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A simulation model to migrate from cross docks to PI-hubs

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Abstract: *Global supply chain optimization to achieve better efficiency in respect of environmental constraints recently motivated several research works on the idea of the physical internet as a worldwide open logistics system intending to bring new models that make the current logistics systems more flexible and sustainable. The developed concept aims to profoundly change the way objects are handled, stored or moved, taking inspiration from the digital internet. Physical Internet reproduces many concepts from the digital Internet. The objective of this paper is to evaluate the contribution of physical internet on reducing logistics costs and improving the quality of service in cross docks. Given the significant difference between the digital and physical systems, such a study is necessary to evaluate the efficiency of investments linked to the implementation of physical internet. Two simulation models are proposed to compare performances of a classical cross dock and a PI-cross dock (PI-hub) under the same flow.*

Keywords: *Physical internet (PI), PI-hub, Cross-dock, PI-container, PI-conveyor, PI-dock, PI-sorter.*

1 Introduction

A new concept named Physical Internet (PI) was presented by Montreuil as a worldwide open logistics system intending to bring new models that make the current logistical systems more flexible and sustainable. In fact, speedy and productivity of a supply chain have become an important factor of growth for organizations. Physical Internet changes the way physical objects are handled, transported, stored, supplied and used, respecting criteria of efficiency and sustainability.

Montreuil, Meller and Ballot (2012) proposed modular and smart containers (PI-container) which are easy to handle, store and transport. Each one of those PI-containers has a unique worldwide identifier which improves the efficiency of handling and routing operations especially in cross-docks. Those PI-containers will be handled using PI-movers such as PI-trucks and PI-conveyors in order to obtain standardized logistics services and a universal logistics network which will be used by accredited users (PI-certified users) from different companies. This universal logistics network is interconnected using locations called PI-nodes which are designed to perform operations on PI-containers such as receiving, storing, assembling and disassembling.

The term ‘cross-docking’ explains the process of receiving goods through unloading docks and then transferring them to the outgoing docks. When products arrive through trucks/trailers, they are allocated to a receiving dock on the receiving side of the cross-dock. Once the products have been unloaded, they can be moved either directly to the outgoing docks or indirectly after passing through the temporary warehouse; they can be unloaded, sorted and scanned to identify their

destinations. After being sorted, products are moved to the other side of the cross-dock terminal via forklifts, conveyor belt, pallet truck or another mean of transportation to their destined loading dock. When the products are loaded, they can then make their way to customers via trucks.

Those existing cross-docks were not originally designed to support the physical internet. Thus, several points differentiate a classical cross-dock of a PI-hub which is a cross-dock adapted to the physical internet (Montreuil B, Meller, Thivierge and Montreuil Z, 2012). In fact, classical cross-docks are generally destined to suppliers and / or customers of a specific company and its suppliers, and handle a variety of volumes and packages (cartons, pallets …). The PI-cross-docks (or PI-hubs) are intended to be used by accredited users (PI-certified) from different companies around the world. They use standardized volumes of PI-containers facilitating the continuous flow of goods in the cross-dock. A PI-container can be made of smaller PI-containers. This encapsulation allows after decomposition to have a new container specifically adapted (weight, volume…) to a specific transportation to a particular destination. The PI-cross-dock consists of a set of automated docks which are interconnected by a flexible convoying system.

The objective of this paper is the simulation of the classical cross-dock and the PI-hub in order to compare their performances with KPIs (Key Performance Indicators) such as the total time spent by a container in the cross-dock (cycle time), the waiting time of outgoing trucks, and the occupation of the resources.

2 Classic cross dock simulation model

2.1 Model overview and parameters

This first model is for the simulation of a classical cross dock with an incoming flow of three different types of household appliances products (type 1, 2 and 3) coming from different suppliers. The model considers three incoming docks, three outgoing docks and a warehouse separated into three areas (one area for each type of product). The cross dock uses 9 forklifts for unloading, loading and storage. For initialization, 3 forklifts are assigned to the unloading docks, 3 for the loading docks and 3 forklifts are assigned to the warehouse. However, all the forklifts are dynamically assigned, they can be used by the docks and the warehouse, for example, if there is a dock not being used then the forklift of that dock can be assigned to another dock or to the warehouse. Each one of the three incoming docks handles one type of products (figures 1 and 2) and each one of the incoming trucks comes with one type of products. For example, an incoming truck carrying product type 1 (Red boxes in figure 1) will be unloaded in dock 1. The quantity of products carried by a truck is an integer value obtained with a uniform distribution with a minimum of 10 and a maximum equal to 20 (UNIF (10, 20)) (all times given in this paper are in minutes). In the outgoing docks, trucks arrive with orders for the three products, the requested quantity for each kind of product is an integer value which follows a triangular distribution with parameters 4, 5 and 6 pallets (min, mod, max), (TRIA (4, 5, 6)).

