Modular Design of Physical Internet Transport, Handling and Packaging Containers

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Abstract

This paper proposes a three-tier characterization of Physical Internet containers into transport, handling and packaging containers. It first provides an overview of goods encapsulation in the Physical Internet and of the generic characteristics of Physical Internet containers. Then it proceeds with an analysis of the current goods encapsulation practices. This leads to the introduction of the three tiers, with explicit description and analysis of containers of each tier. The paper provides a synthesis of the proposed transformation of goods encapsulation and highlights key research and innovation opportunities and challenges for both industry and academia.

Keywords

Physical Internet; Container; Encapsulation; Material Handling; Interconnected Logistics; Packaging; Transportation; Modularity

1. Introduction

The Physical Internet has been introduced as a means to address the grand challenge of enabling an order-of-magnitude improvement in the efficiency and sustainability of logistics systems in their wide sense, encompassing the way physical objects are moved, stored, realized, supplied and used all around the world (Montreuil 2011, Ballot et al. 2014). The Physical Internet (PI, π) has been formally defined as an open global logistics network, founded on physical, digital, and operational interconnectivity, through encapsulation, interfaces, and protocols (Montreuil et al. 2013a).

Recent studies have assessed PI's huge potential over a wide industry and territory spectrum. Estimations permit to expect economic gains at least on the order of 30%, environmental gains on the order of 30 to 60 % in greenhouse gas emission, and social gains expressed notably through a reduction of trucker turnover rate on the order of 75% for road based transportation, coupled to lower prices and faster supply chains (Meller et al. 2012, Sarraj et al. 2013). It has recently been highlighted in the US Material Handling and Logistics Roadmap as a key contribution towards shaping the future of logistics and material handling (Gue et al. 2013).

This paper focuses on one of the key pillars of the Physical Internet: goods encapsulation in smart, world-standard, modular and designed-for-logistics containers (in short, π-containers). Previous research has introduced generic dimensional and functional specifications for the π-containers and made clear the need for them to come in various structural grades (Montreuil, 2009-2013, Montreuil, 2011 and Montreuil et al., 2010). The purpose of this paper is to address the need for further specifying the modular design of π-containers. Specifically, it proposes to generically characterize π-containers according to three modular tiers: transport containers, handling containers and packaging containers.

The paper is structured as follows. It starts in section 2 with a brief review of the Physical Internet and its focus on containerized goods encapsulation. Then it proceeds with a review of the essence of current goods encapsulation, containers and unit loads in section 3. The paper introduces the proposed three-tier structural characterization of π-containers in section 4. Finally, conclusive remarks are offered in section 5.

2. The Physical Internet and goods encapsulation

The Digital Internet deals only with standard data packets. For example, an email to be sent must first have its content chunked into small data components that are each encapsulated into a set of data packets according to a universal format and protocol. These data packets are then routed across the digital networks to end up at their final destination where they are reconsolidated into a readable complete email. The Physical Internet intends to do it similarly with goods having to flow through it. Indeed the Physical Internet strictly deals with goods encapsulated in standard modular π-containers that are to be the material-equivalent to data packets.

This extends the classical single-organization centric unit load standardization concepts (Tompkins et al., 2010), the shipping container (ISO 1161-1984) and the wider encompassing modular transportation concepts introduced nearly twenty-five years ago (Montreuil and Paquet, 1993) and investigated in projects such as Cargo2000 (Hülsmann, 1994), extending and generalizing them to encompass all goods encapsulation in the Physical Internet.

The uniquely identified π-containers intend to offer a private space in an openly interconnected logistics web, protecting and making anonymous, as needed, the encapsulated goods. Indeed, π-containers from a multitude of shippers are to be transported by numerous certified transportation and logistics service providers across multiple modes. They are also to be handled and stored in numerous certified open logistics facilities, notably for consolidated transshipment and distributed deployment across territories. They are to be used from factories and fields all the way to retail stores and homes. Their exploitation getting momentum and eventually universal acceptance requires on one side for them to be well designed, engineered and realized, and on the other side for industry to ever better design, engineer and realize their products for easing their standardized modular encapsulation.

Key enablers of interconnected logistics, the target characteristics of π-containers have been specified in broad terms, as synthesized in Figure 1.

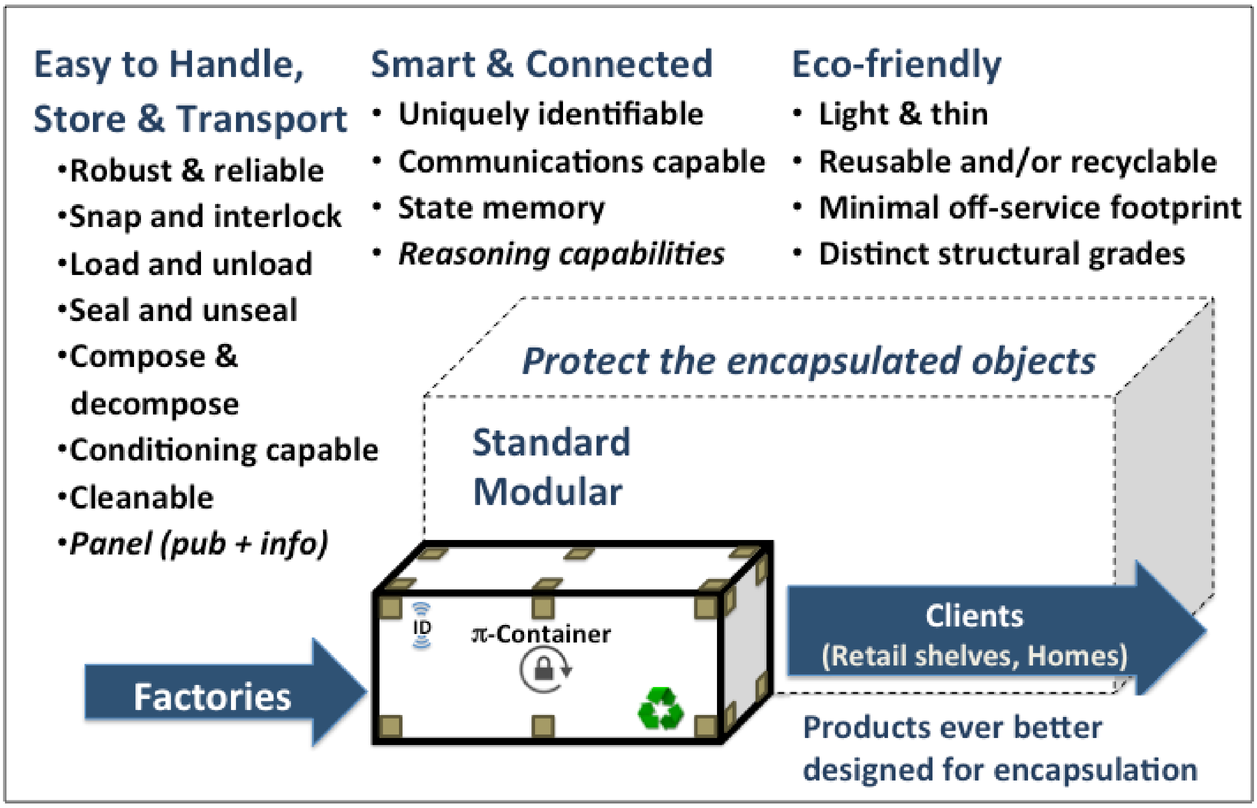

Figure 1. Generic characteristics of Physical Internet containers

From a dimensional perspective, π-containers are to come in modular cubic dimensions from that of current large cargo containers down to pallet sizes, cases and tinier boxes. Illustrative sets of dimensions include {12; 6; 4,8; 3,6; 2,4; 1,2} meters on the larger spectrum and {0,8; 0,6; 0,4; 0,3; 0,2; 0,1} or {0,64; 0,48; 0,36; 0,24; 0,12} meters on the smaller spectrum. The specific final set of dimensions have been left to be determined based on further research and experiments in industry, so that this set becomes a unique world standard acknowledged by the key stakeholders and embraced by industry.

From a functional perspective, the fundamental intent is for π-containers to be designed and engineered so as to ease interconnected logistics operations, standardizing key functionalities while opening vast avenues for innovation (Montreuil, 2011; Montreuil et al. 2010).

Their most fundamental capability is to be able to protect their encapsulated objects, so they need to be robust and reliable in that regard. They must be easy to snap to equipment and structures, to interlock with each other, using standardized interfacing devices. They should be easy to load and unload fast and efficiently as needed.

Their design must also facilitate their sealing and unsealing for security purposes, contamination avoidance purposes as well as, when needed, damp and leak proof capability purposes; their conditioning (e.g. temperature-controlled) as required; and their cleaning between usages as pertinent.

As illustrated in Figure 2, they must allow composition into composite π-containers and decomposition back into sets of smaller π-containers. A composite container exists as a single entity in the Physical Internet and is handled, stored and transported as such until it is decomposed. Composition capabilities are subject to structural constraints. Figure 2 illustrates how such composition/decomposition can be achieved by exploiting the modularity of π-containers and standardized interlocking property.

Even though not technically necessary, π-containers should be easy to panel with publicity and information supports for business marketing and transaction easing purposes as well as for user efficiency and safety purposes.

Designed for interconnected logistics, π-containers are to be efficiently processed in automated as well as manual environments, without requiring pallets.

