Hyperconnected Pickup & Delivery Locker Networks

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***Abstract**: This paper deals with smart locker banks for pickup and delivery in the context of omnichannel business-to-consumer logistics and supply chains. Its main contribution is the conceptualization of hyperconnected smart lockers network designs as an alternative to home delivery for enabling to meet the challenges toward efficiently and sustainably achieving fast and convenient business-to-consumer pickups and deliveries. It gradually explores alternative designs from current practices to solutions exploiting Physical Internet concepts (PI) such as the PI handling containers. The paper identifies key relative advantages and disadvantages of alternative solutions, synthesizes strategic insights for industry, and provides research challenges and opportunities.*

***Keywords**: Smart Lockers, Physical Internet, PI-containers, Last Mile Delivery, Hyperconnected City Logistics, Omnichannel Supply Chains*.

1 Introduction

The courier, express & parcel industry's global market size is growing. Buhler & Pharand (2015) notably reported a growth rate of 5% in value over the 2013-2020 horizon, ranging from 5% in Western Europe and South America to up to 9% and 15% respectively in North America and Asia Pacific markets. As the world is experiencing a global urbanization that is projected to reach 66% of the population by 2050 (currently 54%) with highs in North America (82%), Latin America and the Caribbean (80%), and Europe (73%) (United Nations, 2014), urban areas will experience a dramatic increase in freight deliveries. This could lead to unsustainable traffic congestion, greenhouse gas emissions and noise and air pollution at unprecedented levels (MHI, 2017). Many smart city initiatives (*www.smartcitiescouncil.com*, *www.worldsmartcity.org*, and the U.S. Department of Transportation's Smart City Challenge) aim at understanding the logistics and supply chain challenges of tomorrow's city logistics, developing new application and supply chain innovations in delivery channel, distribution networks, and transportation modes.

The currently emerging pick-at-locker (P@L) business-to-consumer flow alternative, materialized by smart lockers, presents the advantages of being a simple and unstaffed delivery option (B. Montreuil, 2017). Smart locker banks grouping an unattended set of pickup and delivery lockers are a promising solution for last-mile parcel delivery and return, focusing on unsuccessful deliveries and consolidation opportunities. Indeed P@L networks offer convenient pickup locations for consumers, while potentially driving delivery costs down by reducing the number of delivery points and avoiding unsuccessful deliveries leading to multiple delivery attempts. Such networks have the potential of eliminating unsuccessful deliveries, and reducing delivery costs, city congestion, and greenhouse gas emissions (Iwan et al., 2015). This solution is globally emerging and already proven successful in European and Asian markets as a cheaper alternative to home delivery. Figure 1 shows examples of smart locker banks currently operated respectively by DHL (Germany), POPStation (Singapore) Inpost (Poland), and HiveBox (China). Automated and equipped with interactive modules, they allow pickups and deliveries to be performed in a few minutes.

Figure 1: Illustration of Current Smart Locker Banks

One of the challenges of deploying a network of pickup and delivery lockers as an alternative to home delivery is expressed through the uncertainty of the demand. A variable number of packages of a wide range of sizes are to be delivered in a capacity-limited locker bank, making the design and configuration of each bank critical to its capacity (number of lockers and their respective dimensions). In its current form (Figure 1), a smart locker bank has a fixed configuration of lockers of different predefined sizes, aiming at balancing service levels and fabrication costs. It is subject to obsolescence as its design is not flexible. It may also suffer from low space utilization, due to the fact that packages rarely take all the space available in one locker. Indeed, as only a few different sizes of lockers are present in the smart locker banks from Figure 1, it is expected that most packages will not exactly match with the space available in one locker, rapidly decreasing the space utilization of the bank.

This paper aims at conceptualizing smart locker based hyperconnected pickup-and-delivery (P/D) network designs to meet the challenges toward achieving omnichannel logistics efficiently and sustainably while meeting the timely expectations of clients, exploiting key concepts of the Physical Internet (Montreuil, 2011). After the essence of P/D locker networks is defined, four designs are presented in this paper, ranging from current practices to more mature Physical Internet (PI, π) concepts implementation.

2 Hyperconnected Pickup & Delivery Locker Networks

Smart locker banks grouping an unattended set of pickup-and-delivery lockers bring an alternative to home delivery. Currently mostly used for goods ordered through e-commerce channels, providing consumers convenient pickup locations, they could also be used to pre-position items in neighborhood exploiting smart demand predictive analytics. Current customers' expectations in terms of delivery lead time and pickup convenience lead to the need for up to multiple smart locker banks per neighborhood (Montreuil, 2017). Thus, networks of P/D lockers are positioned as a last logistics step before packages reach consumers' homes, and are distributed at the neighborhood level as depicted in Figure 2 in the context of Physical Internet enabled hyperconnected city logistics (Crainic & Montreuil, 2016).

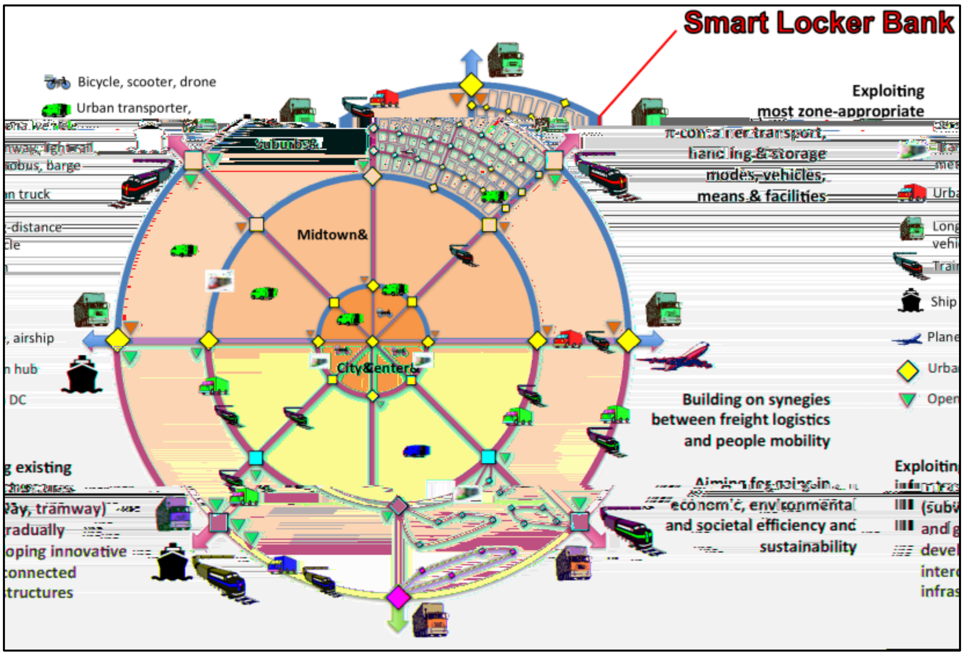

Figure 2: PI Enabled Hyperconnected City Logistics, Highlighting the Role of Smart Locker Banks (Adapted from Crainic & Montreuil, 2016)

Note that smart locker banks are one of the possible alternatives to home delivery proposed in the Physical Internet concepts in the context of omnichannel business-to-consumer logistics and supply chain (Montreuil, 2017). As shown in Figure 3, pick-at-drive and pick-at-store are two other alternatives requiring the final consumer to pick up their goods at some facility. However, smart locker bank networks provide a better level of convenience for some consumers, as they are distributed in neighborhoods, thus closer to homes, and are unattended, mostly accessible at any time.

From a logistic carrier perspective, smart locker banks allow consolidation of deliveries into predictable delivery locations. As P/D points are distributed over a known network, simpler and more efficient routing strategies can be developed to drive both delivery cost and delivery resource needs down, while increasing efficiencies. The potential elimination of unsuccessful deliveries and the need for less delivery resources could dramatically decrease the miles traveled by logistic carriers within urban environment, thus positively impacting city congestion and greenhouse gas emissions.

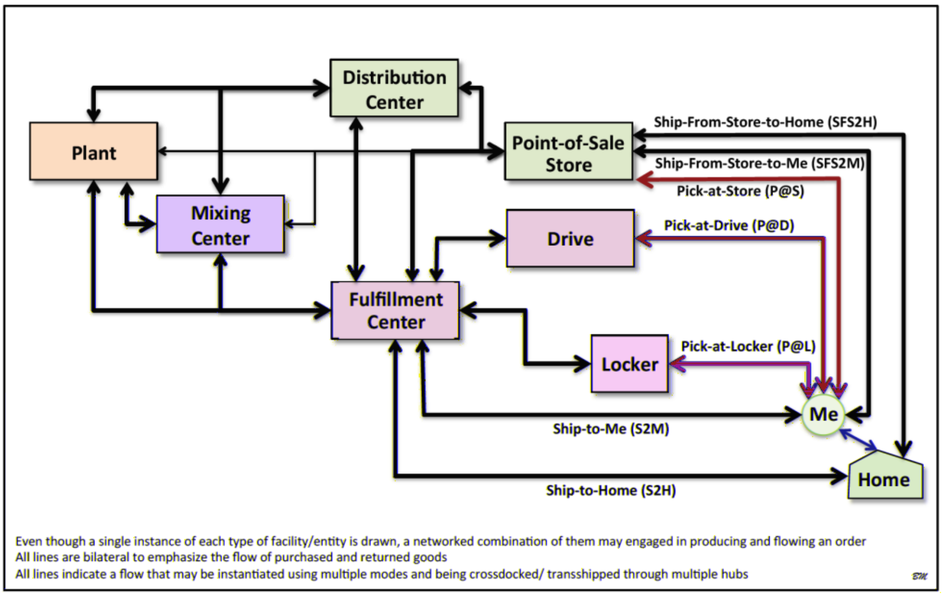

Figure 3: Omnichannel B2C Logistics and Supply Chains Alternatives (Source: Montreuil, 2017)

Another important aspect of the use of smart locker banks as P/D points in an urban environment is the operating model and ownership associated with lockers. Because deploying an extensive network to cover a city relies on a significant level of infrastructure investment (one bank representing a few ten-thousand USD), and operations cost (maintenance, land cost, utilities, insurance, etc.), one may consider opening a locker to multiple parties through partnerships or charging a per-use cost. Moreover, a multi-operator model has the potential to be more efficient as managing aggregated variations of demand could lead to less capacity required than managing variations of demand individually for each player. Also, as smart locker banks are integrated in public spaces and infrastructures, it seems unlikely that municipalities and city planners allow multiple players to deploy their own private network within the same neighborhood. A multi-operator operations model is illustrated in Figure 4 for e-commerce supply chains composed of multiple retailers, using a set of logistic providers and open pickup and delivery points. We may call such a network of smart locker banks a hyperconnected P/D locker network.

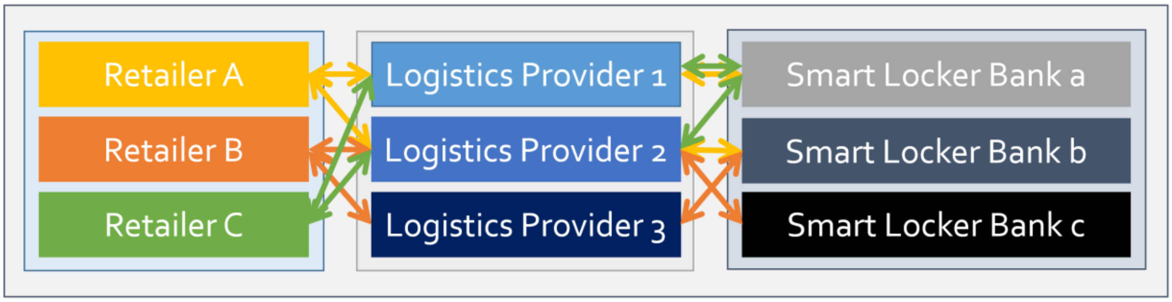

Figure 4: Hyperconnected Multi-Operator Pickup-and-Delivery Lockers (Adapted from Faugere & Montreuil, 2016)

3 Current Practices: Fixed-Configuration Smart Locker Banks

As depicted in Figure 5, smart locker banks in their current form are sets of P/D lockers of predefined sizes arranged in a fixed-configuration bank. Having a network of such banks enables relatively simple implementation. In general the efficiency of a fixed-configuration locker bank shall be highly dependable on (1) homogeneous and consistent demand over time and (2) predictive capability in regard to demand and its evolution, insuring that it may be rightly configured and that this configuration will remain well fitting over time.

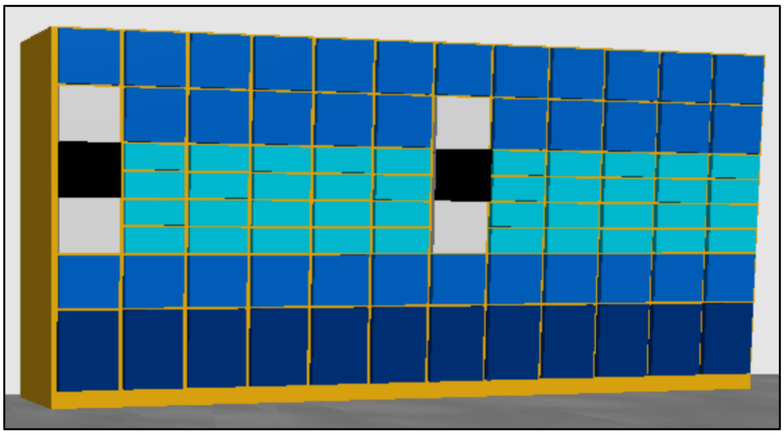

Figure 5: Illustration of Current Smart Locker Bank

The main advantages of this design are:

- It has opportunities for economies of scale relative to design and manufacture standard banks, and to locate them into a network.
- It represents a one-time implementation cost. The network being fixed, there is no need for redesign of the smart locker banks. Moving units to different locations is still possible but will not require structural modifications.

While advantageous in some ways as expressed above, a fixed configuration is constraining when filling up the smart locker bank with packages. Success of delivery will depend on the availability of a locker of sufficient dimensions at the time of the delivery. This is the origin of the main disadvantages of this design:

- It may rapidly become under or over capacitated. Global level of demand may evolve over time, resulting in substantially more or less number of packages to be delivered at a smart locker bank. In such a situation, over time, the design will become obsolete and will see its performance or space efficiency decrease.
- It may not adapt to variation of delivery patterns, punctually and over time, resulting in different package-size mixes. For example, a smart locker bank expecting primarily small-dimension packages will perform well as long as the size mix of packages being delivered stays relatively stable with a strong majority of smaller packages. If the mix changes and the packages being delivered get substantially bigger, the smart locker bank might not have enough lockers of adequate dimensions to receive the new demand, and might have a set of lockers unutilized, too small for the new delivery pattern.

While advantageous in terms of implementation, fixed-capacity smart locker banks can be inadequate when demand evolves or is difficult to predict. The challenge of capacity management and configuration arises, which is the backbone of the next design proposed.

4 Exploiting Modular Towers

Contrasting with the fixed configuration of section 3, we highlight in Figure 6 a smart locker bank conceived as a set of modular towers. The HiveBox locker banks, implemented in large quantities across Shenzhen in China, exploit such modular towers. In Figure 6, each tower is the same width and height, with two columns of lockers having all the same width. The locker bank implemented as a concatenation of such towers. The height of a tower depends mostly on human constraints, as each locker must remain reachable within acceptable levels of effort. The width of a column in a tower may be variable, with the width of its lockers adapted to the column width. This requires more flexible manufacturing than standard-width lockers, columns and towers.

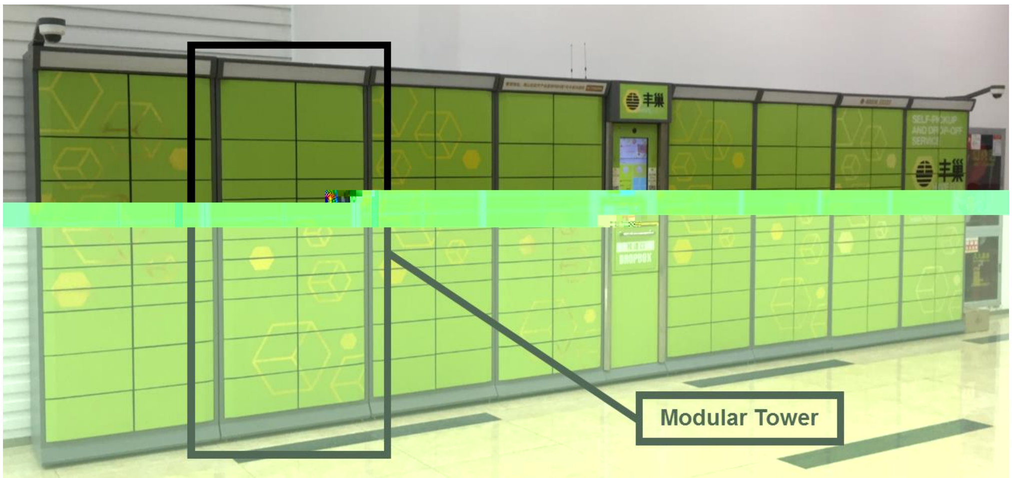

Figure 6: HiveBox Smart Locker Bank, Shenzhen, China, Exploiting Modular Towers

Using tower modularity, the global capacity of a smart locker bank can be adjusted over time by adding/removing modules, within the overall space constraints of the site. Figure 7 shows how the capacity of a smart locker bank can be increased by plugging an additional column module. Note that additional modules can come from a separate source, or simply be moved from a smart locker bank to another within the network when rebalancing its capacity.

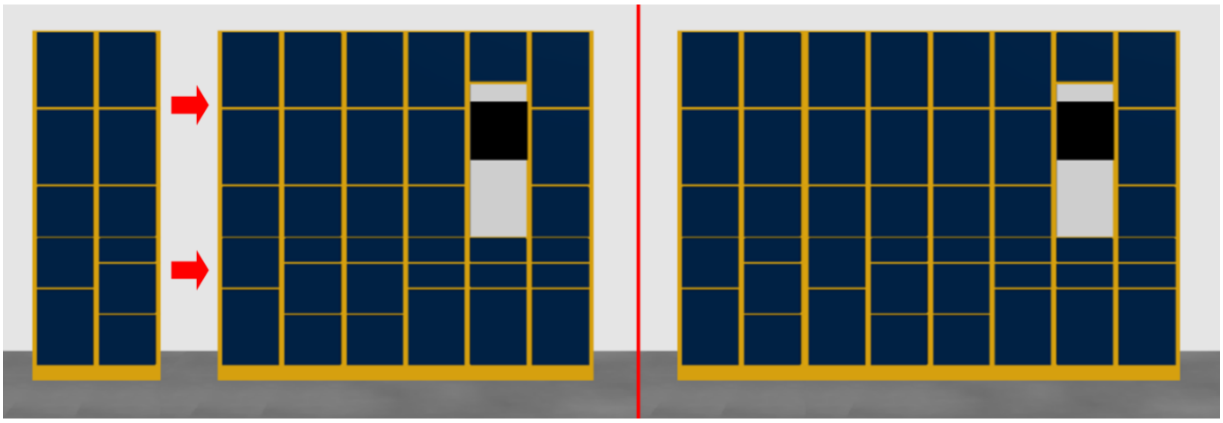

Figure 7: Increasing the Capacity of a Smart Locker Bank by Adding a Modular Tower

This design enables dynamic capacity management over a network of smart locker banks. Smart locker banks with Modular Towers thus offer the following main advantages:

- It can adapt to variations of global demand in modular tower increments: When adequately managed, the network's capacity can be adjusted over time by adding/removing column modules at specific smart locker locations.
- It can be advantageous in highly seasonal markets: For instance, a stock of modular towers can be maintained to enable substantially increase of the network's capacity during peak seasons (Christmas, cyber-Monday, etc.) and ensure minimal footprint during valley seasons.

Note that it would require a slightly more complex system, with the following main disadvantages:

- Assuming significant supply times from modular tower suppliers, it requires a modular tower inventory management system: Modular towers must be held in inventory and distributed over the network in a timely manner as needed; This could represent a significantly high inventory, especially if many types of column modules of different configuration of lockers are held in inventory to enable greater capacity flexibility.
- It needs capacity management policy and frequency: The frequency at which the capacity of the network is adjusted must be defined as well as the policy ruling the addition/removal of tower modules at a specific location; This would also require high visibility on the current configuration of the network and the available inventory.
- It requires distribution capabilities to transport and install/remove tower modules: These tower modules may be heavy and require special handling equipment.
- It can difficultly adapt to variations of demand patterns, such as evolution of the mix of package sizes deployed in the locker banks.

While now accounting for variations of global demand, smart locker banks with modular towers have limited advantages when the mix of package sizes also varies. The next proposed design is adding a level of modularity to account for mix changes.

5 Exploiting Modular Lockers

Taking modularity to the next level, smart locker banks can be composed of individual modular lockers, whether or not the banks exploit modular towers. The locker modules must (1) have modular sizes (as the well-known Lego blocks) harmonized to the bank and modular tower structure dimensions, and (2) have modular connectors enabling their easy addition to, and removal from, a locker bank or tower.

Modular lockers enable a fine-granularity adjustment of the capacity of each locker bank, allowing modifications of the entire configuration, as in illustrated in Figure 8. A locker bank design exploiting locker modularity offers the following main advantages:

- It can adapt to variations of global demand, both in terms of volume and mix, within the limits of the site, the bank structure and/or the tower modules.
- It can be advantageous in highly seasonal markets: a stock of modular lockers can be maintained to enable substantially increase of the network's capacity during peak

seasons and ensure minimal footprint during valley seasons (subject to the same limitations as above.

- It is capable of accounting for variations of delivery patterns: It has the capabilities to adjust its configuration to the change of package size mix over time by adjusting the number of lockers of each modular dimension.

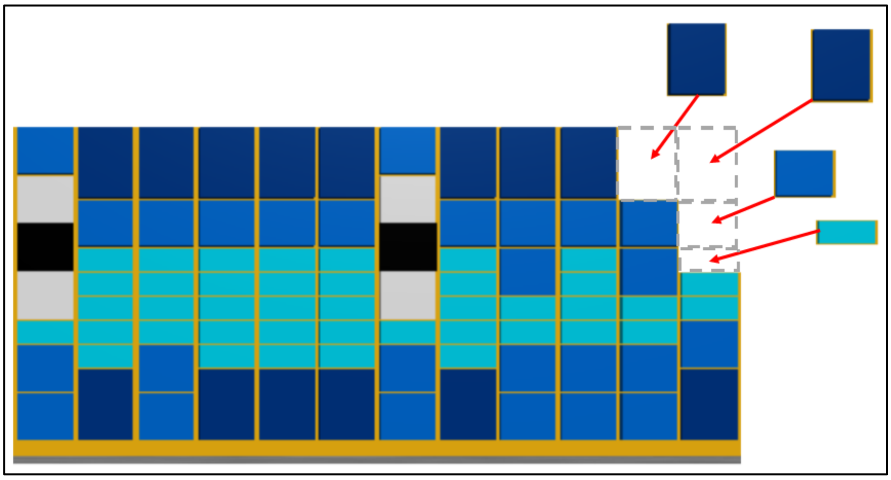

Figure 8: Illustration of a Smart Locker Bank Exploiting Modular Lockers

A smart locker bank design using modular lockers increases the supporting system complexity and has the following main disadvantages:

- Assuming significant supply times from modular locker suppliers, it requires a modular locker inventory management; In this case, modules are smaller than towers yet have a variety of modular sizes.
- It needs capacity management policy and frequency, as induced by modular towers, yet at a more granular level.
- It requires distribution capabilities to transport and install/remove locker modules.

As with modular towers, modular lockers can come from a pooled inventory or be exchanged between smart locker banks when rebalancing the capacity of the entire network.

Note that smart locker banks with modular towers and modular lockers have the potential to mitigate the disadvantages of fixed-configuration locker banks by allowing for capacity management of the network to adjust to variability of demand patterns (global demand and package sizes mix) but are more complex, requiring dedicated inventory, capacity management and distribution systems. Indeed, tower and/or locker modules must be stored, transported, and installed/removed, and the frequency and policy ruling these manipulations must be predefined. It may require a significant amount of resources to manage such a system.

The next proposed design aims at mitigating the resources required by exploiting Physical Internet handling containers (Montreuil et al., 2015).

6 Exploiting Physical Internet Handling Containers

The use of Physical Internet containers as a standard for transportation and storage of physical goods at all levels of supply chains promises significant improvement in space-time utilization of transportation, handling and storage means (Montreuil et al., 2015). Moreover, π-containers and their modular dimensions bring opportunities to develop new logistics designs rethinking the way we deal with physical goods. This section introduces the use of π-containers as pickup and delivery lockers, as an alternative to modular lockers and towers: the π-containers become smart mobile lockers.

In the previous sections, the basic underlying assumption has been that goods to be picked up or deposited were to be done so by putting them from/into a fixed locker, as it commonly used in smart locker banks across the world (e.g. Figures 1 and 6). Here, the proposal is for encapsulating the goods into smart modular π-containers and using these π-containers as smart lockers. As sketched in Figure 9, the π-container lockers can be interlocked to each other, stacked on top of each other or snapped to a simple grid-shape bank structure, using basic Physical Internet concepts and principles as proposed by Montreuil et al. (2010).

As illustrated in Figure 9, smart locker banks have a fixed configuration of lockers of different predefined sizes, aiming at balancing service levels and fabrication costs. The modular designs proposed in preceding sections give some flexibility and enable to modify the configuration of the banks of lockers according to the capacity & configuration management frequency, but are still fixed between the reconfiguration periods. This yields designs good enough for a wide variety of delivery scenarios, but optimal for none, resulting in non-optimal utilization efficiencies and service levels.

Figure 9: POPStation Smart Locker Bank (Singapore Post: www.mypopstation.com)

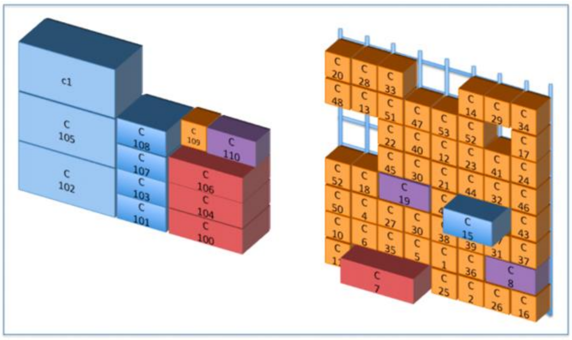

Figure 10: Illustrating π-containers Snapping as Pickup/Delivery Lockers (Source: Montreuil et al, 2015)

A design using π-containers as lockers, exploiting their interlocked stacking and/or grid-snapping capabilities as illustrated in Figure 10, has the potential of eliminating volume utilization inefficiencies and of offering better service levels to users, reaching toward near optimality for each demand scenario. Per the proposed concept, smart π-locker banks, instead of being composed of a set of lockers, are now composed of a basis, a grid-wall of predetermined surface to which π-containers are dynamically snapped as shown in Figure 11. Possible accessories that can be snapped to the grid-wall include interactive modules, protection roof, security cameras and lights.

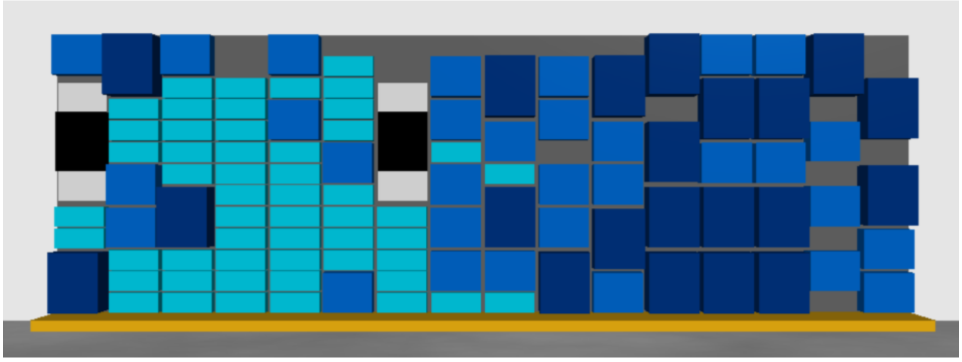

Figure 11: Illustration of a -Container Based Smart Locker Bank at Some Punctual Time

6.1 Physical Internet Handling Containers

Introduced as one of the core concepts of the Physical Internet by Montreuil (2011), the exploitation of smart modular PI containers represents one of the main technological component of the Physical Internet encapsulation of goods framework. Montreuil et al. (2016) have categorized three levels of PI containers: the PI transport, handling and packaging containers, respectively nicknamed π-pods, π-boxes and π-packs. Gazzard and Montreuil (2015) and Landschützer et al. (2015) have focused on the π-boxes that are notably targeted to replace contemporary totes, boxes and cases as core handling unit loads. In the proposed pickup and delivery locker bank architecture, π-boxes are planned to be used as smart mobile lockers.

The fast snapping and interlocking capabilities of π-containers is the foundation of the proposed design, as π-boxes replace current lockers. Indeed, as they can be easily snapped to a grid-wall, a large number of configurations is possible. In order to be practically accessible, an interspace between consecutive π-boxes is represented in Figure 11, allowing extracting a specific π-box when surrounded by others. Arguing that current physical lockers also are separated by some space required by the support structure of the whole smart locker bank, and by the mounts of the doors, it is conservative to assume these interspaces to be of similar scale.

The structure of π-boxes, being robust, reliable and sealable, as well as their communication capabilities and their eco-friendly nature, make them suitable to be used as efficient and safe pickup and delivery lockers, protecting physical goods from weather conditions and theft, while ensuring monitoring and communication of its content to logistics systems.

6.2 Pickup and delivery mechanisms

To perform a delivery or a return, a logistic service provider or a customer just have to snap a π-box at an empty grid position. The exact position at which a π-box is assigned can depend on a predefined policy, real-time optimization, or be chosen by the person at the time of the delivery to the grid-wall. It is also possible for a return or delivery of loose goods to be made in an empty π-box, which would have been left snapped on the grid-wall from a previous delivery.

When a customer comes to pick up its goods, two options are possible:

- The customer opens the front face of the π-box, and picks up the ordered goods. In this case, empty π-boxes will be picked-up by the logistic service provider during the following delivery and then redistributed in the open system.
- The customer picks up and brings the whole π-box home, and later redistributes it in the system (at a store, click-and-collect drive, locker bank, etc.) or uses it for shipping or returning other goods.

6.3 Capacity modularity

The number, size and configuration of π-boxes constituting the goods storage in such an architecture is variable and offers great flexibility. Additionally, the grid-wall itself can be a modular element adding capacity flexibility. Panels constituting a grid-wall can be added/removed, thus expanding/reducing the area of the zone on which π-boxes can be snapped, thus increasing/decreasing the modular capacity of the smart π-locker bank.

This design offers the following main advantages:

- Thanks to the snapping capabilities of π-boxes, it has the potential of significantly improving the handling efficiency and dynamics of deliveries and pickups at smart locker banks, while ensuring the security of goods.
- Its configuration is decided as deliveries and returns occur, when π-boxes are being snapped to the grid-wall.
- It is highly flexible: its configuration and global capacity can adapt seamlessly in real time to variations and seasonality of demand and delivery patterns.
- It does not require locker bank specific resources; π-boxes are resources moving across different tiers of the supply chain; they are thus to be managed globally.
- It is expected to have minimal footprint and to require less upfront investment.

As this design implements a more mature level of Physical Internet concepts, it has the current following main disadvantages:

- It requires the implementation of π-containers, and notably π-boxes, as a mean of transportation, handling and storage in the omnichannel business-to-consumer industry.
- Regarding capacity management, Physical Internet induced hyperconnectivity is essential to ensure the dynamic circulation of π-containers within the network of smart PI-locker banks, as well as more globally, at an inter-network level.
- It requires to face technology challenges in ensuring the security of goods while stored at a P/D point. The π-boxes must be securely snapped to the grid-wall, be sealed and strong enough to protect goods from damages and theft, and be convenient for handling and transportation (ergonomics, weight).

7 Conclusion

Combining Physical Internet inspired hyperconnected city logistics and hyperconnected omnichannel logistics perspective, this paper contributes to the development of last-mile delivery alternatives in the context of omnichannel supply chains by introducing and contrasting a set of hyperconnected pickup-and-delivery locker network design
sustainably achieving fast and convenient business-to-consumer pickups and deliveries.

The options range from current practice, such as fixed configuration locker banks, to those applicable in a mature implementation of the Physical Internet concepts. The modular tower option has already begun to be used in practice while modular lockers can be fully implemented in the short-term horizon. The last option requires several steps as it relies on the use of Physical Internet handling containers (π-boxes) as smart mobile modular lockers. The proposed designs can provide strategic visions on the evolution of dynamics of last-
environment. Overall, four concepts for hyperconnected pickup and delivery locker network designs are proposed, with advantages and disadvantages summarized in Table 1.

Table 1: Comparison of the proposed designs

Option	Main advantages	Main disadvantages
Fixed	• Implementation costs • Economies of scale	• Adaptation to demand variability
Modular Towers	• Adaptation to global demand variations	• Adaptation to delivery patterns variations • Spare modules inventory • Capacity management • Special distribution equipment
Modular Lockers	• Adaptation to global demand variations • Adaptation to delivery patterns variations	• Spare modules inventory • Capacity management • Special distribution equipment
π-Boxes as Mobile Modular Lockers	• Highly flexible configuration and capacity • High P/D efficiency	• Relies on emerging PI containers • Network wise capacity management • Technology challenges

Overall, the following challenges need to be addressed for widespread implementation of hyperconnected smart pickup-and-delivery locker bank networks for omnichannel business-to-consumer supply chains:

- Engineering design: Methods for designing hyperconnected pickup and delivery lockers, locker banks and networks should be defined and tested through analytical studies, optimization and/or simulation based assessments (e.g. Faugere & Montreuil, 2017).
- Efficiency: Demonstration should be made that the proposed designs are increasingly more efficient and are ever more able to fulfill consumers' expectations of faster, cheaper, convenient and reliable deliveries and returns, through analytical, optimization and/or simulation based assessments as well as pilot studies. This should be done at an individual smart locker bank level as well as at a network level.
- Operating policy: Study of the impact of different operating policies on the efficiency of each design should be done through analytical, optimization and/or simulation based assessments.
- Integration: The integration of such designs in a broader omnichannel business-to-consumer logistics and supply chain framework composed of different alternatives such as proposed by Montreuil (2017) should be explored.

The above challenges induce a set of research opportunities. Some of these are to focus on the design of one smart locker bank itself, with various level of Physical Internet concepts. When brought at a network level, there is also need for extending research on business models for the multi-operator use of hyperconnected pickup and delivery networks (e.g. Oktaei et al., 2014) as well as for predictive analytics for last-mile delivery patterns in the context of omnichannel business-to-consumer supply chains.

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