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Topology of Logistic Networks and the Potential of a Physical Internet

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WORKING PAPER

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Summary — The topology of the logistic networks that constitute contemporary logistics is minimally examined or challenged in the assessment and improvement of the performance of supply chains, logistic networks and freight transportation. We show in this paper that the topology of logistic networks has a major performance impact and that it can be significantly improved if the actual organization of flows is substituted by an organization founded on the universal interconnectivity of logistic networks: the Physical Internet. Given the exploratory nature of this work, the demonstration is achieved analytically by exploiting the continuous approximation method. The performance of contemporary vs. Physical Internet enabled network topologies is measured and contrasted through transportation throughput requirements, flow travel, and total costs.

Key words — Physical Internet, Logistics, Transportation, Supply Chain, Network Topology, Efficiency.

I. INTRODUCTION

Logistic and transportation performance improvement is an old topic that has gone through numerous developments: location of warehouses and distribution centers, consolidation, and so on. There is currently a surge of renewed interest in the topic as there is a growing awareness of its environmental consequences: logistics and transportation combine to be among the most important greenhouse gas emission sources in industrialized countries. The

search for more sustainable logistic systems involves numerous technical aspects, yet there is a void of visibility on systems capable of meeting the forthcoming energy and climatic requirements. The organization of logistics and transportation is another way for opening improvement perspectives, as shown in recent works on logistic pooling [2, 14] and multimodal transportation [4, 9, 11]. Yet these research works also highlight the implementation difficulties associated with such solutions. The improvements needed are not minor in any way. They require breakthrough approaches as the logistic and transportation flows keep growing while the targeted worldwide CO_2 emission reductions are on the order of 20% by 2020 and 75% by 2050 [15].

In this paper we present an alternative organization of logistics and transportation, the Physical Internet [7], and we emphasize the implied differences in terms of logistic network topology. Then we progressively study these differences on a flow model, a transportation model and a supply chain model before quantifying their impact in a simple geographical zone. Our demonstration provides a first analytical element of comparison between the performance of the actual organization of logistics and transportation and the performance attainable with a Physical Internet.

II. TOWARDS A NEW ORGANIZATION OF LOGISTICS: THE PHYSICAL INTERNET

A. The need for a new organization of logistics

Our modern economies have increased significantly their dependence on logistics while its development appears unsustainable through numerous symptoms [7]. Let us cite three examples from [7].

- An exponential growth of freight flow travel: an augmentation forecast on the order of 37% of tons-kilometers from 2005 to 2025.
- A major environmental cost: freight transportation is about to become one of the most important CO_2 emission sources in France (14%), having grown by an annual rate of +23% from 1990 to 2006 while the objective is a major reduction of 20% is targeted by 2020, and of 75% by 2050 as stated earlier;
- A congestion of infrastructures, notably in large urban centers where logistics suffers a drastic lack of integration.

In face of this situation, the technological progresses that are anticipated, for example on motorization, will be absorbed by the growth of logistic needs. However, there appears to be a potential way at the organization level. Indeed the logistic services as actually provided are concurrently badly inefficient. For example the global transport efficacy has been estimated to be lower than 10% [1]. Furthermore, logistic services regularly use the least performing transportation modes. For example, trucks are widely preferred to trains, while the CO_2 emission rates of trucks are twenty times higher than trains. Also, energy-hungry small trucks and pickups are often used instead of larger capacity trucks or lighter low-energy trucks while in town. This overall situation stems naturally from the framework within which are organized the logistic services, a framework which is likely becoming ever more inadequate.