Trucks arrive at an incoming dock with a triangular inter-arrival time TRIA (25, 30, 35). The first incoming truck arrives at time 0, and the first outgoing truck arrives 5 min after. Products are unloaded in the reception area of the dock using the available forklifts. The average time to pick up or to put down a product is 0.33 minutes (20 seconds). Each one of the incoming docks has one reception area. In the other side of the cross dock facility, there are three outgoing docks. Trucks arrive with their orders related to one or several products. In order to respect the FIFO rule, forklifts pick up products from the warehouses first. But if the quantity in the warehouse is not sufficient, the requested quantity will be picked up directly from the reception areas, if there is a truck unloading

the requested product. The average speed used for the forklifts is 7 km/h. An overview of the cross-dock facility is presented in figures 1 and 2. All the parameters used in this simulation model are presented in table 1.

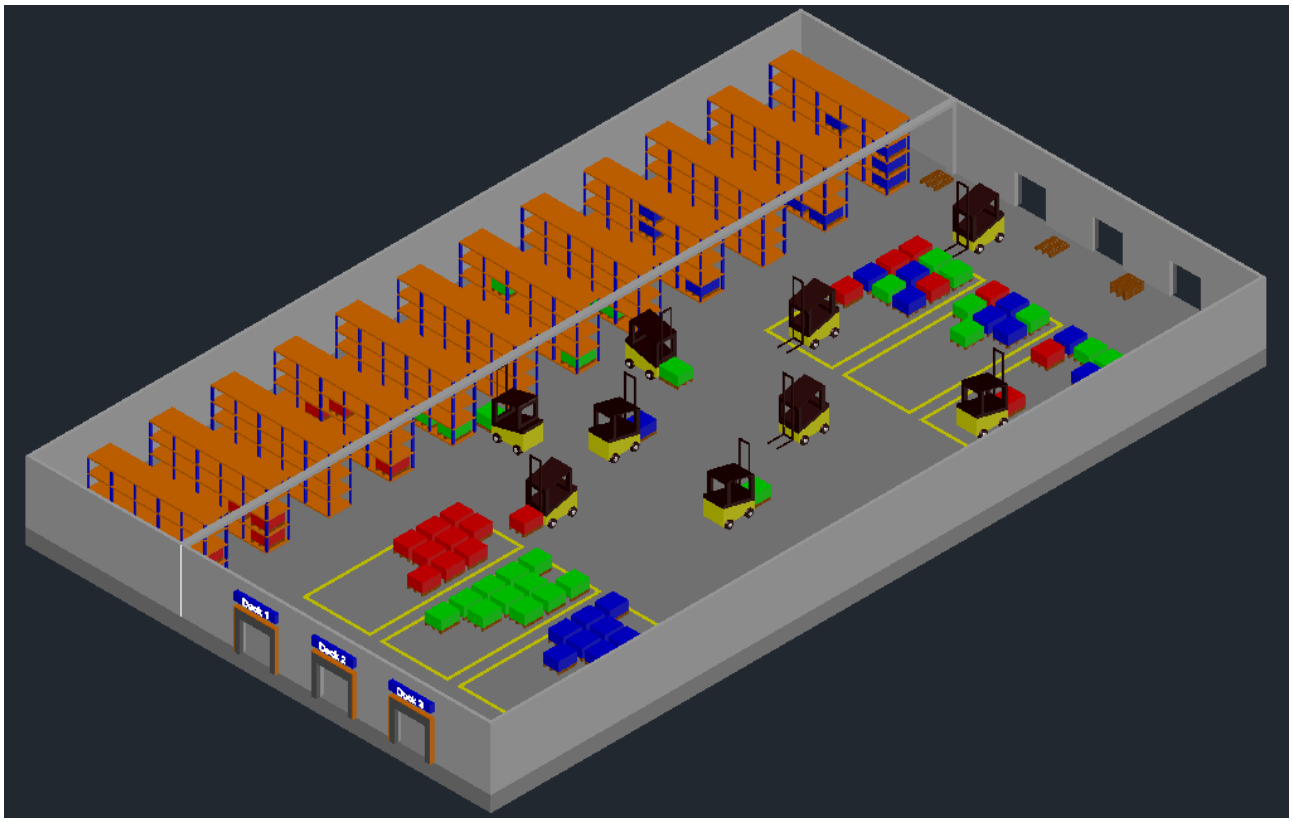

Figure 1: An overview of the cross-dock

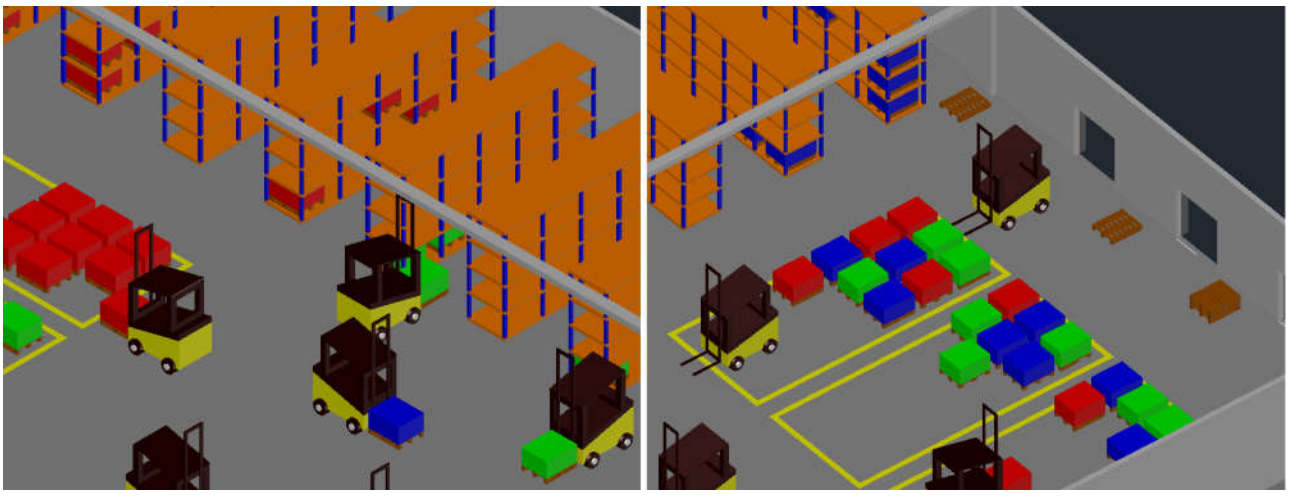

Figure 2: An overview of the cross-dock

Table 1: Parameters for the cross dock simulation model

Parameter		Value
Number of docks	Unloading docks	3
	Loading docks	3
Number of forklifts (assignments at the start of the simulation)	Unloading docks	3
	Loading docks	3
	Warehouse	3
Number of product types		3
Incoming trucks inter-arrival time (in minutes)		TRIA (25, 30, 35)
Outgoing trucks inter-arrival time (in minutes)		TRIA (25, 30, 35)
The quantity of products carried by an incoming truck		AINT* (UNIF (10, 20))
The quantity of products carried by an outgoing truck (integer value)	Type 1 (red)	AINT* (TRIA (4, 5, 6))
	Type 2 (green)	AINT* (TRIA (4, 5, 6))
	Type 3 (blue)	AINT* (TRIA (4, 5, 6))
The average loading and unloading time		20 seconds
The average speed used for the forklifts		7 km/h

*AINT: returns the integer value

2.2 Simulation results

The simulation model is developed using Arena Simulation software (version 13.50). An overview of the cross-dock facility is presented in figures 1 and 2 since the developed model is too large to be represented in this paper. The obtained results are shown in tables 2, 3, and 4, after running the simulation model for 24 hours.

