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# Inventory Control under Possible Delivery Perturbations in Physical Internet Supply Chain Network

Maroua Nouiri<sup>1</sup>, Abdelghani Bekrar<sup>1</sup> and Damien Trentesaux<sup>1</sup>

<sup>1</sup> LAMIH Laboratory, UMR CNRS 8201, University of Valenciennes and Hainaut Cambrésis, Le Mont Houy, 59313, UVHC, Valenciennes, France.

Corresponding author: maroua.nouiri@gmail.com

**Abstract:** Nowadays, the urgent need for sustainable development is imposing radical changes in how to design, produce and distribute the right product, in the right place, at the right time and at the right price. A new paradigm named "Physical internet" has been presented as worldwide open interconnected logistics system to make the current logistical systems more flexible and sustainable. This paper addresses the inventory management in the classical supply chain and the Physical Internet supply chain networks while considering possible perturbations during the delivery of goods between the hubs. We consider a supply chain network configuration from the literature. Two simulation models are proposed to test both the classical supply chain network and the Physical Internet supply chain under perturbations. Three scenarios are considered by varying delivery delays, retailers' demands and the number of trucks for the two simulation models. Several key performance indicators (KPIs) are considered, such as resources usage, transportation cost, storage cost and delivery delays.

**Keywords:** Physical Internet, Inventory Control, Delivery Perturbations, Replenishment, Simulation

## 1 Introduction

Logistics organizations are nowadays expected to be efficient, effective, and responsive while respecting other objectives such as sustainability and resilience. In fact, it should be able to deal with increasing demands for goods while satisfying challenging logistical constraints such as demand uncertainty, lead time, and resources availability. Sustainable development has become a crucial issue in recent years owing to the impact of global warming and carbon footprint awareness the sustainable supply chain management (SSCM).

Recently the "Physical Internet" was proposed by Montreuil, B. (2010) as a solution to the global logistics sustainability grand challenge of improving the economic, environmental and social efficiency. Inspired from the digital internet, the Physical Internet is defined as an open and shared network that interconnect independent logistics networks and services. The smart PI-containers, the PI-nodes and the PI-movers are the key types of Physical Internet elements. By analogy with data packets, the goods are encapsulated and shipped in smart PI-containers which are small modular container with standardized sizes. The PI-containers are moved via PI-movers like PI-trucks, PI-vehicle, PI-boats ...etc. Once the PI-container are transported, they are received, tested, moved, routed, sorted, handled, placed, stored and picked while using PI-nodes like PI-bridges, PI-Sorter, PI-Switch, PI-Hub...etc (Meller et al. 2012).

This work highlights the interest of the PI concept on resilience and sustainability in logistics management, when facing possible perturbations in delivery control model. We propose two Multi agents based simulation models to test both the classical supply chain network and the Physical Internet supply chain under possible delivery perturbations. The tests are performed on real case data of Fast Moving Consumer Goods companies (FMCG) from the work of Pan

et al. (2015). In order to compare the results of the simulation, the same input data and the same configuration are used in the two models. The same scenarios with different probabilities of delivery delays are considered for the two simulation models. Tests are performed also by varying delivery delays, retailers' demands and the number of trucks in the two simulation models. Several key performance indicators (KPIs) are considered, such as resources usage, transportation cost, storage cost and delivery delays.

The rest of the paper is organized as follows: the next section provides a literature review on Inventory Control algorithm in physical internet supply chain network. Section 3 contains the details of the classical and physical internet supply chain simulation models. The inventory control algorithm is detailed in section 4. Simulations scenarios and key performances indicators are reported in section 5. Section 6 provides the experimental results. Finally a conclusion and future work are given with in Section 7.

## 2 Literature review

First works have interested on standardized of PI-components and functional design facilities. Montreuil et al, (2012) provide the physical internet concepts and foundations. Similar to the Open Systems Interconnection (OSI) model for the Digital Internet, Montreuil et al. (2012) proposed an Open Logistics Interconnection (OLI) model for the Physical Internet. Physical Internet transportation network design was first tackled by Ballot, Gobet, and Montreuil (2012). Designing Physical Internet container sets has been addressed by Lin et al. (2014) and Gazzard and Montreuil (2015).