B. The Physical Internet: exploiting the Internet metaphor for rethinking logistics

The proposed paradigm shift is based on the idea that logistics, which relies on closed service networks using heterogeneous means, should be rethought as a system in which, like in the Internet, networks can be seamlessly interconnected [12] through a common operating framework enabling the easy, efficient, robust, safe and secure travel and storage of goods though a variety of means, carriers and facilities across the world as well as within a city [13]. As in the digital Internet with the TCP/IP protocol, it should be possible to progressively integrate dedicated logistic networks into a universally interconnected system [3]. Within the Physical Internet (PI or π) framework, goods are unitized as contents of standard, smart, green containers of multiple modular dimensions. As digital Internet packets, the π-containers are routed according to their π-address from their origin to their destination using the most efficient combination of shared transport, storage and handling means. Through the development of protocols and π-container standards, the aim is to gradually replace a fragmented constraining organization by an open distributed organization. As such, maritime and multimodal container shipping can be seen as a premise, where various goods (food, frozen products, chemicals…) are in individual containers which share the same ship. Since in a Physical Internet goods will be encapsulated in containers, this will require extensions of the contract-and-insurance practices, such as Incoterm, that are in use in international trade. We make the assumption that the current organization used at "sea" could be deployed and extended for "land" logistics. A deployment towards a Physical Internet will inevitably lead to a deep reorganization of logistics and its means. It will also have a definite impact on the way our most common goods will be designed and distributed up to our doors.
As expressed through collaborative work during the Physical Internet NSF Workshop held at Georgia Tech (Atlanta, U.S.A.) in May 2010, the Physical Internet is the natural evolution and integration of container standardization and intelligence, broadband communication, cloud computing, and deregulation in transportation, catalyzed by new logistics business models. The goal is to achieve locally focused systems with global reach that are more economically-, environmentally-, and socially-sustainable than contemporary systems.

C. Comparing the topologies of current logistic networks and of the Physical Internet

The expectations toward a deployment of the Physical Internet correspond notably to a significant reduction of the resources necessary to realize the logistic operations and therefore of their negative effects on the environment through better operational efficacy, elimination of unnecessary journeys and use of more appropriate transportation means.
A consequence of this transition toward the Physical Internet that can be studied corresponds to the implied change of topology of the logistic service networks. This change will have an impact on the needs for transport, flow travel expressed in tons-kilometers (t.km), the use of the diverse transport and storage means, and more generally on the behavior and performance of supply chains.

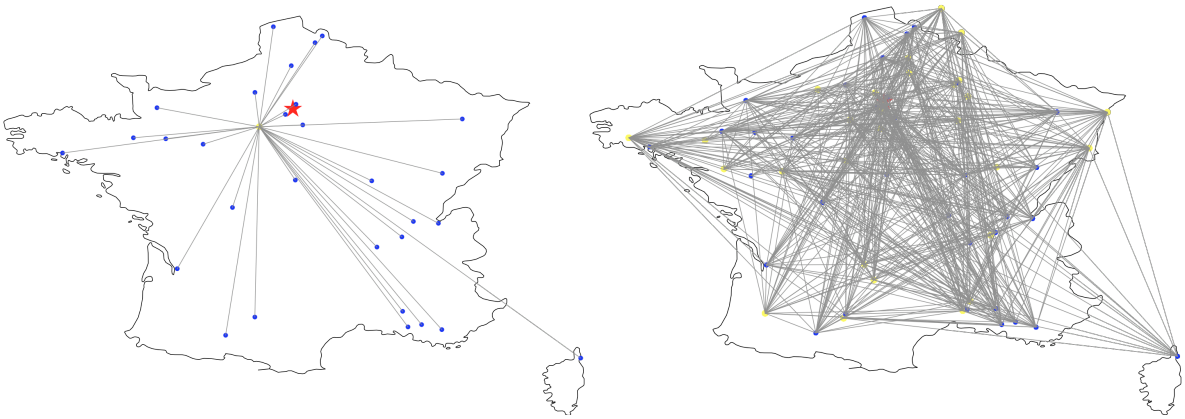

Fig. 1. Logistic organization of a specific supplier and superposition of flows in current supply chains

The left part of Figure 1 depicts the topology of the supply chain feeding regional distribution centers from an industrial warehouse. Its right part shows an example of superposing a few supply chains, forming a network of supply chains as defined by Hakimi et al. [10]. We will show hereafter that this actual superposition does not form an effective network of supply chains. If we consider that, as shown in Figure 2, supplies are achieved through an open supply web as proposed by the Physical Internet, we readily see that we can link the same logistic centers as in Figure 1 by a less complex network with flows easier to optimize. This new network topology has multiple consequences, in particular on the flow travel (t.km), on the volumetric and weight filling of transportation means, and on the storage of goods.

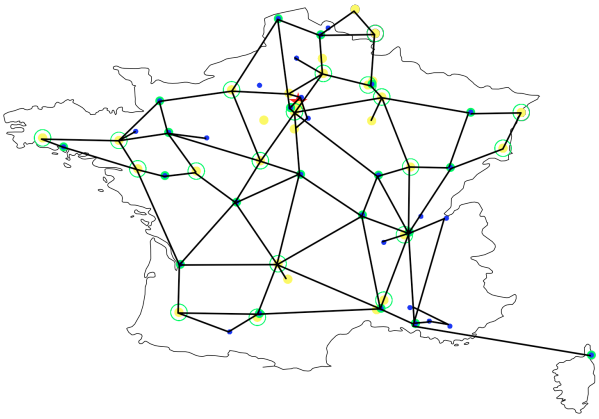

Fig. 2. Illustration of a network of hubs according to a Physical Internet perspective

III. A THREE-STEP LOGISTIC NETWORK TOPOLOGY EVALUATION

Our comparative evaluation of logistic organizational topologies is to be achieved in three steps. The first step measures and compares their flow travel (t.km). The second step switches to the engaged transport means. The third step focuses on supply chain performance in terms of storage requirements. This three-step construction insures both a progressive presentation of the model and the identification of the gains at each step.

