Toward Humanitarian Supply Chains Enhancement by Using Physical Internet Principles

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***Abstract*—Humanitarian organisations need to be efficient and effective and to do so, rely on their supply chain and logistics efforts. However, the urgency context, the destabilised environment as well as large uncertainties often affect the performance of the relief. Symptoms such as redundancies or operation lack, mismanagement and high costs call the methods of humanitarian organisations into question. This research work examines the potentiality that the evolution directly to a hyperconnected world could benefit to humanitarian organisations. To this end, "Physical Internet" a new concept of global logistics networks based on the hyperconnection notion has been studied. Designed to address most of the stakes of tomorrow – multiplication of flows, environmental emergency, performance and speed pressures – it might present various interests for the humanitarian sector. In a first approach, some Physical Internet principles have been projected on typical humanitarian logistics operations related to transportation, storage allocation and inventory management. It appears interests in terms of savings, efficiency, sustainability and responsiveness. However, such reengineering comes with a cost and would require significant change such as a large reshape of the current logistics model and legal framework as well as further reflections regarding information management and technology development.**

***Index Terms*—Humanitarian aid, Supply Chain, Physical Internet, Relief chain, Logistics, Responsiveness, Effectiveness**

I. Introduction

From the very beginning, the main objective of Humanitarian Organizations (HO) is to rapidly alleviate human suffering after a disaster [1]. In other words, when a *"disruption that physically affects a system as a whole and threatens its priorities and goals"* [2] occurs. Different types of disasters exist, whom origin can be natural or man-made and characterised by their predictability and speed, according to the 'sudden-onset' or 'slow-onset' terminology [2]. Such organisations take action when the government is not able to meet the emergency needs of the people affected [3]. Evolving in an emergency context where every minute counts to make a difference between life and death, the humanitarian supply chain (HSC) requires to be efficient and effective [4]. To this end, aid agencies have to overcome many challenges; damaged infrastructure, lack of skilled resources, the uncertainty which makes forecasting difficult and generates stock management issues or even public opinion pressures. Those challenges among others, show the conditions in which aid workers evolve to develop strategies and operate. Furthermore, the increasing environmental awareness about man-made impacts, the scarcity of resources and the strengthening competition for funding, highlight the need to potentially rethink HOs and particularly their models of supply chain. All of this, to keep meeting HOs' objective, intended to relieve suffering people, in future.

To address the many and conflicting challenges of current supply chains, a new concept of 'Physical Internet' (PI) has been developed in a break with current practices. PI is inspired by Digital Internet principles. Instead of dealing with bytes, it is physical elements that are considered. The idea behind the concept is to face various challenges that cover economic, environmental and social aspects, by designing a new way for objects to be moved, deployed, realised, supplied, designed and used in the perspective to make logistics more efficient, sustainable, smart, agile, adaptable, scalable and resilient [5].

In a first approach, the benefits from the PI seem to fit the current stakes quite well the humanitarian sector encounter or is about to face. In this perspective, the following question may arise: Would PI's concepts be relevant to manage humanitarian flows and overcome the current malfunctions? If so, what would it require to address? To answer these questions, this paper starts with a section dedicated to the background and problem statement: the current humanitarian supply system, the challenges encountered, and the maturity associated. Then, it proposes a focus on the PI principles and interests for the humanitarian sector. Finally, a discussion, to identify the research topics to address in the perspective to see this new model of humanitarian supply chain implemented.

II. Background and Problem Statement

Since the beginning of the 21st century, the number, impact and complexity of disasters have significantly increased, and the trend is expected to grow in future [6]. From the last decade records (2007 – 2016), the average of natural disaster represents 354 events, with an average of people affected of 210 million. Besides, the pattern also bends toward an increase in economic losses. Indeed, in 2017, the damages have significantly increased by 49% compared to the average of $141 billion estimated [7]. Those stakes highlight the need for an efficient and effective humanitarian action and supply chain in response to crises. However, the numerous challenges,

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the destabilised supply network and the maturity of the supply chain are barriers slowing the achievement of this objective.