Three KPIs are considered in this paper. First, it is very important to know the total time spent by a product in the cross dock facility, which is one of the most important KPIs. It represents the global performance of the cross dock including the waiting time, transportation time and storing / retrieving time at the warehouse. Second, the average and the maximum time spent by the trucks waiting at the docks for loading / unloading, which is related directly to the availability of the forklifts. Third, the resources usage, which includes the percentage of forklifts utilization and the incoming and outgoing docks usage.

Table 2 shows the average and maximum total time (cycle time) spent by a product in the cross dock facility. The cycle time of a product in the cross-dock is the sum of the time spent waiting at the reception area, being transported by the forklifts, waiting in the warehouse, and waiting to be loaded at the outgoing docks. The cycle time starts once the tuck arrives at the dock and ends when

the product leaves the cross-dock on an outgoing truck. As can be seen on table 2 the average cycle time varies between 93.86 and 131.05 minutes and reaches a maximum of 278.06 minutes (4h 37min) for the product 3.

Table 2: Cycle time of the three products in the cross dock (in minutes)

	Product 1	Product 2	Product 3
Average time	131.05	93.86	114.8
Maximum time	246.03	136.22	278.06

The waiting time (average and maximum) in the incoming and outgoing docks is presented in table 3. It represents the average and the maximum time spent by a truck waiting to be loaded or unloaded at the docks using the available forklifts, including warehouse's forklifts if they are not requested to store or retrieve a product in the warehouse. As shown in table 3, the average waiting time varies between 11.23 and 12.66 minutes at the unloading docks and varies between 12.51 and 21.58 minutes at loading docks.

Table 3: Waiting time in unloading and loading docks (in minutes)

	Unloading			Loading		
	Dock 1	Dock 2	Dock 3	Dock 4	Dock 5	Dock 6
Average time	12.66	11.23	12.36	12.51	18.51	21.58
Maximum time	25.68	20.33	23.39	21.90	29.99	69.78

The resources usage is presented in table 4. It shows the percentage of utilization of the unloading / loading docks and forklifts. As can be seen, forklifts are always used in the cross dock (almost 100% of the simulation time). For the unloading / loading docks, the average usage varies between 37.4% and 69.2%.

Table 4: Cross dock resources usage (%)

	Unloading			Loading			Forklifts (9)
	Dock 1	Dock 2	Dock 3	Dock 4	Dock 5	Dock 6	
Average	42.2 %	37.4 %	42 %	42.6 %	61.8 %	69.2 %	99.8 %

3 PI-hub simulation model

3.1 Model overview and parameters

This second model is for the simulation of the automated cross dock (PI-hub), keeping the same inter-arrival time between incoming and outgoing trucks TRIA (25, 30, 35) and the same level of incoming products UNIF (10, 20) and orders TRIA (4, 5, 6). The characteristics used in the cross dock facility are also the same as for the first model (the surface, the distances and the number of incoming and outgoing docks). However, instead of using forklifts, automated loading and unloading resources (PI-docks) connected to a sorting area (PI-sorters) using PI-conveyors are considered. The average speed used for the PI-conveyors is 2.77 m/s (10 km/h). In the PI-cross dock, manual forklifts for storing and retrieving products in the temporary warehouse are replaced by an automated storage and retrieval system (AS/RS) that is connected directly to the sorting area with three storage and retrieval machines, one machine for each kind of product. When a truck arrives to an incoming dock, the PI-dock unloads automatically the products which will be moved to the PI-sorters using PI-conveyors as shown in figures 3 and 4. Trucks' orders are served using the available products in the warehouse. The required products are picked up using the AS/RS system and then they come through the sorting area (PI-sorters) and to the PI-dock through PI-conveyors. However, if the requested quantity is not sufficient to serve the truck and if there is a truck being unloaded in an incoming PI-dock then the products arrive directly from that incoming PI-dock to the outgoing PI-dock where the product is requested. The parameters used in this simulation model are presented in table 5.