A. Modeling

Given the exploratory nature of this work, the model selected for evaluating the logistic network topologies in based on the continuous approximation methodology [5, 6]. This approach, even though less precise than simulation or optimization, is privileged here because it allows an analytical formalization and therefore enables an understanding of the factors differentiating the studied topological organizations.
The classical supply chain modeled for our purposes is constituted of a set of retailers operating stores fed by their distribution centers, and a set of manufacturing suppliers feeding from their factories a central warehouse supplying the retailers' distribution centers, as shown in Figure 3. This chain could be extended downstream and upstream, yet it is already representative of supply chains for consumer goods, new vehicles, and so on.

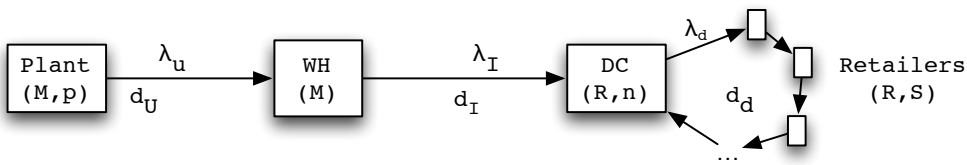

Fig. 3. Classical structure of a supply chain

We consider a territory of area A within which exists a total demand Λ over a planning horizon. We assume that this demand is homogeneously distributed across the territory. The territory is divided in n regions and hosts R distributors. Each distributor possesses S stores for covering the set of regions. These stores are positioned randomly in an homogeneous manner. They are supplied by regional distribution centers and each distributor owns one such regional distribution center per region. These distribution centers are themselves supplied from warehouses belonging to the suppliers. We consider that each supplier M has one warehouse fed by its P manufacturing plants. Each of these plants makes a different product and they are spread homogeneously across the territory. All suppliers have therefore the same number of plants and warehouses while all retailers have the same number of distribution centers and warehouses. We acknowledge that this is a strong hypothesis, imposed for simplifying notations and readability of equations, which could be relaxed without much difficulty.

B. Measuring the generated flow travel for each organization and computing a lower bound on flow travel

In order to evaluate the current logistic organization, we formalize flows for each segment of the supply chains. The first type of segment links a supplier's plant and its warehouse. The number of such segments is equal to the product of the number M of suppliers and their number P of plants, or M·P. We assume that the total production equals to the total demand and that the production of each supplier is spread uniformly across its factories. Thus, the production of a specific plant can be computed through equation (1).

$$\lambda_U = \frac{\Lambda}{M \cdot P} \tag{1}$$

The expected flow travel can thus be defined as $f_U = \lambda_U \cdot \mathrm{E}(d(P,WH)) = \lambda_U \cdot d_U$ where $\mathrm{E}(d(P,WH))$

is the expected Euclidean distance between a generic plant *P* and the generic warehouse *WH*. In the same manner, the expected flow travel between a warehouse and a distribution center is given by $f_l = \lambda_l \cdot \mathrm{E}(d(WH,DC)) = \lambda_l \cdot d_l$ with

$$\lambda_l = \frac{\Lambda}{M \cdot R \cdot n} \tag{2}$$

Indeed, flows are segmented by producer, retailer and region.
Finally the downstream flows are regional flows realized through tours from each distribution center of a retailer to the stores it supplies. The volume λ_d to distribute is equal to the total demand divided by the number of retailers and regions.

$$\lambda_d = \frac{\Lambda}{R \cdot n} \tag{3}$$

The distance to travel is estimated by the continuous approximation method [6]. The resulting estimation of the length of a tour deserving the *S/n* stores of a retailer in a region can be computed using equation (4) where *A/n* is the identical area of every region and *k'* is a constant (*k'*=0.75 for Euclidean distance).

$$d_d = k'\sqrt{\frac{S}{n} \cdot \frac{A}{n}} = \frac{k'}{n}\sqrt{S \cdot A} \quad \text{since} \quad n \geq 0 \tag{4}$$

Flow travel from distribution centers to stores is defined based on the flow measure convention used in France for the European Commission statistics [8]. With this convention flows supplied by delivery tours are counted as half the t.km, thus:

$$f_d = \frac{1}{2}\lambda_d \cdot d_d \tag{5}$$

Expected flow travel evaluation is performed using the same methodology, yet the flows have a different structure as shown in Figure 4.

