Exploring the Physical Internet Concept to Improve Disaster Relief Operations

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ABSTRACT

This research explores the applicability of the Physical Internet (PI) to disaster relief operations. The PI is a groundbreaking logistical system in which standardised packages are routed through a hyperconnected network of logistics providers and facilities. Based on a review of the literature and publicly available information from emergency responding agencies and the media, we use the 2016 Kaikoura earthquake to identify six key requirements that support the efficient movement of relief items following a disaster. We then consider how the PI can support these requirements. We conclude that a fully integrated logistics system in which relief items move seamlessly across a web of interconnected transport modes and operators can enhance the speed, flexibility and reliability of emergency responses. By discussing a concept that has received very little attention in the disaster management literature and identifying new ways of improving emergency responses, this study aims to stimulate debate within the disaster relief sector.

Keywords

Emergency Response; Disaster Relief Operations; Physical Internet; Logistics; Supply Chain Management.

INTRODUCTION

When a disaster strikes, essential resources such as medical supplies, water and shelter must be deployed without delay. Efficient distribution and successful emergency responses call for dynamic and flexible movements of goods in response to continually updated information due, for example, to emerging needs or suddenly inaccessible roads (L'Hermitte, Bowles, Tatham and Brooks, 2015). However, experience shows that fragmented operations, the under-utilisation of resources, unconsolidated shipments, the lack of coordination and collaboration, inefficient transport, bottlenecks in the delivery process, and delays are common in relief operations (Ado, Ben Othmane, Matei and Montreuil, 2014; Fogarty, 2014; L'Hermitte, Tatham and Bowles, 2014; McLean, Oughton, Ellis, Wakelin and Rubin, 2012).

The objective of this explorative research is to investigate the applicability of the groundbreaking concept of the Physical Internet (PI) to address these issues. The PI proposes that goods can be moved seamlessly across a web of interconnected transport modes, operators and platforms similarly to how the digital Internet routes data packets (Ballot, Montreuil and Meller, 2014). In a PI system, goods are packed into standardised logistics units and automatically routed from origin to destination through a hyperconnected network of logistics providers and facilities. Thus, the PI is conceived as a system of fully integrated modes, actors and facilities that enable seamless and efficient movements of goods by supporting shipment consolidation, increasing asset utilisation, optimising routing, and speeding up deliveries (Montreuil, 2011; Montreuil, Meller and Ballot, 2012).

We argue that the PI principles have the potential to change relief operations and to support smooth flows of urgently needed relief items in the aftermath of a disaster. Although the PI is receiving growing attention from academics, practitioners and policy makers (Sternberg and Norrman, 2017; Treiblmaier, Mirkovski and Lowry, 2016), research on this topic is virtually non-existent in the disaster management discipline. We, therefore, opted for a qualitative research approach designed to deepen the understanding of the concept and stimulate debate within the emergency relief sector.

Based on a review of the relevant academic literature and publicly available information from emergency responding agencies and the media, we firstly use the Kaikoura earthquake that occurred in the South Island of New Zealand (NZ) on 14th November 2016 to identify six key requirements that support the efficient movement of relief items in the aftermath of a disaster. We then identify six characteristics of the PI and explore how these characteristics can support the requirements of emergency response operations. We conclude that the PI principles have the potential to enhance the speed, flexibility and reliability of emergency responses. In other words, a fully integrated and collaborative logistics system in which relief items and information move seamlessly across a web of interconnected transport modes and operators could increase the efficient deployment of urgently needed relief items.

The remainder of this paper is structured as follows. The next two sections present the emergency management framework in place in NZ and recount the events following the Kaikoura earthquake. Then, the concept of the PI is examined and its applicability to the emergency management context is discussed. This study's limitations are also identified before final observations and recommendations are provided.

NZ EMERGENCY MANAGEMENT FRAMEWORK

This section briefly presents the NZ emergency management framework and focuses, more specifically, on logistics since this function is in charge of managing the response resources, including relief items. This section also shows that collaboration, ongoing communication, and resource sharing are key factors of successful emergency responses.

NZ's exposure to multiple natural disasters, including earthquakes, storms, floods and landslides, as well as the need for rapid and well-coordinated responses to these events led the NZ Government to introduce a Coordinated Incident Management System (CIMS) in 1998 (subsequently revised in 2014). CIMS establishes a joint response framework to be used by the emergency management agencies at all levels (incident, local, regional and national). The framework ensures consistent responses to a wide range of emergency situations (from small, single-agency operations to complex emergencies requiring the participation of multiple responders). Designed as a scalable and modular system, CIMS describes how responses can be expanded or downsized, and how a variety of resources and capabilities can be mobilised or demobilised to respond to the specific circumstances of an event (NZ Government, 2014).

CIMS supports the coordination and integration of the activities of a broad range of NZ responders, including Civil Defence and Emergency Management (CDEM), the Police, Fire Service, Ministry of Health, and Defence Force (NZ Government, 2014). Because emergency management takes place across multiple responding agencies at the incident, local, regional and national response levels, collaboration and resource sharing between actors are key characteristics of NZ relief operations. In particular, when one agency is unable to meet its own resource needs, it must cooperate with other agencies and response levels (DPMC, 2015; MCDEM, 2015).

CIMS also allocates the diverse tasks and responsibilities to be undertaken in emergency responses to seven functions: Control, Intelligence, Planning, Operations, Logistics, Public information management, and Welfare. The primary responsibility of the logistics function is to source and track the personnel, equipment, supplies, facilities and service resources needed to support emergency response activities. These resources must be made available at the right time, to the right place, in the right quantities and in a good condition. More specifically, the logistics function is responsible for managing supply (sourcing, procuring, storing, loading and tracking resources), arranging transport, and managing facilities (sourcing and maintaining the buildings and land used during the emergency). It also manages the response personnel (including volunteers) and establishes and maintains information technology networks to support communication between responders (MCDEM, 2015; NZ Government, 2014).