A set of facility types that would be necessary to operate a PI are proposed. Such facilities were termed PI-nodes. The complete set of PI-nodes included: transit nodes, switches, bridges, hubs, sorters, composers, stores and gateways (Ballot et al, 2013).

Other works have attempted to evaluate the performance of the physical internet on logistics from an economic, environmental and social point of view. These works are based on analytical optimization and/or simulation modeling based experiments. Many researchers focused on proposing methodologies and models for addressing the impact of Physical Internet on planning and operations decisions in logistic networks. In the literature, much attention is devoted to the collaborative transport planning optimization issue. Sarraj et al. (2014) introduced protocols for PI transportation. They model the asynchronous shipment and creation of containers within an interconnected network of services, and the best path routing for each container and minimize the use of transportation means

In the literature, much attention is devoted to study the PI-containers' internal routing problem in PI-hubs (road-rail, road-road...etc); for example: Pach et al. (2014), Walha et al. (2014) and Chargui et al. (2018). Other authors treated the external routing problem (PI-hubs interconnection); for instance: Kim and Montreuil (2017), Pan et al. (2015) and Yang et al (2015).

Due to its importance, the inventory control problem is well studied in the literature. Kim and Montreuil (2017) studied hyperconnected mixing centers; they proposed a simulation-based methodology to compare three configurations. In the first configuration, the manufacturers can serve the distribution centers of the retailers directly from the plants of the manufacturers. The second configuration uses dedicated mixing centers. In the third configuration, hyperconnected mixing centers are used to serve the distribution centers of the retailers. Their simulation result showed how hyperconnected mixing centers can improve the delivery rate and reduce inventory.

Yang et al (2015) studied the inventory management for fast moving goods in a network of hubs. They proposed a mathematical model for the problem and a simulated annealing heuristic. They compared and evaluated four source selection strategies.

In their work, Pan et al (2015) presented a simulation study for inventory control in the classical supply chain and the Physical Internet supply chain by keeping the same network and data while changing the network interconnectivity.

Many authors have considered perturbations when designing the physical internet supply chain. Yang et al (2017) proposed a multi-agent simulation model for the resilience of freight transportation in the Physical Internet while considering disruptions at the hubs. They proposed two dynamic transportation protocols to deal with various types of disruptions.

Our research fits in the scope of evaluating physical internet's performances by using two multi-agent based simulation models for both the classical and the Physical Internet supply chain. Three scenarios are performed on the two simulation models by varying three parameters: the delivery delays, the retailers' demands and the number of trucks. The simulation models are detailed in the next section.

### 3 Two Multi-agent based simulation Models

#### 3.1 Classical supply chain model

In this simulation, a real case data of Fast Moving Consumer Goods companies (FMCG) from the work of Pan et al. (2015) is considered. Figure 1 illustrates the supply network used in this simulation studies modeled by Netlogo. It is an Agent-based Simulator. Netlogo has four types of agents: "turtles", mobile or static, which are decisional entities; "patches", static, which provide a grid representation of the environment; "links", which are agents that connect two turtles; and "the observer" who is in charge of giving instructions to the other agents. In this study, the supply chain components were modeled with just turtles, breeds and links. Breeds are an agentset of turtles. The classical and physical internet supply chains are designed as network of nodes linked by NodeLinks. These later represent the routes between logistic centers. The class diagram of the supply chain network is presented in figure 2.

As we can see in figure 1, the logistic network is composed from a plant, a warehouse (WC), two distribution centers (DC1, DC2) and two retailers (R1, R2).