A. The present humanitarian supply network

When a disaster strikes the government has, as first responders, to provide humanitarian assistance to its affected people. As soon as, the needs over exceed the government's capacity, help form HOs is requested [8]. To forward emergency items to the targeted location, a dedicated supply network is set up. One part, called the upstream chain, is permanent and is strategically located to cover most of the world regions [4]. Usually, it ends up at the Regional/Worldwide warehouse which acts as a buffer and represents a decoupling point. The second part, the downstream chain, takes place in the disaster area [4]. It adapts to the available infrastructure and stops at the point of consumption e.g. the beneficiaries. In this global chain, relief supplies can come from outside the disaster (upstream section mainly) area or locally (downstream section) via donations or suppliers.

A typical international disaster relief chain is available hereafter (See Fig. 1). In this type of supply network, the global physical flow may generally come from a boat or a plane. Products are transported by railway or trucks during long-haul trips before reaching the Regional/Worldwide warehouse. Whatever global or local suppliers are, the financial flow goes from warehouses to vendors while it is the opposite in the donation case [9]. Within the downstream chain, the physical flow leaves the Regional/Worldwide storage area to reach local warehouses. The distance to connects warehouses decrease according to the storage proximity and size. Finally, local warehouses oversee the last mile delivery to supply relief shelters recently set up. They can use vehicles to ensure the delivery or may have to adapt to local transportation conditions and thus, privilege animals or carts [10].

In a humanitarian context, each crisis requires the creation of a new supply chain. The upstream part remains static, but the needs vary and so, the donators and suppliers as well. Besides, the downstream part adapting to the crisis area suppose new settings and partnerships. Consequently, the fresh connection between nodes is often fragile and subject to various challenges.

B. Humanitarian main challenges

The humanitarian domain encounters many challenges that affect its performance and raise the question of a review of its supply chain. First, the location impacted by the disaster becomes an adverse environment which limits the scope of the humanitarian relief. The growing number of people on earth and the development of territories increase the complexity of disasters and their impacts. The urgency context pushes aid workers to work under pressure, responding as fast as possible since the first 72 hours are critical to save lives [9]. Besides, the presence of a politicised environment makes humanitarian relief decisions delicate and subject to outside pressures. As an illustration, the space dedicated to humanitarian operations is often chosen by the government or military and can be limited for security or political reasons [12]. Secondly, the high uncertainty regarding the disaster occurrence, location and damages make difficult assessing and anticipating the needs in resources [13]. Besides, the fact that information systems are not well established induces a lack of data accuracy and reliability [11]. Consequently, agents are often sent to the ground to evaluate the situation and lose precious time [14].

Limited resources availability is another big challenge for aid agencies. Indeed, when a crisis occurs, the transport network and infrastructure are often unusable or presently under-equipped [15]. There is also a lack of skilled and available human resources to join the aid forces [9]. Finally, HOs regularly lack financial resources to perform their mission and wait for donations. Moreover, donations utilisation is restricted by contributors' decision and is regularly unsolicited [16]. Public opinion is also another factor to consider in raising funds. In this perspective, media is a key player since the attention provided to a disaster has a real influence on the amount perceived [17]. Besides, aid agencies' image is also precious to maintain to attract donations which has led to the creation of a marketing department within HOs [18].

The convergence of numerous and various players to the disaster location is probably the main challenge that organisations have to deal with. Indeed, the diversity in objectives, equipment and methods poses coordination and last mile issues [16] and thus, slow down operations' effectiveness [19]. Besides, the absence of a regulation to define stakeholders' roles creates confusion about organisations' objectives and generates operation redundancies or lacks [17].