Since ongoing communication and interactions among functions and agencies are critical to emergency operations, mechanisms are in place to capture and disseminate information, and to provide visibility on logistics operations. In particular, responding agencies use a common, web-based information management tool called Emergency Management Information System (EMIS) that is designed to maintain situational awareness, record information, track data and generate reports. From a logistics perspective, EMIS is used to store documents (e.g. resource request forms), to create and process resource requests, and to track tasks and resources. Resources are tracked through several processes to enhance supply chain visibility from the time a responding agency requests them to the time they are no longer needed. Thus, the records are maintained/updated when resources are requested, received, stored, issued to field teams, and returned/disposed of (MCDEM, 2015).

THE KAIKOURA EARTHQUAKE

This section uses the 2016 Kaikoura earthquake to illustrate the logistics of disaster relief operations. It also identifies a number of key requirements that support the rapid, flexible and reliable deployment of emergency supplies.

On 14th November 2016, a 7.8-magnitude earthquake struck the north-eastern part of the South Island of NZ and was followed by multiple severe aftershocks. The earthquake triggered 21 fault ruptures over more than 150 kilometres and caused significant land movements and deformations. Although the earthquake was widely felt, the most severe damage and disruptions were experienced in the upper South Island (MCDEM, 2017b; Wotherspoon, Palermo and Holden, 2017). In particular, the earthquake caused massive infrastructure destruction and heavy disruption to the transport network when roads were buried by landslides, railway lines were swept away, and bridges and tunnels were destroyed. The earthquake isolated thousands of people (local residents and tourists) and severely disrupted supply chain operations (Davies, Sadashiva, Aghababaei, Barnhill, Costello, Fanslow, Headifen, Hughes, Kotze, Mackie, Ranjitkar, Thompson, Troitino, Wilson, Woods and Wotherspoon, 2017).

Immediate closure of some major transport routes occurred, including State Highway 1 (SH1), NZ's main highway connecting Picton (the entry point to the South Island), Kaikoura and Christchurch. The Main North Line railway, a rail freight line running on the East Coast of the South Island and carrying about 1 million tonnes of freight between Picton, Kaikoura and Christchurch before the earthquake, was also immediately closed. These closures were rapidly followed by further road cut-offs, in particular SH7 and other smaller inland roads such as Route 70. As a result, severe freight disruptions on the East Coast of the South Island occurred and multiple communities, including the township of Kaikoura (a popular touristic destination with a permanent population of over 3,500 people), became inaccessible by road (Davies et al., 2017).

The NZ Transport Agency reported a total of 5,000 landslides (up to 500,000m^3 in size) and 3,300 road and rail items requiring repair (NZ Transport Agency, 2018). While the road and rail networks were severely damaged, the air transport infrastructure (including the regional airport of Kaikoura) was mostly unaffected. Moreover, despite the damage due to the uplifting of the sea bed, the Kaikoura Port remained accessible to small boats (Davies et al., 2017). Figures 1-4 illustrate some of the major infrastructure damage around Kaikoura, including the road and rail closures in the immediate aftermath of the disaster.

Figure 1: SH1 and the Rail Line Near Kaikoura (Source: Mitchell, 2016)

Figure 2: SH1 and the Rail Line Near Kaikoura (Source: Twitter, 2016)

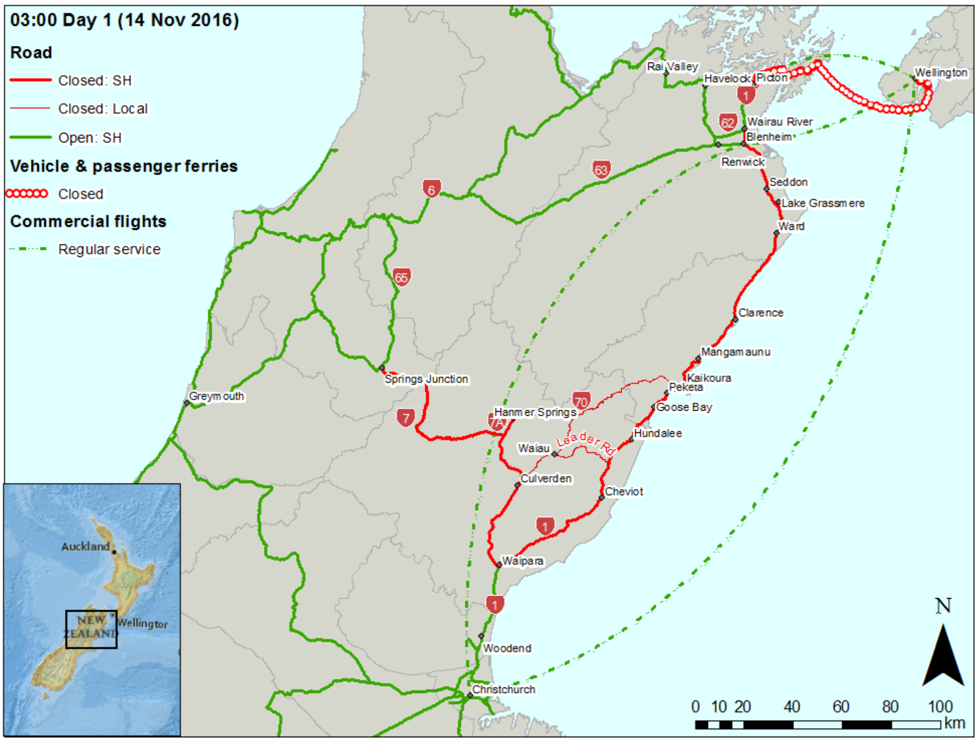


Figure 3: Road Closures in the Kaikoura Area on Day 1 (Source: Davies et al., 2017)