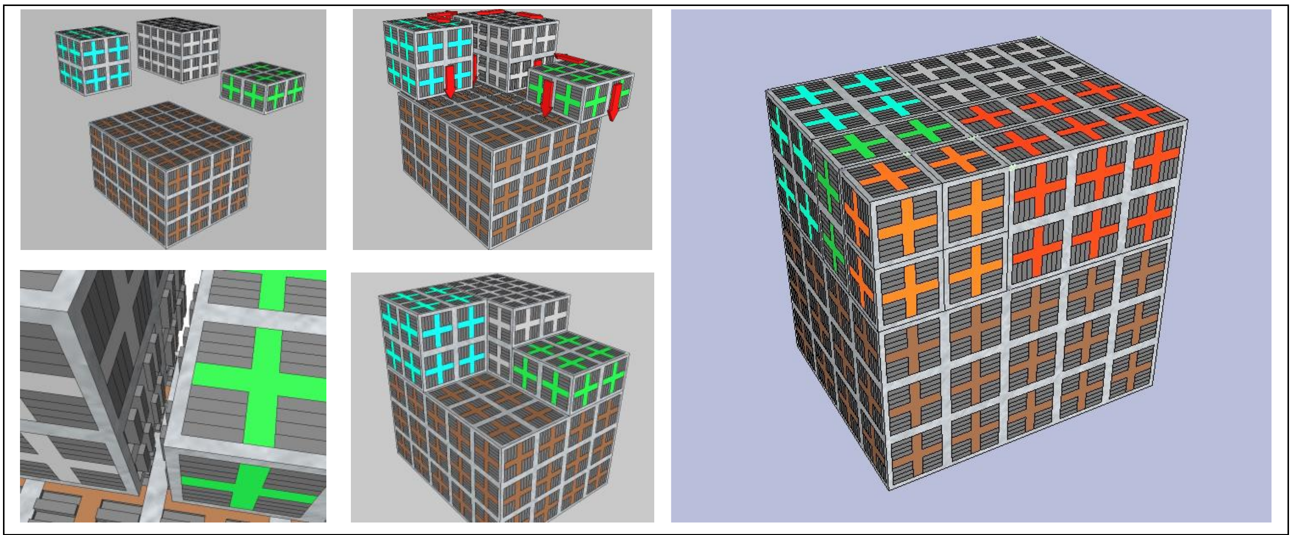

Figure 2. Conceptual design illustrating the modularity and the composition functionality of π-containers (Source: original design by Benoit Montreuil and Marie-Anne Côté, 2012)

From an intelligence perspective, they are to take advantage of being smart, localized and connected, and should be getting better at it as technology evolves. As a fundamental basis, they must be uniquely identifiable. They should exploit Internet-of-Things standards and technologies whenever accessible (e.g. Atzori et al. 2010). Using their identification and communications capabilities, π-containers are to be capable of signaling their position for traceability purposes and problematic conditions relative to their content or state (breakage, locking integrity, etc.), notably for security and safety purposes.

The π-containers should also have state memory capabilities, notably for traceability and integrity insurance purposes. As technological innovations make it economically feasible, they should have autonomous reasoning capabilities. Thus, they are to be notably capable of interacting with devices, carriers, other π-containers, and virtual agents for routing purposes (Montreuil et al., 2012).

From an eco-friendliness perspective, π-containers are to be as light and thin as possible to minimize their weight and volume burden on space usage and on energy consumption when handled and transported. They are to be efficiently reusable and/or recyclable; to have minimal off-service footprint, and to come in distinct structural grades well adapted to their range of purposes.

3. The current state of goods encapsulation and unit load design

In order to better comprehend the subsequently introduced characterization of π-containers, it is important to revise the current state of goods "encapsulation". In order to achieve this in a compact manner, this section exploits a multi-tier characterization of goods encapsulation that is depicted in Figure 3.

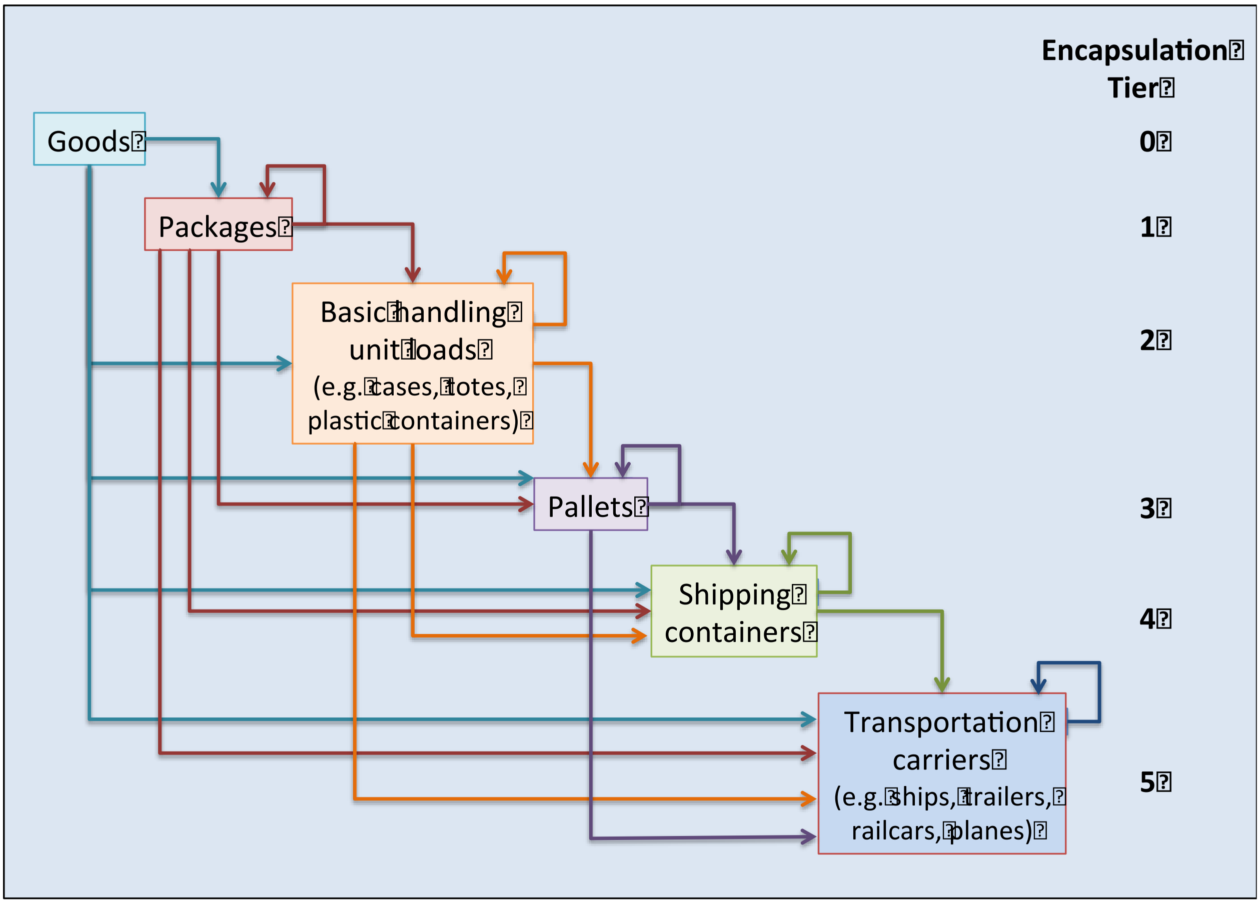

Figure 3. Current encapsulation practice characterization

Encapsulation tier 1: goods packaging

At the first encapsulation tier, goods are packaged in boxes, bottles and bags as illustrated in Figure 3 for consumer goods. The packaging may be done in a single layer or several layers. When exploited, the package is usually the basic selling unit of goods to consumers and businesses. Packaging is subject to product design, mostly related to its dimensions, weight and fragility. Indeed the package must protect its contained product. This involves many compromises between the size of the packaging, regulations, its materials, as well as with the inclusion of protective filling materials and fixations. It often ends up with the actual product using a fraction of the package space.

Figure 3. Illustrative consumer goods packaging
Source: www.bestnewproductawards.biz (2012)

Packaging is also subject to marketing needs. This is hugely important in the retail industry as the package is often what the consumer sees and touches when deciding whether to purchase the product or not in retail stores. Hence packages get all kinds of prints, colors and images. Packages have become differentiating agents affecting sales. This is less the case in industrial and e-commerce settings. In industrial B2B contexts, the purchasing decision is mostly subject to pricing, functional, technical and delivery time specifications and assessments. With e-commerce, the purchasing decision is done facing a smartphone, tablet or computer, mostly based on images, videos, descriptions, expert rankings, word-of-mouth, peer-to-peer comments, promised delivery time as well as total price including taxes and delivery fees. The consumer sees the packaging only upon receiving the product at home or a e-drive, when he has already committed to buy it.

Logistics considerations such as ergonomic manual and/or automated handling have usually very limited impact on package design for specific goods. This is a world currently dominated by packaging design and engineering, product design and engineering, and marketing. As asserted by Meller et al. (2012), this leads to situations whereas a consumer packaged goods manufacturer making and selling 1000 distinct products may well end up with 800 distinct package sizes.

Encapsulation tier 2: basic handling unit loads

At the second encapsulation tier, packages encapsulating goods are grouped into basic handling units such as cardboard cases, totes and containers. Figures 4 and 5 provide typical examples. In some settings, goods are directly unitized, bypassing packaging encapsulation.

Cases are often single-use while totes and containers are mostly reusable and returnable. The former are usually much cheaper than the latter.