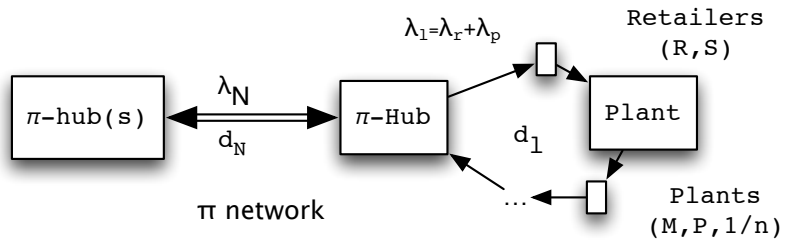

Fig. 4. Network structure of a supply chain in the Physical Internet, exploiting π-Hubs as defined in [10]

As shown in Figure 4, within the Physical Internet framework it is convenient to evaluate two segments: a pickup and delivery segment and an inter-hub segment. It is assumed that both distribution and collection are achieved through the same tours. Thus the first and last segments of Figure 3 become local loops in Figure 4. Indeed there is now one such loop per region. The local flow is constituted of the upstream flows from all plants in the region and of the downstream flows feeding all the stores of every retailer in the region. Expected local flow travel can be computed through equation (6) which is based on (4) and similar to (5).

Equation (6) exploits the fact that the increase in the density of points to be visited allows to subdivide the region, reducing the length of each tour while keeping the same service level. Otherwise all the products would just travel across the entire region without the benefit of the increase of the density.

$$f_l = \frac{1}{2}\left(\lambda_r + \lambda_p\right)\cdot k'\sqrt{\frac{S+\frac{MP}{n}}{n\left(R+\frac{MP}{n}\right)}\cdot\frac{A}{n}} = \frac{\Lambda}{n^2}\cdot k'\sqrt{\frac{\left(S+\frac{MP}{n}\right)\cdot A}{R+\frac{MP}{n}}} \quad \text{since} \quad \lambda_r = \lambda_p = \frac{\Lambda}{n} \tag{6}$$

In the same manner, flow travel in the inter-hub network within the Physical Internet is provided by $f_N = \mathrm{E}(\lambda_N \cdot d(N_{In}, N_{Out}))$ where N_{in} and N_{out} designate the entry π-hub and the exit π-hub. Accordingly, $d(N_{in}, N_{out})$ is the distance traveled between the entry π-hub and the exit π-hub The expression is specified in function of the topology of the studied network and each origin and destination π-hubs.

As a complement, it is also possible to determine a lower bound on the flow travel required to supply the overall demand from the plants to the retail stores. It corresponds to a direct flow of the required quantity from each plant to each store traveling the Euclidean distance separating the plants from the stores. This flow travel is provided by $f_{LB} = \mathrm{E}(d(P,S))\cdot \lambda(P,S)$. $\mathrm{E}(d(P,S))$ is defined as the expected distance between a generic plant P, with a non-substitutable product, and a generic store S. The flow $\lambda(P,S)$ between a plant and a specific store is provided by equation (7).

$$\lambda(P,S) = \frac{\Lambda}{M\cdot P\cdot R\cdot S} \tag{7}$$

These elements are applied in the case addressed hereafter.

C. Integrating the modeling of transportation and its effectiveness

Shifting from modeling flows to modeling transportation requires to deal with two factors. The first is the organization of transportation with fixed periods, full loads, and so on. The second is about defining the capacity of vehicles.

In order to represent a variety of cases and to approximate the current way of doing, we made the following hypotheses:

- The planning horizon is sliced in t which are to be used for supply when organized in a periodic way;
- The upstream transport between a plant and a warehouse, in the classical structure of the SC, is performed by full load trucks, fixing the expected time laps between departures;
- Transport between a warehouse and a distribution center is performed at steady rhythm every t period within the horizon, in the classical structure of the SC and between the π-hubs in the Physical Internet network;
- Transport between a distribution center and a store is performed through regional tours shortly spaced by a multiple of x where $x \geq 1$.

