider (3PL) as an Orchestrator, *Journal of Business Logistics*. 32 (2011) 40–54.
- [6] G. Büyüközkan, O. Feyzioğlu, M. Şakir Ersoy, Evaluation of 4PL operating models: A decision making approach based on 2-additive Choquet integral, *International Journal of Production Economics*. 121 (9) 112–120. doi:10.1016/j.ijpe.2008.03.013.
- [7] S. Hertz, M. Alfredsson, Strategic development of third party logistics providers, *Industrial Marketing Management*. 32 (2) 139–149. doi:10.1016/S0019-8501(02)00228-6.
- [8] P. Hosie, B. Sundarakani, A.W.K. Tan, A. Koźlak, Determinants of fifth party logistics (5PL): service providers for supply chain management, *International Journal of Logistics Systems and Management*. 13 (2012) 287–316.
- [9] M.J. Goedkoop, C.J. Van Halen, H.R. Te Riele, P.J. Rommens, Product service systems, ecological and economic basics, Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ). 36 (1999) 1–122.
- [10] Y. Zhang, S. Liu, Y. Liu, R. Li, Smart box-enabled product–service system for cloud logistics, *International Journal of Production Research*. 54 (2016) 6693–6706. doi:10.1080/00207543.2015.1134840.
- [11] P. Zheng, T.-J. Lin, C.-H. Chen, X. Xu, A systematic design approach for service innovation of smart product-service systems, *Journal of Cleaner Production*. 201 (2018) 657–667. doi:10.1016/j.jclepro.2018.08.101.
- [12] E. Ballot, B. Montreuil, R. Meller, *The Physical Internet: The Network of Logistics Networks*, La documentation Française, Paris, France, 2014.
- [13] S. Pan, Opportunities of Product-Service System in Physical Internet, *Procedia CIRP*. 83 (2019) 473–478.
- [14] A. McKay, S. Kundu, A representation scheme for digital product service system definitions, *Advanced Engineering Informatics*. 28 (2014) 479–498. doi:10.1016/j.aei.2014.07.004.
- [15] T.S. Baines, H.W. Lightfoot, S. Evans, A. Neely, R. Greenough, J. Peppard, R. Roy, E. Shehab, A. Braganza, A. Tiwari, J.R. Alcock, J.P. Angus, M. Bastl, A. Cousens, P. Irving, M. Johnson, J. Kingston, H. Lockett, V. Martinez, P. Michele, D. Tranfield, I.M. Walton, H. Wilson, State-of-the-art in product-service systems, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 221 (2007) 1543–1552. doi:10.1243/09544054JEM858.
- [16] O.K. Mont, Clarifying the concept of product–service system, *Journal of Cleaner Production*. 10 (2002) 237–245. doi:10.1016/S0959-6526(01)00039-7.
- [17] A. Annarelli, C. Battistella, F. Nonino, Product service system: A conceptual framework from a systematic review, *Journal of Cleaner Production*. 139 (2016) 1011–1032. doi:10.1016/j.jclepro.2016.08.061.
- [18] J. Lee, H.-A. Kao, S. Yang, Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment, *Procedia CIRP*. 16 (2014) 3–8. doi:10.1016/j.procir.2014.02.001.