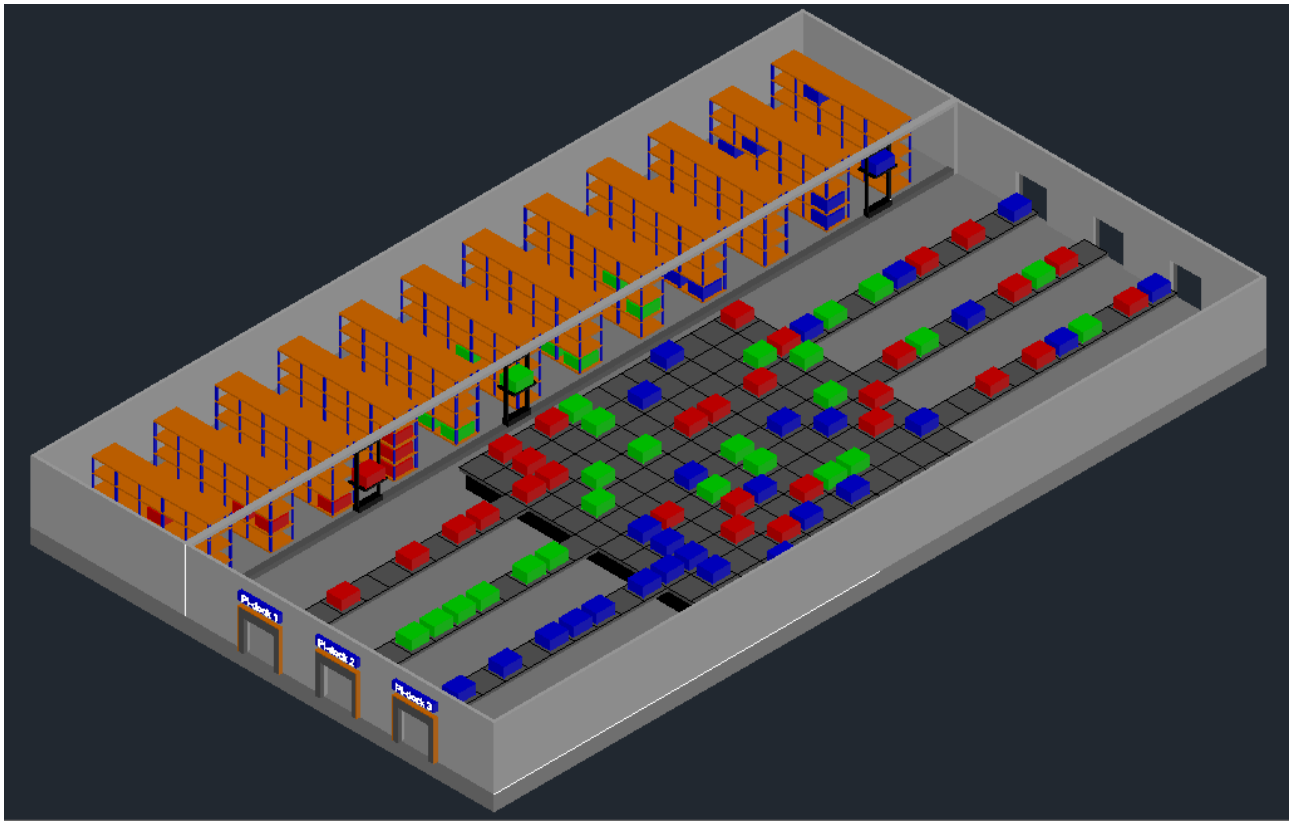

Figure 3: An overview of the PI-hub

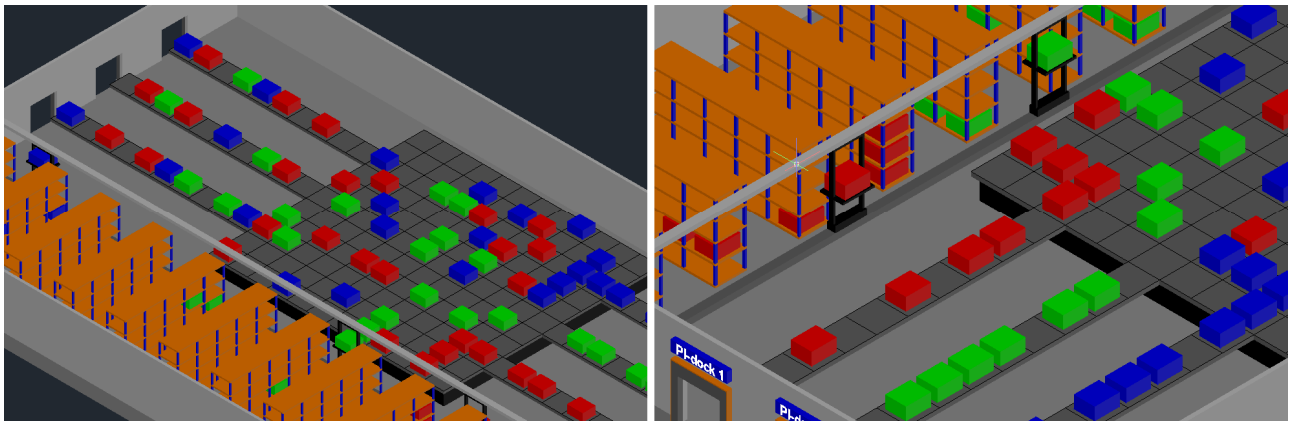

Figure 4: An overview of the PI-hub

Table 5: Parameters for the PI-hub simulation model

Parameter		Value
Number of PI-docks	Unloading PI-docks	3
	Loading PI-docks	3
Number of AS/RS machines		3
Number of product types		3
Incoming trucks inter-arrival time (in minutes)		TRIA (25, 30, 35)
Outgoing trucks inter-arrival time (in minutes)		TRIA (25, 30, 35)
The quantity of products carried by an incoming truck		AINT* (UNIF (10, 20))
The quantity of products carried by an outgoing truck (integer value)	Type 1 (red)	AINT* (TRIA (4, 5, 6))
	Type 2 (green)	AINT* (TRIA (4, 5, 6))
	Type 3 (blue)	AINT* (TRIA (4, 5, 6))
The average loading and unloading time		10 seconds
The average speed used for the PI-conveyors		10 km/h

*AINT: returns the integer value

3.2 Simulation results

The results are presented in tables 6, 7, and 8. The running time of the simulation is 24 hours. An overview of the PI-hub facility is presented in figures 3 and 4.

Table 6 shows the cycle time (average and maximum), spent by a product in the cross dock facility. As shown in table 6 the average cycle time varies between 67.15 and 85.08 minutes and reaches a maximum of 131.70 minutes (2h 12min).

Table 6: Cycle time of the three products in the PI-hub (in minutes)

	Product 1	Product 2	Product 3
Average time	85.08	78.04	67.15
Maximum time	131.70	120.70	67.15

The waiting time (average and maximum) in the incoming and outgoing PI-docks are presented in table 7. As can be seen, the average waiting time was greatly minimized; it varies between 0.63 and 0.64 minutes (about 38 seconds) at the unloading docks and it reaches 2.7 minutes at the loading docks with 25.15 minutes as a maximum waiting time.