Under these four hypotheses, it is possible to express the requirements in terms of transport means having an individual capacity v, for each of the preceding flow travel settings considered here as *linehauls lh*.

$$N_v(lh) = \frac{\lambda(lh)}{v} \tag{8}$$

Let us start with the flows not dealt with using full loads, but rather on a periodic basis. For these flows, we consider that the transport means efficacy is growing with the ratio between the flow intensity and the transport means capacity over a given transport segment. In order to model this effect, we propose to use a function *g* expressing the transport efficiency relative to the ratio between transport size and flow. Formalized in equation (9), this function contains a parameter ß allowing to sweep through different situations, from a transportation really hard to optimize, corresponding to ß =1, to a quasi perfect transportation with ß=3.

$$g(\lambda,v,\beta) = 1 - \left(\frac{\lambda}{v} + \beta\right)^{-\beta} \tag{9}$$

Figure 5 illustrates the evolution of transportation efficacy under distinct values of β. When β is set to three, function *g* grows slightly from 0.96 to nearly one, always near perfect efficacy. When β is set lower values to climb toward better efficacy is slower and reach at best a lower efficacy, e.g. roughly 0.9 when β is set to one.

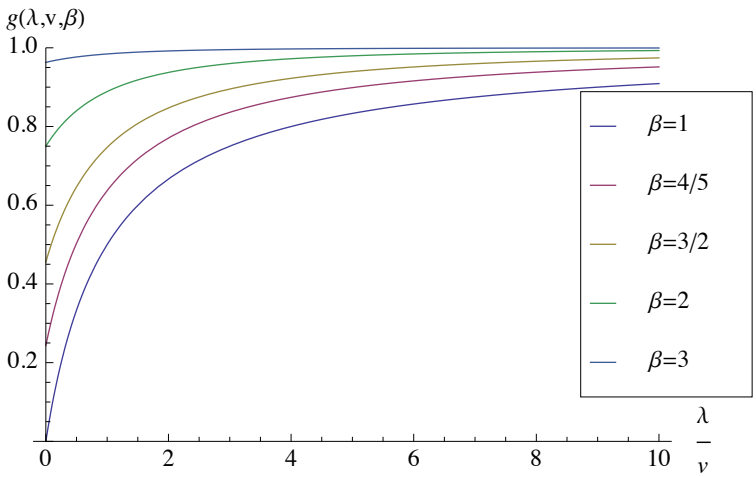

Fig. 5. Transport efficacy curve

For such types of flows, the expected transport means requirements *N'* generated by a flow λ are computed using equation (10).

$$N'_v(\lambda,t) = \frac{\lambda}{v \cdot t} \cdot \left(1 - \left(\frac{\lambda}{v \cdot t} + \beta\right)^{-\beta}\right) \tag{10}$$

The expected total distance travelled by the means along a segment and for a flow can be expressed through equation (11).

$$D(lh) = N_v(\lambda(lh)) \cdot d(lh) \quad \text{ou} \quad D'(lh,t) = N'_v(\lambda(lh),t) \cdot d(lh) \tag{11}$$

From these elements can be computed the expected total travelled distance for each case. The expected emissions of pollutants and greenhouse gas resulting from these transports could also be computed exploiting the methods described in [2].

D. Integrating a first modeling of the impact on supply chains

Within our framework, logistic costs are hereafter expressed through a transport cost c^t and an inventory cost c^i associated with the logistic activities. Excluded from our analysis are the safety stock cost associated with a product availability policy and the storage cost generated by production lot sizing as well as loading and unloading costs in all terminals. The expected total cost C is the sum of the transport and inventory costs.

$$C = c^t \sum_{lh} N_v\left(\lambda(lh)\right)\cdot d(lh) + \frac{c^i}{2}\sum_{hubs}\left(q_{IB} + q_{OB}\right) \tag{12}$$

The quantities q_{IB} et q_{OB} represent respectively the entry and exit stocks of a plant, a warehouse, a distribution center or a π-hub, as presented by Daganzo [14]. These stocks are function of the demand as well as either the supply period or the means size depending on the transport policy used. Expected loading and/or unloading operations at each point are here neglected, as they are in similar in the following application (+5% of transfer trough π-hubs versus traditional transfer trough warehouse and distribution centers).