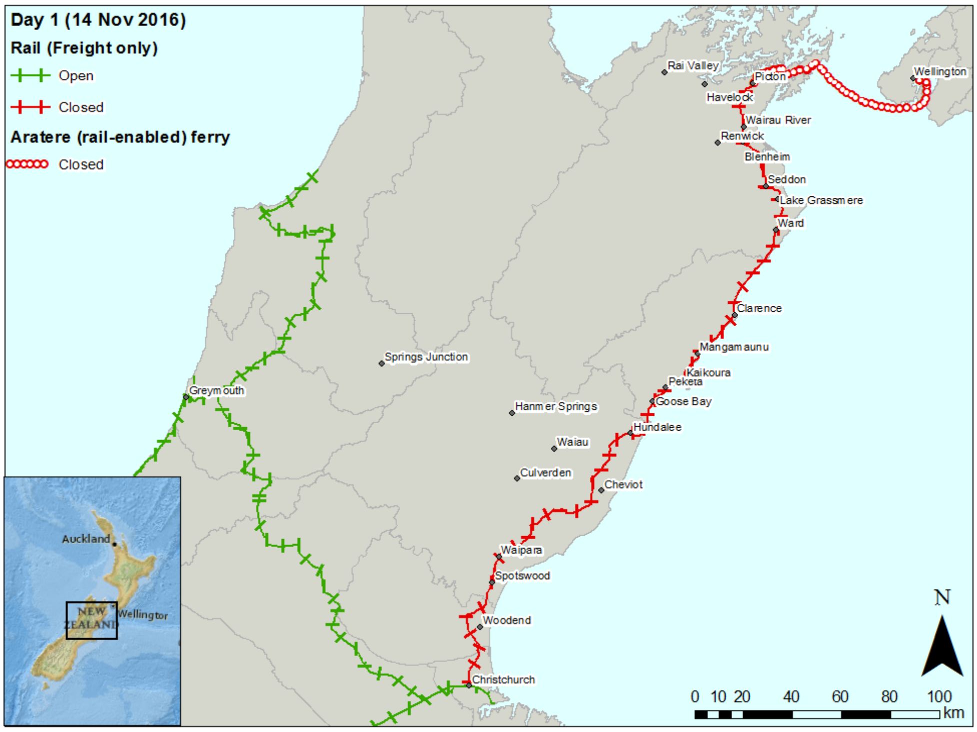


Figure 4: Rail Closures in the Kaikoura Area on Day 1 (Source: Davies et al., 2017)

The emergency response was activated by the NZ Ministry of Civil Defence & Emergency Management (MCDEM) on 14th November (Day 1). MCDEM requested the assistance of 64 supporting agencies at the local, regional and national levels, including the NZ Fire Service, Police and Defence Force, as well as Red Cross and six private organisations. By 15th November (Day 2), Kaikoura was established as the most heavily affected community (MCDEM, 2016, 2017b).

The extreme infrastructure damage and some severe weather conditions in the days following the earthquake impeded the relief operations and required the use of Defence Force resources. On Day 2, four NZ Air Force NH90 helicopters delivered 1.3 tonnes of water, 300kg of food, and diesel to the residents of Kaikoura. On Day 3, three Squadron helicopters delivered five tonnes of aid and C-130 Hercules Air Force airplanes were used to drop 5,000 litres of water to the township. On Day 4, the NZ Air Force used the Squadron helicopters to deliver two additional tonnes of supplies.

An Overland Force convoy of 27 trucks (Medium Heavy Operational Vehicles) managed to reach Kaikoura only on Day 5. By Day 10, the Overland Force had delivered 155 tonnes of urgently needed supplies (including medical supplies, petrol, diesel, gas bottles, fresh food, milk and water) to the township (NZ Defence Force, 2016). In the following 13 days, daily convoys of the NZ Defence Force transported supplies to Kaikoura by the inland road, Route 70. This road remained closed to non-army vehicles until Day 23, when controlled access was made available to emergency services and residents. On Day 38, Route 70 reopened and Kaikoura became accessible during daylight hours via the southern part of SH1 (Davies et al., 2017). SH1 was finally reopened on both sides of Kaikoura in December 2017 following the 13-month rebuild (Hayward, 2017b; Hayward, Wright and Lewis, 2017). The rail freight line on the East Coast reopened in September 2017, some 10 months following the earthquake (Hayward, 2017a).

The Kaikoura earthquake changed the broader transport patterns around the upper North Island of NZ. In particular, air and coastal shipping movements increased. They not only supported the relief efforts in the immediate aftermath of the earthquake, but also helped make up for the lost rail freight capacity and supported the routine movements of goods over the long term. For example, 14 days following the earthquake, NZ's rail operator (KiwiRail) shifted freight from rail to ship by offering a new coastal service called NZ Connect. It also combined rail and coastal shipping between Auckland and Christchurch (Davies et al., 2017; Kilroy, 2016).

Also severe was the impact of the Kaikoura earthquake on road traffic movements. In particular, demand for road haulage suddenly increased and alternative routes had to be used (Aitken, 2017; Davies et al., 2017). As a result, delivery times became significantly longer. For example, the distance from Picton to Christchurch increased by 250 kilometres when trucks were rerouted on the inland road, which increased the travel time from

4½ hours to 8 hours (Stevenson, Becker, Cradock-Henry, Johal, Johnston, Orchiston and Seville, 2016). Another consequence was that the road transport industry experienced an acute shortage of truck drivers (Aitken, 2017). Ultimately, the Kaikoura earthquake highlighted the vulnerabilities in NZ's road and rail networks, as well as the valuable contribution of the normally under-utilised coastal shipping capacity in a disaster situation (Ladbrook, 2017; Van Beynen, 2016).

The above accounts of the logistical response to the Kaikoura earthquake enabled us to identify six key requirements that support the efficient movement of relief items in the aftermath of a disaster:

1. Efficient interagency coordination;
2. Efficient collaboration with commercial logistics operators;
3. Efficient utilisation of the available resources;
4. Seamless and uninterrupted transport flows;
5. Rapid freight movements between transport modes;
6. Rapid routing/re-routing due to sudden changes in available transport routes/modes.