Table 7: Waiting time in unloading and loading PI-docks (in minutes)

	Unloading			Loading		
	Dock 1	Dock 2	Dock 3	Dock 4	Dock 5	Dock 6
Average time	0.64	0.63	0.64	2.25	2.29	2.70
Maximum time	0.68	0.68	0.68	10.75	6.93	25.15

The PI-docks usage (average and maximum) is presented in table 8. PI-conveyors, PI-sorters and AS/RS machines usage are presented in table 9. As can be noted in table 8, the PI-docks average usage varies between 2% and 9%. It was greatly improved comparing to the docks in the first model and the facility is able to receive more trucks.

Table 8: PI-docks usage (%)

	Unloading			Loading		
	PI-dock 1	PI-dock 2	PI-dock 3	PI-dock 4	PI-dock 5	PI-dock 6
Average	2.1 %	2 %	2.1 %	7.7 %	7.6 %	9 %

Table 9: PI-conveyors, PI-sorters and AS/RS machines usage (%)

	AS/RS machines			PI-Conveyors (Average)	PI-Sorters (Average)
	Machine 1	Machine 2	Machine 3		
Average	20 %	19 %	20 %	0.73 %	0.2 %
Maximum	100 %	100 %	100 %	62 %	16 %

4 Comparing results

4.1 Cycle time

As shown in table 10, the average cycle time for the three products was reduced by 31%. As has been noted, the cycle time is the total time spent by a product in the cross dock. For instance, product 1 spent an average time of 131 minutes (2h 11min) in the cross dock, which was reduced to 85 minutes (1h 25min) in the PI-hub model. This means, that the waiting time in the unloading / loading docks and the retrieving / sorting time were reduced too. Moreover, this will affect also the waiting time of the trucks at the unloading / loading docks. As shown in the next section (4.2 Waiting time) the waiting time at the docks was reduced by 90%.

Table 10: Comparing average cycle time of the three products (in minutes)

	Product 1	Product 2	Product 3
Cross dock	131.05	93.86	114.88
PI-hub	85.08	78.04	67.15
Deviation %	-35.08 %	-16.85 %	-41.55 %
Average %		-31.16 %	

4.2 Waiting time

As shown in table 11, the average waiting time in the unloading and loading docks was reduced by 90%. The waiting time was reduced using the PI-docks which unload and load products automatically instead of using forklifts. The forklifts are used by all the docks. For example, if there is a truck being unloaded, all the available forklifts, including the forklifts used at the warehouse, will be assigned to that dock to unload the truck. If all the docks are being used at the same time, then each one of the forklifts will be assigned to one dock which increases the waiting time.

Table 11: Comparing the average waiting time in docks and PI-docks (in minutes)

	Unloading			Loading		
	Dock 1	Dock 2	Dock 3	Dock 4	Dock 5	Dock 6
Cross dock	12.66	11.23	12.36	12.51	18.51	21.58
PI-hub	0.64	0.63	0.64	2.25	2.29	2.7
Deviation %	-94.94 %	-94.39 %	-94.82 %	-82.01 %	-87.63 %	-87.49 %
Average %			-90.21 %			

4.3 Resources usage

As can be seen in table 12, docks usage was reduced by 90%. In the cross dock, forklifts are used to load and unload the trucks. First, the dock requests the closest available forklifts to unload the truck. When the forklifts are assigned, they pick up the products, transport them to the reception area and then go back to the truck and pick up the next product. So there are many steps to unload the truck, which increases the waiting time at the docks, therefore, the dock usage will be increased.

Table 12: Docks usage (%)

	Unloading			Loading		
	Dock 1	Dock 2	Dock 3	Dock 4	Dock 5	Dock 6
Cross dock	42.2 %	37.4 %	42 %	42.6 %	61.8 %	69.2 %
PI-hub	2.1 %	2 %	2.1 %	7.7 %	7.6 %	9 %
Deviation %	-95.02 %	-94.65 %	-95 %	-81.92 %	-87.7 %	-86.99 %
Average %	-90.22 %					

In the PI-hub, resources are not used all the time, as shown in tables 12 and 13. Each one of the 6 docks has one loading / unloading machine, which handles automatically the products, and they cannot be assigned to a different dock. Also, the cycle time affects the waiting time at loading docks, because trucks' orders are retrieved and transferred quickly to the loading docks using the AS/RS system, PI-sorters and the PI-conveyors. For this reason, the PI-docks usage was reduced.

Table 13: Comparing PI-conveyors, PI-sorters and AS/RS machines usage (%)

		Cross dock	PI-hub
AS/RS machines	Machine 1	-	2 %
	Machine 2	-	1.9 %
	Machine 3	-	2 %
6 PI-Conveyors (Average)		-	0.73 %
PI-Sorters (Average)		-	0.2 %
Total Average Usage of PI-Resources (AS/RS machines, PI-Conveyors and PI-Sorters)		-	11.98 %
9 Forklifts (Average)		99.8 %	-
Deviation %		-87.99 %	

5 Conclusion

To sum up, as has been noted, the average total time (cycle time) spent by the three products in the cross dock is reduced by 31%. The waiting time in the docks is reduced by 90% and the resources usage is reduced by 87%. Further research is ongoing on more complicated configurations related to the system of an industrial partner. Furthermore, complicated parameters will be implemented to those two basic simulation models such as forklifts acceleration, machines failure, workers schedule and shifts including lunch pauses, etc. Moreover, many assignment algorithms will be considered in the new models while assigning resources to the jobs, and products to their trucks. However, from those initial results; it is very clear that if the arrival and the departure of trucks are well synchronized, PI-cross docks can greatly improve actual quality of service and resources occupation. The implementation of the physical internet must be done softly since companies are often afraid of large investments and big changes. The automation of the cross-docks is a big step toward the physical internet, which benefits are demonstrated by the proposed models.

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