IV. APPLICATION TO A GEOGRAPHICAL SPACE

In order to quantify the above model, we apply it to a geographical space composed of seven hexagonal regions. As shown in Figure 6, we assume a distribution center per region in the current logistics model and a π-hub per region in the Physical Internet logistics model, as well as a warehouse per supplier at the center of the geographical space in the current logistics model. These logistic nodes are not optimized in terms of quantity, only in terms of location. The left side of Figure 6, focused on the current logistics model, shows the coupling between a supplier's warehouse and a retailer's regional distribution centers: there are M times R instances of this schematic, corresponding to all supplier-retailer couplings. The right side of Figure 6, focused on the Physical Internet model, has a single instance, showing the couplings between the regional π-hubs. The distributed factories and stores are not depicted in Figure 6 even though they are present in both models.

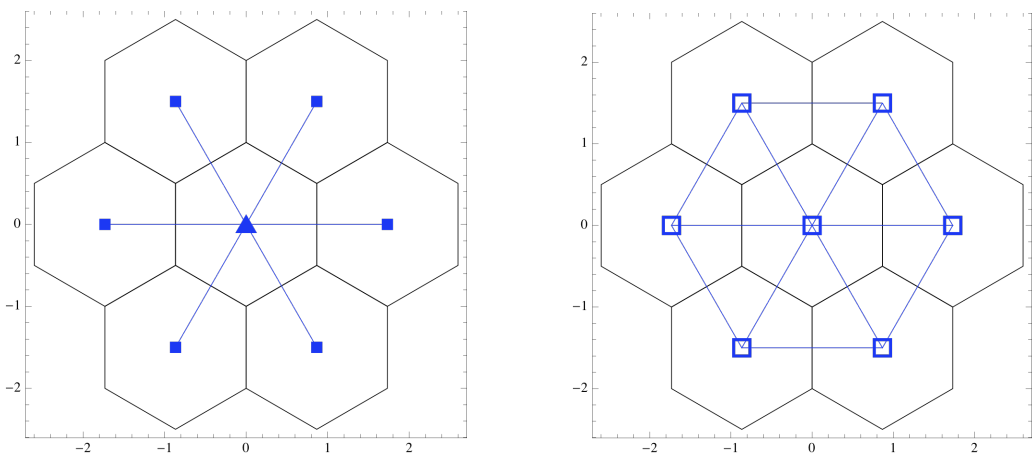

Fig. 6. Contrasting in the left side a supplier-retailer instance of the coupling between the supplier's warehouse and the retailer's distribution centers in the current logistics model and,

in the right side, the couplings between the regional π-hubs in the Physical Internet logistics model

We define α as the length of a regional hexagonal side. The area of a region is thus $\frac{3}{2}\sqrt{3}\cdot\alpha$ and the total area is $A=\frac{21}{2}\sqrt{3}\alpha$. We hereafter apply the modeling of section three to the geographical space.

A. *Computing expected flows and expected flow travel*

In order to our compute the expected flow travel, we need to compute the various expected inter-node distances in both models. First we focus for the current logistics model on the distance between a factory and the central warehouse for each supplier, the distance between a supplier's warehouse and the distribution centers of a retailer, and the tour distances in the regions.

In order to compute the expected distance between a supplier's factory and its central warehouse, we approximate the overall space by a disk of radius $\frac{3}{2}\sqrt{3}\cdot\alpha$, which corresponds at worst case to an error of 4% checked by Monte-Carlo simulation. The expected distance between a distributed factory and the central warehouse can thus be estimated to be 2/3 of the radius, so $E(d(P,WH))=\sqrt{3}\cdot\alpha$.

The expected distance between a supplier's central warehouse and a regional distribution center of a retailer requires to distinguish seven cases. There are six regions for which the distance can be estimated as shown above as $\sqrt{3}\cdot\alpha$ and there is the central region with an estimated zero, assuming approximate identical central location of both the warehouse and the distribution center in the region. Thus the expected distance between a regional distribution center and a warehouse can be estimated as $E(d(WH,DC))=\frac{6}{7}\sqrt{3}\cdot\alpha$.

The expected distribution tour length, with substitution of specific area data and store number, is:

$$E(d_d)=\frac{k'}{7}\sqrt{\alpha^2\cdot S\cdot\frac{21}{2}\sqrt{3}}$$

Summing all flow travel components allows to estimate the expected total flow travel in the current logistics model through equation (13).

$$F_{actual}=\sum_{Upper\ flows}\lambda_U d_U+\sum_{Inter\ flows}\lambda_I d_I+\sum_{Distrib\ flows}\lambda_d d_d=\Lambda\cdot\left(\alpha\sqrt{3}+\alpha\frac{6}{7}\sqrt{3}+\frac{1}{2}\cdot\frac{k'}{7}\sqrt{\alpha^2\cdot S\cdot\frac{21}{2}\sqrt{3}}\right) \quad (13)$$

In the Physical Internet logistics model, two expected distances and an expected flow must be estimated.

The expected regional pickup-and-delivery touring flow travel estimation equation (6) can be applied to each of the seven regions; leading to the following equation witch integrates expression of flows and area in this case:

$$F_l=\frac{\Lambda\cdot k'}{7}\sqrt{\frac{\left(S+\frac{MP}{7}\right)\cdot\frac{21}{2}\alpha^2\sqrt{3}}{R+\frac{MP}{7}}}$$

The expected inter-hub flows can be estimated by computing the expected flows shipped from each hub to the other hubs by assuming a shortest path travel. When there exists more than one shortest route then the flow is assumed to be spread equally among the possible paths. The right side of Figure 6 exhibits 12 undirected inter-hub links, corresponding to 24 directed links. The flows to be transported are $2\,\Lambda/n^2$ on the twelve exterior links and $3\,\Lambda/n^2$ on the twelve radial links.
The expected total inter-hub flow travel can thus be estimated as: $F_N = \frac{60\Lambda}{7^2}\alpha\sqrt{3}$

The expected overall flow travel for the Physical Internet model can thus be estimated through equation (14):

$$F_{PI} = \frac{\Lambda}{7}\cdot\left(\frac{60}{7}\alpha\sqrt{3} + k'\sqrt{\frac{\left(S+\frac{MP}{7}\right)\cdot\frac{21}{2}\alpha^2\sqrt{3}}{R+\frac{MP}{7}}}\right) \tag{14}$$

Given the complexity of the geographical space, the expected distance necessary for the computation of the lower bound on flow travel has been estimated using 1,000,000 Monte-Carlo simulation samplings, resulting in an expected $E(d(P,S)) = 2.17\alpha$. The lower bound on flow travel is thus estimated as $F_{LB} = 2.17\cdot\alpha\cdot\Lambda$.
Figure 7 illustrates the impact of the alternative logistic organizations on flow travel.

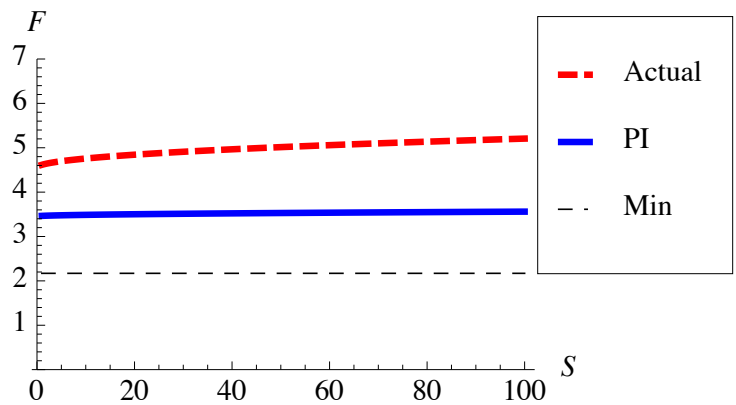

Fig. 7. Comparative performance of the current and Physical Internet logistic organizations and the lower bound flows *F*, as a function of the number of stores *S*, for R=10, M=100, α=1 and Λ=1

Figure 7 reveals clearly the dominance of the Physical Internet solution in this case with ten retailers and 100 suppliers. In general, for the proposed network topology, the Physical Internet solution is always significantly better the current solution as soon as there are some distinct clients.

B. Comparing transport efficiency and robustness

Beyond the flow travel comparison made above, our modeling reveals that the current logistic organization fragments flows and generates empty travel. This allows a multi-level assessment

of the transport gains obtained with a Physical Internet organization. First, as shown in Table 1, the Physical Internet allows a better usage of the transport means over each segment.

Table 1 Comparison of truck loading for ß=3/2, R=10, M=100, P=10, Λ/t=3000 and x=2.

Transport segment	To WH	To DC or to Hubs	To store	Repositioning
Actual organization	100%	65%	48%	0%
Physical Internet	NA	99%	99%	NA

When transportation is more difficult to optimize in the current organization, the gain in performance with the Physical Internet increases. Through equations 11, 13 and 14, we can compute the impact on transport integrating its efficiency. For example, Figure 8 shows the total distance travelled D (in km) is always less in the Physical Internet as compared to the current logistic organization. Furthermore it shows that the Physical Internet organization is less impacted by difficult transportation optimization as shown in the left part of the Figure.

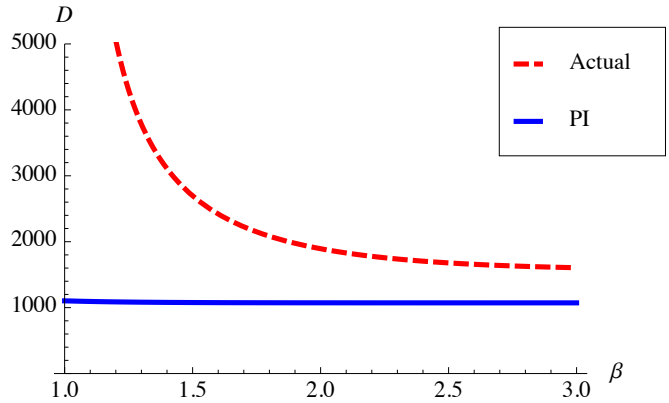

Fig. 8. Impact of transport optimization complexity parameter β on the total traveled distance D by transport means for v=33, t=10, x=5, Λ=10 000 and all other parameters as in Figure 7

C. Comparing the cost of the alternative logistic organizations

In order to complete the costing of the alternative organizations, the supply chain inventory costs are estimated for both organizations using equation (12) for each network node, taking in consideration whether they depend on delivery frequency or full vehicle loading.
The resulting expected overall cost ratio between the current logistics and a Physical Internet is depicted in Figure 9 as a function of transport optimization complexity parameter β and of the ratio γ of unit inventory vs transport costs c^i/c^t. Figure 9 shows clearly that the overall cost ratio is always lower than one, meaning that the Physical Internet is more performing than the current logistic organization whatever the transportation efficiency. It would be possible to exhibit even more favorable Physical Internet dominance by integrating other parameters such as safety stock requirements.

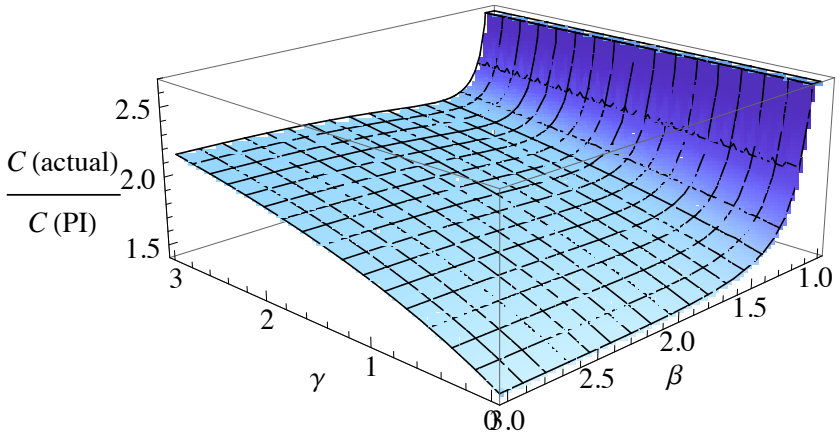

Fig. 9. Relative impact on supply chains cost according to previous parameters and g = ci/ct

V. Conclusion and perspectives

In this paper, we have shown through the examination of the original works on the Physical Internet that it offers an alternative to the current logistics organization and to logistics pooling. Through a fundamental analytical model, we have put in evidence three levels of evaluation and potential gains: flow travel, transportation and supply chain inventory in a distribution context. For each of these three levels, the Physical Internet organization has revealed to be a significantly dominating solution.

The uncovered potential of the Physical Internet makes it possible to attain the targeted worldwide division by four in logistics-generated CO_2 emission while still relying heavily on truck transportation means as currently done. If we switch to less polluting means, the improvements could be even more spectacular.

It is however important to place our work in its intended exploratory context. It thus includes a number of simplifying assumptions that translate into potential future research avenues. A first perspective consists of extending our work to more realistically configured geographical spaces and to real data so as to study the robustness of our early results and to highlight the stakes at national and international levels with import and export of goods. A second perspective is to enhance the model of the supply chain with safety stocks, products localizations, loading, unloading and transfer cost trough the WH, hubs, etc. to minimize the logistics costs and environment footprint. From a more ambitious perspective, in order to obtain more precision and realism in assessing the operation and potential performance of the Physical Internet, an international research project has been launched to simulate how it transforms and potentially improve mass retail distribution and supply flows in the France territory.

VI. References

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