- [19] S. Pan, D. Trentesaux, Y. Sallez, Specifying Self-organising Logistics System: Openness, Intelligence, and Decentralised Control, in: T. Borangiu, D. Trentesaux, A. Thomas, P. Leitão, J.B. Oliveira (Eds.), *Service Orientation in Holonic and Multi-Agent Manufacturing : Proceedings of SOHOMA 2016*, Springer, 2017: pp. 93–102. doi:10.1007/978-3-319-51100-9\_9.
- [20] Y. Zhang, S. Ren, Y. Liu, T. Sakao, D. Huisingh, A framework for Big Data driven product lifecycle management, *Journal of Cleaner Production*. 159 (2017) 229–240. doi:10.1016/j.jclepro.2017.04.172.
- [21] S. Ren, Y. Zhang, Y. Liu, T. Sakao, D. Huisingh, C.M.V.B. Almeida, A comprehensive review of big data analytics throughout product lifecycle to support sustainable smart manufacturing: A framework, challenges and future research directions, *Journal of Cleaner Production*. 210 (2019) 1343–1365. doi:10.1016/j.jclepro.2018.11.025.
- [22] M. Garetti, P. Rosa, S. Terzi, Life Cycle Simulation for the design of Product–Service Systems, *Computers in Industry*. 63 (2012) 361–369. doi:10.1016/j.compind.2012.02.007.
- [23] X. Qiu, H. Luo, G. Xu, R. Zhong, G.Q. Huang, Physical Assets and service sharing for IoT-enabled supply Hub in industrial park (SHIP), *International Journal of Production Economics*. (2014). doi:http://dx.doi.org/10.1016/j.ijpe.2014.09.001.
- [24] A. Valencia, R. Mugge, J.P.L. Schoormans, H.N.J. Schifferstein, The Design of Smart Product-Service Systems (PSSs): An Exploration of Design Characteristics, *International Journal of Design*. 9 (2015) 16.
- [25] F. Vendrell-Herrero, O.F. Bustinza, G. Parry, N. Georgantzis, Servitization, digitization and supply chain interdependency, *Industrial Marketing Management*. 60 (2017) 69–81. doi:10.1016/j.indmarman.2016.06.013.
- [26] J. Hagberg, M. Sundstrom, N. Egels-Zandén, The digitalization of retailing: an exploratory framework, *International Journal of Retail & Distribution Management*. (2016). doi:10.1108/IJRDM-09-2015-0140.
- [27] D. Bechtsis, N. Tsolakis, D. Vlachos, E. Iakovou, Sustainable supply chain management in the digitalisation era: The impact of Automated Guided Vehicles, *Journal of Cleaner Production*. 142 (2017) 3970–3984.
- [28] M.A. Waller, S.E. Fawcett, Data Science, Predictive Analytics, and Big Data: A Revolution That Will Transform Supply Chain Design and Management, *Journal of Business Logistics*. 34 (2013) 77–84. doi:10.1111/jbl.12010.
- [29] Z. Li, A.V. Barenji, G.Q. Huang, Toward a blockchain cloud manufacturing system as a peer to peer distributed network platform, *Robotics and Computer-Integrated Manufacturing*. 54 (2018) 133–144. doi:10.1016/j.rcim.2018.05.011.
- [30] X.T.R. Kong, H. Luo, G.Q. Huang, X. Yang, Industrial wearable system: the human-centric empowering technology in Industry 4.0, *J Intell Manuf.* (2018). doi:10.1007/s10845-018-1416-9.
- [31] Orange Labs, Thing'in - the things' graph platform, (2019). <https://hellofuture.orange.com/en/thingin-the-things-graph-platform/>.
- [32] M.R. Rasouli, R.J. Kusters, J.J.M. Trienekens, P.W.P.J. Grefen, Service orientation in business networking: a demand-supply chain perspective, *Production Planning & Control*. 30 (2019) 2–19. doi:10.1080/09537287.2018.1519730.
- [33] R.F. Lusch, Reframing Supply Chain Management: A Service-Dominant Logic Perspective, *Journal of Supply Chain Management*. 47 (2011) 14–18. doi:10.1111/j.1745-493X.2010.03211.x.
- [34] J.T. Mentzer, B.P. Konrad, An efficiency/effectiveness approach to logistics performance analysis, *Journal of Business Logistics*. 12 (1991) 33–62.
- [35] E.S. Bernardes, M.D. Hanna, A theoretical review of flexibility, agility and responsiveness in the operations management literature: Toward a conceptual definition of customer responsiveness, *International Journal of Operations & Production Management*. 29 (2009) 30–53. doi:10.1108/01443570910925352.