Beyond the connection between HOs, it is also, at the core, within aid agencies' organisation themselves that there are challenges to overcome. Basically, the current way, operations management is performed, shows limits in terms of effectiveness, efficiency and sustainability. Indeed, a limited knowledge transfer [12], performance measurement [20] and control of distribution [16], as well as long-term consideration often ignored, and neglect of environmental impacts [21] are the source of mismanagement of resources and high costs. Besides, the firefighting approach, defined as *"situations where people rush from one crisis to one another without fixing each of them properly and clogging them"* [12], mainly used during the response phase generates a lot of waste and forces to omit optimisation considerations. Finally, the emergency context, the destabilised transport network and the novelty of the downstream part of the supply network make logistics efforts inefficient and under-exploit. Indeed, regarding transport, impracticable roads limiting the access to crisis areas [16] while the unavailability of transportation and long procedures slow down the goods reception to the point of demand [1]. Furthermore, the variety of the physical flow (food, tools and equipment), the different packaging formats and the storage conditions, required by specific items, complicate the flow management and generate regular less-than-truckload transports [16]. Besides, the often inappropriate and/or unsolicited donations provoke underused products or waste that represent additional operations and mobilise re-

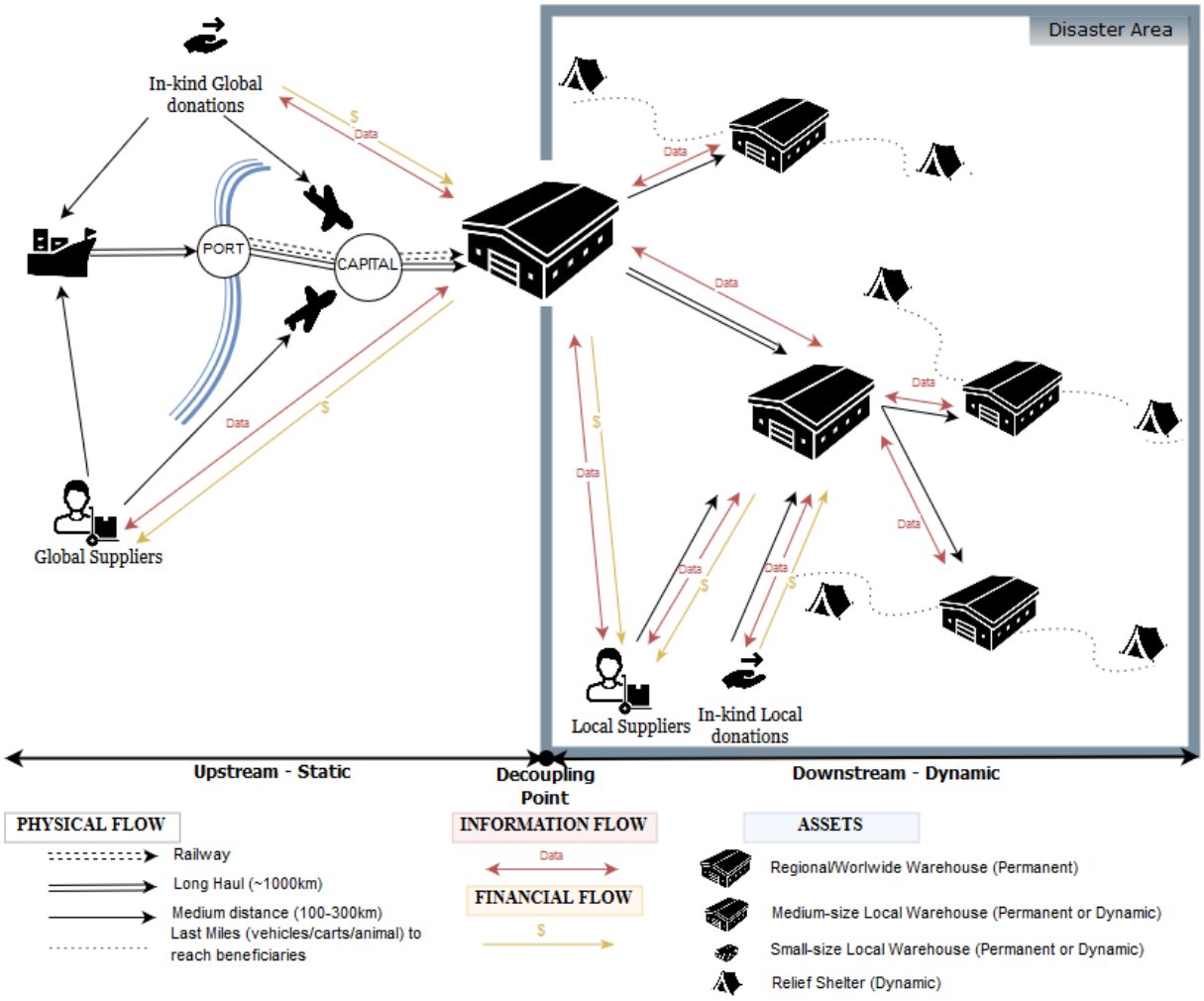

Fig. 1. Illustration of a typical international relief chain – Inspired from [9], [11], [10]

sources [16]. Relief items and donations benefit from limited monitoring along the chain while funders' expectations grow toward better accountability [11]. Finally, the unsuitability of warehouses, plus the insufficiency regarding humanitarian needs [16] generate underutilisation of storage facilities and increase lead times. As highlighted, the humanitarian sector faces many and diverse challenges that affect its performance. Recently, logistics and supply chain have been recognized as representing 80% of the disaster-relief efforts [12] and are determining factors for operations' success [2]. Such reveal identifies the supply chain as a subject of improvements to address most of the stakes of HSCs.

C. Humanitarian Supply Chain maturity

Before rushing for new logistics improvements, a deviation is required to get a better insight into current HSC maturity and understand its mechanisms.