Figure 1: Classical supply chain network designed for simulation

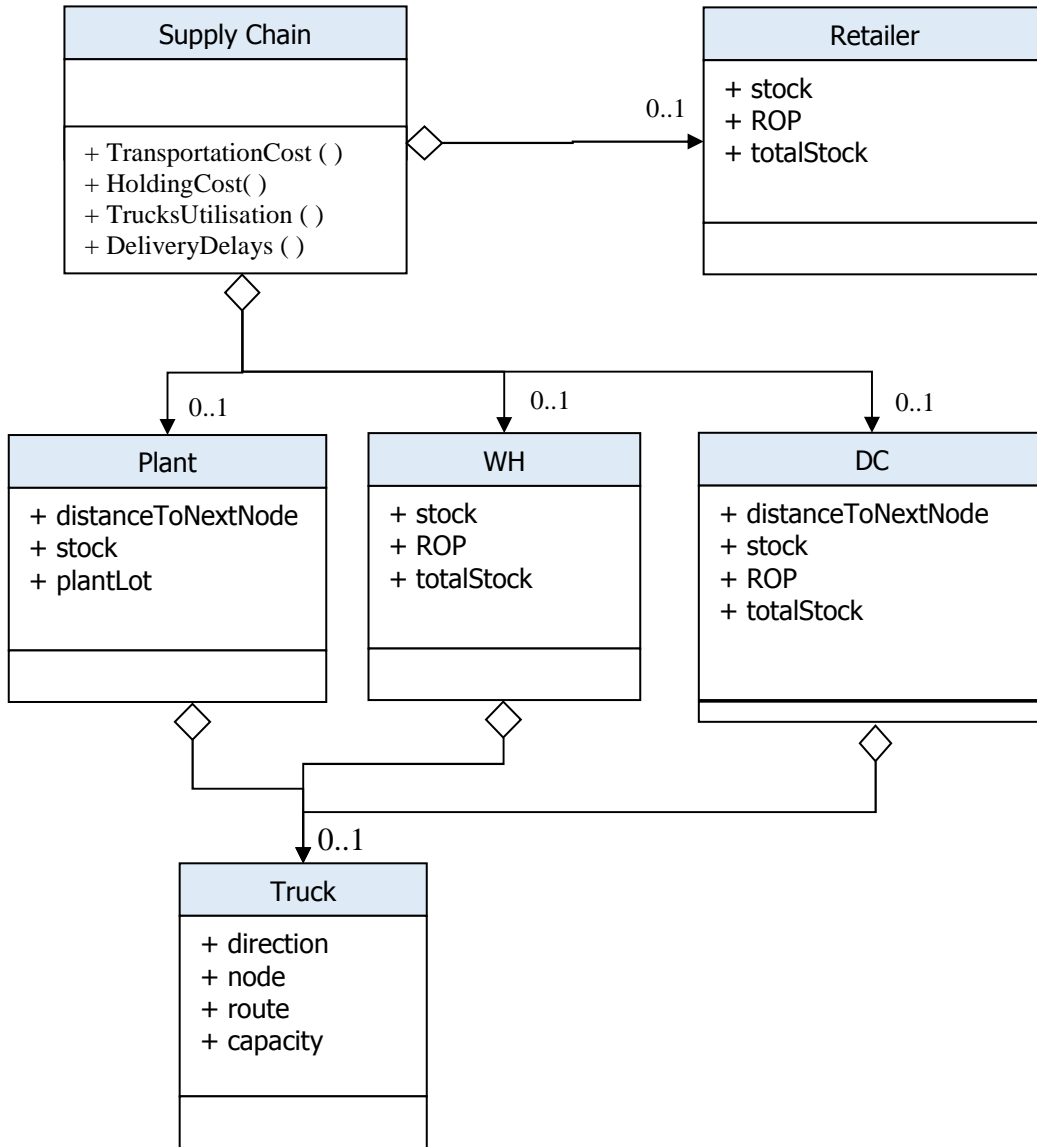


Figure 2: Class diagram of the classical supply chain network

Table 1 represents the fixed simulation parameters used in the classical supply chain network taken from Pan et al. (2015). It is composed of 4 columns. The 8 parameters are fixed in all classical supply chain simulation scenarios. The lead time represents the time needed to deliver the goods to the customers. The lot size represents the quantity of product units used in the procurement process. The reorder point (ROP) represents a level of inventory which triggers a procurement order to replenish that particular inventory stock. The distance between different node in the classical supply chain model are summarized in table 2.