Figure 4. Cardboard cases used as handling unit loads
Source: www.ukpackaging.com

Figure 5. Typical returnable totes and containers
Source: www.buckhorninc.com

From a logistics perspective, the cubic format of cardboard cases makes them easier to handle than odd-shaped loads. Their low price and recyclability often leads users to adopt a throw-after-usage operation, avoiding the need for reverse logistics of cases. They are most often designed to fit the unitizing needs of a specific product or family of products, leading businesses to use often hundreds of distinct cases with specific dimensions. Cases often lack good handles to ease their handling, so they either have to be clamped or held from the bottom for manual or automated handling purposes. For example, their conveyance forces the use of roller or belt conveyors to support them. For storage purpose, their structural weakness and their lack of snapping devices force to lay them on a smooth strong surface (such as racks and pallets).

In the parcel logistics industry, in order to help streamlining their logistics network and offering competitive pricing, the service providers prefer using their specific formats. Shippers who want to use their own formats are usually charged stiffer prices. Also, in order to avoid excessive pricing, shippers have to certify that their cases meet shock-resisting specifications, which often force shippers to double box their goods, the outer case protecting the inner case containing the goods: this increases significantly the material and operational costs of load unitizing in cases.

Generally, returnable handling totes and containers are differently designed for logistics than cases, often for the specific context they are used in. Often times, they have handles, are easy to open and close multiple times, and are structurally stronger, allowing higher stacking capability. As shown in Figure 6, many are foldable or stackable when empty to limit the reverse logistics induced by the need for redeploying them. As they offer limited security and are designed for specific purposes and users, totes and plastic containers are mostly used in limited ecosystems, such as within a facility, a company, a client-supplier dyad, a collaborative supply chain or a specific industry, such as for fresh produce in a specific territory.

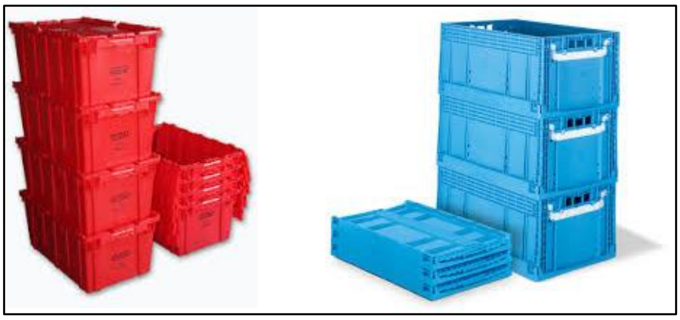

Figure 6. Illustrating the collapsible and stackable capabilities of some returnable plastic containers
Source: www.pac-king.net and www.ssi-schaefer.us

Encapsulation tier 3: palletizing
At the third goods encapsulation tier, basic handling unit loads such as cases and returnable plastic containers are unitized on pallets, often shrink wrapped to stabilize their tridimensional packing.

Figure 7. Two extreme examples of cases grouped as a unit load on a pallet
Source: www.123rf.com and www.rajapack.co.uk

Figure 7 contrasts on the left side an homogeneous pallet typical of upstream supply chain operations, with similar cases here laid out in an optimized fashion, and on the right side an heterogeneous pallet typical of downstream supply chain operations, with highly disparate cases, containers and individual goods shrink wrapped in a much less compact and stable layout. It is common to use secondary pallets and slip sheets between pallet layers in downstream operations.

Pallets have been characterized as one of the most important innovations ever in the material handling, logistics and supply chain domains, having a huge impact on productivity by easing the movement of multiple goods, cases, etc., as a single entity, using functionally standardized fork equipment (e.g. Vanderbilt, 2012). Figure 8 illustrates several pallet-handling contexts.

Figure 8. Pallets handled by forklift, walkie rider and AS/RS system
Source: www.us.mt.com, www.chetwilley.com and www.directindustry.fr

Pallets come in multiple grades and dimensions. There are some attempts at standardization, such as the Euro-Pallet in Europe, a four-way pallet made of wood with 1200×800×144 mm dimensions. These correspond to one of the six sets of dimensions approved by ISO, the others being 1016 x 1219 (40 x 48 in inches), 1000 x 1200, 1165 x 1165, 1067 x 1067 (42 x 42) and 1100 x 1100 (ISO, 2009). In order to emphasize the lack of worldwide standardization, only two (those identified in inches) of these six sets of ISO dimensions are amongst the top 12 pallet dimensions in North America (Wikipedia, 2014).

There are companies that specialize in providing pools of pallets shared by their clients, insuring their quality, making pallets available when and where their clients need them, involving relocating pallets and tactically positioning them based on client usage expectations.

Encapsulation tier 4: Shipping containers

At the fourth encapsulation tier lies the shipping container that contains some combination of goods themselves, in their unitary packaging or in basic handling unit loads such as cases, themselves either stacked directly on its floor, and/or loaded on pallets in pallet-wide swap boxes or containers.

Illustrated in Figure 9, shipping containers are rugged, capable of heavy-duty work in tough environmental conditions such as rain, ice, snowstorms, sandstorms and rough waters in high sea. They come roughly in 2,4 by 2,4 meter section, with lengths of 6 or 12 meters (20 or 40 feet). There are numerous variants around these gross dimensions, notably outside of the maritime usage.

Figure 9. A shipping container

Maritime containers have strong structural capabilities enabling their stacking, often up to three full and five empty high in port terminals, and even higher in large ships. Figure 10 depicts the wide exploitation of their stacking capabilities in a temporary storage zone of a port.

Figure 10. Stacked shipping containers

In complement to their quite standard dimensions, they have standardized handling devices to ease their manipulation. As illustrated in Figure 11, this has lead to the development and exploitation of highly specialized handling technologies for loading them in ships and unloading them from ships, to move them around in port terminals and to perform stacking operations.

Figure 11. Shipping-Container adapted handling equipment in port operations

Based on facts from Levinson (2006), Ballot et al. (2014) have shown that the shipping container has contributed to reduce by a factor of four the USA-France maritime transport cost and by a factor of ten the cost associated with having a load transiting through a port, from the pre-container era in 1960 to the container era in 2006. The shipping container has indeed become a key pillar of global trade as currently experienced, with global supply chains, global outsourcing and offshoring, and global markets.

Encapsulation tier 5: Transportation carriers

At the fifth transport-focused encapsulation tier, goods are loaded into carriers so as to be transported from their source to their destination. Such carriers notably include road based trucks, semi-trailers, delivery vans, scooters and bicycles; railcars; barges and ships; as well as airplanes, zeppelins and drones.

Figure 12. Semi-trailers carrying logs and cars directly without further encapsulation
Sources: www.commercialmotor.com/big-lorry-blog/logging-trucks-in-new-zealand
and en.wikipedia.org/wiki/Semi-trailer_truck

Figure 13. Palletized cases in semi-trailers with highly different space filling rates
Source: www.alcoppertrans.com.pl and www.defoulloir.forumactif.com

As emphasized in Figure 3, carriers may encapsulate goods directly such as in the examples from the lumber and car industries provided in Figure 12. Yet in most cases, they transport goods already encapsulated at a previous tier. Figure 13 illustrates semi-trailers encapsulating pallets of cases, with much better filling ratio in the left side example than in the right side example. Indeed the right side represents a typical case where the pallets and cases are such that pallets cannot be stacked on top of each other in the semi-trailer, leading to filling ratios on the order of 60% in weight and volume.

Shipping containers are ever more used in multimodal contexts, as illustrated in Figure 14, where they are encapsulated on a semi-trailer, on railcars, and on a specialized container ship.

Figure 14. Shipping containers carried on semi-trailer, train and ship
Sources: www.tamiya.com, www.kvtransport.gr and www.greenship.com

4. Proposed three-tier modular design of Physical Internet containers

The Physical Internet concept proposes to replace by standard and modular π-containers all various packages, cases, totes and pallets currently exploited in the encapsulation tiers one to four of Figure 3. Yet clearly, these must come in various structural grades so as to cover smartly the vast scope of intended usage.

In a nutshell, it is proposed as depicted in Figure 15 that three types of π-containers be designed, engineered and exploited: transport containers, handling containers and packaging containers. The transport containers are an evolution of the current shipping containers exploited in encapsulation tier 4. The handling containers replace the basic handling unit loads and pallets exploited in encapsulation tiers 2 and 3. The packaging containers transform the current packages of encapsulation tier 1. These are respectively short-named T-containers, H-Containers and P-containers in this paper.

Transport containers

Transport containers are functionally at the same level as current shipping containers, yet with the upgrading generic specifications of π-containers. T-containers are thus to be world-standard, modular, smart, eco-friendly and designed for easing interconnected logistics.

T-containers are to be structurally capable of sustaining tough external conditions such as heavy rain, snowstorms and tough seas. They are to be stackable at least as many levels as current shipping containers.

From a dimensional modularity perspective, their external height and width are to be 1,2m or 2,4m while their external length is to be 12m, 6m, 4,8m, 3,6m, 2,4m or 1,2m. These dimensions are indicative only and subject to further investigations leading to worldwide satisfactory approval. The thickness of T-containers is also to be standard so as to offer a standard set of internal dimensions available for embedded H-containers.

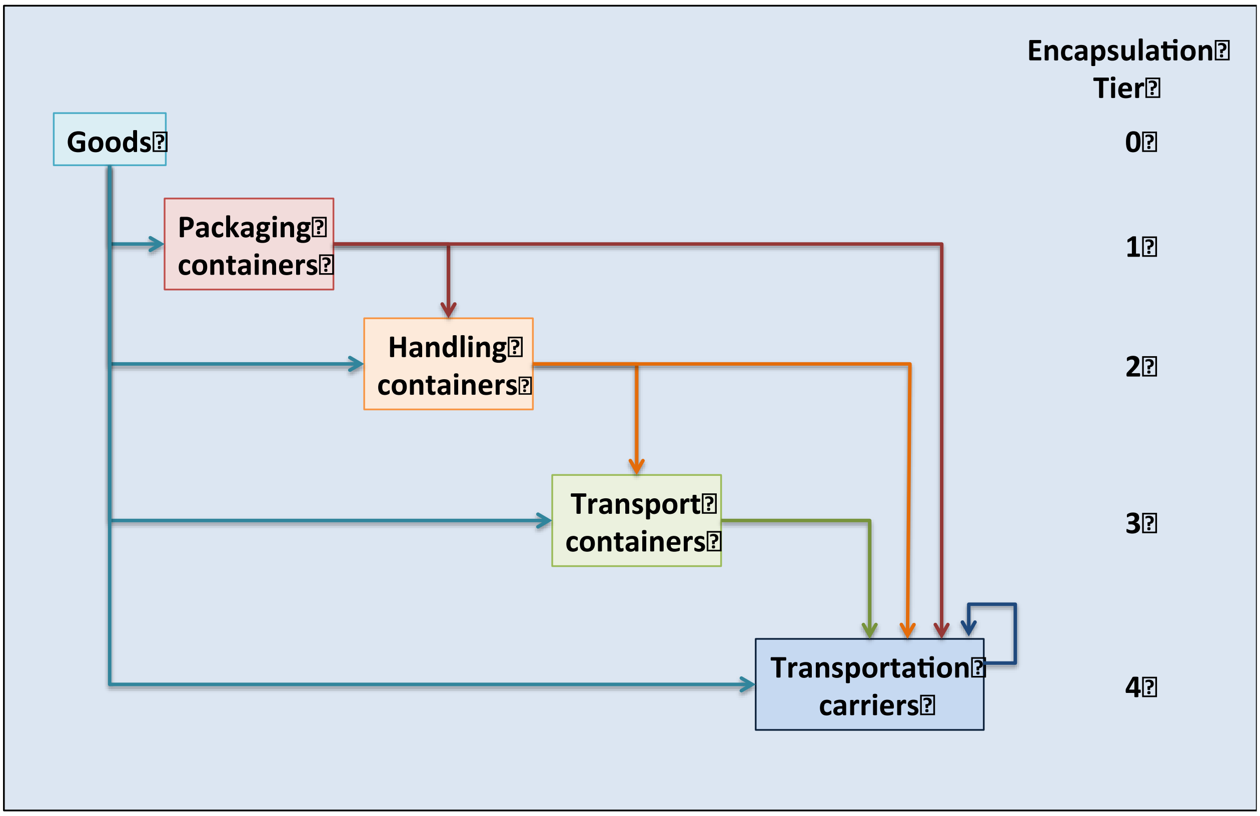

Figure 15. Proposed Physical Internet encapsulation characterization

In order to generalize the identification and external dimensions of T-containers, it is proposed to define them according to their basic dimension, specified above as 1,2m. This basic dimension is corresponding to a single T unit. As detailed in Table 1, a T-container whose length, width and height are 1,2m, as shown in Figure 15, is to be identified formally as a T.1.1.1 container. Similarly, a 6m long, 1,2m wide, 1,2m high T-container can be identified as a T.5.1.1 container.

As can be seen in Table 1, the majority of T-container volumes are unique, with two being the maximum number of distinct T-container dimensions having the same volume. This has lead to a way to shorten T-container identification, indeed the short name in the second column of Table 1. According to this naming, the formally named T.1.1.1 container of Figure 15 is short named a T-1 container, due to its unitary volume, and the short name for a T.5.1.1 container is T-5. The short name for the T.5.2.2 container of Figure 17 is T-20S to distinguish it from the T-20L short name for the T.10.2.1 container that is the only other T-container with a volume of 20 T units. The suffixes L and S respectively refer to long and short.

Table 1. Identification and external dimensions of T-containers

T-container identification		External dimensions (T units)				External dimensions (m, m3)			
Full name	Short name	X	Y	Z	Volume	X	Y	Z	Volume
T.1.1.1	T-1	1	1	1	1	1.2	1.2	1.2	1.73
T.2.1.1	T-2	2	1	1	2	2.4	1.2	1.2	3.46
T.3.1.1	T-3	3	1	1	3	3.6	1.2	1.2	5.18
T.4.1.1	T-4L	4	1	1	4	4.8	1.2	1.2	6.91
T.5.1.1	T-5	5	1	1	5	6	1.2	1.2	8.64
T.10.1.1	T-10L	10	1	1	10	12	1.2	1.2	17.28
T.2.2.1	T-4S	2	2	1	4	2.4	2.4	1.2	6.91
T.3.2.1	T-6	3	2	1	6	3.6	2.4	1.2	10.37
T.4.2.1	T-8L	4	2	1	8	4.8	2.4	1.2	13.82
T.5.2.1	T-10S	5	2	1	10	6	2.4	1.2	17.28
T.10.2.1	T-20L	10	2	1	20	12	2.4	1.2	34.56
T.2.2.2	T-8S	2	2	2	8	2.4	2.4	2.4	13.82
T.3.2.2	T-12	3	2	2	12	3.6	2.4	2.4	20.74
T.4.2.2	T-16	4	2	2	16	4.8	2.4	2.4	27.65
T.5.2.2	T-20S	5	2	2	20	6	2.4	2.4	34.56
T.10.2.2	T-40	10	2	2	40	12	2.4	2.4	69.12

Formally, the modular dimensions of a T-container can be expressed as:

$$d_f^{Te} = f b^T \qquad \forall f \in F^T \tag{1}$$

$$d_f^{Ti} = d_f^{Te} - 2t^T \qquad \forall f \in F^T \tag{2}$$

Where

d_f^{Te} : External dimension of a T-container side of factor f

d_f^{Ti} : Internal dimension of a T-container side of factor f

b^T : Base dimension of a T-container, here exemplified as 1,2m

t^T : Standard thickness of a T-container side

f: Modular dimensional factor

F^T : Set of modular dimension factors f, here exemplified as $\{1; 2; 3; 4; 5; 10\}$

Figure 16 depicts a conceptual rendering of a T-1 container. It shows its sides to be identical. Each side is represented as having a frame composed of an internal X-frame coupled to an external edge-frame. Each side is shown to have five standard handling interfaces represented as black circles. Each side is shown to have an internal surface protecting visually and materially the content. Here the surface is drawn in dark red. As all subsequent renderings, the conceptual rendering of Figure 16 is not to be interpreted as a specific specification but rather simply as a way to illustrate the concept in a vivid way. Much further investigation and engineering work are required prior freezing such specifications.

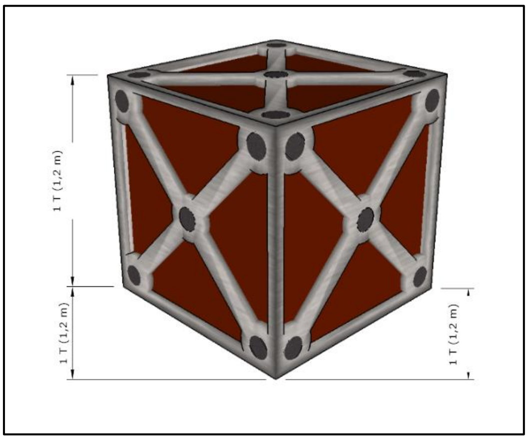

Figure 16. Illustrating a 1,2m long, wide and high transport container: T.1.1.1 or T-1 container

Figures 17 and 18 illustrate the modularity concept by showing the longer T-5 and T-20S containers built from an assembly of the same modular sides as a T-1 container. Figure 19 draws the full set of potential T-containers corresponding to Table 1, from the smallest T-1 to the largest T-40. By coincidence, the T-40 container whose length is 10 T units, or 12 meters, corresponds to the approximate 40-foot shipping container length, making it easy to remember.

It is important to note that the eighteen T-container sizes define the potential spectrum. Further investigations may show that some of those sizes add limited value due to their infrequent expected usage and should not be offered. This would be of particular importance when T-containers are constructed in monolithic fashion and of lesser importance when they are constructed in modular fashion using basic side units as graphically depicted in Figures 16 to 19.

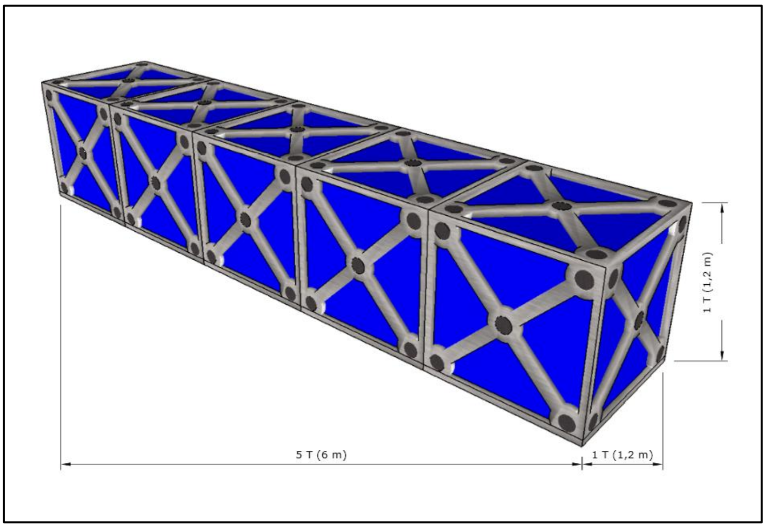

Figure 17. Illustrating a 6m-long 1,2m-wide, 1,2m-high transport container: T.5.1.1 or T-5 container

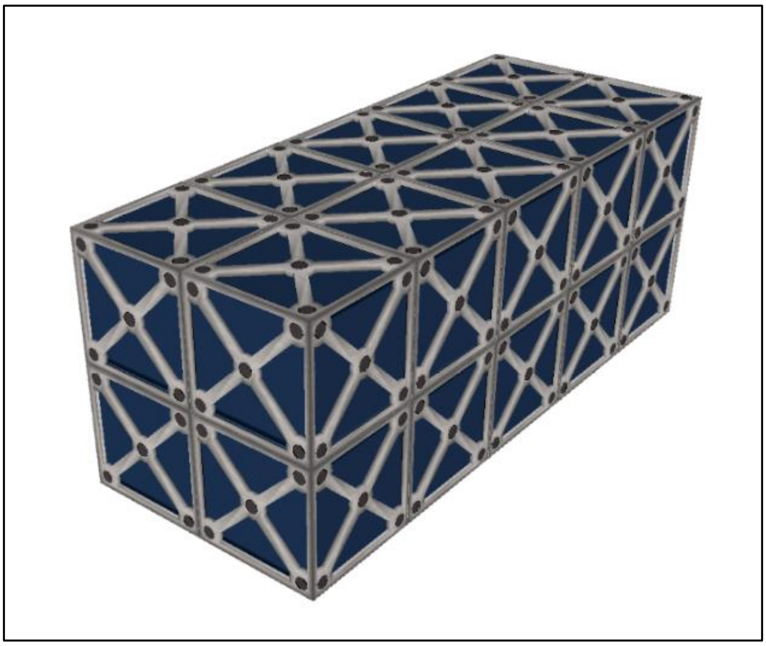

Figure 18. Illustrating a 6m-long, 2,4m-wide, 2,4m-high T-container: T.5.2.2 or T-20S container

Figure 20 provides an example of container on the market that exhibits some of the characteristics of T-containers. It is marketed as a flexible, stacking, interlocking, collapsible, trackable and inter-modal mini container designed to carry virtually any kind of freight (www.convertibletrailers.com/the-autobox/). It was originally designed to fit car trailers that usually go back empty to the car manufacturer, allowing using them for supplying parts to the plant. This illustration is not meant as publicity for this autobox, but rather as an indication that industry-lead innovations are already heading in the direction of T-containers.

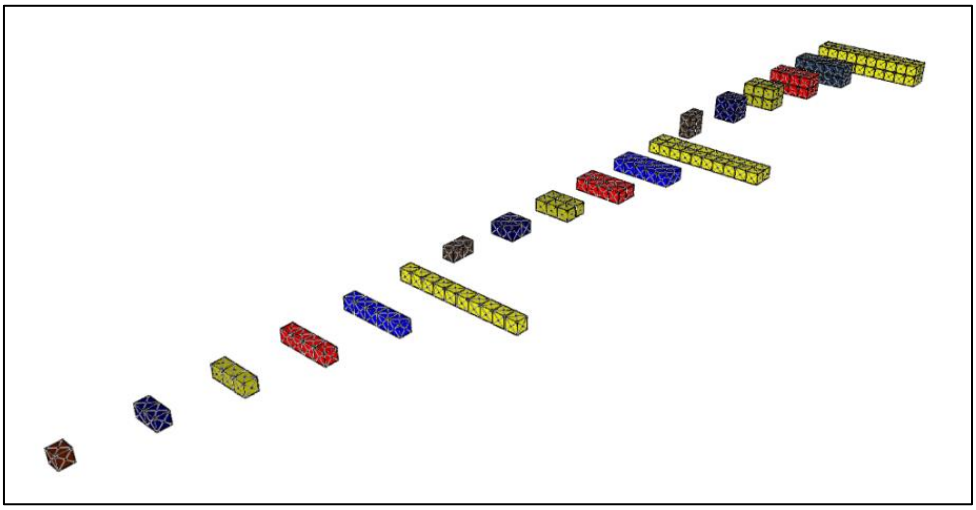

Figure 19. Modular spectrum of T-container sizes from T.1.1.1 (T-1) to T.10.2.2 (T-40)

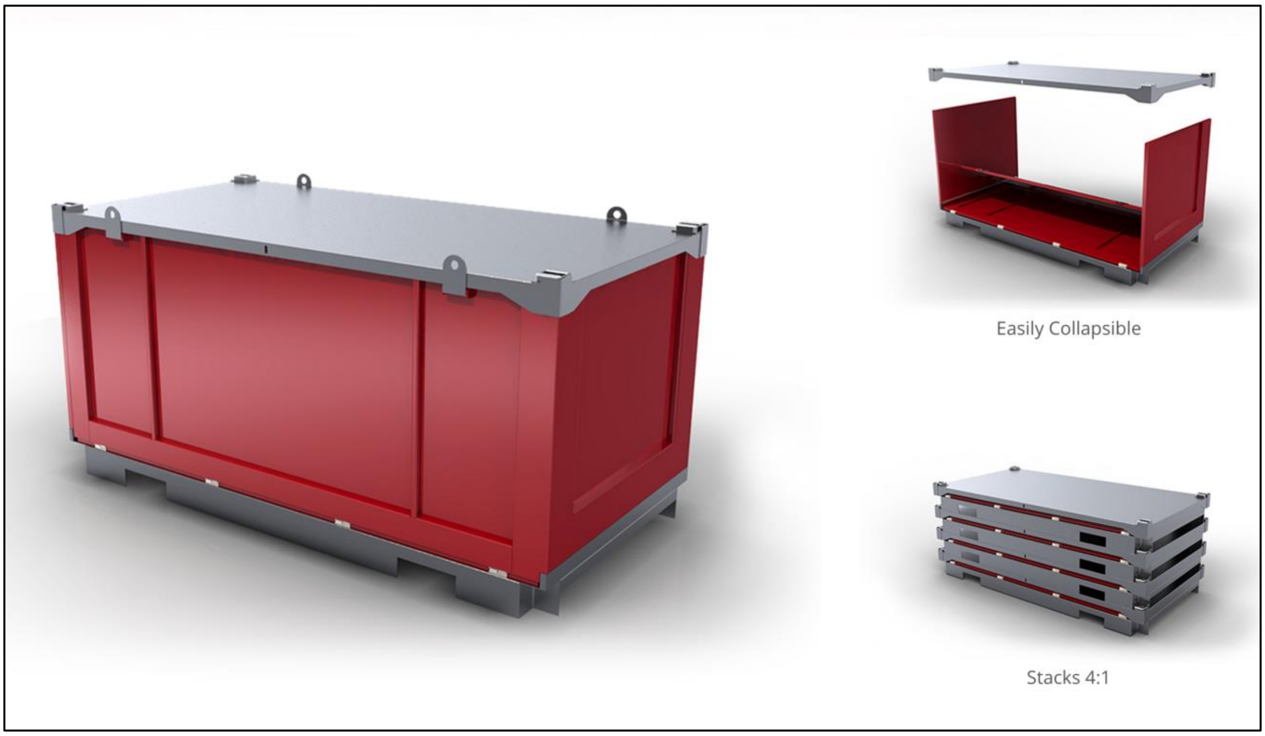

Figure 20. Autobox: an example of container with some desired characteristics of T-containers
Source: www.convertibletrailers.com/the-autobox/

By depicting various modular T-containers loaded on a truck and semi-trailers of distinct flatbed lengths, Figure 21 helps contrasting the current rigidity of the 6m or 12m long shipping containers with 2,4m by 2,4m section with the much higher flexibility offered by the proposed T-containers with modular dimensions.

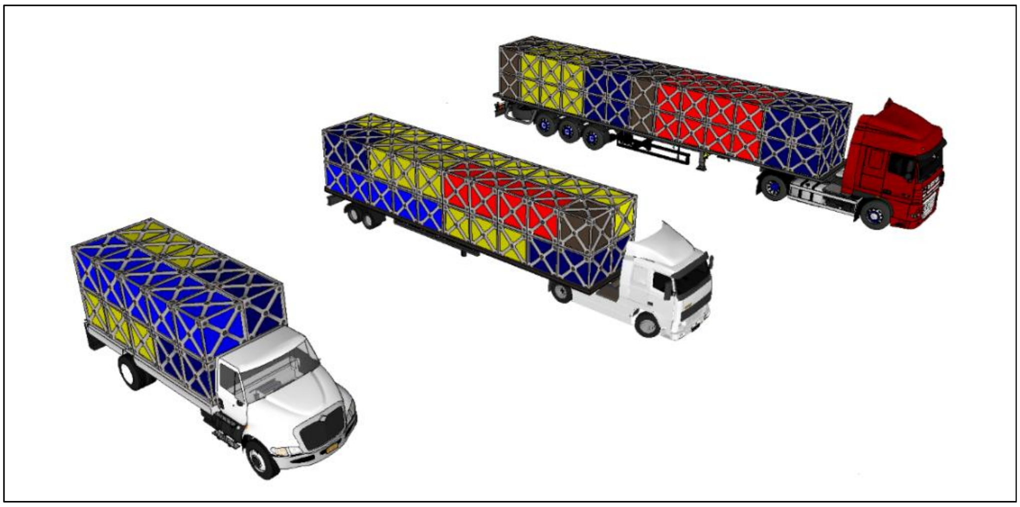

Figure 21. T-containers carried on π-adapted flatbed trucks and semi-trailers

Figures 22 and 23 emphasize the fact that exploiting standard, modular and designed-for-interconnected-logistics T-containers enables using handling technologies adapted to the Physical

Internet in general and to dealing with T-containers in particular. Figure 22 shows a semi-trailer containing several T-containers that is first backed up to a docking station so as to unload one T-container and loading another T-container. The T-container to be unloaded is side-shifted onto a π-conveyor and moved inside the logistic facility. Then the T-container to be loaded is side-shifted from a π-conveyor on the other side onto the semi-trailer where it is interlocked with the adjacent T-container on the semi-trailer for secure travel. Figure 23 shows how a π-adapted stacker similar to those in current port terminals can be used to load a T-container on a semi-trailer.

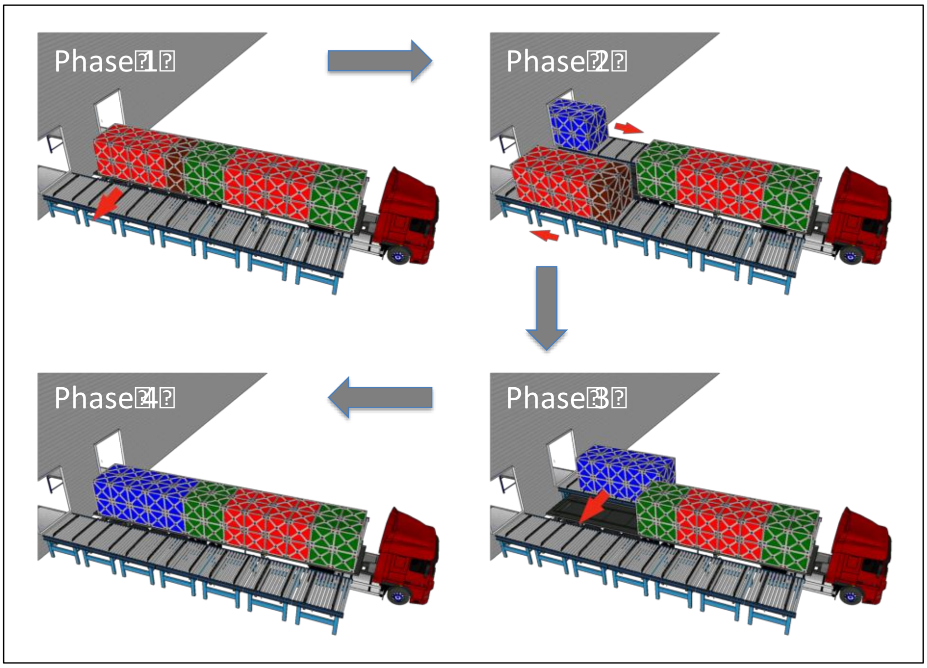

Figure 22. Conveyor based unloading and loading T-containers from semi-trailer

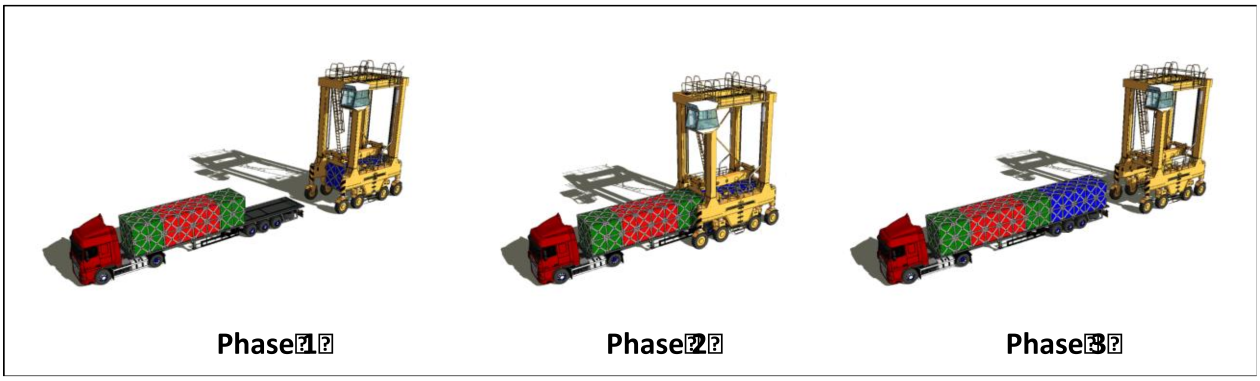

Figure 23. Loading a T-container on a π-adapted semi-trailer using a π-stacker

As the previous examples focused on road-based transportation, Figures 24 and 25 respectively highlight how T-containers can offer the same level of added flexibility and efficiency to rail and sea travel. In both cases, they show modular T-container applications that are normally restricted to 6m and 12m long containers. For example, Figure 25 shows a container ship adapted to carry modular T-containers composed into the equivalents of the classical 6m and 12m long containers.

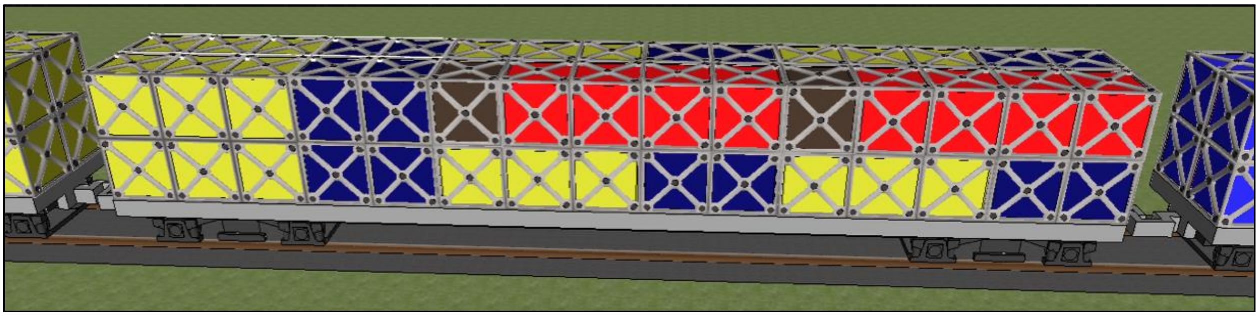

Figure 24. Modular T-containers loaded on adapted flatbed π-railcars

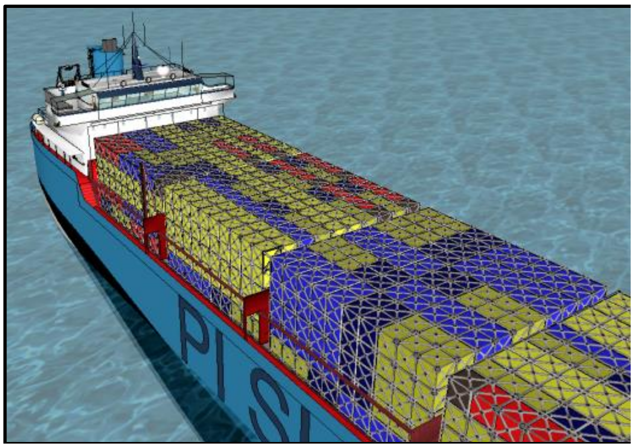

Figure 25. Modular T-containers loaded on a π-ship

Transport containers have been described above in much detail so as to make vivid the distinctions and similarities with current containers. In the next sections, the handling and packaging containers are described in a more compact fashion, emphasizing only the key attributes as the essence of the proposed changes is similar to transport containers.

Handling containers

Handling containers are functionally at the same level as current basic handling unit loads such as cases, boxes and totes, yet with the upgrading generic specifications of π-containers. Handling containers are conceptually similar to transport containers, as they are both Physical Internet containers. They could be designed to look as T-containers shown in Figures 17 and 18. In order to contrast them with T-containers, in this paper H-containers are displayed as in Figure 2. Note that H-containers are also nicknamed π-boxes.

A key difference between transport and handling containers lies in the fact that H-containers are smaller, designed to modularly fit within T-containers and dry-bed trailers and railcars. Figure 26 illustrates a T-container filled with a large number of H-containers, depicting the exploitation of their modularity to maximize space utilization.

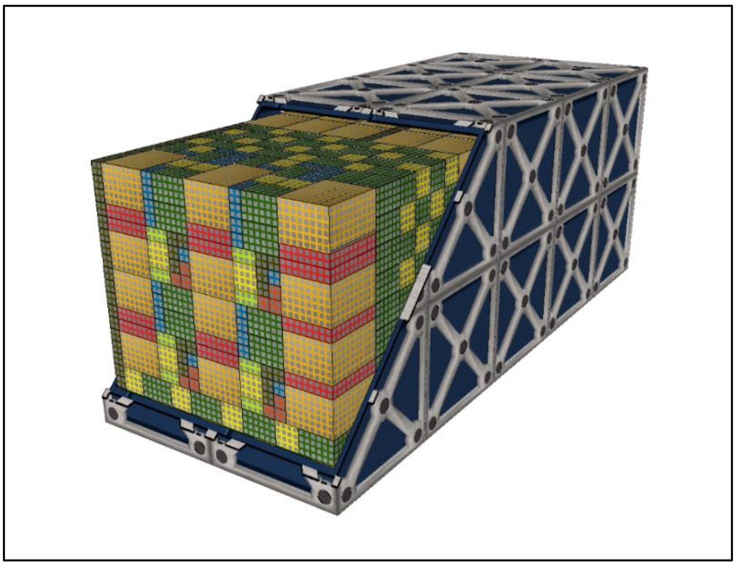

Figure 26. H-containers encapsulated in a T-container (sliced to show its content)

A second key difference is that they only have to be able to withstand rough handling conditions, mostly within facilities, carriers and T-containers. So they are structurally lighter, being less rugged than T-containers. They have to be stackable, at least the interior height of a T-container (see Figure 24), higher in storage facilities, yet less high than T-containers in ports. H-containers, given their inherent interlocking capabilities and their robust structure, are designed to support and protect their content without requiring pallets for their consolidated transport, handling and storage.

Figure 27. H-container prototyped in 2014 in the Modulushca project
Source: www.modulshca.eu

The Modulushca project, under the leadership of Technical University of Graz, has designed and produced a first-generation prototype of H-containers. The prototype is depicted in Figure 27 and is thoroughly described in Modulushca (2014). It has the capability of interlocking with others located above and below it through an elaborate locking mechanism, yet does not allow sideway interlocking. Even though it currently does not have all the desired characteristics for H-containers, it is indeed a first step along an innovation journey toward ever better π-boxes. The Modulushca is currently working a second-generation prototype for H-containers.

From a dimensional modularity perspective, their dimensions are roughly to be on the order of series such as 1,2m, 0,6m, 0,48m, 0,36m, 0,24m and 0,12m or 1,2m, 0,8m, 0,6m, 0,4m, 0,3m, 0,2m and 0,1m. These dimensions are indicative only and subject to further investigations leading to worldwide satisfactory approval. Here a 1,2m dimension is meant to signify that it fits within a T-1 container as described in Table 1, taking into consideration the thickness of T-containers. So, based on the series above, one can generically use 1-2-3-4-5-10 and 1-2-3-4-6-8-12 series to describe H-containers. So, assuming a basis at 0,1m using the second series, then a H.2.4.6 container refers to a 0,2m*0,4m*0,6m approximate cube.

Formally, the modular dimensions of a H-container can be expressed as follows, assuming that the largest-size H-container has to fit perfectly in the smallest-size T-container:

$$b^H = \left(d_1^{Ti} - 2s^H\right)/f^H \tag{3}$$

$$d_f^{He} = f b^H \qquad \forall f \in F^H \tag{4}$$

$$d_f^{Hi} = d_f^{He} - 2t^H \qquad \forall f \in F^H \tag{5}$$

Where

d_f^{He} : External dimension of a H-container side of factor f

d_f^{Hi} : Internal dimension of a H-container side of factor f

b^H : Base dimension of a H-container

t^H : Standard thickness of a H-container side (significantly smaller than t^T)

s^H : Standard maneuvering slack between T-container interior side and encapsulated H-containers

f^H : Maximum modular dimensional factor for a H-container

F^H : Set of modular dimension factors f for H-containers, here exemplified as $\{1;2;3;4;5;10\}$ or $\{1;2;3;4;6;8;12\}$.

As contrasted with the huge number of customized sizes of current cases, boxes and totes, the modular dimension factor sets limit strongly the number of potential H-container sizes. For example, Table 2 demonstrates that exploiting the set $\{1;2;3;4;6;8;12\}$ leads to a set of 84 potential H-container sizes, each composed of six modular sides from a set of 28 potential modular-size sides. It is not the goal of this paper to advocate using all these modular sizes in industry or to rather trim the number of modular sizes to a much lower H-container set. This is to be the subject of further research and of negotiations among industry stakeholders. Basically, a larger set enables a better fit of goods in H-containers yet induces more complexity in manufacturing, deploying, flowing and maintaining π-boxes. The exploitation of modular sides attenuates this complexity hurdle.

Meller et al. (2012) and Lin et al. (2014) provided optimization-based empirical insights relative to the compromises involved in setting the portfolio of allowed handling container sizes.

Table 2. Set of 84 H-container sizes using the {1; 2; 3; 4; 6; 8; 12} modular factor set and a set of 28 modular side sizes

				Identification of H-container sides side dimensions and number of each one																											
H-Container	X	Y	Z	S.1.1	S.1.2	S.1.3	S.1.4	S.1.6	S.1.8	S.1.12	S.2.2	S.2.3	S.2.4	S.2.6	S.2.8	S.2.12	S.3.3	S.3.4	S.3.6	S.3.8	S.3.12	S.4.4	S.4.6	S.4.8	S.4.12	S.6.6	S.6.8	S.6.12	S.8.8	S.8.12	S.12.12
1	1	1	1	6																											
2	1	1	2	2	4																										
3	1	1	3	2		4																									
4	1	1	4	2			4																								
5	1	1	6	2				4																							
6	1	1	8	2					4																						
7	1	1	12	2						4																					
8	1	2	2		4						2																				
9	1	2	3		2	2						2																			
10	1	2	4		2		2						2																		
11	1	2	6		2			2						2																	
12	1	2	8		2				2						2																
13	1	2	12		2					2						2															
14	1	3	3			4											2														
15	1	3	4			2	2											2													
16	1	3	6			2		2											2												
17	1	3	8			2			2											2											
18	1	3	12			2				2											2										
19	1	4	4				4															2									
20	1	4	6				2	2															2								
21	1	4	8				2		2															2							
22	1	4	12				2			2															2						
23	1	6	6					4																		2					
24	1	6	8					2	2																		2				
25	1	6	12					2		2																		2			
26	1	8	8						4																				2		
27	1	8	12						2	2																				2	
28	1	12	12							4																					2
29	2	2	2								6																				
30	2	2	3								2	4																			
31	2	2	4								2		4																		
32	2	2	6								2			4																	
33	2	2	8								2				4																
34	2	2	12								2					4															
35	2	3	3									4					2														
36	2	3	4									2	2					2													
37	2	3	6									2		2					2												
38	2	3	8									2			2					2											
39	2	3	12									2				2					2										
40	2	4	4										4									2									
41	2	4	6										2	2									2								
42	2	4	8										2		2									2							
43	2	4	12										2			2									2						
44	2	6	6											4												2					
45	2	6	8											2	2												2				
46	2	6	12											2		2												2			
47	2	8	8												4														2		
48	2	8	12												2	2														2	
49	2	12	12													4															2
50	3	3	3														6														
51	3	3	4														2	4													
52	3	3	6														2		4												
53	3	3	8														2			4											
54	3	3	12														2				4										
55	3	4	4															4				2									
56	3	4	6															2	2				2								
57	3	4	8															2		2				2							
58	3	4	12															2			2				2						
59	3	6	6																4							2					
60	3	6	8																2	2							2				
61	3	6	12																2		2							2			
62	3	8	8																	4									2		
63	3	8	12																	2	2									2	
64	3	12	12																		4										2
65	4	4	4																			6									
66	4	4	6																			2	4								
67	4	4	8																			2		4							
68	4	4	12																			2			4						
69	4	6	6																				4			2					
70	4	6	8																				2	2			2				
71	4	6	12																				2		2			2			
72	4	8	8																					4					2		
73	4	8	12																					2	2					2	
74	4	12	12																						4						2
75	6	6	6																							6					
76	6	6	8																							2	4				
77	6	6	12																							2		4			
78	6	8	8																								4		2		
79	6	8	12																								2	2		2	
80	6	12	12																									4			2
81	8	8	8																										6		
82	8	8	12																										2	4	
83	8	12	12																											4	2
84	12	12	12																												6

Figures 28 to 30, sourced from Montreuil et al. (2010), highlight the potential for innovative handling technologies exploiting the characteristics of H-containers. Figure 28 shows that π-boxes do not require pallets to be moved, even a composite π-box, as the handling vehicle can have devices enabling to snap, lift and carry the H-container. It also shows that wheels can be easily snapped underneath a π-box so that a human handler or a mobile robot can readily carry it, potentially using snap-on handles. Furthermore, if the wheels are motorized and smart, then when snapped to the H-container, the set becomes an autonomous vehicle.

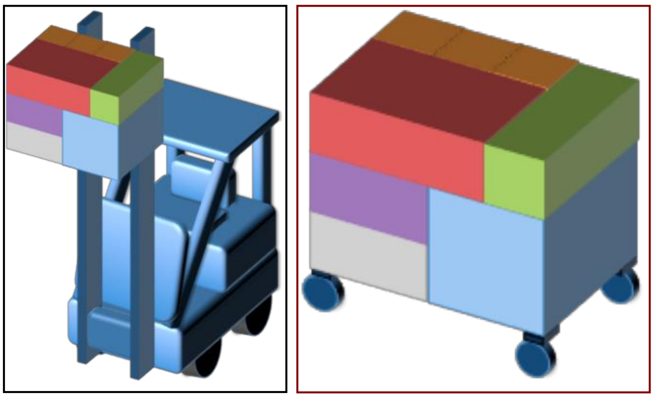

Figure 28. Composite H-container moved (1) snapped to a forkless lift truck and
(2) using snapped wheels manually or autonomously if they are motorized and smart
Source: Montreuil et al. (2010)

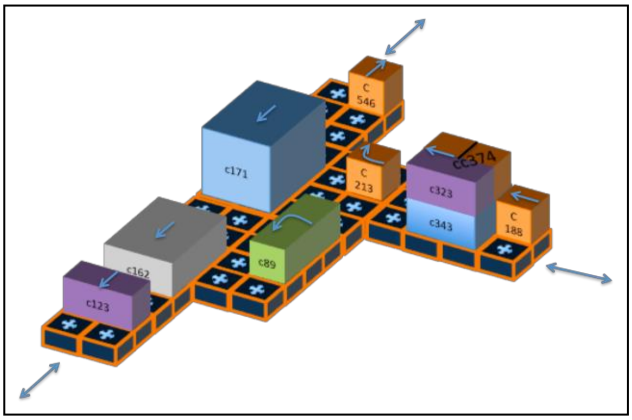

Figure 29. H-containers conveyed on a flexible conveyor grid adapted to the modular sizes
Source: Montreuil et al. (2010)

Figure 29 illustrates how conveying technologies can be developed to allow efficient and flexible flow of π-boxes, here using the plug-and-work concept introduced by Furmans et al. (2010). Figure 30 focuses on storage. It illustrates the stacking capabilities of H-containers. It also provides a glimpse at potential innovative storage technologies such as modular storage grids to which stored π-boxes are simply snapped in a highly efficient and flexible fashion.

Specific company-standardized handling containers are already in used in industry, with significant impact. Figure 31 provides an example in the appliance industry. It depicts appliances encapsulated in modular handling containers. It allows moving several of them concurrently with a lift truck by simply clamping them from the sides. It also allows to store them in the distribution center without relying on storage shelves, indeed by simply stacking them. The Physical Internet aims to generalize and extend such practices through world standard H-containers designed for interconnected logistics.

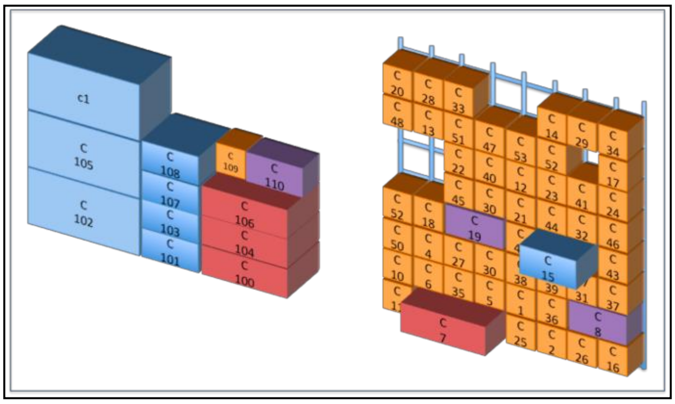

Figure 30. H-containers stacked and snapped to a modular storage grid
Source: Montreuil et al. (2010)

Figure 31. Illustrating the current use of modular handling containers
in an appliance distribution center
Source: Eric Ballot (left) and Sergio Barbarino (right)

Packaging containers

Packaging containers, short named P-containers or π-packs, are functionally at the same level as current goods packages embedding unit items for sales, as shown in Figure 3, the kind seen displayed in retail stores worldwide.

P-containers are Physical Internet containers as T-containers and H-containers, with the same generic characteristics. Yet there are three key characteristics that distinguish them.

1. The need for privacy is generally minimal as, to the contrary, goods owners want to expose the product, publicity and instructions to potential buyers.
2. The need for robust protection of their embedded goods is lowest as the H-containers and T-containers take on the bulk of this responsibility; so they are to be lightest and thinnest amongst Physical Internet containers.
3. The need for handling and sorting speed, accuracy and efficiency is maximal as they encapsulate individual product units.

Figure 32 illustrates the concept of π-packs as applied to cereals, toothpaste and facial tissues. The π-packs are here composed of display sides, reinforced standard tiny edges and corners acting as interfaces with handling devices, and they have modular dimensions. Figure 33 purposefully exhibits a toothpaste dispenser being loaded into a P-container, looking at first glance just like current toothpaste boxes on the market. Yet the P-container characteristics described above simplify very significantly the efforts and technologies necessary to move, pick, sort, and group them at high speed For example, it enables improved A-frame technologies, cheaper and more efficient, or innovative alternative technologies.

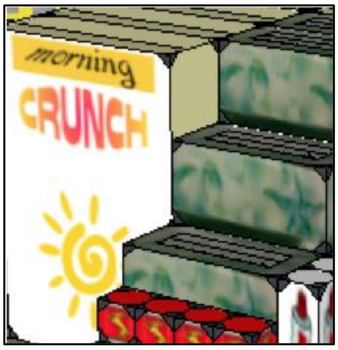

Figure 32. Illustrative consumer-focused P-containers

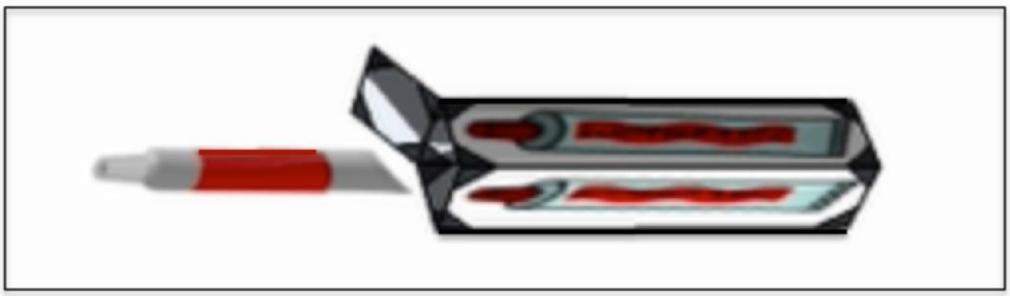
Figure 33. Toothpaste dispenser being loaded into a P-container

As illustrated in Figure 34, the dimensional modularity of π-packs enables their space-efficient encapsulation in H-container for being flowed through the multiple distribution channels, all the way to retail stores, e-drives or households.

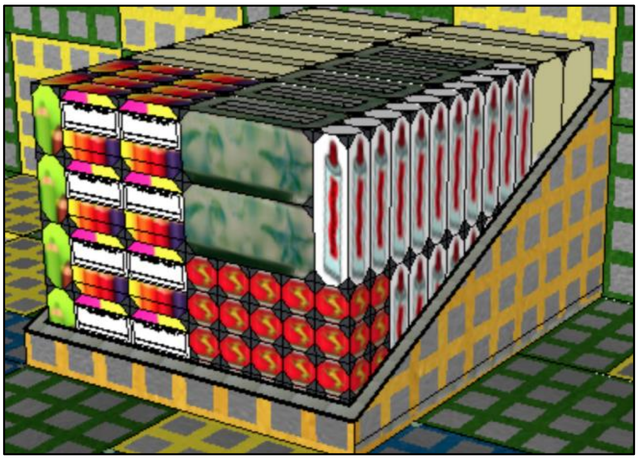

Figure 34. Multiple modular P-containers efficiently encapsulated in a H-container

From a dimensional perspective, P-containers are in the same realm as H-containers, yet are not generally expected to go as large as the largest 1,2m*1,2m*1,2m H-containers. So, given that their bases are in the same order, P-containers are to have dimensional factors of series such as 1-2-3-4-5 or 1-2-3-4-6-8 in line with yet shorter than H-containers.

Formally, the modular dimensions of a P-container can be expressed as follows, assuming that the smallest-size P-container has to fit perfectly in the smallest-size H-container:

$$b^P = d_1^{Hi} - 2s^P \tag{6}$$

$$d_f^{Pe} = f b^P \qquad \forall f \in F^P \tag{7}$$

Where

d_f^{Pe} : External dimension of a P-container side of factor f

b^P : Base dimension of a P-container

s^P : Standard minimal maneuvering slack between H-container interior side and encapsulated P-containers

f^P : Maximum modular dimensional factor for a H-container

F^H : Set of modular dimension factors f for H-containers, here exemplified as {1; 2; 3; 4; 5} or {1; 2; 3; 4; 6; 8}.

Note that the need for standardizing the thickness and internal dimensions of P-containers is debatable, explaining why it is omitted in the above formalization. For the Physical Internet itself, standardization is functionally not necessary. It is necessary for T-containers as H-containers must modularly fit within them, and for H-containers as P-containers must similarly fit modularly within them. Only goods are to be encapsulated in P-containers. Variability in thickness may allow to adjust it to provide adequate protection to the encapsulated goods. On the other hand, standardizing the thickness of P-containers provides a strong advantage in guiding and aligning product designers worldwide with a fixed set of usable space dimensions within the P-containers they are to be encapsulated.

5. Conclusion

The three-tier characterization of transport, handling and packaging containers proposed for the Physical Internet enables generalizing and standardizing unit load design worldwide, away from single-organization centric unit load design as engraved in textbooks such as Tompkins et al. (2010).

It offers a simple and intuitive framework that professionals from all realms and disciplines can readily grasp. It simplifies unit load creation and consolidation. It is bearer of innovations that are to make transshipment, crossdocking, sorting, order picking, etc., much more efficient. This is true within a type of container as well as across types, notably enabling significant improvement in space-time utilization of transportation, handling and storage means.

The proposed three-tier characterization also catalyzes a shift from the current paradigm of dimensioning the packaging to fit individual products, which leads to countless package dimensions, towards a new paradigm where product dimensioning and packaging dimensioning and functionality are adapted to modular logistics standards.

There are strong challenges towards the appropriation by industry of the modular transport, handling and packaging containers. These challenges cross technical, competitive, legacy and behavioral issues. For example, there must be consensus on the base dimensions and factor series for each type of container. There must also be consensus on standardized thickness of T-containers and H-containers. The container thickness, weight and cost must be controlled in order to minimize the wasted space and loading capacity, and to make the containers profitably usable in industry. The same goes with the handling connectors (allowing snapping and interlocking), relative to their cost, size, ease of use, position on the containers of each type.

Beyond the containers themselves, there must be engagement by the material handling industry to create the technologies and solutions capitalizing on the modular three-tier containers. Similarly, the vehicle and carrier (semi-trailer, railcar, etc.) industry must also get engaged. New types of logistics facilities are to be designed, prototyped, implemented and operationalized that enable seamless, fast, cheap, safe, reliable, distributed, multimodal transport and deployment of the three interconnected types of π-containers across the Physical Internet.

Indeed, the proposed characterization opens a wealth of research and innovation opportunities and challenges to both academia and industry.

Acknowledgements

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