Both sectors, humanitarian and business, show complementarities that may profit to one another. Indeed, the commercial supply chain is assessed as efficient but not really agile whereas, for the humanitarian sector, the agility is a prerequisite but shows a lack of efficiency [9]. It clearly appears cross-learning interests, but only targeting efficiency, since effectiveness and sustainability are also the expected order qualifiers of tomorrow, is restrictive and will require additional efforts in the near future.

A supply chain, whatever the sector, evolves gradually according to different maturity levels:

- Atomistic – An atomistic supply chain is a fragmented network where isolated elements are considered and managed through solo operations. It is characterized by long lead time, big lots, large inventory and a push strategy. This type of supply chain was typical during the 70s and is mostly obsolete.
- Integrated – Today, most companies are in the integrated area where the network is considered as global with an end-to-end vision. Production and distribution are dedicated, centralized and intensively bounded. The main features are EDI communication, Just-in-time and Lean concepts, high level of assets, short lead time and a pull strategy.
- Collaborative – In this supply chain, there is vertical and

horizontal integration of partners to constitute a large strategic alliance and partnerships. The main interests are the potential economy of scale and the long-term vision, but such supply chain presents long durations before reaching agreements and deploying solutions as well as a lack of flexibility.

- Hyperconnected – The network is based on open-hubs and collaborative platforms for both information and physical flows. The key characteristics are flexibility, efficiency, resilience, sustainability and real-time monitoring.

It has been assessed that, currently, the humanitarian supply chain is at the atomistic level while the commercial sector at the integrated. Logically, to improve its maturity level, the humanitarian sector should climb up one level after another to pursue its goals. This choice would mean: first, having dedicated assets across the globe, then developing collaborative networks and processes and finally, sweep up what has been done to move to the hyperconnected environment. However, by doing so, HSC would lose lots of time and money and would probably not catch-up its delay with the business sector. By considering, bypassing all the intermediate steps to directly target the hyperconnected level, organizations would gain in terms of savings, efficiency and sustainability.