In the proposed model, there are many other parameters like number of trucks, the capacity of trucks, the demand of retailers, etc. The value of those parameters is not fixed and changes from one scenario to another. This part is detailed in section 4.

Table 1: Parameters of experimental simulation of classical model

N°	Parameters	Unit	Value
1	Lead time DC to R	Days	7
2	Lead time WH to DC	Days	10
3	Lead time Plant to WH	Days	14
4	Lot Size Retailer 1	units	76
5	Lot Size Retailer 2	units	90
6	ROP Retailer 1	units	27
7	ROP Retailer 2	units	47
8	ROP WH	units	45
9	ROP DC 1	units	25
10	ROP DC 2	units	25
11	Production Lot to plant	units	1200
12	Lot size WH_DC	units	50
13	Lot size Plant-WH	units	100
14	Stock_init_R1	units	103
15	Stock_init_R2	units	137
16	Stock_init_WH	units	200
17	Stock_init_DC	units	50

Table 2: The distance between nodes in classical supply chain network

Node	Plant	WH	DC1	DC2	R1	R2
Plant	-	700km	-	-	-	-
WH	-	-	350 km	350km	-	-
DC1	-	-	-	-	100km	-
DC2	-	-	-	-	-	100km

### 3.2 Physical internet supply chain model

In the Physical Internet network, the warehouse and the two distribution centers are replaced by three open PI-Hubs with fully interconnected architecture (see figure 3). Thus, several new replenishment paths are possible. The only main difference between the two logistics networks is the interconnectivity of network. Table 3 resumes the distance of allowed paths between different nodes. The values marked in blue color in table 3 refer to the distances of new connections in the supply chain network after applying the physical internet paradigm. As we can see from fig.3, there are new connections between plant and different PI-hubs,

fully interconnected network between Pi-hubs and also new connections between hubs and different retailers in the system.

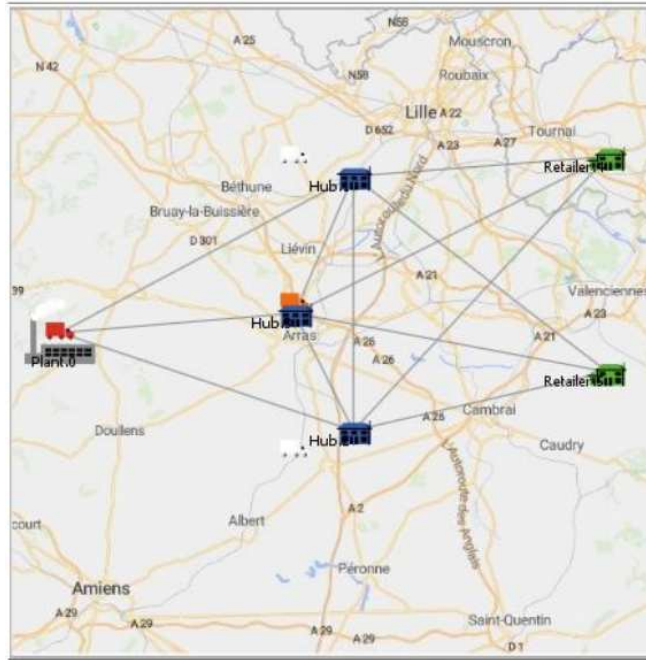


Figure 3: Physical Internet supply chain network designed for simulation

Table 3: The distance between nodes in physical internet supply chain network

Node	Plant	Hub3	Hub1	Hub2	R1	R2
Plant	-	700 km	979 km	979 km	-	-
Hub3	-	-	350 km	350 km	427 km	427 km
Hub1	-	-	-	495 km	100 km	505 km
Hub2	-	-	-	-	505 km	100 km

## 4 Inventory control algorithm

The inventory management is a part of supply chain management and is a key role in the performance of supply chains. This work studies the effect of perturbation, the holding cost variation, the transportation cost and the average of resources utilization in inventory control in classical and physical internet supply chain.