Table 1 shows how the events following the Kaikoura earthquake illustrate these requirements. Later, this paper will argue that the PI principles can support these six requirements and, ultimately, streamline emergency responses.

Emergency response requirement	2016 Kaikoura earthquake
1. Efficient interagency coordination	A key element in NZ's CIMS is the need for multiple responding agencies to collaborate and coordinate their relief activities. The response to the 2016 Kaikoura earthquake, which was beyond the capacity of a single organisation, illustrates this need. As mentioned earlier, 64 supporting agencies at the local, regional and national levels were involved in the relief operations.
2. Efficient collaboration with commercial logistics operators	Mobilising and using the expertise and resources of commercial organisations (e.g. the providers of coastal shipping services when road or rail transport is unavailable) increase the flexibility of the emergency response operations.
3. Efficient utilisation of the available resources	The response to the Kaikoura earthquake shows that multiple logistics resources can be used to deliver the goods to the affected communities. In particular, the unavailability of the road and rail networks in the Kaikoura area brought the valuable contribution of the normally under-utilised coastal shipping capacity into focus.
4. Seamless and uninterrupted transport flows	The continuous and rapid deliveries of urgently needed relief items to the communities isolated by the Kaikoura earthquake required efficient transport flows, as illustrated by the emergency deliveries completed by the different services of the NZ Defence Force in the aftermath of the disaster.
5. Rapid freight movements between transport modes	The response to the Kaikoura earthquake shows that various transport modes can be used to move goods in the aftermath of a disaster. The combined rail/ship service offered by KiwiRail illustrates this point. Swift movements of goods between transport modes support smooth deliveries.
6. Rapid routing/re-routing due to sudden changes in available transport routes/mode	The Kaikoura earthquake was a highly dynamic logistics environment, as illustrated by the sudden road/rail closures due to extreme infrastructure damage and severe weather conditions. Transport needed to be adapted to deal with emerging constraints (e.g. road/rail closures or less efficient road transport due to the longer travel times) and opportunities (e.g. available air or coastal shipping capacity).

Table 1: Emergency Response Requirements (Source: The Authors)

THE PHYSICAL INTERNET

This section focuses on the PI. Since this concept is new to the emergency management discipline, the following subsections go into the details of what the PI is, before identifying the components of a PI system and discussing how the concept has been addressed in the literature and in practice. Ultimately, a number of key characteristics that have the potential to support efficient logistics operations in the aftermath of a disaster are identified.

The Physical Internet Concept

The term "Physical Internet" was first used in 2006 on the front page of a special report of *The Economist* dedicated to logistics operations (The Economist, 2006). The catchy headline led a small pool of researchers to explore the analogy between the flow of digital data and the flow of material goods. In particular, Montreuil and his colleagues (Montreuil, 2011; Montreuil, Meller and Ballot, 2010, etc.) conceptualised the PI concept and, in doing so, envisioned a system that radically changes logistics operations and reinvents the way goods can be moved, stored, handled and delivered across the world.

The digital Internet has revolutionised information and telecommunication technologies by encapsulating data in packets and moving them freely across an open and interoperable computer network. Using the digital Internet as a metaphor, the PI is defined as a logistical system in which standardised, modular packages are automatically routed from origin to destination through a hyperconnected network of logistics providers and facilities (Ballot et al., 2014; Montreuil, 2011). The PI encapsulates goods of various sizes and shapes in standardised logistics units, and efficiently moves them across a network of interconnected operators and platforms. Thus, the PI is conceived as a system of fully integrated modes, actors and facilities that support seamless logistics operations, including transport, handling and storage (Montreuil et al., 2012).

Multiple authors (e.g. Montreuil, 2011; Pan, Ballot, Huang and Montreuil, 2017) argue that the PI can address the costly inefficiencies of the current logistics model such as empty trucks and delays. In particular, the PI can drive significant improvements in transport and logistics by supporting shipment consolidation, increasing asset utilisation, optimising routing, and speeding up deliveries. Such efficiencies can be induced at the level of a facility (e.g. a warehouse), the level of a city, a country and, ultimately, the whole world (Montreuil, 2011).

A related concept, synchromodality, is particularly relevant to this study since the previous section showed that modal shifts are a critical component of emergency operations in NZ. Synchromodality is defined as the real-time planning of, and shifting between, modes and routes to create efficient transport flows (van Riessen, Negenborn and Dekker, 2015). In synchromodal transport, movements of goods are booked mode-free so that the modal split and the route can be optimised for each shipment. Synchromodality requires close and ongoing communication and collaboration between the participating transport operators, as well as sophisticated planning that is supported by the use of modern technologies. Technologies not only capture location and contextual data from various sources, but also support routing decisions (Pfoser, Treiblmaier and Schauer, 2016).

Three Key Components of a Physical Internet System

Load Unitisation and Standardisation

The concepts of load unitisation and standardisation refer to the packing of small items into standard unit loads that can be handled by mechanical equipment and moved between modes of transport without handling each item individually. In the current logistical system, standard unit loads include, among other things, shipping containers and pallets. Unitisation and standardisation support efficient transport flows and the reduction of delivery times. For example, the ISO standard 20- and 40-foot shipping containers facilitate the integration of transport, the development of door-to-door services and the optimisation of capacity, loading, unloading and stacking (ICS, 2010).

The PI goes beyond these existing practices and applies load unitisation and standardisation more broadly to smaller loading units called PI-containers. Designed in different sizes (from small boxes to large shipping containers), PI-containers aim to facilitate the packing, storage, handling and routing of goods along the supply chain. To prevent the wastage of space and, ultimately, the movement and storage of air, PI-containers come in a variety of standard dimensions that allow for the modular packing of smaller loading units (e.g. boxes) into larger ones (e.g. shipping containers) (Montreuil, 2011). Figure 5 illustrates the modularity and unitisation of PI-containers.

