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Towards An Interconnected Distribution Planning Framework

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Abstract: *The recently introduced Physical Internet (PI) opens the way to more efficient and sustainable logistics enabled by smart interconnected networks of open hubs, distribution centers (DCs) and fabs. This paper focuses on interconnected distribution planning exploiting the PI-empowered Open Distribution Web that allows any business to dynamically deploy its products across geo-markets, in numerous open DCs owned and operated by other businesses. Such a context requires rethinking how distribution is to be planned as current frameworks are too static and constrained. The paper introduces an interconnected distribution planning framework structured through four interlaced levels: network, distribution, deployment and delivery. Each level has its specific set of decisions to be optimized in a dynamic rolling horizon context. Exploiting an illustrative case, the paper provides insights on the concepts and methods at the core of the proposed framework.*

Keywords: *Interconnected Distribution, Physical Internet, Open Distribution Web, Distribution Planning Framework.*

1 Introduction

Physical distribution is about channeling the products of a business to its customers. The set of decisions and operations within distribution induces various costs, including mainly transportation and inventory holding costs that represent almost 77% of logistics operations costs (Burnson, 2012). This makes distribution one of the most potentially value adding areas of logistics operations.

The goal of distribution planning is known to be providing the right product/service at the right place at right time with right quality to satisfy customers while optimizing profits. However, many studies have reported that current distribution systems fail to achieve this ideal.

For instance, it is reported that 8.2% of shoppers fail to find on-shelf the product(s) they are looking for. Retailers suffer 3.1% net lost sales while huge inventory valued 1.1 trillion$ available (Frankle, 2006). A significant portion of consumer products that are made never reach the right market on time, ending up unsold and unused (Montreuil, 2011). In addition, almost one-third of kilometers traveled by freight transport vehicles are run empty (McKinnon, 2000) and the mean load factor of road transport is approximately 70% (Pan et al., 2010). These are clear indicators of the inefficient and unsustainable performance of current distribution and logistics, resulting in increasing economic logistics burden as well as increasing non-renewable energy consumption and greenhouse gas emissions.

In our opinion, several characteristics of the current distribution systems contribute to their present inefficient and unsustainable performance. These include inventory centralization, off-shore production centers, dedicated storage facilities and lack of standardization. To benefit from the economies of scale offered by full truck shipments, many companies centralize their storage in a few locations far from large parts of their geo-markets. Centralized distribution systems can be easily challenged by demand seasonality and instability. Moreover, they are not capable of competing with leading companies who offer same day or next-day delivery to the top metropolitan statistics areas. Also, the storage facilities dedicated to a company are mainly owned or leased using contracts with a three-year average commitment. The long-term commitment to these locations makes the adaptation of the distribution network to the changes in the demand and logistics cost very challenging.

From another perspective, many companies have off-shored their production to countries with low-wage labor markets, such as China, Vietnam, Mexico and India. In many cases the primary materials needed for feeding production are coming from the business's origin country or a third country. In addition, the largest markets of such companies are mainly located in the origin country. This imposes many unnecessary travels around the world.

Moreover, the lack of standardization in packaging and information system makes collaboration difficult. All together, these characteristics of present distribution systems force researchers to reach out for novel distribution systems, such as interconnected distribution.

The goal of this paper is twofold. First, it aims to introduce the concepts of Interconnected Distribution System and of an Open Distribution Web (ODW) enabled by the Physical Internet (Montreuil, 2011). Second, it aims to present the interconnected distribution planning framework developed to assist managers exploiting PI-enabled ODW.

The structure of the paper is as follows. Section 2 describes the interconnected distribution concept through a distribution systems categorization and an introduction to the Physical Internet and its enabled Open Distribution Web. Section 3 introduces the Interconnected Distribution Planning (IDP) framework. Finally section 4 synthesizes the paper's contributions and discusses future research avenues.

2 Introduction to Interconnected Distribution Systems

2.1 Distribution System categorization

Current distribution systems can be segregated as being either dedicated or collaborative. The former consists of a private distribution network in which the entire planning and operations are performed in order to add value to a single company. This contrasts with the collaborative distribution systems that are built upon the co-planning and/or cooperation of a set of partnering companies in shared distribution networks.

In a dedicated distribution system, at the strategic planning level, the location and mission of distribution centers are determined, as well as their capacity and technology, and the markets to be served by each DC are selected. The distribution facilities are either owned by the company or leased under contracts engaging the company for at least 2-3 years. Therefore, tactical and operational level decisions such as inventory management strategy and deployment are bounded by strategic plans that cannot be easily and frequently altered.

As a result of long-term commitment to the private DCs, the dedicated distribution systems are weak for facing changes in the business environment. Demand seasonality leaves their capacities and technologies unused for parts of the year. Moreover, to stay competitive, companies need to keep up with those offering same-day or next-day delivery to their top markets. For companies exploiting vast geographical area such as North America, this may mean running at least 15 DCs located in proximity to the metropolitan statistics areas. The ability of a company to reach such fine performance level is overshadowed by the risk of investing in so many facilities. However, the challenges businesses encounter by distribution decentralization is not limited to the investment ability. Transportation cost from plant(s) to many DCs scattered in a large geographical area, and from these DCs to the markets, is efficient only if order quantities are large enough to perform full-truck shipments. Otherwise, products having to be stored closer to the top markets result in frequent small-quantity shipments and over-inventory through the distribution network, which is not economically and environmentally efficient and sustainable.