III. Toward a hyperconnected humanitarian supply chain

The "Physical Internet" (PI) is a new concept of global logistics networks based on the notion of hyperconnection. This section provides a better insight into PI stakes and fundamentals and highlights the potential benefits for the HSCs.

A. Physical Internet presentation and stakes

The PI has been defined as: *"[an] hyperconnected global logistics system enabling seamless open asset sharing and flow consolidation through standardised encapsulation, modularization, protocols and interfaces"* [22]. The term hyperconnected has been introduced to underline the *"intense connection of components on multiple layers, ultimately anytime, anywhere"* [22]. In fact, it is inspired by the Digital Internet principles. Instead of dealing with bytes, components can be digital (transactions), physical (items), operational (procedures), business (payment, contracts), legal (insurances, customs) or people.

The emergence of such a concept is related to multiple challenges that supply chains have to consider to remain competitive. Indeed, the environment increasing awareness, physical flow multiplication, speed and performance pressures as well as consumers' growing expectations or even cost reduction preoccupations have caused the appearance of symptoms of logistics inefficiency and unsustainability [5]. Among them, transport issues (low fill rates, empty or excess travel, multimodal inefficiency, congestion…), storage issues (storage facility utilisation and needs…), delivery issues (unavailability, speed, accuracy…) or even security issues (information and objects) [23]. The idea behind the PI is to face those challenges that finally cover economic, environmental and social aspects, by designing a new way for objects to be moved, deployed, realised, supplied, designed and used in the perspective to make logistics more efficient, sustainable, smart, agile, adaptable, scalable and resilient [23].

The main advantages of the PI concept are the perspective of various savings, its design that considers environmental impacts and allows gas emission reduction, plus its integration of agility and resilience aspects. On the other hand, it is in total rupture with the current logistics model and its deployment would require high financial investment and an agreement from organisations to reorganise and a change in habits [5].

B. Interests for the Humanitarian Sector

As developed in the previous part, the HSC faces various challenges in many domains. Basically, it encounters problematic related to data collection and information systems, the precariousness of the local environment that poses relief issues, the lack of resources, coordination issues and external pressures which have an impact on logistics' results.

By considering PI principles, some proposals of PI-humanitarian supply network applications have been designed (See Fig. 2, 3 & 4). The idea is to strategically cover the territory and provide as much support as possible whatever the disaster location is, while optimising and limiting waste.

In current HSCs, formed by suppliers (vendors or donators), warehouses and beneficiaries, the physical flow goes from one actor to another directly, on a one-to-one basis. The difference with a hyperconnected transportation is the positioning of multiple open hubs that form a network and would connect partners. Thus, the flow would transit from one hub to another before reaching its destination. As open hubs, they are not dedicated to a single organisation and consequently, flows from different HOs going toward the same direction can be consolidated [23] (See Fig. 2). The benefits should be significant in terms of efficiency. As an illustration, in the business sector, it has been measured a reduction of transportation cost with an improved fill rate from 65% to 85% and about 60% reduction of greenhouse gas emissions and 15% of distance travelled [23].

In the current relief network system, aid agencies also own dedicated distribution centres to store products. With the PI, there would be open distribution centres positioned to form a network. As open hubs, the flow from any organisation could transit through the network and be deployed in a dynamic and agile manner according to the demand and the transport network's state [16]. Besides, by exploiting existing infrastructure (airport, subway, tramways, highways and ports) and open hubs, the benefits would be visible in the delivery speed, particularly for the last-mile delivery thanks to an increase of responsiveness. Indeed, as simply illustrated with (See Fig. 3, if each colour represents one HO with a specific emergency product, according to the position, the delivery may take 1 to 4 length units. With the open hub network, products would be stored in many hubs offering a faster and larger cover.