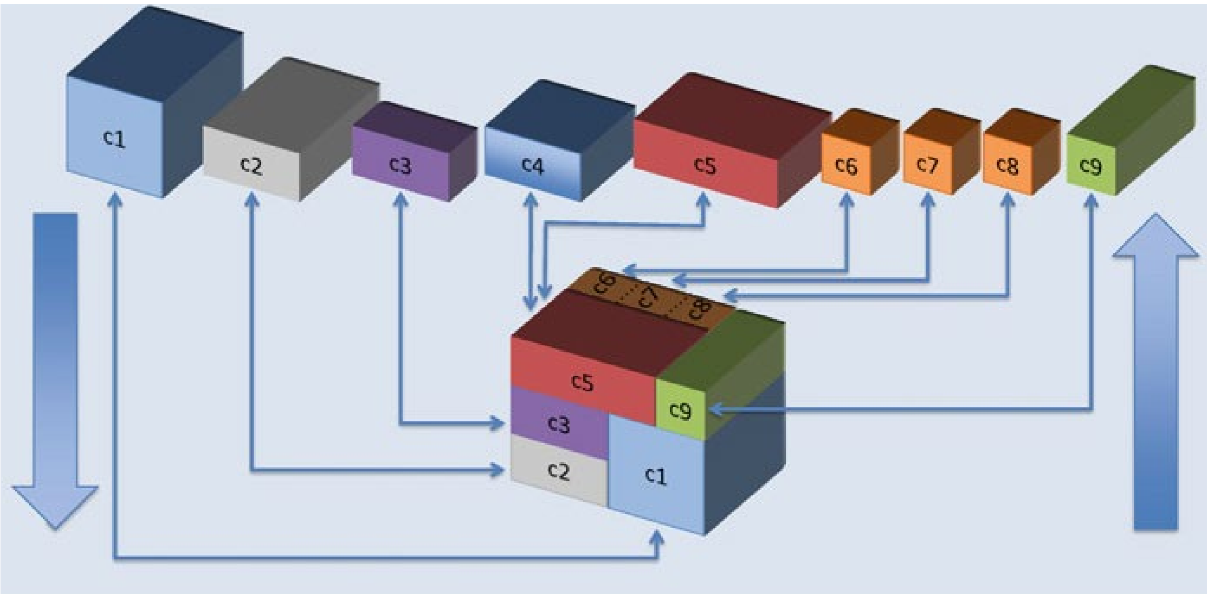


Figure 5: Modularity and Unitisation of PI-Containers (Source: Montreuil, 2011)

Interconnected Network

A seamless flow of PI-containers requires end-to-end interconnectivity between supply chain operators and facilities. Like standardisation, the concept of interconnectivity is not new and has been discussed widely in the logistics and supply chain management literature (Butner, 2010). However, Montreuil (2011) goes one step further by designing a fully integrated network of physical sites and facilities (so-called PI-nodes, such as warehouses, sorting yards, cross-docking platforms, ports, etc.), actors (e.g. transporters), and systems to interconnect them (e.g. information, standards and protocols). Operations carried out at the PI-nodes include transit (transferring PI-containers from one vehicle/mode to another), sorting (receiving PI-containers, sorting them according to their destinations, and shipping them again), and storage (Montreuil, 2011).

In contrast with today's logistics systems, which mostly use proprietary resources and pre-established agreements between independent companies (e.g. a supplier and a transporter), the PI conceives an open network of multiple organisations. These organisations maintain both competitive and collaborative relationships as they make their logistics capacity (transport, storage, handling, etc.) available on demand and a 'per use' basis. Since shippers can use the resources of, and deploy their PI-containers through, any capable logistics operator (not only those with which they have pre-established contractual agreements), the PI offers every organisation access to a wider web of shared logistics resources and services. Using the best available resources regardless of which operator owns them enables organisations to optimise their deliveries in regard to cost, reliability, and speed (Mervis, 2014; Montreuil, 2011).

The performance of the participating organisations and physical facilities must be continuously measured and reported to assess which best resources are available. The key service performance areas include speed (e.g. delivery lead time), throughput (e.g. the number of PI-containers moved within a period of time), reliability (e.g. on-time deliveries) and safety/security (e.g. undamaged deliveries). Having this information readily available enables the system participants to make informed decisions when selecting PI-services (Montreuil, 2011).

Unlike existing logistical systems, which tend to be based on a point-to-point system (i.e. the transport of goods from origin to final destination) and have the disadvantage of cargo being rarely available for the return trip, the PI conceives a segment-to-segment system, namely a series of short hauls between multiple nodes. In such an arrangement, PI-containers move through interconnected, short-distance segments in consideration of every routing condition in real time (Montreuil, 2011). Routing is, therefore, dynamic and adaptable to emerging opportunities (e.g. available capacity on a specific transport mode) or emerging constraints (e.g. congestion, inaccessible road) to optimise the movement of goods (Montreuil, 2011).