### 4.1 Inventory control model in classical supply chain

The figure 4 illustrates the flow chart of the inventory control algorithm in classical supply chain model. After receiving a demand from a lower level, every node compares its stock level with the reorder point (ROP). If the stock level is lower than the ROP, an order of replenishment is sent to the upper level. The right side of figure 5 represents the lower and upper level of the classical supply chain. As we can see, the upper level of the retailer is the distribution center, the warehouse is the upper level of DC, and the plant is the upper level of WC. Otherwise, if the stock level is greater than ROP, the node sends the order to the client and the stock level is updated. The available stock will be decreased by the ordered quantity.

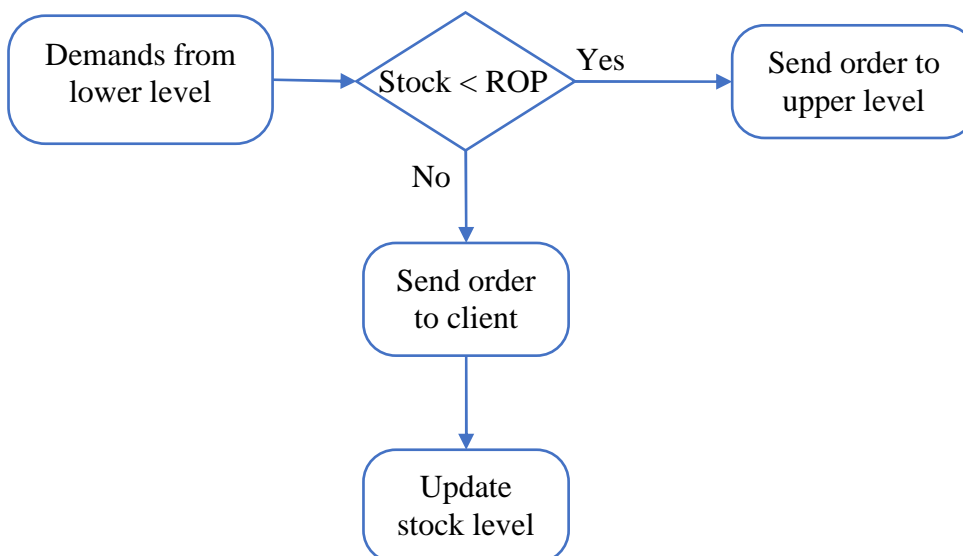


Figure 4: Flow chart of inventory control algorithm in classical supply chain

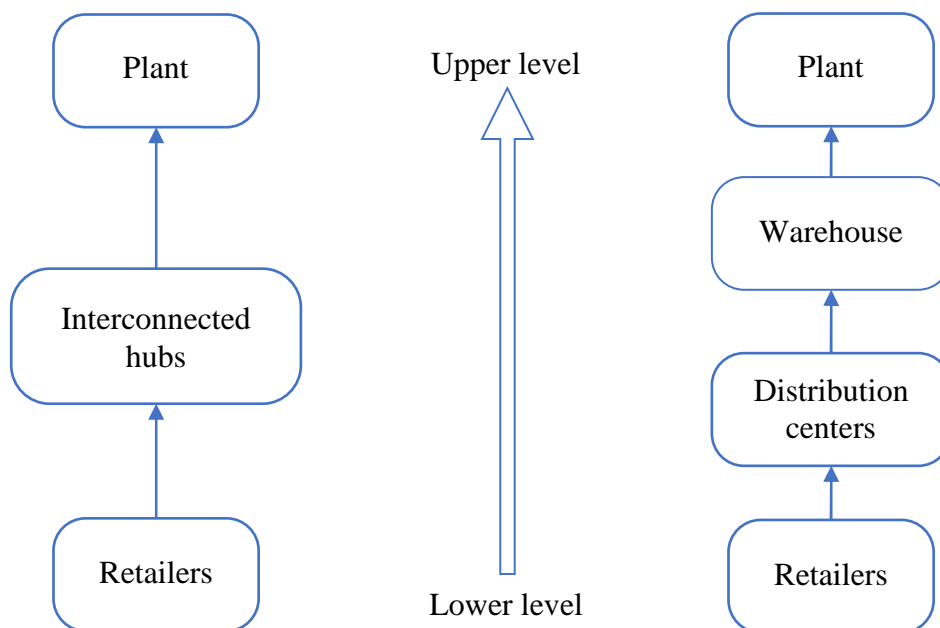


Figure 5: Lower and upper level from classical and PI supply chain

#### 4.2 Inventory control model in physical internet supply chain

The figure 6 illustrates the flow chart of the inventory control algorithm in physical internet supply chain model. The inventory model is the same used in the classical supply chain expect some modifications. If the stock level is lower than the reorder point, there isn't only one upper level. The left side of figure 5 shows that the upper level of retailers is interconnected hubs. The inventory model should select a replenishment source before sending the order.