- [36] R. Bhamra, S. Dani, K. Burnard, Resilience: the concept, a literature review and future directions, *International Journal of Production Research*. 49 (2011) 5375–5393. doi:10.1080/00207543.2011.563826.
- [37] C. Labuschagne, A.C. Brent, R.P. Van Erck, Assessing the sustainability performances of industries, *Journal of Cleaner Production*. 13 (2005) 373–385.
- [38] B. Montreuil, Toward a Physical Internet: meeting the global logistics sustainability grand challenge, *Logistics Research*. 3 (2011) 71–87. doi:10.1007/s12159-011-0045-x.
- [39] S. Pan, E. Ballot, G.Q. Huang, B. Montreuil, Physical Internet and interconnected logistics services: research and applications, *International Journal of Production Research*. 55 (2017) 2603–2609. doi:10.1080/00207543.2017.1302620.
- [40] S. Henrik, N. Andreas, The Physical Internet – review, analysis and future research agenda, *International Journal of Physical Distribution & Logistics Management*. 47 (2017) 736–762. doi:10.1108/IJPDLM-12-2016-0353.
- [41] T. Ambra, A. Caris, 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*. (2018) 1-18 (in press). doi:10.1080/00207543.2018.1494392.
- [42] A. Korzhenevych, N. Dehnen, J. Bröcker, M. Holtkamp, H. Meier, G. Gibson, A. Varma, V. Cox, Update of the handbook on external costs of transport, 2014.
- [43] A. Tukker, Product services for a resource-efficient and circular economy – a review, *Journal of Cleaner Production*. 97 (2015) 76–91. doi:10.1016/j.jclepro.2013.11.049.
- [44] B. Montreuil, E. Ballot, W. Tremblay, Modular Design of Physical Internet Transport, Handling and Packaging Containers, in: Smith et al. (Ed.), 2016.
- [45] Y. Sallez, S. Pan, B. Montreuil, T. Berger, E. Ballot, On the activeness of intelligent Physical Internet containers, *Computers in Industry*. 81 (2016) 96–104. doi:10.1016/j.compind.2015.12.006.
- [46] Y. Sallez, T. Berger, T. Bonte, D. Trentesaux, Proposition of a hybrid control architecture for the routing in a Physical Internet cross-docking hub, *IFAC-PapersOnLine*. 48 (2015) 1978–1983. doi:10.1016/j.ifacol.2015.06.378.
- [47] E. Ballot, B. Montreuil, C. Thivierge, Functional design of physical internet facilities: a road-rail hub, in: Montreuil et al. (Ed.), 2014.
- [48] R.D. Meller, B. Montreuil, C. Thivierge, Z. Montreuil, Functional design of physical internet facilities: a road-based transit center, in: Montreuil et al. (Ed.), 2014.
- [49] B. Montreuil, R.D. Meller, C. Thivierge, Z. Montreuil, Functional design of physical internet facilities: a unimodal road-based crossdocking hub, in: Montreuil et al. (Ed.), 2014.
- [50] GS1, EPC Information Services (EPCIS) Version 1.1 Specification, 2019. [http://www.gs1.org/sites/default/files/docs/epc/epcis\\_1\\_1-standard-20140520.pdf](http://www.gs1.org/sites/default/files/docs/epc/epcis_1_1-standard-20140520.pdf).
- [51] M.L. Katz, C. Shapiro, Network Externalities, Competition, and Compatibility, *The American Economic Review*. 75 (1985) 424–440.
- [52] D.D. Garcia-Swartz, F. Garcia-Vicente, Network effects on the iPhone platform: An empirical examination, *Telecommunications Policy*. 39 (2015) 877–895. doi:10.1016/j.telpol.2015.07.011.
- [53] J. Mattila, T. Seppälä, J. Holmström, Product-centric Information Management: A Case Study of a Shared Platform with Blockchain Technology, in: 2016. <http://www.escholarship.org/uc/item/65s5s4b2>.
- [54] M. Savelsbergh, T. Van Woensel, 50th anniversary invited article—city logistics: Challenges and opportunities, *Transportation Science*. 50 (2016) 579–590.
- [55] S.A. Melnyk, R. Narasimhan, H.A. DeCampos, Supply chain design: issues, challenges, frameworks and solutions, *International Journal of Production Research*. 52 (2014) 1887–1896. doi:10.1080/00207543.2013.787175.
- [56] D.C. Mcfarlane, S. Bussmann, Developments in holonic production planning and control, *Production Planning & Control*. 11 (2000) 522–536. doi:10.1080/095372800414089.