Supporting Technologies

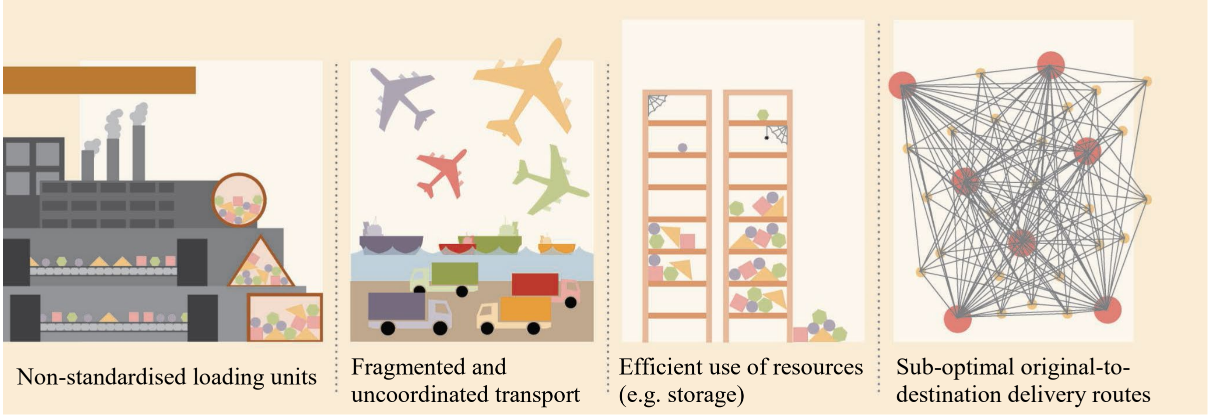
Developing the PI's collaborative future to transform logistics operations requires supply chain data and real-time visibility on operations in order to optimise the movement of goods and, when needed, quickly adjust them. Thus, in a PI system, goods need to be tracked along the supply chain and contextual data, such as traffic and weather data, need to be captured to support predictive analytics and proactive responses to logistical issues. Data also enable prescriptive analytics and the definition of a course of action to address incoming problems (e.g. re-routing goods to avoid a weather-related issue and subsequent road closure). Ultimately, the PI is expected to support automated route optimisation, namely autonomous, end-to-end movements of goods based on artificial intelligence and machine learning (Gesing, Peterson and Michelsen, 2018).

Some existing and emerging technological developments can be leveraged to enhance interconnectivity and improve the efficiency of physical flows. In particular, the Internet of Things (IoT) can play a critical role in the implementation of the PI. The IoT is a network of interconnected and interacting devices and technologies that track the movements of goods and monitor contextual parameters by making use of microchips and sensors embedded in physical objects (Atzori, Iera and Morabito, 2010; Lee and Lee, 2015). The primary purpose of the IoT is to establish critical links between the physical and the digital environments by supporting the collection of supply chain data and their real-time transmission to information systems. Ultimately, the IoT supports data-driven supply chain management and operational analytics by enhancing object control and enabling quick and autonomous decision making about the movement of goods (Laurent, Pfeiffer, Sommerfeld, Willems, Chollet, Castiaux, Bruneton and Sainlez, 2017).

In addition to the IoT, the distributed ledger technology is relevant to the PI as it changes how organisations relate to each other and creates more integrated and collaborative ecosystems. A distributed digital ledger, also known as a 'blockchain', is a shared data platform that enables authenticated data communication and the widespread sharing of real-time information among authorised participants. The blockchain is based on a common computing language and a distributed database that is available to every supply chain participant, rather than a closed, proprietary system and company-to-company interfaces that hinder the seamless flow of information (Cecere, 2017; Laurent et al., 2017). The blockchain technology can also be used to create smart contracts, i.e. digital agreements whose compliance and performance are monitored and linked to the information and preconditions available in the blockchain. In short, a blockchain, enables unrelated organisations to trust each other and collaborate, and can ultimately be used to streamline and speed up supply chain operations (Laaper, Joseph, Quasney, Yeh and Basir, 2017). Blockchain and the IoT are intersecting and complementary tools for the implementation of the PI. While the IoT enables the collection and communication of data from the physical world, blockchain supports their authentication and digital exchange among the participating entities (Laurent et al., 2017).

Towards the Implementation of the Physical Internet

In the same way that the digital Internet created new generations of businesses and business models, the PI will require organisations to reinvent themselves and embrace new operational practices and organisational changes (Montreuil, 2011). Ultimately, the PI posits a paradigm shift and a move away from the current logistics system that is based on non-standardised loading units, actors and facilities that operate independently, fragmented and uncoordinated operations, the inefficient use of assets and facilities, and sub-optimal shipping routes. Instead, the PI is characterised by a system of standardised and modular containers, an integrated network of actors and platforms, pooled and interconnected operations, efficiently used assets and facilities, and optimised and flexible shipping routes (Mervis, 2014). Figures 6 and 7 illustrate this paradigm shift.


Non-standardised loading units

Fragmented and uncoordinated transport

Efficient use of resources (e.g. storage)

Sub-optimal original-to-destination delivery routes

Figure 6: The Existing Logistics System (Source: Mervis, 2014)

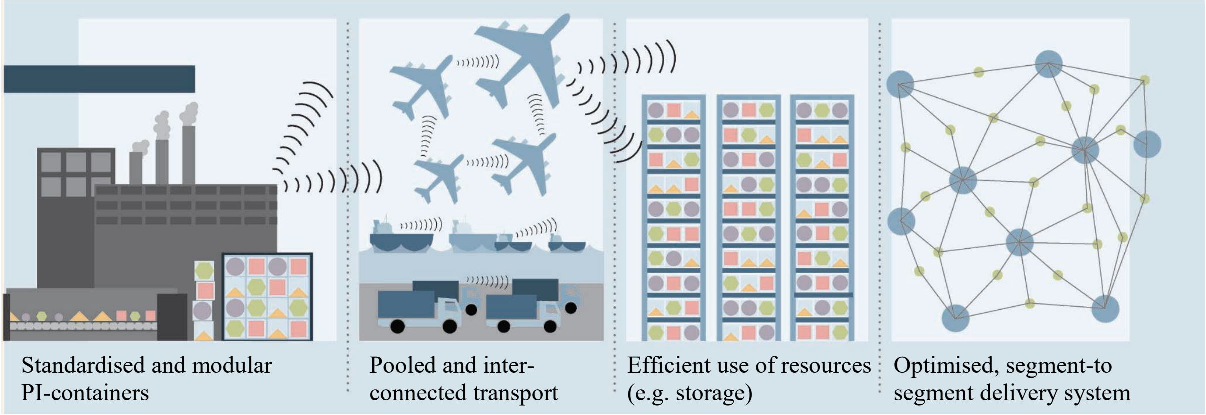


Figure 7: A PI-Enabled Logistics System (Source: Mervis, 2014)

Although the PI is a promising concept, and academics, practitioners and policy makers have intensified their efforts towards its realisation, it is infeasible to achieve such an extensive collaborative and efficient future from one day to the next. As no direct global cutover is possible, the PI can only be deployed progressively (ALICE, 2015). According to Sternberg and Norrman (2017), many issues also remain to be discussed and resolved, including the development of standards as well as changes in the way organisations think and operate. The road to the implementation of the PI is, therefore, not only full of promises, but also full of hurdles. That being said, it is recognised that even limited and focused initiatives inspired by the PI principles could bring considerable benefits to logistics efficiency (Treiblmaier et al., 2016).

The Physical Internet in the Literature and in Practice

Given its potential, the PI is receiving growing attention from the academia. For example, Sternberg and Norrman (2017) included 46 publications in their review of the PI literature and Treiblmaier et al. (2016) identified 101 publications on the PI. Some academic journals have also dedicated special issues to the concept, including the *International Journal of Production Research* (Pan et al., 2017) and the *Journal of Business Logistics*. Moreover, the PI has attracted significant amounts of funding and several research projects have engaged academics, practitioners and governments. This includes a €5 million project supported by the European Union. This project, called Modulushca (Modular Logistics Units in Shared Co-modal Networks), is designed to develop a standardised modular container able to transit across transport modes as well as the protocols needed to connect the containers to the operators that handle them (Modulushca, 2015). Further emphasising the importance of the PI, the industry-led European Technology Platform of the Alliance for Logistics Innovation through Collaboration in Europe (ALICE) has placed the concept at the heart of its 2050 vision for logistics and supply chain management, and has defined a comprehensive roadmap towards its implementation (ALICE, 2015).

Despite the growing interest for the PI in the logistics literature and in practice, to the best of our knowledge, published research in an emergency management context is limited to two conference papers. In the first, Ado et al. (2014) identify a number of inefficiencies in humanitarian logistics operations and, by adopting the PI principles, develop a conceptual model that supports a higher level of interconnectivity between the various humanitarian actors (e.g. donors, governments, NGOs, suppliers, and beneficiaries). In the second paper, Gerschberger, Treiblmaier, and Montreuil (2015) explore how the development of an open, interconnected transport and delivery system can be used to increase the resilience of disaster-affected geographical areas.

While research on the PI in the context of emergency response operations is very limited, the humanitarian logistics literature discusses a number of PI-related topics. These include standardisation (McGuire, 2015; Schulz, 2008), modularity (Jahre and Fabbe-Costes, 2015), consolidation (Vaillancourt, 2016), optimised routing and distribution (Maghfiroh and Hanaoka, 2018), network configuration optimisation (Maharjan and Hanaoka, 2018), agile movements of goods (Charles, Lauras and Van Wassenhove, 2010; L'Hermitte, Tatham, Bowles and Brooks, 2016), as well as supply chain integration (Kim, Pettit, Beresford and Harris, 2018). Also discussed is data analytics (Masood, So and McFarlane, 2017; Whipkey and Verity, 2015) and the use of digital technologies, including cloud computing (Schniederjans, Ozpolat and Chen, 2016) and the Internet of Things (Sinha, Kumar, Rana, Islam and Dwivedi, 2017). Although the PI is not explicitly discussed, the fact that such topics appear within the humanitarian logistics literature indicates the relevance of the PI to disaster relief operations.

APPLICABILITY OF THE PHYSICAL INTERNET TO EMERGENCY RESPONSE MANAGEMENT

This section explores how some key features of the PI can support the previously identified requirements of emergency response operations. The six PI characteristics included in Table 2 widely support the efficiency requirements of logistics relief operations. Taken together, these characteristics streamline emergency response management and speed up the deliveries of relief items, as subsequently explained.

		Emergency response requirements					
		Efficient inter-agency coordination	Efficient collaboration with commercial logistics operators	Efficient use of the available resources	Seamless and uninterrupted transport flows	Rapid freight movements between transport modes	Rapid routing/re-routing due to sudden changes in the transport routes/modes available
Physical Internet characteristics	Standardised and modular loading units	✓	✓	✓	✓	✓	✓
	Open pool of hyperconnected operators and facilities	✓	✓	✓	✓	✓	✓
	Logistics resources used on an on-demand, per-use basis	✓	✓	✓	✓	✓	✓
	Widespread availability of real-time information	✓	✓	✓	✓	✓	✓
	Route optimisation supported by predictive and prescriptive analytics				✓	✓	✓
	Multi-segment movements of goods			✓	✓	✓	✓

Table 2: PI-Supported Efficient Flows of Disaster Relief Items (Source: The Authors)

Standardised and Modular Loading Units

Using standardised and modular loading units increases compatibility and interoperability and, thereby, has the potential to enhance cooperation and collaboration among responding agencies and with commercial operators. Moreover, standardisation and modularity can support the optimisation of the available emergency response capacity by eliminating wasted space, for example in the vehicles used to move relief items. Standardisation and modularity can also enhance transport integration and streamline logistics operations, including the loading, unloading and transhipment of emergency supplies. This has the potential to enable rapid freight movements between agencies/organisations and between transport modes, as well as swift routing adjustments to respond to changes, risks, or opportunities along the supply chain (e.g. sudden road closure preventing the access to disaster-affected communities).

Open Pool of Hyperconnected Operators and Facilities

An open pool of hyperconnected operators and facilities has the potential to improve the flow of relief items by making the logistics capacity of the participating agencies and operators accessible to every responder. As well as enabling emergency agencies to access a broader range of services, including intermodal transport, an open resource pool can support a better use of the available resources, for example NZ's under-utilised coastal shipping capacity. Ultimately, an interconnected network of operators, transport modes, and physical sites can support the seamless movement of relief items by redefining collaboration and by better balancing the supply and demand of logistics services across a network of responding agencies and commercial service providers.