In fact, physical internet enables more supply and replenishment options. So the upper level is not predefined like in the classical supply chain model. Thus a decision module is needed to be integrated in order to select a replenishment source from the candidates solutions. In this work, the upper level is selected according to its distance and its level of stock. The closest



one to the destination (in terms of km) with sufficient available inventory to fill the order is chosen. It means that we select the source that has the lowest distance and that has a sufficient inventory stock.

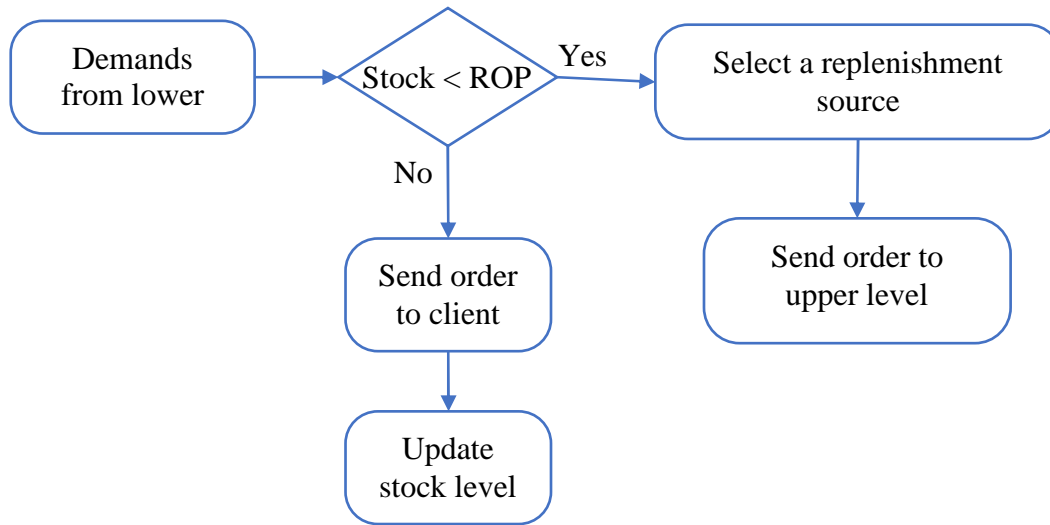


Figure 6: Flow chart of inventory control algorithm in physical Internet supply chain network

## 5 Simulations Scenarios and Key Performance Indicators

The two simulations models are developed using the multi agent environment Netlogo (Wilensky, 1999). This last was chosen for its openness, friendly implementation, its agent-oriented programming approach. This section gives the details of different scenarios and the KPI used in this simulation study.

### 5.1 Simulations Scenarios

#### 5.1.1 Scenario 1: Behavior with different retailers demands

A first scenario has been designed to represent different types of retailer's strategy. We consider three types of demands: daily purchase, periodically purchase or random purchase. Daily demand submits to normal distribution (mean values and standard deviation values) Periodic demand submits to uniform distribution. The last demand strategy is random value between 0 and 45.