To overcome the shortcomings of dedicated distribution systems, companies have been interested in collaborative distribution. The main idea of collaboration is about identifying and exploiting win-win situations among companies. Pooling is one of the most practiced logistics collaboration, especially among European countries (e.g. Cruijsse et al. 2007, Pan et al. 2010). It consists of pooling logistics services and facilities between several companies to optimize the use and operation of the logistics function or to access a service unavailable individually. In general a collaborative distribution system allows actors to partially overcome the constraints of conventional systems by means of developing synergies with partners. The partnering companies can invest in new DCs jointly or share their current facilities to reduce their strategic costs. At tactical and operational levels, they can collaborate on transportation or hire a logistics service provider to transport and deliver their consolidated products.

Compared to the dedicated distribution systems, more network structure adaptability and distribution and transportation operations efficiency are offered by collaboration. However, collaboration is inherently challenged by some difficulties rising from areas such as partner selection, gain determination and sharing, negotiation and coordination, and finally information and communication technology capabilities (Cruijsse et al. 2007). Moreover, the performance gain by exploiting collaborative distribution systems in terms of shorter delivery delays and access to a larger number of facilities is still limited to the number of partnering companies and facilities being shared in the group.

Figure 1 shows a sample collaborative distribution web formed by five partnering dedicated distribution networks.

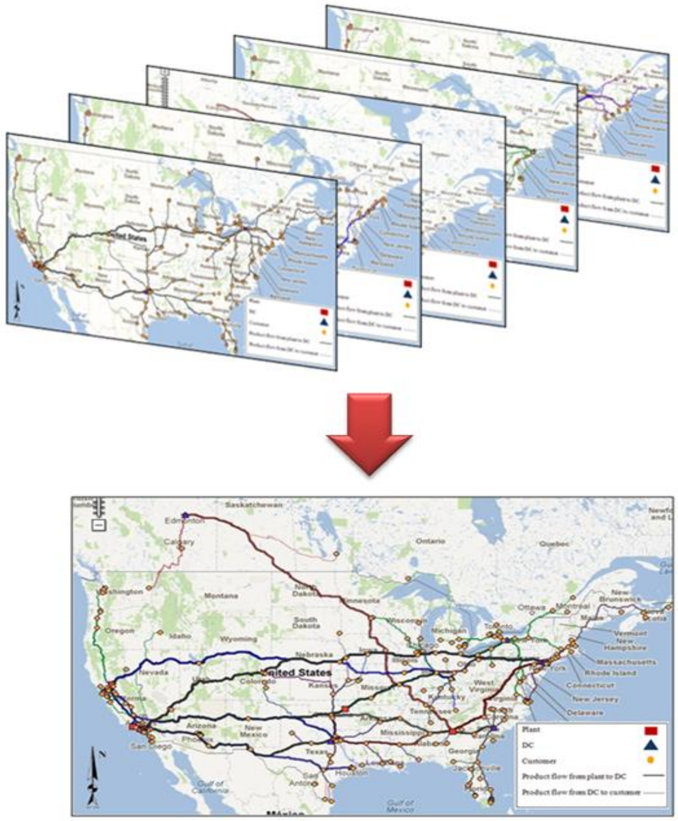


Figure 1. Contrasting a dedicated distribution web composed of 5 private distribution networks and a collaborative distribution web shaped by the same 5 companies (Sohrabi et al. 2012)

Concluding from our arguments above, we would like to point out to highly desirable characteristics for a distribution system. First, it should have cheap and flexible access (notably in terms of contract length restrictions) to DCs and warehouses adjacent to populated geographical areas. Knowing that only in United States over 500 thousands DCs and warehouses (Montreuil, 2011) and warehouses located almost anywhere in the country, the potential already exists. Imagine companies allowed to exploit the unused capacities in these facilities instead of investing in buildings or leasing new facilities. It would be challenging for DC owners to deal with a large and changing variety of product types, sizes and owners. Accordingly, distributing products stored in several locations owned by other companies might not seem secure and easily synchronized by user companies. Users should be aware of their products location and DC owners need to be able to easily and fairly access, handle and pick up the products of all companies exploiting their facility. Both parties certainly expect secure interconnection in terms of data and information privacy, also the financial transactions.

As previously discussed, a company decentralizing its distribution and targeting short and efficient delivery to its markets, surely needs a cheap, fast and reliable transportation system to operate deployment and delivery. Benefiting from economies of scale in transportation cost through consolidation, notably in full truck shipment, is a target for current distribution systems. Yet, ideally a distribution system should not have to incur delays and extra storage and transportation for reaching economic truckload shipping order quantities: it should be able to ship goods at the equivalent of case and pallet sizes nearly at the same price as full truckload prices.

The next section sheds light on the fundamentals of Physical Internet and more particularly, the open Distribution and Mobility Webs that it enables. PI offers a vision that can catalyze a fundamental rethinking of distribution systems. At the core, it aims to improve by an order of magnitude the worldwide efficiency and sustainability of logistics systems, by reshaping the way physical entities are being moved, handled, stored, realized, supplied and used all around the world. Due to the diversity of the concepts tackled in Physical Internet initiative and the focus of this research on distribution, the reader is invited to consult (Montreuil, 2011 and 2013, Montreuil et al. 2013) for a comprehensive overview of Physical Internet fundamentals.

2.2 Introduction to Physical Internet and Interconnected Distribution Web

From the highlights of the previous section, it stems that there would be highly significant gains from having a distribution system interconnecting the current dedicated and/or collaborative distribution systems. Interconnectivity refers to the quality of a system to have its components seamlessly interconnected (Montreuil et al., 2013). From a logistics perspective, it means easing the movement of physical entities from one component to another, their storage or treatment within any of its capable constituents, as well as responsibility sharing and contracting between actors (Montreuil et al., 2013). However, enabling such interconnection in an efficient and sustainable way requires major transformations in logistics from various aspects such as business model, production system, packaging, information technology and so on. The Physical Internet offers a vision for driving such transformation towards order-of-magnitude gains in logistics efficiency and sustainability (Montreuil, 2011).

The Physical Internet is an open global logistics system exploiting universal physical, digital and operational interconnectivity enabled by world standard encapsulation, protocols and interfaces (Montreuil et al., 2013). At the core, PI deals strictly with world-standard, modular, eco-friendly and smart π-containers that range from box size to cargo container size in a Lego way. It relies on a new breed of logistics equipment, facilities and systems designed for dealing efficiently with such π-containers. At the surface, similar to the web sites and applications built upon digital internet that are available for internet users, companies exploit PI through its enabled Logistics Web, schematically depicted in Figure 2. Montreuil (2011) defines:

"The Physical Internet empowers a global and open Logistics Web enabling producers, distributors, retailers and users to supply, realize, move and store for a fast, efficient and reliable response to quickly evolving demand. In a Logistics Web, products embedded in π-containers can be efficiently and seamlessly moved from sources to destinations through a Mobility Web. They can be dynamically deployed in numerous open logistics facilities all across a Distribution Web. They can be realized (made, assembled, finished, personalized, retrofit, and so on) in a wide variety of open realization centers spread across a Realization Web. Materials, parts and products can be supplied through a wide set of open suppliers, contractors and providers within a Supply Web."

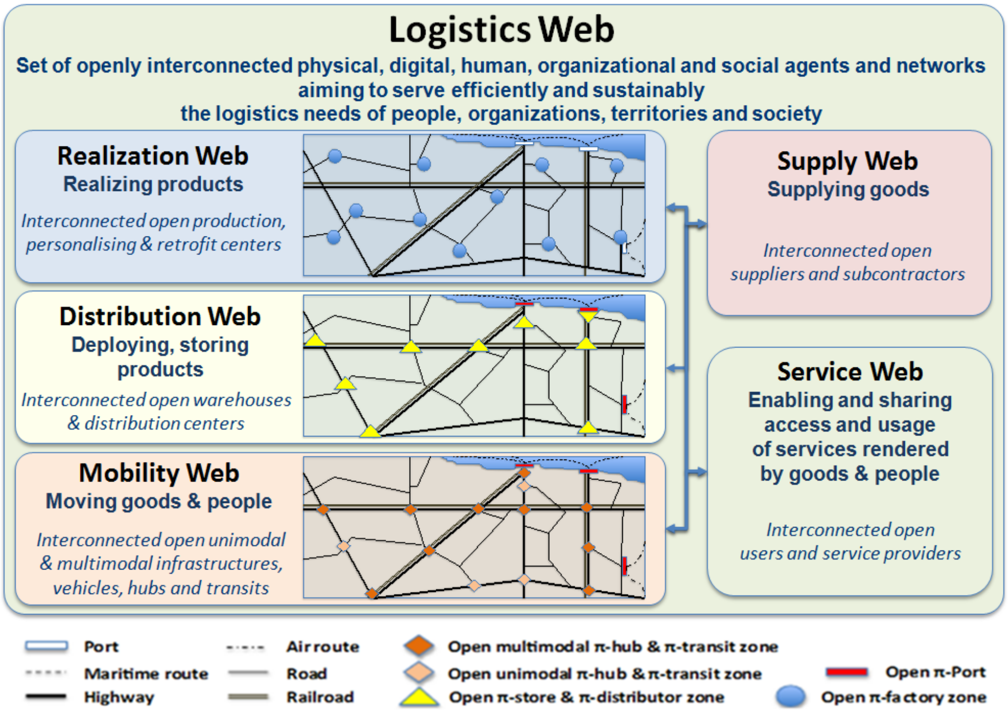


Figure 2. Physical Internet enabled Logistics Web and its key constituents (Montreuil et al., 2013)

Key to this paper is the Distribution Web enabled by the Physical Internet. This Distribution Web is the global set of openly interconnected physical, digital, human, organizational and social actors and networks. It aims to fulfill the worldwide dynamic and evolving needs for ever more efficient and sustainable distributed deployment and accessibility of goods (Montreuil et al., 2013). The Distribution Web leads the way to the emergence of open interconnected distribution systems within which distribution networks can be dynamically redesigned and adapted and finely attuned to the market conditions. It offers efficiency through better facility utilization, distributed near-market storage, faster and more reliable service to customers, and robustness in response to demand volatility and supply disruptions.

At this point, we focus on the planning and decision making process in the interconnect distribution system enabled by PI. Is it possible and desirable to plan and manage a system more complex and with higher expectations in terms of efficiency and sustainability the same way as dedicated and collaborative systems? In the next section, we argue that a new framework is needed to tackle interconnected distribution planning, first to master its inherent complexity and second to gain from the added degrees of freedom offered by a PI-enabled Distribution Web.

3 Interconnected Distribution Planning framework

We propose an interconnected distribution planning framework including four interlaced planning levels as depicted in Figure 3. Each of these levels is the subject of a specific subsection hereafter.

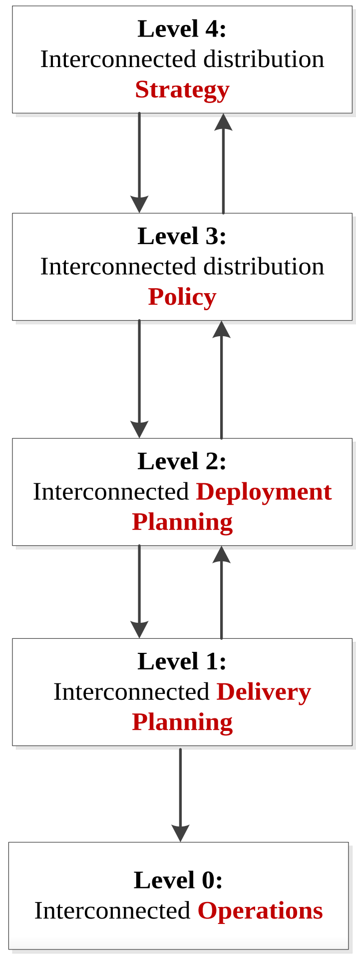


Figure 3. The interlaced levels of Interconnected Distribution Planning framework

Contrary to current hierarchical planning approaches such as Advanced Planning (Stadtler, 2005), each planning level can be dynamically updated. The predetermined planning horizon selected for each planning level indicates the time span of forecasts, decisions and activities to be planned at that level and it does not imply a fixed planning frequency. For instance if the planning horizon of a planning level is three months, it is not meant that this planning should be performed four times a year. It does rather mean that at any time the revision of this planning level is found necessary, it will be performed spanning the decisions over a planning horizon covering the next three months.

The call for updating a planning level is made by monitoring the value of some performance indicators (some instances are given in the following subsections). Noteworthy, at any time, whenever decisions at a level are updated, it implies that decisions in the lower planning levels may have to be revised.

3.1 Interconnected Distribution Strategy

The first planning level focuses on the interconnected distribution strategy for a relatively long-term horizon compared to the other planning levels. Depending on the clock speed of the company (Fine, 1998), this horizon may for example cover several years, a year, a season or a month. The goal is to establish the interconnected distribution network configuration scheme and find the preferred open distribution centers to exploit.

The configuration scheme includes determining the number of DC echelons in the network, the target response time to offer markets and the number of DCs at each echelon required in each market region. Usually the larger the serving geographic area is the higher number of distribution echelons companies need to implement. The reason is simple; to supply distribution centers from close sources (upper echelon DCs) instead of waiting for the supply from plant (which might be located far from some market areas). The response time targeted for a market is influenced by its historical demand and/or population. For example, largely populated US states such as California, Texas and New York can be the top selling markets of almost any business and it is logical for some companies to offer them their quickest response time service.

Setting the target response time for each market, the minimum number of DCs can be determined. As an illustration, consider a sample manufacturer company aiming to serve the United States and Canada’s markets. Figure 4 shows the population distribution in the company's target geo-markets. It also indicates the location of the top 40 metropolitan statistics areas.

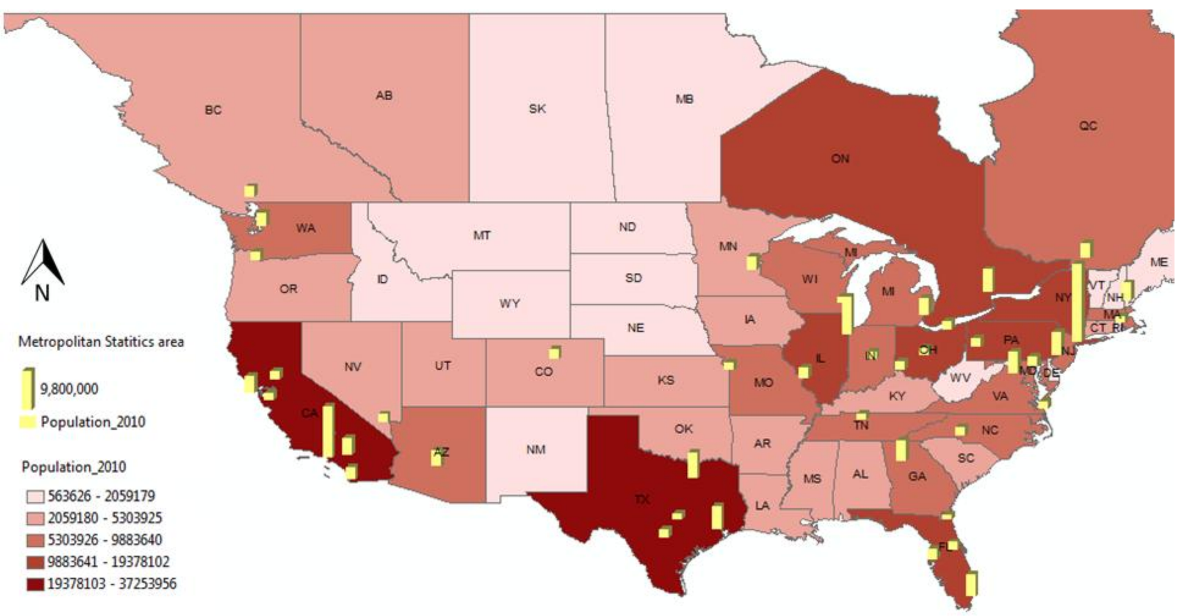


Figure 4. The distribution of population in US and Canada (based on census 2010 and 2011)

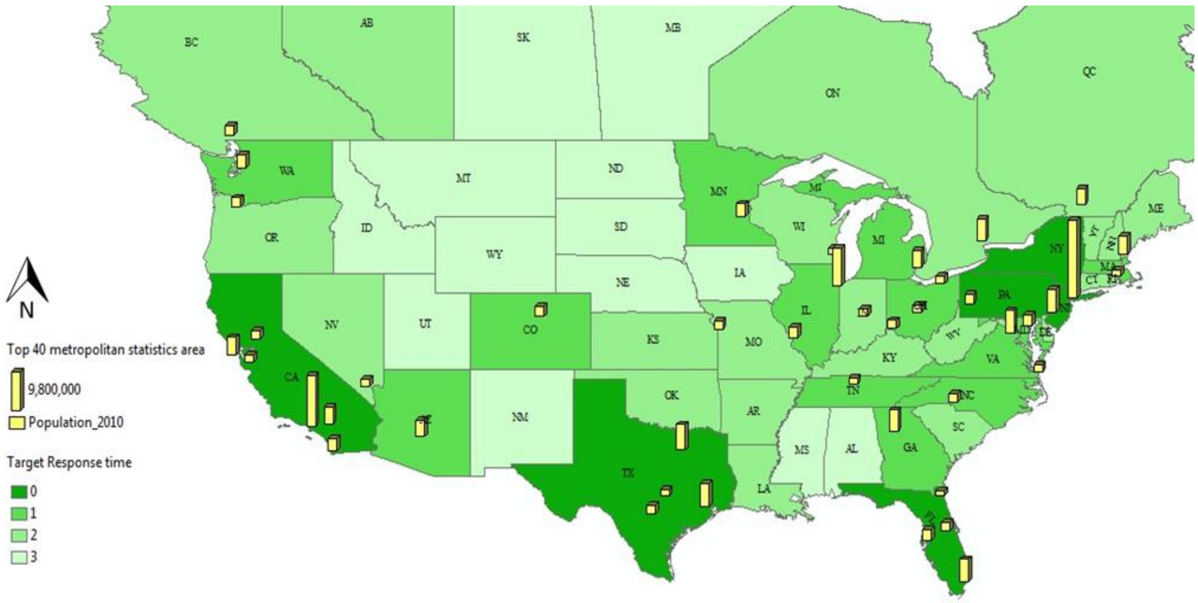


Figure 5. The desired response time offered to markets by sample manufacturing company

The manufacturer has to determine the delivery lead time it wants to offer to its customers in its targeted markets. Figure 5 presents such a potential offer highlighting the target delivery time in each U.S. state and Canadian province. It has decided to offer same-day delivery in six geo-market areas and a range from next-day to three-day delivery in the other geo-markets. Note that such a plan can be time-phased, for example with an offering for this year and more aggressive offerings in the years to come.

Continuing with the same company example, based on the vast geographical area it serves, its managers have opted for a two-echelon distribution system. The DCs in which inventory is to be held in the first echelon (e-1) have generally larger storage capacity, as they keep higher levels of inventory since they serve both their proximity markets and preferred second-echelon (e-2) DCs. The company is generally to store lower inventory in selected e-2 DCs that are located very close to markets and have higher inventory turnover. The minimum number of second echelon DCs to serve each market is determined by categorizing markets based on their geographical extent and population rank, respecting the target response time.

The preferred distribution network consists of the open DCs location to be exploited by the company and their mission in terms of being the primary or secondary source of the market(s). The primary sources DC can keep between 85-100% of the target inventory to serve a specific market. However the secondary source, stores a complementary low percentage of safety stock to supply the market in times the primary DC ends up running out of stock. Decisions such as the number of DCs to serve each market and the distribution of stock among primary or secondary DCs are strongly influenced by managerial insights. Here we present a typical interconnected distribution planning framework through the manufacturing company example which can be easily adjusted according to the characteristics of each individual company.

In order to configure the preferred distribution network of the sample company, applying a heuristic approach, a distribution network design problem is solved to find the location of first and second echelon DCs minimizing the total logistics costs (including transportation and DC exploiting and inventory holding cost) and respecting the target response time. Figure 6 shows the location of 20 e-2 and three e-1 DCs, two of which are integrated to the production plants of the company. Noteworthy, the location of these DCs are subject to change at any time as pertinent during the planning and operations. The company does not own the DCs nor lease them. As the agreement between open DC's owner company and user company can be short-term, the distribution strategy level can be re-planned in accordance to the changes in the demand or costs.

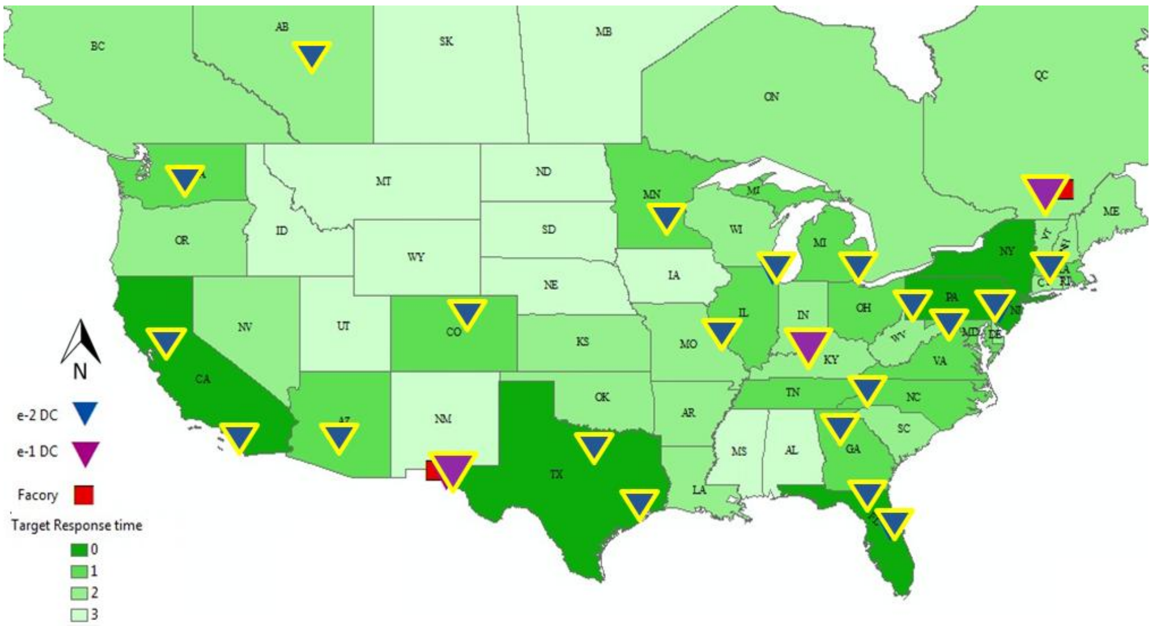


Figure 6. The preferred distribution network configuration of the sample manufacturing company

3.2 Interconnected Distribution Policy

The goal of this planning level is to set the distribution policy for a mid-term planning horizon (e.g. season, month) by determining the distribution policy system and parameterizing it. It is not intended here to enforce a novel distribution policy system; well-known (s,S) and (s,Q) or predetermined replenishment frequency can be applied depending on the managers insights. However the major element of this planning level is to parameterize the selected policy for each product (or product family) at each open DC concerning the markets they serve and the DC's role in terms of being the primary or secondary source. A one-size-fits-all strategy may easily fail in an interconnected distribution context, as the mission of each DC can be completely different from another one storing the same products.

For the sample company, a $(s,S)_{plt}$ system is selected which should be parameterized for each product p at each DC l and each month/season t. In order to attune the distribution policy to the changes in demand and mitigate the impact of errors caused by imperfect demand forecast, monitoring the percentage of the forecast error over the real demand allows updating the distribution policy parameterization process. Figure 7 presents a single product's distribution policy system at two e-2 DCs of the sample company.

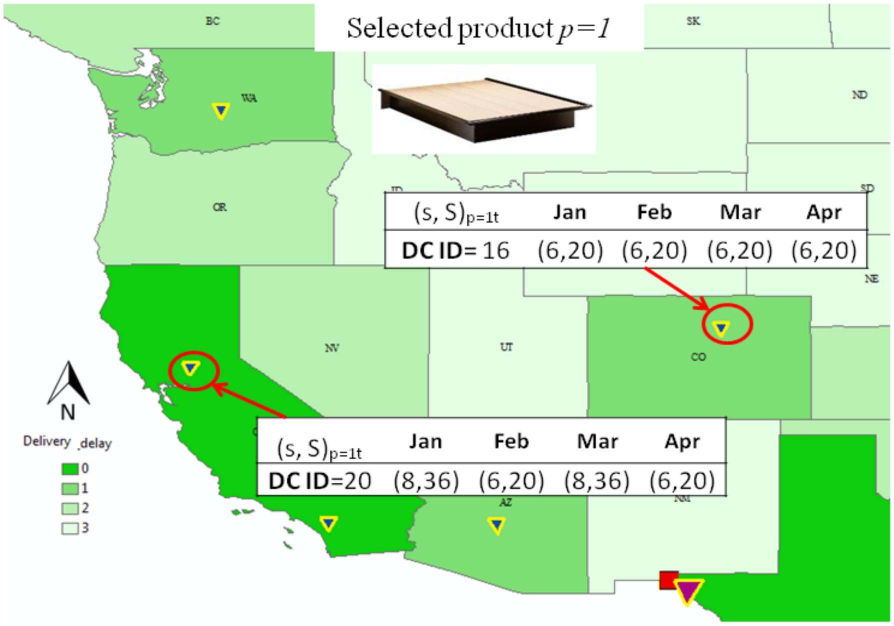


Figure 7. The interconnected distribution policy of the sample manufacturing company for a single product at two selected e-2 DCs for a four- month horizon

3.3 Interconnected Deployment Planning

At this level, for a relatively short-term planning horizon (e.g. month, week) the deployment of products within the preferred distribution network is determined. A novel approach is proposed for this purpose, capable of dynamically deploying products from multiple sources and redeploying them when required.

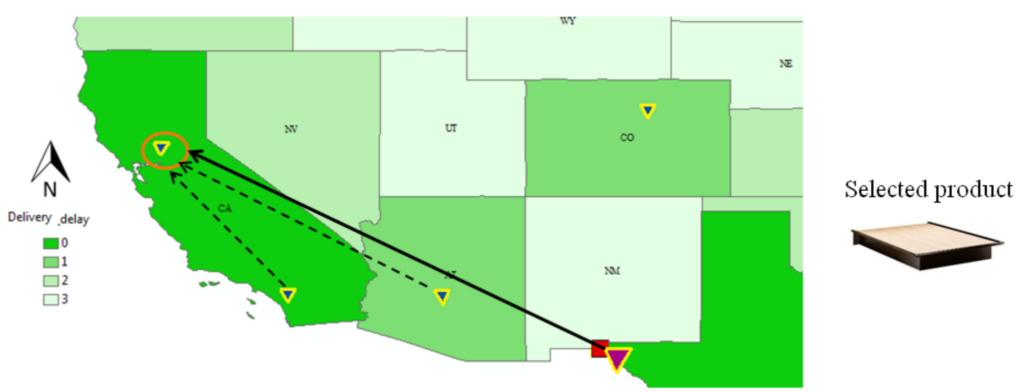
The interconnected deployment planning approach developed here is called dynamic deployment (DD). Basically, it is a Distribution Resource Planning (DRP) like approach defined to suit the dynamic context of interconnected distribution. There are similarities between dynamic deployment and the classic DRP method such as the fact that a rolling horizon planning approach is applied. Yet in dynamic deployment, the refresh pace is faster. For example, after orders arrive each day, the forecast error is calculated and the deployment planning is revised if the error is significant. There are major differences between DD and DRP, such as the fact that each DC can be supplied by more than one source (whether plant or other DCs). A hands-on example will help in understanding the differences deeper.

Table 1 shows a typical dynamic deployment planning table filled in for the selected product of the sample company with seven-day planning horizon starting from January first. The rows distinguished by different color present the changes regarding to the supplementary features of dynamic deployment approach compared to the classic DRP. Each DC can be the source of other DCs. When this is the case, the outgoing flow is indicated in the *Out transit* row. Moreover, DCs can be replenished from various sources depending on the availability of product at each source. The best fitting one with enough on-hand inventories to supply the DC whether partially or completely is specified in the DC source row and the lead time from DC to this source is considered in the ship date from the source.

Table 1. The dynamic deployment approach

DC ID	DC Echelon	Past Due	Day						
20	2		1	2	3	4	5	6	7
Required *p*			8	9	3	2	10	17	2
In transit *p*									
Out transit *p*									
Projected on hand *p*		28	20	11	8	34	24	7	5
Planned shipment Receipt date *p*						30		29	
DC source and lead time						e-1 at TX		e-1 at TX (16 units) and e-2 at CA (13 units)	
Planned shipment Ship date *p*			30		16		13		

As indicated in Figure 8, selected DC (ID=20) main source is an e-1 DC nearby the closest plant (connected by a plain arrow). Also two other adjacent DCs can supply DC 20, in case of shortage. The inventory strategy determined in the previous planning level sets the reorder point and maximum inventory target of the selected product at DC 20 for the month of January to be (8, 36). As indicated in the figure, the first replenishment to be received on day 4 is sourced by the e-1 DC. However the second replenishment on day 6 is jointly sourced by two DCs, as the main source does not possess the total replenishment on hand (see the table at the bottom of the same figure). Noteworthy, the second replenishment could have been sourced solely from e-2 DC, but as this DC's main mission includes serving markets, it will only supply the other e-2 DCs in cases of shortage.



Source DC for 20	Lead time [Day]	On hand inventory per day						
		1	2	3	4	5	6	7
e-1 at TX	3	55	20	16	10	150	110	85
e-2 at CA	1	24	21	18	40	32	26	22
e-2 at AZ	2	16	16	10	10	10	8	4

Figure 8. The deployment plan for a selected DC of the sample company (single product)

3.4 Interconnected Delivery Planning

The last interconnected distribution planning level concentrates on customer delivery in a very short-term planning horizon (e.g. day, shift or hour). The goal is to select the source of each delivery among open DCs which are eligible to serve a customer. When the ordered product is available at the closest DC to the customer, selecting the delivery source is simple (the best delivery scenario). However, tight inventory at the closest DC may entail serving the customer from another DC in a way to minimize the total transportation cost and respect the target response time promised to the customer (transportation problem).

Figure 9 a) shows orders for a single day from all customers of a single market, here the California State. Part b) represents a delivery scenario where each preferred closest DC has sufficient inventory to deliver all its preferred orders, and part c) depicts a scenario where some products have to be delivered to a customer from a DC which is not the closest to it and optimization has to be performed to assign the delivery source for each ordered product.

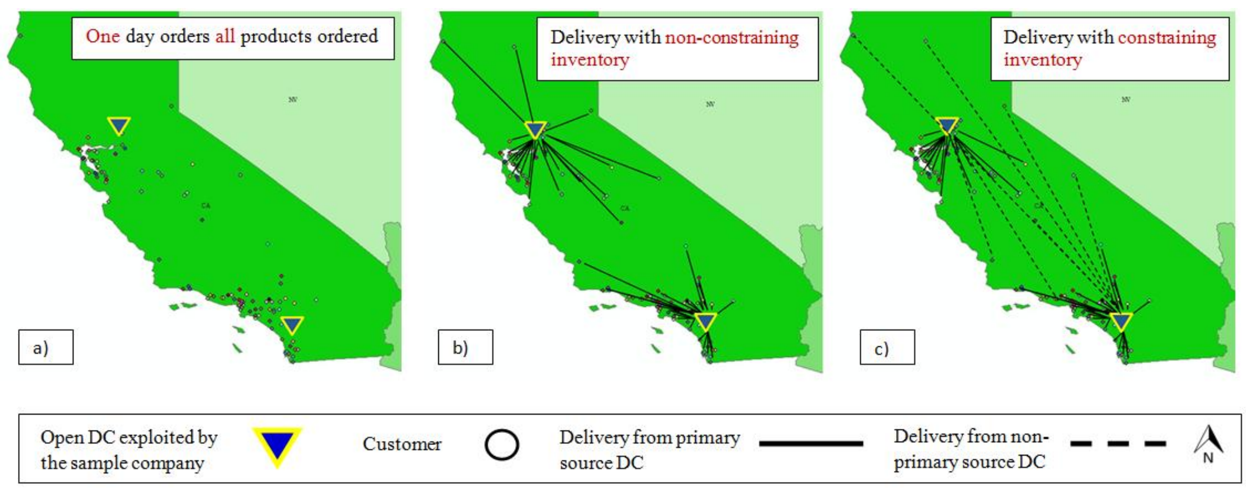


Figure 9. Delivery planning in the presence of non-constraining vs. constraining inventory at preferred DCs

The transportation operations in an interconnected distribution web are performed by exploiting PI-enabled Open Mobility Web that is built upon the interconnection of open transportation hubs, terminals and fleet. From each location, whether a plant or DC, products embedded in PI-containers (Montreuil, 2011) are shipped to the closest open hub. The PI transporting vehicles generally do not travel longer than 4-5 hours away from the hometown to enhance the safety and life quality of transportation workers, notably truck drivers. Thus, from each hub, received loads will be picked up, openly consolidated and transported to the next open hub towards the final destination, charged on a pay-per-use basis.

4 Conclusion

To leverage the efficiency and sustainability of current static and inflexible distribution systems, interconnected distribution systems enabled by Physical Internet are targeted in this paper. Such interconnection can be formed by exploiting openly available DCs and warehouses owned by a wide range of businesses, exploiting PI standard and secure encapsulation, protocols and interfaces. Decentralizing storage in as many open DCs as required within key geo-markets, together with exploiting open mobility web, can potentially enable companies to improve their customer service and on-demand product availability in targeted markets, reduce transportation and distribution costs as well as the GHG emission generated by their operations. They can also adjust their distribution network to the changes in the business environment by dynamically redeploying products within the open Distribution Web.

In this paper, a four-level framework is presented to help managers plan their network design as well as their product distribution, deployment and delivery so as to best exploit the availability of an open Distribution Web. The planning horizon of each level is relatively shorter than in conventional distribution planning. In addition, monitoring key performance indicators, planning decisions can be revised at any time.

The conceptual framework presented in this paper is being applied to a real manufacturing company data in a team project in collaboration with another Ph.D. student Salma Naccache and two research professionals François Barriault and Edith Brotherton supervised by Professor Benoit Montreuil. In the course of this project we simulate both the dedicated (actual) and interconnected (proposed) distribution system of the company in order to investigate the potential efficient and sustainable performance to gain by exploiting PI-enabled open distribution web. The primary results of this project are published in the IPIC 2014 conference proceedings by Naccache et al. (2014 a & b).

Further research is needed to elaborate the proposed framework in more depth, to develop the models associated to the key decisions to be taken at each level, to develop the exact and heuristic optimization approaches to solve these models, to assess the potentiality of the framework analytically and through simulation, to conceptualize and prototype the decision support systems supporting the actors, and to field test the approach in living labs.

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