Logistics Resources Used on an On-Demand, Per-Use Basis

Sharing capacity requires the various logistics resources to be made available to every responding agency on an on-demand and per-use basis. Doing so can increase collaboration between organisations that normally operate as separate entities, in particular between responding agencies and commercial organisations. On-demand capacity can also streamline logistics relief operations by enhancing operational flexibility and enabling emergency responders to deploy the relief items through an extensive network of actors based on their respective capabilities, proven performance, and available capacity. Moreover, on-demand services can optimise the use of logistics resources, support the rapid routing/rerouting of relief items, and speed up the movements between responders, commercial operators and transport modes.

Widespread Availability of Real-Time Information

As illustrated earlier in this paper, emergency responders operate in complex and dynamic environments, and typically face a high level of operational uncertainty and unpredictability. Under such conditions, having quality information is critical and supports effective decisions regarding the deployment of relief items. Key information includes the nature and the volume of the relief items needed, the actual location and quantities of the supplies stored or in transit, the available resources, and the disaster-specific circumstances (e.g. road accessibility). The widespread and real-time availability of this information provides visibility on relief operations, increases risk awareness, and supports informed and rapid logistics decisions.

In addition, disseminating this information to all channel partners in an ongoing and simultaneous way enables responders, commercial logistics providers, and modal operators to optimise capacity and coordinate their actions and the freight movements. Real-time information can also support the rapid and dynamic rerouting of emergency shipments as soon as, or even before a disruption such as a road closure occurs or an opportunity arises.

Route Optimisation Supported by Predictive and Prescriptive Analytics

The collection and dissemination of relevant supply chain information can support predictive and prescriptive data analytics and, in turn, enable well-founded decision-making that ensures that the relief items are deployed and delivered most efficiently, namely by selecting the most efficient route and transport mode. In a further step, data analytics can support the automation of freight movements, i.e. actions triggered without human intervention, such as the automatic re-routing of relief items or the automatic shifting between operators and/or transport modes in response to changes and disruptions along the relief supply chain.

Multi-Segment Movements of Goods

A PI network is made of a number of segments through which goods are moved based on the best delivery conditions on each segment. In emergency relief operations, a segment would be a portion between two points of the network or between two different transport modes. Continuously querying and adjusting the segment/modal routing can support a better use of the available resources in addition to enabling agile freight movements and timely deliveries of urgently needed relief items to disaster-affected communities.

To summarise, a PI-enabled emergency management system is an integrated and collaborative logistics network in which full visibility on the movements of relief items enables standard-sized packages to be automatically routed and re-routed across transport modes and network participants (both responding agencies and commercial operators). Routes are optimised based on the logistics capacity available and the existing/arising constraints and opportunities along the relief supply chain. Based on the above discussion, we argue that such a system has the potential to create efficiencies in emergency management operations by enabling shipment consolidation, increasing asset utilisation, optimising the routing of relief items, and speeding up deliveries to those affected by a disaster. Although this should be further investigated (see next section), the existence of a hyperconnected network of emergency management actors and commercial operators could have reduced the overreliance on the NZ Defence Force until Day 23 of the Kaikoura emergency response by rapidly mobilising alternative transport options (e.g. coastal shipping) and commercial services (e.g. the KiwiRail combined rail/ship service). That said, a new emergency response paradigm cannot be implemented overnight. Therefore, the emergency management community needs to adopt a pragmatic, incremental approach, namely identify the challenges and inefficiencies in the current emergency delivery processes and determine how the PI can help mitigate/overcome them.

LIMITATIONS AND FURTHER RESEARCH

This qualitative study is based on the academic literature and publicly available documentation. Consequently, the value of the PI for disaster relief operations requires further investigation with input from experienced emergency management practitioners and the gathering of logistics data related to actual relief operations (e.g. data from logistics reports and EMIS). Such data could support an evaluation of the logistics performance of the Kaikoura emergency response and the identification of the inefficiencies in the flow of relief items. Going one step further, obtaining data about the movements of emergency supplies in the aftermath of the Kaikoura earthquake would enable researchers to simulate an alternative response based on the PI principles and mechanisms. By doing so, research could provide strong evidence of the potential improvements and benefits of the PI over the current emergency management system in place in NZ.

In addition, research should be extended beyond the NZ context, including humanitarian environments where national authorities have no adequate response capacity and call for international aid agencies to participate in the relief effort. Hence, this paper paves the way for our own and others' future research, including the conceptualisation and testing of a robust and comprehensive PI model that supports efficient movements of relief items in the aftermath of a disaster.

CONCLUDING COMMENTS

Successful disaster relief operations call for responsive and flexible movements of goods in order to make the relief items available when and where they are needed by those affected. This paper extends the principles of the PI to disaster relief operations, a research context that, so far, has received very little attention in the PI literature. Our work illustrates how key characteristics of the PI are applicable to the emergency management area and how a fully integrated and collaborative logistics system has the potential to increase the efficient deployment of urgently needed relief items. In doing so, we suggest that operating a restricted PI in disaster relief operations (what could also be called a 'Physical Intranet') might enhance the speed, flexiliby and reliability of emergency response deliveries.

Amid calls for a disaster response shake-up in NZ (Bayer, 2018; Long, 2018; MCDEM, 2017a) and growing evidence that extremely destructive disasters will strike the South Island (Earley, 2018), we recommend that the responding agencies evaluate the PI concepts when reflecting on their current practices. They should consider how such concepts could reshape emergency operations and enable them to move to a system where pre-arranged company-to-company agreements are no longer required, and where standard-sized packages are dynamically handled and transported by a variety of interconnected operators and modes.

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