Details of different strategy are defined and presented in Table 4.

Table 4: The different type of retailer's demand strategy

Type	Daily demand	Periodic demand	Random
Demand of R1	Mean = 20, S.D. = 4	UNIF(20,40)	Rand (0, 45)
Demand of R2	Mean = 35, S.D. = 7	UNIF(20,40)	Rand (0, 45)

#### 5.1.2 Scenario 2: Behavior with external perturbation

A second scenario has been designed to be representative of a major external perturbation: when an incident is happen in the route that related two nodes. For example, the failure in the route between DC1 and R1 or the route between WH and DC2, etc. In that way the delivery time is delayed. Thus the system should solve the routing problem reactively.

There are also internal perturbations that can happen in supply chain like perturbations inside PI-hub (failed conveying units, forklifts failures, automated storage and retrieval system (AS/RS), etc). This type of perturbation is not treated in this work.

Table 5: The different type of perturbation's level

Type	Low	Medium	High
route	UNIF(1, 2) days	UNIF(3, 5) days	UNIF(5, 8) days

### 5.1.3 Scenario 3: Behavior with different number of trucks

A third scenario has been designed to integrate the change in the number of trucks and the capacity of each one. We suppose that each node have the same number of trucks with the same capacity. Table 6 describes different combination of capacities and number of trucks. For example, the low Medium level (2, 30) means that each node have 2 trucks with 30 capacity intern of number of pallets except retailers.

Table 6: The different type of perturbation's level

Capacity of trucks \ Number of trucks	Low	Medium	High
Low	(2, 20)	(2, 30)	(2, 40)
Medium	(5, 20)	(5, 30)	(5, 40)
High	(10, 20)	(10, 30)	(10, 40)

## 5.2 The key performances indicators

This section discusses the key performance indicators used in the simulation models. Transportation cost, Holding Cost, resources utilization and the delivery delays are the functions considered in the simulation model to evaluate the performance of the replenishment policies.

- **The holding Cost:** the inventory cost used in the simulation model is taken from Pan et al 2015 and is calculated as follows:

$$HoldingCost = Volume * days * p \text{ (€/day m3)} \quad (1)$$

Where the product unit is measured in a full pallet (which is 1.73 m3), the variable *days* takes 1 value if stocks are present at a hub at day *i*, otherwise it takes 0. The variable *p* refers the cost per day which is equal to 0.11 Euro/ (day m3) if the goods are at the warehouse, distribution center and hub level. At the Retailer's the cost is equal to 0.165 Euro/ (day m3) because the holding inventory at shops is more expensive.

- **The transportation Cost:** For one truck used, the transportation cost function depends on the distance traveled by the truck and the cost per km. It is calculated as follows:

$$Transportaion Cost = distance * p \text{ (€/km)} \quad (2)$$

We suppose that there is full truckload transportation, which is usually the case in the FMCG supply chain. The variable  $p$  equals to 1.4 €/km taken from Pan et al (2015).

- **The trucks utilization:** In this model, we suppose that each node have its own fleet of trucks. All trucks have the same capacity. The rate of utilization trucks is calculated as follows:

$$Utilisation\ Rate = \frac{nbtrucks_{used}}{nbtrucks_{total}} * 100 \quad (3)$$

Where the number of trucks used is calculated as follows:

$$nbtrucks_{used} = \frac{ordered_{quantity}}{trucks_{capacity}} \quad (4)$$

We calculates also the average of utilization rate as follow

$$Average\ Utilization\ Rate = \frac{UR_{plant} + UR_{WH} + UR_{DC1} + UR_{DC2}}{4} \quad (5)$$

- **The average of delivery delays:** that represents the delays that occur during the delivery of goods. It calculated by number of days

$$Average_{deliverytime} = \frac{\sum (deliverytime - leadtime)}{Number_{days}} \quad (4)$$

Where the *deliverytime* is the real amount of time that goods take to arrive at their destinations. The *leadtime* is a predefined time needed to deliver the goods.

