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From Integrated to Interconnected B2C E-Commerce Distribution: An agent-based simulation Assessment

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Abstract: *Current e-commerce logistics systems are based on the integration of the closed and private distribution systems of different stakeholders including manufacturers, distributors and Third Party Logistics (3PLs). The integrated e-commerce distribution systems suffer from conventional distribution inefficiency and unsustainability symptoms such as underuse of distribution center capacities and important physical flows resulting in important greenhouse gas emissions and fuel consumption as well as operating underused capacity vehicles. In order to overcome B2C e-commerce inefficiencies, Physical Internet (PI) enabled interconnected distribution is a potent alternative to conventional logistics through its use of an open Distribution Web supported by the exploitation of an open Mobility Web.*

We present in this paper a multi-agent simulation based analysis of the implication of PI enabled interconnected e-commerce distribution, where operational strategies are implemented through the behavior of autonomous software agents, like optimization based dynamic inventory balancing deployment planning. We report improvements in economic, social and environmental performances of interconnected B2C distribution scenarios in comparison with performances of integrated B2C distribution scenarios. We quantify the performances of a leading furniture manufacturer through key performance indicators of simulated scenarios across different distribution stages from the manufacturer factories until reaching the final E-Consumer.

Keywords: *E-Commerce, Physical Internet, Interconnected Distribution, Performance, Sustainability, Agent-Based Simulation.*

1 Introduction

Business-to-Consumers (B2C) e-commerce distribution systems of leading players such as Amazon.com and NewEgg.ca are currently typically operated through the integration of their suppliers' private distribution networks and the parcel delivery system of their preferred contracted third party logistics (3PL) service provider (e.g. DHL, FedEx and UPS). The online order placement and delivery can be summarized through the six following steps. (1) An e-consumer orders online a product from the e-retailer website. (2) The online order information is then transmitted from the e-retailer to the supplier's information system. On its side, and depending on its consolidation strategy, (3) the supplier consolidates its consumer orders and ships them to a dropping location of the e-retailer's preferred 3PL, from where the 3PL (4) collects the orders of concern and (5) ships them through its hub-and-spoke network until (6) the final leg when it is locally dispatched for delivery at the consumer home or an agreed upon pick-up location, such as a click-and-collect drive. Figure 1 illustrates this six-step process from the perspective of a supplier having to deal with multiple e-retailers and third-party logistics providers, as is the focus of this paper.

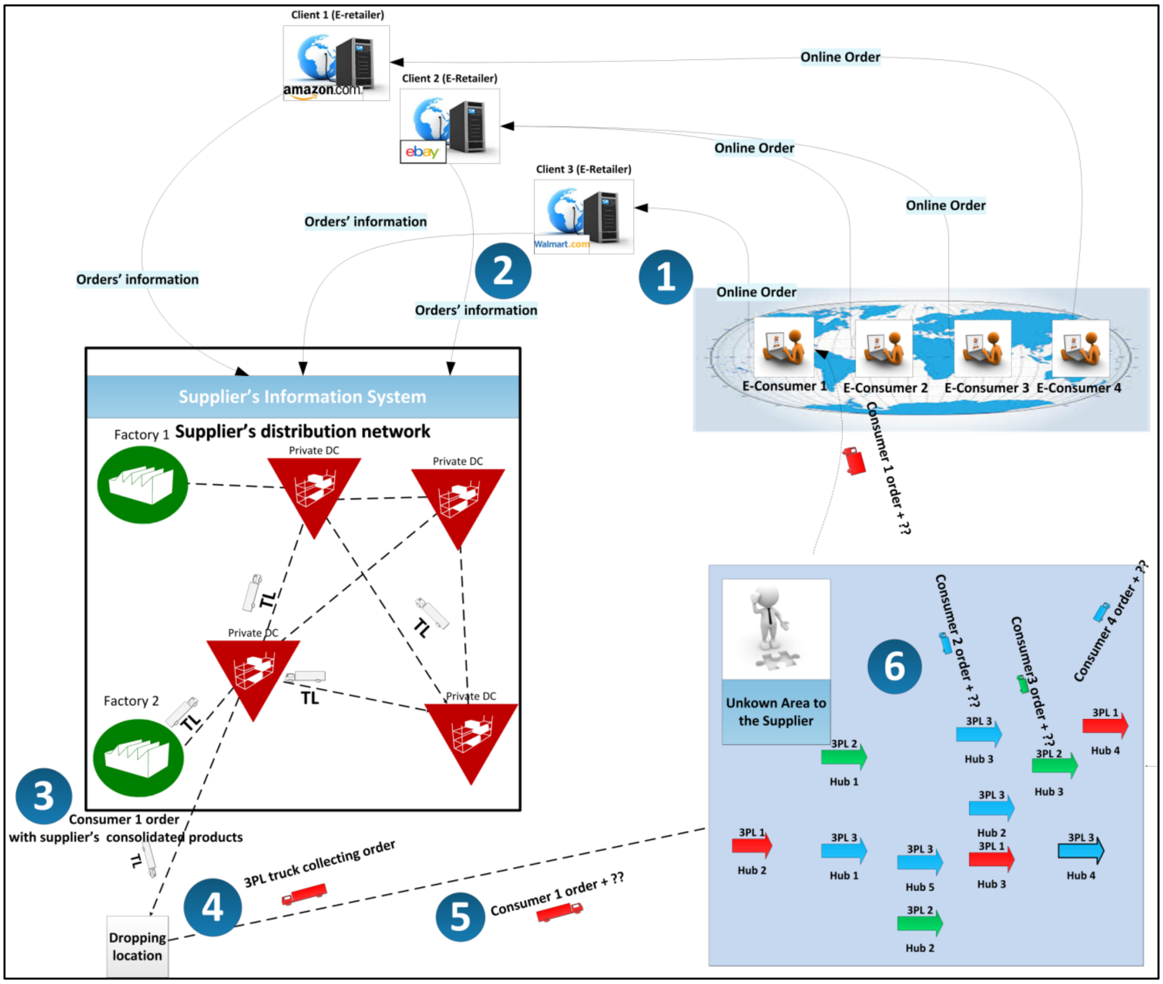

Figure 1: The overall B2C Distribution process from the supplier's perspective

The backbone of current multi-actor complex integrated B2C distribution systems lays on classic logistics systems that suffer from inefficiency symptoms such as the underuse of distribution center capacities or important physical flows resulting in important greenhouse gas emissions as well as operating underused capacity vehicles. Through the operation of interconnected distribution webs, the Physical Internet (PI) Initiative (Montreuil, 2011, 2013) targets overcoming inefficiency symptoms through the operation of open distribution centers, while deploying and delivering products through the web of mobility. PI enabled interconnected distribution systems are potent alternative candidates to current integrated distribution systems in the context of B2C E-Commerce distribution.

The aim of this paper is to validate the assertion that the exploitation of interconnected distribution by an e-supplier improves the distribution system efficiency and sustainability from economic, social and environmental perspectives. To this end, we adopt a multi-agent based simulation approach which is suitable to model and mimic complex system dynamics such as B2C distribution systems.

First, in section 2, we present a review actual integrated B2C E-Commerce distribution systems, contrasting them with the arguments defending the PI interconnected distribution as a solution for solving inefficiency and sustainability issues of these systems. In section 3, we present the agent-based simulation models we developed to enable empirical comparative analysis of integrated B2C distributions versus interconnected B2C distribution systems. Section 4 details the simulation scenarios we used to investigate actual and alternative integrated B2C distribution system as well as an alternative interconnected B2C distribution system of a leading e-commerce furniture manufacturer that currently operating three distribution centers located nearby its factories located near Québec City (Canada) and the city of Juarez (Mexico). Section 4 also reports on the simulation results. Finally, we conclude in section 5 by highlighting the main findings from our current research and presenting future research avenues for further investigating interconnected B2C distribution systems.

2 Literature Review

The backbone of e-commerce logistics is notably based on the participation of suppliers and parcel delivery service providers (Vergnion and Montreuil, 2001; Lim, H. and Shio, 2011). Suppliers deploy physical goods and fulfill online demand while parcel delivery service providers are responsible for delivering physical goods from the suppliers' distribution centers to drop points close to final consumer location (Yu and Xiu-yan, 2010). The overall resulting distribution systems, from suppliers to the end consumers of their products, suffer from inefficiency and unsustainability symptoms as underuse of distribution center capacities (Kämäräinen and Punakivi, 2002) or important physical flows resulting in important greenhouse gas emissions and fuel consumption as well as operating lowly filled vehicles (Taniguchi and Kakimoto, 2003). In B2C e-commerce logistics, economies of scale are hard to achieve and distribution costs may increase because of instable consumer demand (Lv and Zhang, 2010). Distribution cost evolution depends not only on consumer demand profiles, but also on the distribution sector (Zhu and Kraemer, 2002).

In order to overcome B2C e-commerce inefficiency aspects, PI enabled interconnected distribution systems are an interesting alternative candidate to current integrated distribution systems (Montreuil, 2011). With the Physical Internet, a Distribution Web is responsible for storing physical objects encapsulated in modular containers while a Mobility Web is responsible for moving these containers from source to destination in relay mode through open hubs (Hakimi et al., 2012). The Distribution Web exploits the use of open distribution centers offering storage spaces to heterogeneous suppliers, according to their storage capacity needs, without engaging these suppliers in leasing or possessing distribution centers (Montreuil et al., 2012). The number and location of open distribution centers in which a supplier stores its container-encapsulated products are set so they are close to both suppliers and consumers. The "on-demand" storage space in open distribution centers and their geographic location is an interesting solution to the distribution center capacity underuse issue in e-commerce. Furthermore, the efficiency of the Mobility Web can improve not only transportation costs incurred to the e-suppliers, but also overall vehicle fuel consumption and induced greenhouse gas emission.

The conventional integrated B2C distribution and the alternative interconnected distribution consist in complex systems where several processes from various actors interact in order to run the operations of the deployment and delivery of online ordered products. Then there is a need for a decision support tool in order to analyze and compute performances from both distribution systems. