From a classical Cross dock to a PI cross dock: Latest Advances and New Challenges.

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Abstract
Physical Internet is a new concept based on the encapsulation of cargo via the adoption of standardized containers (called PI-containers), and the use of standard protocols for routing them between logistics actors. For the physical internet approach becomes a reality, the efficient management of cross-docking facilities (called in the following PI-hubs) is essential. Fast and flexible transfer of PI-containers from one carrier to another is the main activity of a PI-hub. The objective is to ensure the rapid and synchronized transfer of containers through the interconnected logistics networks. The paper focuses on differences between a classic cross dock and a PI-hub and then presents various transformations to a cross dock to become a PI-hub.

Key words: Physical internet; cross dock; PI-hub; PI-containers.
I. Introduction:

In today’s logistical environment where small orders and frequent deliveries are expected, cross docking offers an important advantage. It is a logistic activity that consolidates shipments from inbound trailers to outbound trailers in buildings known as cross docks. At each cross dock, each inbound trailer typically arrives from different origins, carrying shipments meant for different destinations. These shipments are then quickly unloaded from the inbound trailers, sorted, consolidated, and reloaded onto outbound trailers for different destinations. Typically, all shipment handling is completed within a day, with little or no holding of stock in the cross dock.

Cross docking offers a significant cost advantage. Instead of shipping small orders directly as less-than-truckload (LTL) shipments between origins and destinations, cross docking consolidates small orders into truck-load (TL) shipments. With cross docking, more frequent and economical deliveries are now viable as inbound and outbound trailers are now more fully loaded per trip. With frequent shipments, lesser inventory is also needed at the origins and destinations to avoid stock-outs. Many companies, such as Wal-Mart and Harp’s Food Stores, reported significant savings in transportation, inventory, and stock-out costs after implementing cross docking in their systems [1]. Kinnear [2] also reported similar improvement after implementing cross docking at Goodyear in Great Britain.
In fact, in comparison to traditional warehouses, a cross dock carries no or at least a considerably reduced amount of stock. Whenever an incoming truck arrives at the cross dock, it is assigned to a dock door, where inbound loads are unloaded and scanned to determine their intended destinations. Then, loads are moved across the dock and loaded onto outbound trucks for an immediate delivery elsewhere in the distribution system. This requires a synchronization of inbound and outbound loads, so that transportation times and temporary storage at the cross dock are kept as low as possible. In addition to that, cross docking allows a consolidation of differently sized shipments with the same destination to full truck loads, so that economies in transportation costs can be realized [2]. These advantages make cross docking an important logistics strategy receiving increased attention in today's globalized competition with its ever increasing volume of transported goods. Success stories on cross docking which resulted to considerable competitive advantages are reported for several industries with high proportions of distribution costs like retail chains (Wal Mart) mailing companies (UPS) and automobile producers like Toyota.

On the other hand, a new concept has just been updated in recent years; indeed the physical internet (PI, π) which was presented by Montreuil [3] as a response to the Global Logistics Sustainability Grand Challenge. It is defined as an open global logistics system...
founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. The PI enables an efficient and sustainable Logistics Web that is both adaptable and resilient. Several scientific issues are defined in Ballot et al. [4]; Montreuil et al.[5] and Sarraj et al.[6]:

• $\pi$-facilities design allowing a quick and flexible transfer of the $\pi$-containers ($\pi$-hubs)
• $\pi$-containers design and definition,
• Modular containers impact on shipped volume,
• Open network impact on the freight distribution,
• …

In this paper we are more interested in the study of $\pi$-hubs that came to replace the current cross docks. The study of PI-hubs began with (Montreuil et al [5] in 2010, the authors provide functional designs of a unimodal road-based cross docking hub designed specifically to exploit the characteristics of modular PI-containers so as to enable the efficient and sustainable transshipment of each of them from inbound trucks to outbound trucks. The objective of their work is to provide a feasible design to meet the objectives of this type of facility, identify ways to measure the performance of the design, and to identify research models that would assist in the design of such facilities.

As we previously mentioned. The main objective of this paper is to remind the different work to date in terms of PI-hubs, and then to compare with the current cross docking. The remainder of this paper is organized as follows: In Section 2, we give a historical overview of classical cross docking and formally define the most important cross docking problems. In Section 3, we consider the PI-hubs; we define this new notion and present a literature review, stages of pi-cross docking and various key performance indicators found in the literature. Finally, in Section 4, we offer our directions for future research within the area of Pi-hubs.

II. From classical cross docking:

Speed and productivity of a supply chain has become an important factor of growth for organizations. Cross-docking is just one strategy that can be implemented to help achieve a competitive advantage. Implemented appropriately and in the right conditions, it can provide
significant improvements in efficiency and handling times. In this section we will define this notion, then we describe the different operations in a cross dock and finally present different problems related to cross docking systems present in the literature.

What is cross docking?

A plant manufacturing consumer goods tends to produce in big batches, and thus sends full truckloads of one type of products. But a retailer hardly ever needs high volumes of a single product. A traditional way to cope with the problem is to make the products transit through a stock. The stock can be located in the manufacturer’s plant, near the retailer’s shop, or somewhere in between. The manufacturer can push all the production to storage while retailers pull only the needed quantity. This solution is quite flexible but has a major drawback: stock is expensive [7].

Cross-docking proposes an alternative solution: To transfer goods directly from the truck coming from the manufacturer to several outbound trucks going to different retailers. The outbound trucks are loaded with goods coming from different manufacturers (different inbound trucks). On the whole, the goods stay less than 24 hours in the platform, which accelerates the flow of goods and eliminates most of the storage costs – making it a lean approach as emphasized by Cook et al. [8]. For a formal definition of cross-docking, we refer to the definition proposed by the Council of Supply Chain Management Professionals in their glossary: “Cross-docking: distribution system in which merchandise received at the warehouse or distribution center is not put away, but instead is readied for shipment to retail stores. Cross-docking requires close synchronization of all inbound and outbound shipment movements. By eliminating the put-away, storage and selection operations, it can significantly reduce distribution costs”. Council of Supply Chain Management Professionals [9].

In short, the objective of this type of organization being to reduce stocks throughout the supply chain, functioning will be the following one:

- Reception of products from suppliers.
- Unload products on a central zone between the two quays (inbound and outbound docks)
- Order picking on the same zone [generally we try to optimize the loading to send complete pallets]
- Load trucks to deliver customers.
Cross docks can exist in different forms (Napolitano [10]). Bartholdi, Gue, and Kang [11] suggested two ways to classify cross docks. One way is to classify them as pre and post-distribution cross docks. In a pre-distribution cross dock (Figure 2), the destinations R1, R2 and R3 are predetermined and labeled on the shipments before they arrive at the cross dock. Workers can then transfer such shipments directly from inbound to outbound trailers bound for R1, R2 and R3. In a post-distribution cross dock (Figure 3), inbound freight arrives without a pre-determined destination, and workers at the cross dock assign the destinations to the shipments. This offers the advantages of postponing the final destinations, maintaining confidentiality of the final destinations, and delaying the performance of certain value-adding activities, such as price-tagging and re-packing, at the cross docks. A post-distribution cross dock thus normally requires more floor space to stage freight for these value-adding activities.
Figure 2: A PRE-DISTRIBUTION CROSS DOCK

Figure 3: A POST-DISTRIBUTION CROSS DOCK
A second way to classify cross docks is according to the method of staging freight. There are the single-stage, two-stage, and free-staging methods. In a single-stage cross dock, pallets are unloaded and placed into staging lanes corresponding to either the receiving or shipping doors. Inbound pallets are normally staged into lanes that correspond to the receiving doors when final destinations are still unknown on arrivals. However, if the arriving pallets are already pre-packed or can be re-sorted (easily at the receiving doors) for different destinations, the pallets are probably better staged into lanes that correspond to shipping doors. Staging pallets according to shipping doors offers the shipping crew a better visibility of the pallets waiting at each shipping door, and may facilitate a better utilization of trailer space during loading. For more details about this way of classification, the reader can consult the work of Yang et al. [12]

To illustrate how a cross-dock works, we decide to use an example of an I-shape cross dock with 12 doors studied by [12]. One side of the cross dock is for receiving, while the other is for shipping. As inbound vehicles arrive at the cross dock, each vehicle is assigned to an available receiving door. The vehicle is then unloaded; and its shipments are transferred and loaded, either directly or indirectly onto vehicles parked at shipping doors. Once an outbound trailer is fully loaded, it is hauled away and replaced with an empty vehicle.

Forklifts are typically used to unload, move and load pallets from inbound to outbound vehicles. One or more forklifts may be assigned to each receiving door at the same time. Figure bellow shows an example of a forklift (shown as a dark square) assigned to receiving door R1. This forklift will wait in a lane QR1 for access into R1. Assuming that the pallet retrieved is for shipping door S4, the forklift will then move the pallet along path p2 and turn into lane QS4. If the staging area and outbound trailer at S4 are occupied by another forklift delivering a pallet, the forklift will wait in lane QS4. If door S4 is clear, the forklift waiting in the lane QS4 will move along path p3 into S4. Once it has unloaded its pallet, the forklift will travel along path p4, turn back into lane QR1, and wait to retrieve another pallet at R1, its assigned receiving door.
According to the authors, discussions with operators of cross docks suggested that loading a pallet onto a trailer is twice difficult as unloading it from a trailer. The mean times for loading a pallet onto a trailer from its staging area and for unloading a pallet from a trailer to its staging area are then estimated to be 3.0 minutes for loading and 1.5 minutes for unloading. The tasks to pick up (or place) a pallet at a receiving (or shipping) staging area are much easier, and the mean time is estimated to be 0.5 minutes.

To summarize, a cross docking terminal is an intermediate node in a distribution network which is exclusively dedicated to the transshipment of truck loads. In contrast to traditional warehouses, a cross dock carries no or at least a considerably reduced amount of stock. Whenever an incoming truck arrives at the yard of a cross dock, it is assigned to a dock door, where inbound loads are unloaded and scanned to determine their intended destinations. The loads are then sorted, moved across the dock and loaded onto outbound trucks for an immediate delivery elsewhere in the distribution system.
Literature review:

Research work on cross docking has been mainly conducted on such areas as cross-docking system and layout design, network design, cross-docking operations planning and scheduling, truck to door assignment, sequencing and scheduling and truck scheduling.

Rohrer [13] discussed modeling methods and issues as they are applied to cross docking systems. Apt and Viswanathan [14] addressed a framework for understanding and designing cross-docking systems and discussed techniques that can improve the overall efficiencies of logistics and distribution networks. Napolitano [10] classified the various types of cross-docking operations. These include manufacturing, distribution, transportation, retail and opportunistic cross-docking. In general, cross-docks are complex, requiring a high degree of coordination between suppliers, customers and distributors to create shipments based on anticipated supplies and demands.

Donaldson et al. [15] studied a network of cross docks for the US Postal Service where 148 Area Distribution Centers serve as cross docks, each receiving, sorting, packing and dispatching mail according to operating schedules. Chen, Guo and Lim[16] studied cross-docking network scheduling where time windows for deliveries and pickups are considered. They also considered cross dock handling costs which are used to penalize delays.

Also there are quite amount of research work on cross-docking facility design. Bartholdi and Gue [17] determined the best shape for a cross dock by analyzing the assignment of receiving and shipping docks. Li et al. [18] considered short term scheduling of material handling inside the terminal for a given truck schedule. They model the jobs and resources as a machine scheduling problem and present a meta-heuristic for its solution. Yu and Egbelu [19] studied the scheduling issue of inbound and outbound trucks in cross-docking systems with temporary storage. They try to find the scheduling sequence for both inbound and outbound trucks to minimize total operation time when a storage buffer to hold items temporarily is located at the shipping stock.

An important number of papers deal with the truck-to-door assignment problem, this problem consists in allocating trucks to doors at a given point in time. Methods of solving these problems were different from one author to another, some papers have chosen exact methods as in [20], [21] and [17]. Other groups opted for
heuristics like [22] and[23]. For metaheuristics, we find evolutionary algorithms as in [24], genetic algorithms in [25], tabu search [26], a PSO [27] and a memetic algorithm in [28].

Finally, the cross docking has proven effective in reducing the transportation and storage costs; however, it remains inadequate to the current world requirements that thinks rather environment. In fact, we need another approach which can be introduced in the new system. In fact, the way physical objects are moved, stored, realized, supplied and used throughout the world is economically, environmentally and socially inefficient and unsustainable. Benoit Montreuil (Physical internet manifesto). From this idea, we can say that classical cross docks are not able to support the new logistics system, the next section will explain different aspects between classical cross docks and the PI cross docks.

III. The π-cross dock

The work of Montreuil [3], Ballot et al. [4] showed that the current logistics systems have reached their limits in economic, ecological (eg. Greenhouse gas emissions) and societal (eg. Truck drivers working conditions). To increase the sustainability of logistics systems, an innovative new paradigm was introduced: Physical Internet (Physical Internet or PI) [3]. It is a metaphor of the informational Internet: an information frame is then similar to a freight container, and a protocol associated with an information flow becomes a protocol associated with a physical flow of goods. The PI is based on the encapsulation of cargo through the adoption of standardized containers (called PI containers) and the use of standard protocols for routing containers between logistics actors.

To summarize, efficient management of cross-docking facilities (PI-hubs) is essential to achieve the goals of physical internet. The fast and flexible transfer of PI- containers from one carrier to another is the main activity of a PI-hub. Different types of modal shifts may be considered (eg, road-rail, road-road maritime rail ...) with the objective to ensure the rapid transfer and synchronized containers through the interconnected logistics networks. It has been shown in a study [29] that loading activities in the PI-hubs are the most essential activities that must be studied in depth.
1. Literature review:

In the very recent field of the Physical Internet, few studies have been conducted at the PI-hubs. In [30], [5], and [31], the authors have proposed different PI-hub architecture for road-road transfer type or rail-route transfer type. These studies were primarily intended to produce a functional design, validate the operation of a PI-hub and assess its performance (e.g., volume of PI-containers treated, transit time in the PI-hub). In each case, a simulation study was used to model and validate the normal operation of the PI-hub. However, any disturbance on the conveyor system or on the support resources of unloading / loading the PI-containers were taken into account in the simulation studies. In the following, we will try to detail the content of these papers.

Montreuil et al.[5] present a functional design of physical internet facilities: A Unimodal road-based crossdocking hub. This paper covers a unimodal road-based crossdocking hub designed specifically to exploit the characteristics of Physical Internet modular containers so as to enable the efficient and sustainable transhipment of each of them from its inbound truck to its outbound truck, the primary goal was not to produce the optimal functional design of a unimodal road-based crossdocking π-hub. Rather, their primary goal was to produce a functional design that performed at an acceptable level in terms of user key performance indicators (KPIs). The authors also reported KPIs that a facility operator is likely to consider. Second, in their work, the authors used simulation as a means to assess capacity requirements and evaluate their designs. Third is the design process itself, they introduced an iterative π-hub design.

Ballot et al [30] present a functional design of a road-rail hub. The purpose of a PI road-rail node is to enable the transfer of PI containers from their inbound to outbound destinations. Therefore, a road-rail π-hub provides a mechanism to transfer π-containers from a train to another one or a truck or from a truck to a train. The objective of the paper is to provide a functional design that performed at an acceptable level in terms of user key performance indicators (KPIs) and to explore its robustness with various flows. This design, only handling a subset of π-containers, already shows a possible improvement by an order of magnitude by sorting containers instead of railcars as marshaling yards do. To illustrate their subject, they proposed an instantiation of the design for a specific configuration. The proposed
design only provides approximate numbers and no optimization of needed resources. The authors precise that in this process, it will be particularly helpful to have discussions with companies able to supply the technologies embedded in the hub in order to further validate, and amend as necessary, the hypotheses made here, especially the handling times, conveyor speeds, sorting algorithms, just to mention the more important ones.

Meller et al. [31] also provide a functional design of physical internet facilities, this time a Road-Based Transit Center. The mission of a π-transit node is to enable the transfer of π-carriers from their inbound to outbound destinations. Therefore, a road based π-transit provides a mechanism to transfer π-trailers from one truck to another. The objective of their paper was to produce a functional design that performed at an acceptable level in terms of user key performance indicators (KPIs). They also reported KPIs that a facility operator is likely to consider. Then they have to establish what details are needed to provide when one provides a functional design going forward and used simulation as a means to evaluate their designs. Finally used a linear, sequential design process to allocate resources initially, and then used simulation of the total system in an attempt to fine-tune those resource allocations.

Moreover, at this stage of development of the Physical Internet, very little research has addressed the routing problems in PI-hub [30, 31]. A recent work [32,33] proposed a decentralized control approach to avoid blockages on a matrix of PI conveyers. However, these works are for small boxes occupying only one conveying module and do not take into account the different sizes of containers which may require more modules.

In [29], the authors studied the delivery of PI containers in a PI rail-road inspired by [30,4] This study aimed to determine the parameters that have significant impact on the effectiveness of PI-hub. The parameters studied were the size of PI-containers, number of trips in the system, number of conflicts between PI-containers and loading time in trucks. Interested readers can refer to [34] and [29] and [37] for a study on the specific problems of allocating and routing in a rail-road PI hub. The simulations presented in [29] showed that in the PI-hub, truck loading activity constitutes a bottleneck. In order to optimize the transfer of PI-containers, an interesting solution is to group several smaller PI-containers in front of the truck in question so
that they can take and load at once (rather than multiple times requiring a total larger load time). This is why, Yves Sallez et al.\cite{35} proposed a grouping method. This approach is described below:

The concept of "active" product \cite{36} is used to solve this loading problem. Decision-making and communication skills are associated with PI-containers allowing them to play an active role in constitution of each group of containers. The approach used for grouping is based on the Contract-Net communication protocol \cite{37}, which is particularly well suited to solve problems of interaction between decision-making entities, but with one major difference. Indeed, the initiator PI-container does not solicit other PI-containers for a service, as in Contract-Net, but rather offers them a service (group). The grouping approach which aims to load several PI-containers at one time in view of a fixed size is described in Figure 2 for the case of a group with size 3 (the initiator and 2 other PI containers):

1) Proposition: The first PI-container (the initiator) that arrives at its destination truck calls for PI-containers that could be grouped and loaded with it.

2) Answer: Concerned PI-Containers answer him stating their arrival time (time estimated to be in front of the truck to load).

3) Decision: The initiator chooses the PI-containers based on two parameters:
   - The group size limit (set by the strategy) that determines the maximum number of PI-containers in a group,
   - Arrival times sent by other PI-containers. The initiator container then chooses the PI-containers with an earliest arrival time to form a group without exceeding the size limit.

4) Dissemination of choice: initiator container sends selected PI-specific containers in their places in the group that will form on the right. It also sends a refusal to unsuccessful PI-containers.
The simulation results obtained showed the interest of grouping PI-containers. The group has reduced by 30% the time to evacuate PI-containers within the PI-hub. Grouping PI-containers was performed taking into account various parameters such as the number of PI-grouped containers, the waiting time as possible before loading group.

2. Essentials of the \( \pi \) cross-docking process:

As the exchange of \( \pi \)-containers from one carrier to another is the core activity of the \( \pi \)-hub, we hereafter explain step by step this important cross docking process. For this demonstration, we present the different stages of the PI cross docking proposed by Montreuil et al [39] that uses standardize size of \( \pi \)-containers that have all 2.4 meters large and height, but can have a length of 1.2, 2.4, 3.6, 4.8, 6.0 and 12.0 meters; they assume that driver-truck-trailer trios and driver truck pairs are to be maintained. For illustration purposes, they use three trucks that have different intended destinations. As shown in Figure 4, the cross docking process is divided in six sub processes.
Figure 8: The cross docking process and its key sub-processes (Montreuil[39])

Arrival
Tracks arrive at the hub, are checked and then dispatched to a dock

Unloading
n-containers to be transhipped are unloaded in the receiving zone of the hub

Reconfiguration
n-containers remaining on the trucks are slid to create group by to-be-unloaded destination

Departure
Ready trucks are checked then allowed departure from the hub

Loading
Composed n-containers are loaded on their dispatched truck

Preparation
n-containers in the hub are recomposed by next truck and unloading destination, then directed near their dispatched truck
1. Arrival process
Upon their arrival, the driver, truck/trailer, and its \( \pi \)-containers are registered, verified and scanned for security purposes. Then they will be directed either directly to a dock or first to a waiting buffer and then a dock when available.

2. Unloading process
Once the next destination of a truck/trailer has been established, then all its carried \( \pi \)-containers not aimed for this next destination must be offloaded. These are handled by the crossdocking facility so as to load them in time on their assigned carriers.

3. Reconfiguration process
The reconfiguration process aims to ease the overall crossdocking processes at the current \( \pi \)-hub and the next ones. It consists of sliding the \( \pi \)-containers remaining on the truck/trailer so that they are grouped by unloading destination that is the destination at which a \( \pi \)-container is planned to be unloaded from the truck/trailer, while letting sufficient space between groups to insert in the appropriate group the \( \pi \)-containers to be loaded next.

4. Preparation process
Once the \( \pi \)-containers have been unloaded from their inbound carriers, they are engaging in the preparation process that will get them composed appropriately with other \( \pi \)-containers and brought in time to be loaded in their next carrier towards their subsequent destination on their path to final destination, as conceptually depicted in Figure 7.

5. Loading process
The loading process is essentially a mirror image of the unloading process. The groups are (composite) \( \pi \)-containers are loaded in their appropriate space on the carrier. All loaded \( \pi \)-containers have the same next destination. Each group of loaded \( \pi \)-containers has the same unloading destination.

6. Departure process
The departure process is also a mirror image of the arrival process. Upon departure, the driver, truck/trailer, and its \( \pi \)-containers are registered, verified and scanned for routing integrity and security purposes. This notably makes that the right driver drivers the right truck pulling the right trailer strictly carrying the right \( \pi \)-containers in the right position (see Figure 8), and that none of the security seals have been violated.
It is clear that the classical cross docking is more complex than the Pi-cross docking. Indeed the use of PI-containers makes easier the unloading and loading tasks, which generates a minimized processing time.

3. From a classical cross dock to a PI-hub: What needs to change?

The existing cross docks were not originally designed for exploiting and enabling the physical Internet. Several points differentiate a cross dock adapted to the physical Internet (called π-cross dock) from a classic cross dock. The major difference comes from the basic principle of "openness"/ standardization of the Physical Internet. Indeed, classic cross docks are generally restricted to suppliers and / or customers of a specific company and its partners / suppliers. The π-cross docks are the ones to be used by an entire community of accredited users (π-certified) from different companies.

To move from classical cross dock to a π-hub, it must go through several stages:

- The Physical Internet operating a regular mesh π-cross docks, the number of sources and destinations at each π-cross dock is reduced [5]. So the number of cross dock have to increase to cover the physical internet networks.

- The classic cross docks treat a wide variety of volumes and freight packages (eg cartons, shrink-wrapped pallets, or loose bulky items) while the PI is based on the use of π-container volumes facilitating standardized continuous circulation of products flows, particularly within the π-cross docks and more generally in the whole physical Internet (at the level of a region or territory). The smart, modular, standard π-containers are arriving and departing on π-transporters that are designed to load, transport and unload efficiently with π-containers. We note that these containers can be loaded and unloaded from the top, back, left and right as best fit with minimal constraints on the order of loading and unloading; and also from the front when the trailer is unhooked from the truck. While it is customary to unload/load a trailer in a range from 15 minutes to a couple of hours in contemporary hubs, a π-trailer can normally be unloaded/ unloaded in a few minutes depending on the technology used. As a revealing illustration, it is quite conceivable to expect a full load of π-containers to be unloaded concurrently in the order of one minute if they are interlocked together, forming a single composite π-
container [38]. From all that proceeds, the new container must be
developed to meet all these requirements.

Contrary to conventional cargo (passive only), a π-container
have to be equipped with processing capabilities to a certain decision-
making autonomy.

In a classic cross dock, depending on the type of cargo,
handling is executed rather manually (eg using forklifts) or based on
a poorly automated transport system (eg, a conveyor-belt system) Van
Belle et al.[38]. In a π-cross dock, unloading, handling and loading of
π- containers must be based on the highly automated means. To this
end, the π-cross dock consists of a set of automated inbound and
outbound docks able to unload / load very quickly π- containers.
These docks are interconnected by a flexible conveyor.

Classical cross docks generally deal with a large number of
inbound sources and outbound destinations. Indeed, specific docks are
often assigned to each of these sources and destinations with local
source/destination docks in one zone of the hub and long-distance
docks in another zone. In a π-hub, there generally is a much smaller
pool of active sources and destinations.

Table 1 summarizes the differences between classical cross dock
and a PI-hub

<table>
<thead>
<tr>
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<th>Classical cross dock</th>
<th>PI-hub</th>
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<tbody>
<tr>
<td>Number of sources/Destinations</td>
<td>Important</td>
<td>Reduced</td>
</tr>
<tr>
<td>Packing</td>
<td>Pallets, cartons,….</td>
<td>Π-container</td>
</tr>
<tr>
<td>Decision making autonomy</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Handling, Transport system</td>
<td>Manual or poorly automated</td>
<td>Highly automated means</td>
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*Table1. A comparison between classical and PI cross docks*

Based on this comparison, we can say that the classical cross docks
are still far from sustainability requirements imposed by the physical
Internet, simulation studies have shown that new cross dock (pi-hubs)
will have very significant performance compared to classical cross
docks.
The design and engineering of classical cross docks are not centered on combined economical, environmental and societal efficiency and sustainability while for \( \pi \)-hubs this is an essential part of their fabrics: a fast, seamless, reliable, agile and resilient operation; a small environmental footprint in terms of greenhouse gas emissions, energy consumption, materials wastage, and pollution (air, noise, etc.); an appreciated haven for truck drivers, with minimal disturbance to its neighboring environment; a cheap cross docking cost and outstanding service for users.

4. **KPIs of Design**

In their work, Montreuil et al.[5] precise that two interesting sets of key performance indicators (KPIs). The first set of KPIs is from the perspective of “customers” of the \( \pi \)-hub and the second set is from the perspective of the operator of the \( \pi \)-hub. We summarized these KPIs below:

From the customer's point of view; the main KPIs can be grouped as follows:

- Average and maximum throughput time, average capacity utilization of departing carriers, average percentage departing in preferred direction and the average percentage expedited assignments

For the operator of the road-based \( \pi \)-hub, there is the typical trade-off between capacity and costs. The authors concentrate on KPIs related to the capacity of the \( \pi \)-hub: Area of \( \pi \)-hub site and facility, number of inbound and outbound gates, number of docks, number of inbound and outbound gate queuing places, number of parking bays in the buffer (trucks/trailers), number of \( \pi \)-containers that can be processed concurrently within the hub facility, average percentage of trucks/trailers declined entrance due to hub overflow.

To prove the effectiveness of their design, the authors were based on simulation to evaluate their KPIs; they report that studies and simulations have demonstrated that the PI-cross docking greatly improves economic, environmental and social sustainability.

In the following, we summarize how the conceptual design proposed by Montreuil et al.[5] of a road based cross docking \( \pi \)-hub contributes to economic, environmental and social sustainability. In fact, trailers are fuller and less empty miles between the end of one assignment and the beginning of the next assignment. They add that relay networks will emerge as the network topology, and with the volume of flow at a sufficient level, will permit the opportunity for
drivers to be assigned to loads that are traveling less than a half-day’s drive from their domicile location.

The authors reported that a simulation of a physical internet implementation in the food supply chain in France provides evidence that the sustainability improvement potential is huge [5]. In fact, from an economic point of view, the various scenarios tested performed better by up to 25% compared to the reference scenario of actual operations, mostly due to freight consolidation across unimodal road-based π-hubs and bimodal road-rail π-hubs. From an environmental point of view, results already show that a t.km reduction of 10% is possible; a gain from current 59% fill rate of carriers (expressed in weight) to between 70% and 75.5%, and a 58% reduction of CO2 emissions with adequate modal split between rail and road. The availability of efficient open π-hubs is a key to enabling this environmental gain.

From a social point of view, results highlight a 98% reduction of nights spent on the “road” by drivers; A reduction of distance traveled by trucks of 61%, by increasing the traveled reference distance realized on railroads, thanks to the size of trains; and a decrease of needed truck driver jobs by 40% a slight increase in train drivers jobs. This is achieved both by modal transfer from road to rail and by much more efficient road based operations, this was the the focus of their paper.

On the other hand, Ballot et al.[30] precise also in their paper that there are two sets of key performance indicators (KPIs) exactly like in [5]. From the Customer’s Perspective, the main six are: Processing Time of trains, number of trucks per hour, empty places on transportation means, average connections offered, maximum container’s transit time and the average percentage departing in preferred direction trucks.

From the Operator’s Perspective, there is the typical tradeoff between capacity and costs. So, for now, authors concentrate on KPIs related to the capacity of the road-rail π-hub: Area of road-rail π-hub, number of railcars processed in parallel per stop, number of π-containers processed in parallel per railcar, number of load and unload bridges for, number of rows to store and sort π-containers before loading to trains, number of rows to store and sort π-containers after unloading from trains, number of inbound and outbound gates,
number of Parking Bays in the buffer and the average Percentage Trucks/Trailers Declined Entrance (due to space issues in the π-hub).

Afterwards, authors had also to prove how their conceptual design of a road-rail π-hub contributes to economic, environmental and social sustainability. In fact, with simulation they reported that: From an economic point of view, the various scenarios tested performed better with improvement up to 25% compare to the reference scenario of actual operations. From an environmental point of view, several indicators were defined. Ton.km, modal split, fill rate and CO2 are the most important ones. The results show that -10% of t.km is possible. For the fill rate expressed in weight, the actual number is 59%, while the Physical Internet reaches between 70% and 75.5% with limited flows. But the most impressive result comes from the CO2 emissions with a cut down by 58%. According to the same study, they measured 98% reduction of nights spent on the “road”, a reduction of distance travelled by trucks of 61%, with 7% of the traveled reference distance now realized on railroads, thanks to the size of trains. In terms of truck driver jobs, it indicates a decrease from 1500 jobs needed to 600 and a creation of 75 train driver jobs. Finally, the networks themselves will lead to less congestion and to a higher quality of life for employees. The road-rail π-hub appears to be crucial enabler towards a more sustainable logistics.

From them, Meller et al [31] also studied KPIs in association with their design (two sets also). From the Customer’s perspective, the main four KPI’s are the average throughput time, average percentage departing in preferred direction, average percentage expedited assignments.

From the Operator’s Perspective the main KPI’s are: The area of transit center, number of inbound and outbound gates, number of switch bays, number of parking bays and average percentage trucks/trailers declined entrance.

The authors affirmed that shared, collaborative transportation networks consisting of well-run transit centers allow for, on average: Trailers are fuller. And the networks themselves will lead to a higher quality of life for drivers. Also they add that they are trying through their design process to impact the environmental and social sustainability of the logistics system. They finally reported the results of the simulations in term of all KPIs.
Finally, all authors agree on the fact that all these indicators have not yet reached an optimum level and there are still improvements to be made to improve the service level of these PI hubs. Sure, this cannot be achieved overnight, but a lot of research and work is still required.

**Conclusion**

The principal goal of our work was to present the progress of research in term of physical internet facilities especially PI-hubs that will replace the classical cross docks. First we tried to state some papers dealing with classical cross docking, then the differences between the classic cross-dock and PI hubs as well as the transformations necessary to achieve the objectives set by the physical internet.

We note that research at this level is still poor; few studies have focused on the study of PI hubs. Authors who dealt with it have proposed designs for these facilities and were based on simulation to prove the effectiveness of their designs, so they proposed and studied key performance indicators related to their designs.

To transform the current cross docking to a PI-cross docking that could show its effectiveness, on the economic, environmental and social plans, a lot of work remains important. However, the improvement of these centers remains insufficient. In fact, to reach a global optimization, we must act on the entire supply chain namely the routing problems. This is why, by combining the two notions (routing problems and cross docking system) we can ensure a higher service level.

As prospects, we will try to treat the development of containers routing models and is reflective work performed from Internet and requirements imposed on physical transit containers and not data packets.

Thus, it is necessary to outline the requirements that will have to support such a physical network in terms of routing. Then start from existing techniques in Internet and offer new algorithms for determining the route of the containers.
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