## 6 Experiments and simulation results

The simulation models are implemented in the multi-agent programmable modeling environment NetLogo. This tool was chosen for its functionalities allowing distributed control approaches to be modeled naturally. NetLogo contains the appropriate elements to model each decisional entity, its behavior(s) and its interactions with other decisional entities.

All the scenario tests are performed on a machine Intel(R) Core i7 CPU 1.80 GHz with 8GB of RAM. Each scenario is replicated 10 times and is evaluated according to the 4 KPI cited previously.

### 6.1 Scenario 1: varying number of trucks and capacities

This section resumes the results of testing the scenario number 1 while varying the number of trucks and their capacities. In this case, the retailer's strategy demand is daily. As we can, the physical internet supply chain improves the Holding cost, transportation cost and truck utilization. This is due to the new connections related between hubs. Another important conclusion is that the average of delivery delays is null. In fact, the physical internet paradigm allows new routes between logistics centers. Even if connection between R1 and Hub1 is interrupted, the R1 send its demand to the Hub 2 or Hub3.

Table 7: The result of scenario 1

Level	Holding Cost (euro)		Transportation Cost (euro)		Trucks Utilization (%)		Average Delivery Delays	
	CSC	PISC	CSC	PISC	CSC	PISC	CSC	PISC
(2, 20)	69.1	52.3	2212.23	2085.79	48.62	47.52	0.02	0
(2, 30)	69.89	57.21	1582.93	1264.87	31.14	32.7	0.04	0
(2, 40)	71.82	52.64	1224.53	1501.47	21.72	19.87	0.16	0
(5, 20)	66.11	53.98	2315.37	2715.82	20.35	20.3	0.13	0.01
(5, 30)	69.27	69.36	1628.2	1527.2	12.84	12.84	0.1	0
(5, 40)	69.24	66.98	1342.6	1342.6	9.5	10.24	0.05	0
(10, 20)	65.66	45.76	2398.9	2808.9	10.49	10.49	0.2	0.009
(10, 30)	75.14	74.34	1353.8	1214.8	5.32	4.79	0.26	0
(10, 40)	66.45	56.45	1452.73	1172.73	5.12	4.08	0.33	0

## 6.2 Scenario 2: varying retailer's strategy demand

This section resumes the results of testing 3 types of retailer's strategy demands. We evaluate the effect of this parameter on KPI values in classical and supply chain network. In this experiment, the (low, high) level in term of combination (truck, capacity) is used (20, 40) .

As we can, the physical internet supply chain improves the Holding cost, transportation cost and truck utilization even if we have different retailer's demands strategy. The average of delivery delays is null.

Table 7: The result of scenario 2

Level	Holding Cost		Transportation Cost		Trucks Utilization		Delivery Delays	
	CSC	PISC	CSC	PISC	CSC	PISC	CSC	PISC
Daily Demand	71.13	59.1	1288	1207.3	22.7	19.65	0.18	0
Periodic Demand	56.94	48.3	1878.33	1645.32	33.32	28.89	0.06	0
Random Demand	102.92	98.45	95.67	76.23	1.779	2.69	0.17	0

## 5 Conclusion

In this paper, two multi-agent simulation models were developed to test the performance of both the classical and the Physical Internet supply chain in term of transportation cost, holding cost, resources utilization and delivery delay. Different scenarios have been performed by varying the number of trucks and their capacities, the retailers' demand strategies and the level of perturbations. The results showed that the physical Internet supply chain is more efficient compared to classical supply chain. The Holding cost, the transportation cost, the average truck utilization and the average of delays are improved. Another interesting prospect concerns the simulation of the effect of physical internet on supply chain network composed from many plants and grouping centers while considering various types of products with different volumes. Next studies will be led on the integration of

external routing constraints for trucks between hubs while considering perturbations and time windows.

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