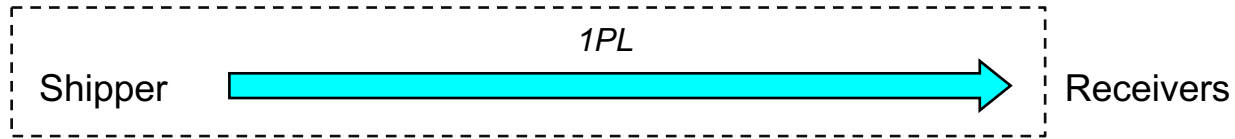
- [57] A. Giret, V. Botti, Holons and agents, *Journal of Intelligent Manufacturing*. 15 (2004) 645–659. doi:10.1023/B:JIMS.0000037714.56201.a3.
- [58] F. Tao, J. Cheng, Q. Qi, M. Zhang, H. Zhang, F. Sui, Digital twin-driven product design, manufacturing and service with big data, *Int J Adv Manuf Technol*. 94 (2018) 3563–3576. doi:10.1007/s00170-017-0233-1.
- [59] D. Ivanov, A. Dolgui, A. Das, B. Sokolov, Digital Supply Chain Twins: Managing the Ripple Effect, Resilience, and Disruption Risks by Data-Driven Optimization, Simulation, and Visibility, in: D. Ivanov, A. Dolgui, B. Sokolov (Eds.), *Handbook of Ripple Effects in the Supply Chain*, Springer International Publishing, Cham, 2019: pp. 309–332. doi:10.1007/978-3-030-14302-2\_15.
- [60] K. Nowicka, Smart City Logistics on Cloud Computing Model, *Procedia - Social and Behavioral Sciences*. 151 (2014) 266–281. doi:10.1016/j.sbspro.2014.10.025.
- [61] J. Leukel, S. Kirn, T. Schlegel, Supply Chain as a Service: A Cloud Perspective on Supply Chain Systems, *IEEE Systems Journal*. 5 (2011) 16–27. doi:10.1109/JSYST.2010.2100197.
- [62] A. Mourad, J. Puchinger, C. Chu, A survey of models and algorithms for optimizing shared mobility, *Transportation Research Part B: Methodological*. 123 (2019) 323–346. doi:10.1016/j.trb.2019.02.003.

<b>Service Level Objectives</b>	<b>Short Description</b>
Effectiveness	How well a goal is adequately met [34]
Efficiency	How well the resources expended are utilised to meet a goal [34]
Agility	Ability of a system to rapidly reconfigure [35]
Flexibility	Ability of a system to change status within an existing configuration [35]
Resilience	Ability of a system to return to its original state or move to a new, more desirable state after being disrupted [36]
Sustainability	Ability of a system to protect, sustain, and enhance the human and natural resources that will be needed in the future while meeting the desired goal [37]

Table 1. The most important service level objectives faced by SC and logistics today

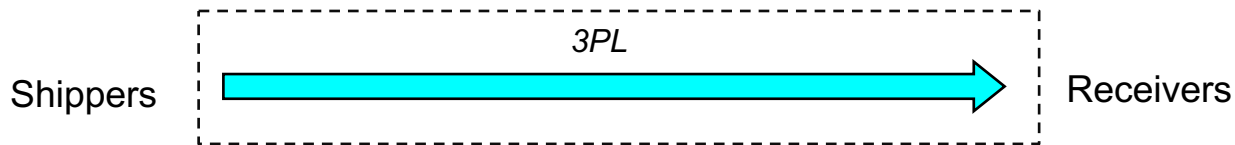
### Stage 1: In-house logistics (since the beginning)

Managed by a single-shipper/receiver for dedicated clients/suppliers



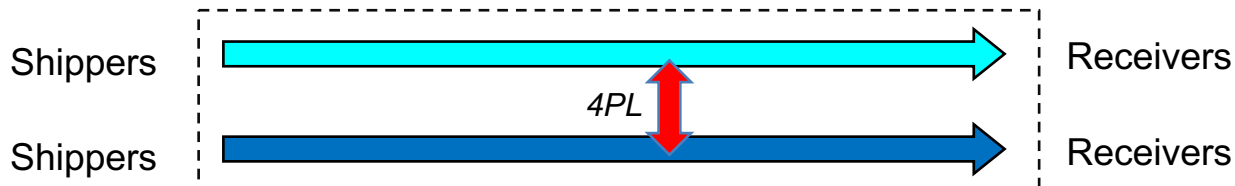
### Stage 2: Outsourcing and vertical collaboration (After 70's)

Managed by asset-based 3PL for a dedicated supply chain



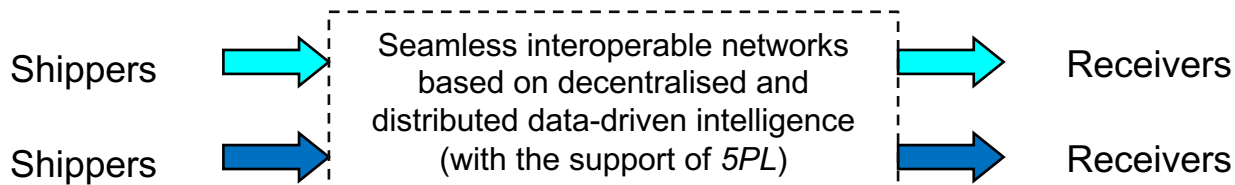
### Stage 3: Sharing resources and horizontal collaboration (After 2005)

Coordinated by neutral asset-free 4PL for cross supply chain network

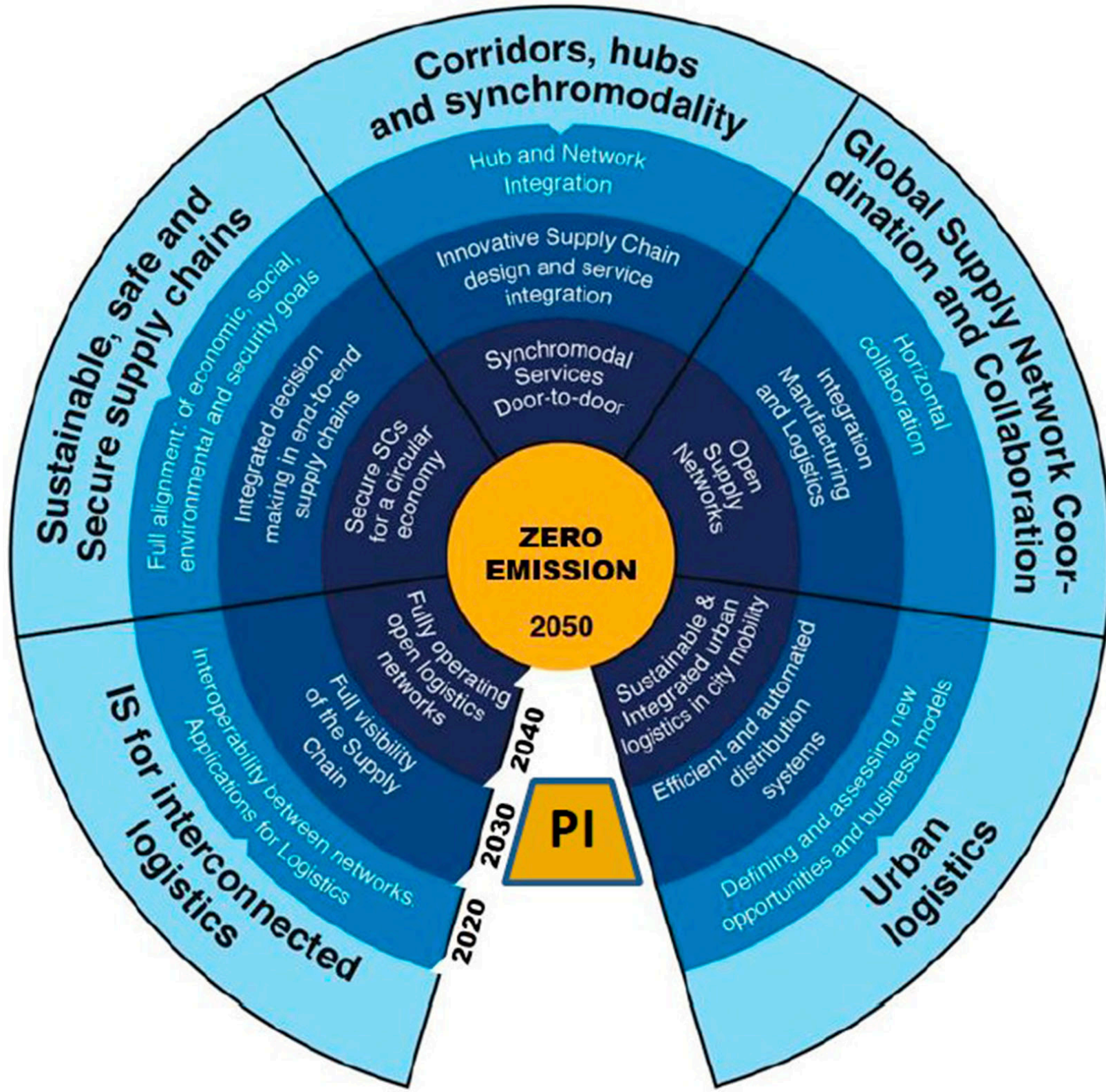


### Stage 4: Openness and interoperability (After 2010)

Data-driven smart coordination for open networks









## Stakeholders

- Demanders (Shippers, Receivers)
- Service providers (3PL, 4PL, 5PL)
- Society (government, inhabitants...)

- *Demands*
- *Constraints*
- *Objectives*
- *Expertise*
- *Capacity*

- *Services*
- *Values*

- *Demands*
- *Constraints*
- *Objectives*
- *Expertise*
- *Capacity*

- *Services*
- *Values*

## Smart Connected Products

- PI-containers
- PI-means, PI-hubs
- Databases, data platforms, API

- *Decisions*
- *Control*

- *Data / Information*

## Intelligent Systems

- PI system
- SCM or logistics system
- Infrastructure system

## Service Demanders

- Shippers (upstream SC)
- Receivers (downstream SC)

## Service Providers

- 3PL (eg. transport, inventory)
- 4PL (eg. coordination, optimisation)
- 5PL (eg. data science, IoT, ICT)

## Society

- Community and inhabitants
- Government authorities
- Policymakers



Demand-data  
Generation

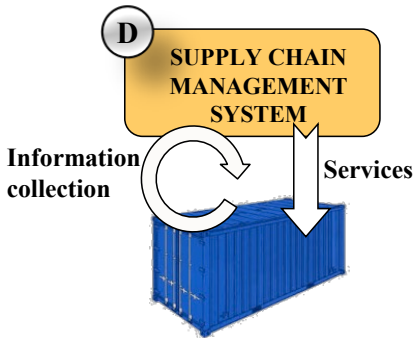


Product-data  
Generation



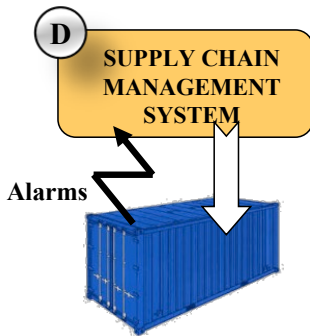
Environment-data  
Generation

Data-driven new service design and value creation



**CLASS #1**

**Information handling**



**CLASS #2**

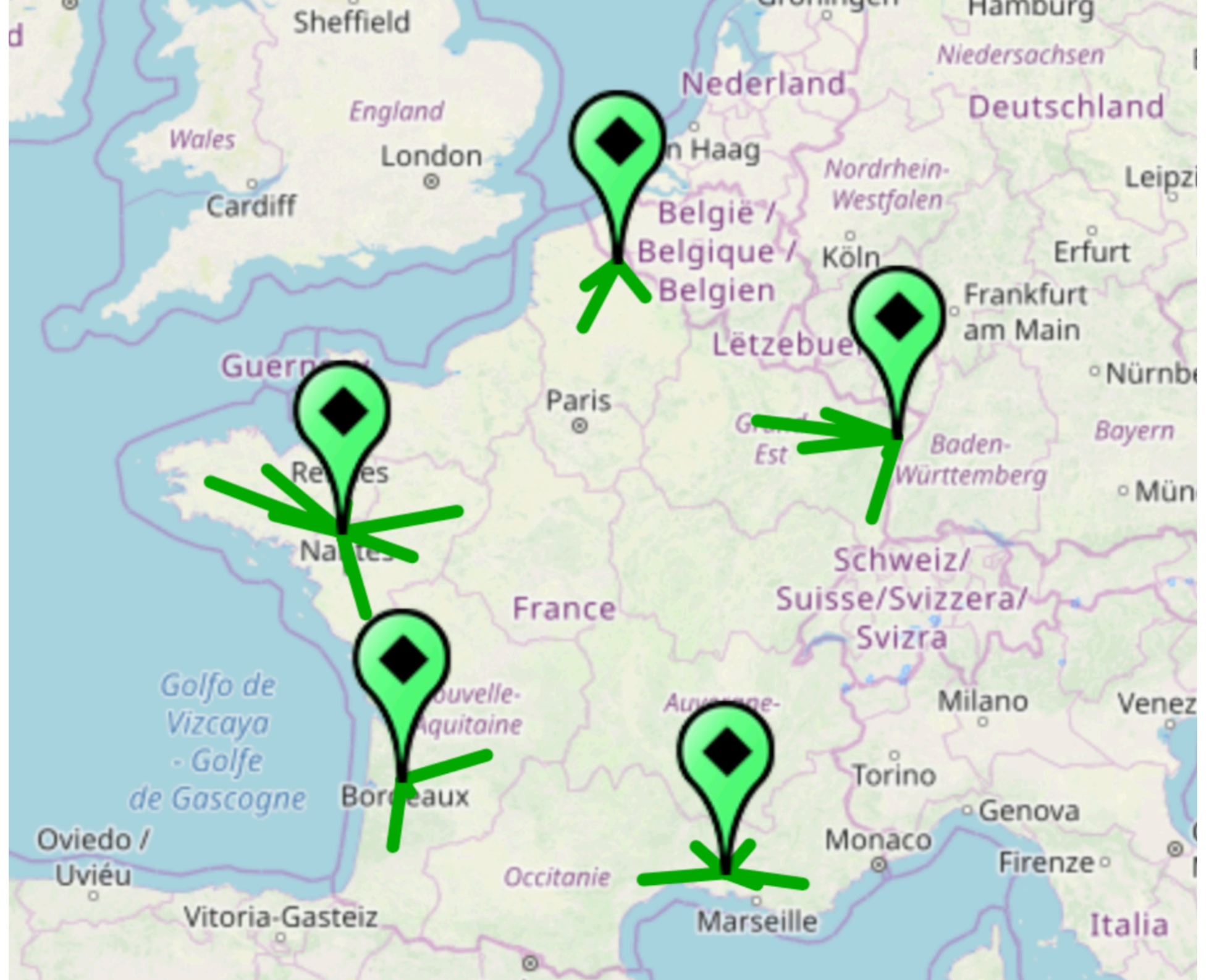
**Problem notification**

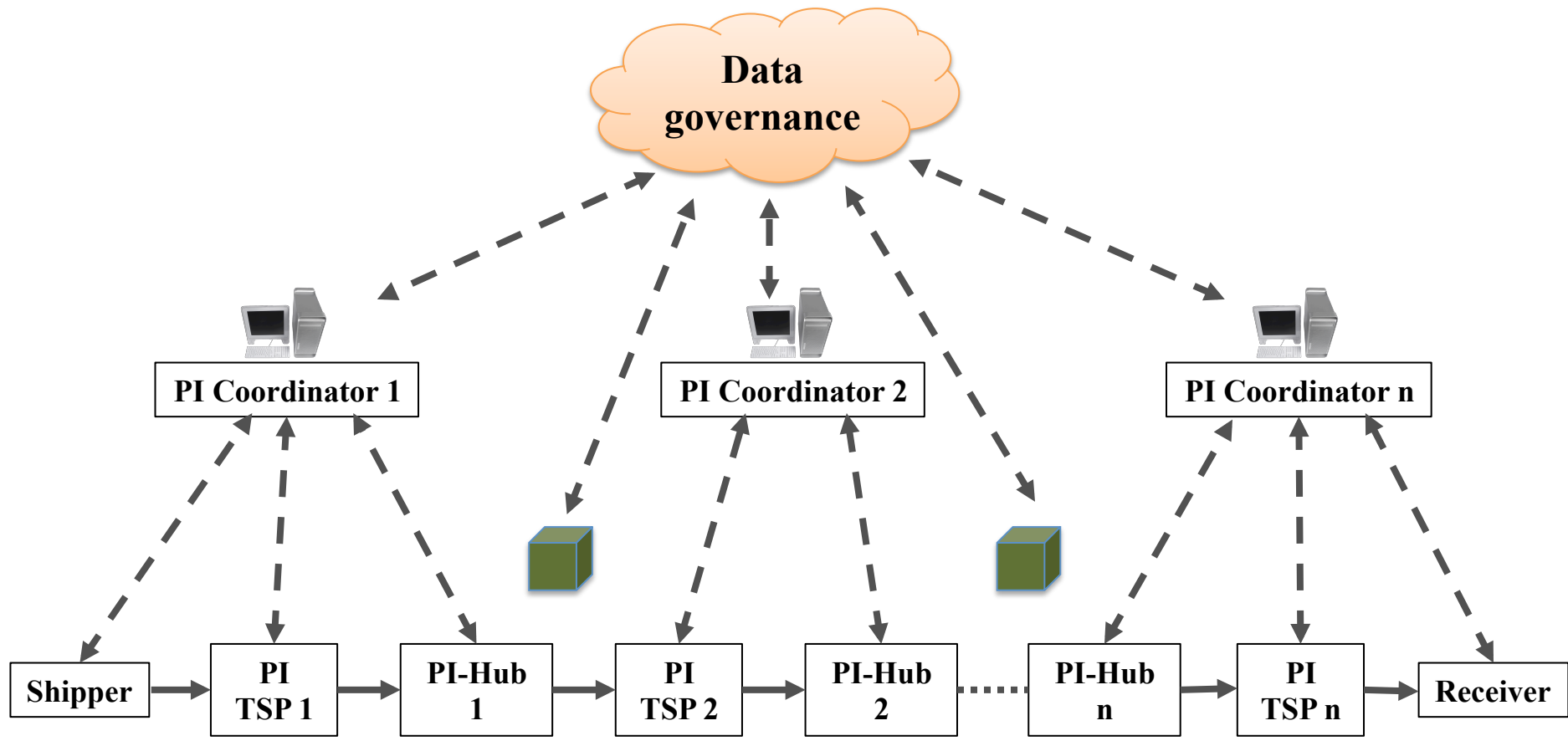


**CLASS #3**

**Decision making**

**D** : Decisional capabilities





PI-Container



PI-Container Movement



PI-Container User



Information Flow