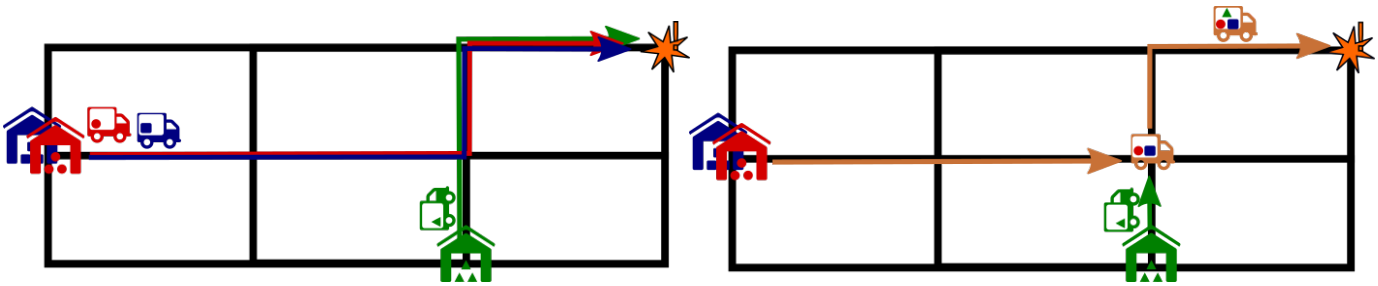

Fig. 2. (on the left) AS-IS situation of one-to-one flows versus (on the right) flow consolidation with open-hubs

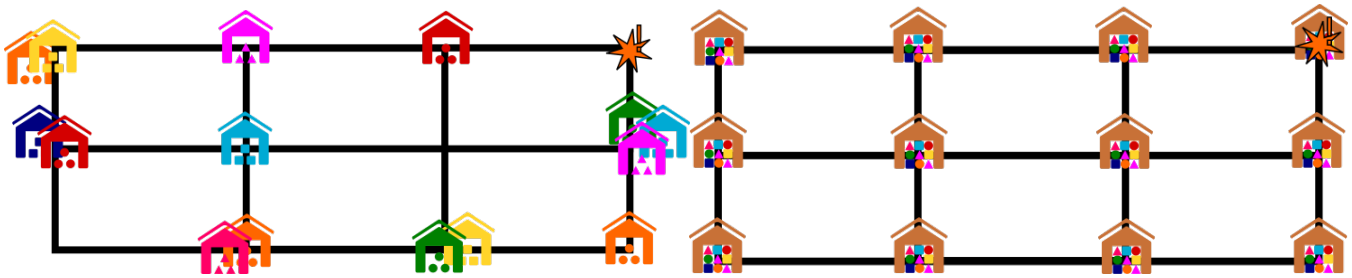

Fig. 3. (on the left) AS-IS situation of dedicated distribution centres versus (on the right) an open-hub network

Organisation, methods, objectives and tools differences create many coordination issues between the humanitarian actors. One suggestion of the PI concept is to facilitate communication and exchanges by the use of standardised contracts and protocols [5]. Besides, the connection to a common logistics IT platform would allow partners gaining in visibility on relief items inventory across the globe and taking opportunity of transversal exchanges according to one another's needs. Also, warehouses would be shared, and stocks from different HOs mixed to optimise storage capacity [16] (See Fig. 4, on the left).

PI also proposes encapsulating goods in PI containers. Indeed, modular containers would be developed in the perspective to be easy to handle, store and transport. Besides, they would be smart, connected and eco-friendly to protect the encapsulated objects. Those containers would be designed to easily snap together since the interest is to maximise truck fulfilment or storage [14]. Furthermore, if those boxes were unmarked they would become generic in terms of property (See Fig. 4, on the right). The idea is to open up the inventory to all aid agencies to avoid redundancies and better manage the demand. The use of IoT systems to monitor stocks would be beneficial to master lead-times and provide the accountability donators are expecting [5].

In conclusion, hubs, taking opportunity of strategic areas or existing facilities would be deployed to form a network. In terms of logistics, the benefits would be a reduction of the delivery lead time and gas emission, an optimisation of transport means and storage areas, as well as an increase of resilience. The hubs would be opened in the perspective to gather stocks from different HOs and manage them according to the needs. In the case of a disaster, the responsiveness would be optimal since there would always at least one hub close to the disaster area. However, such concept of PI-humanitarian supply chain is in total rupture with current models and thus would require severe organisation restructuring and high financial investment. Besides it should consider taking opportunity of local resources and knowledge.

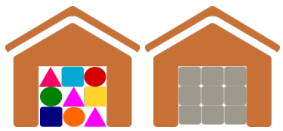

Fig. 4. (on the left), optimisation of storage capacity by mutualizing stock from different organisations (on the right), optimum storage optimisation using unmarked PI-containers

IV. Discussion and Research Agenda

PI is a relatively new concept, imagined in 2011 and spread to the public in 2014. It has gained lots of interests in both academic and industrial sectors. Indeed, the concept of PI presents various advantages in terms of efficiency and sustainability as such. Oriented at the start for the commercial sector, it shows many potential interests for the humanitarian domain. However, the reflection around a hyperconnected humanitarian relief chain requires further development and additional solutions to serve as much as possible the needs of this particular supply network. Moreover, for the moment, only one paper [14] discuss it.

Before seeing the implementation of such a specific chain, and the technical changes identified in the previous section, several essential components are required to prepare the ground for a global PI-humanitarian supply chain.

First, in the perspective to facilitate collaboration towards an open and secured information exchange, the current information network should be rethought. Indeed, a new kind of

architecture able to capture events from any type of technology, make information available for all via the normalisation and secured with restricted access is required. As inspiring for this architecture, it exists for the retail sector, the Electronic Product Code global approach (EPC global). Designed in this perspective, the coding can be read by any type of readers which generate event creation. Then, the information is normed, stored and shared via an EPC Information Service (EPCIS) that players would have to adopt [21]. Additionally, to capture and exchange data, advanced technology is also necessary. The Internet Of Things (IoT) project seems a good candidate to undertake this role. Indeed, it aims at capturing information with sensors and is able to answer Web requests or interact with other objects [19]. After that, new operational protocols would have to be developed to make the connection between players easier. Indeed, to make transversal exchange, procure items or cross a border, the flow would gain in speed if operations and protocols were generalised. However, it requires an agreement from many and diverse actors [5] plus, a significant reshaping of norms and legal frameworks.

To benefit from PI principles, mentalities would also have to evolve in various domains. Currently, actors are used to play on their own and keep private information. However, as the saying underlines it: *"Alone, I go faster; together, we go further"*, actors should consider the benefits from collaborating since it is a pillar of the PI concept. Besides, as it is currently occurring with the emerging DDMRP philosophy, efforts should focus on the speedup of the flow to deliver the beneficiary rather than fussing for meeting personal objectives that often diverge, even within the same organisation [24]. Finally, the environmental emergency urges actors to consider long-term benefices since the impact can be significant despite their lack of short-term interests.

Finally, large investments and efforts would be necessary to emerge from the ground or rehabilitate infrastructure to support the concept of open hubs and multimodal network. Indeed, transport mode shifts would have to be redesigned both in terms of facilities and information connectivity which, today, mainly limit the development of multimodality [25]. Reflections about product use and handling would also have to be led to improve aid workers as well as beneficiaries' conditions.

TABLE I
SYNTHESIS OF RESEARCH AGENDA RECOMMENDATIONS

Further scientific reflections regarding the concept
Design of a new information system able to collect, save and share data It must also be secured, reliable and accessible to many
Development of technologies able to capture data and interact with information systems
Creation of standardised protocols and procedures
Reshape of norms and legal frameworks at a global scale
Change in mentalities driven by proofs of concept
Set-up of the open-hub network
(Re)design and/or rehabilitation of facilities to faster connectivity and shifts
Further reflections/innovations about product use

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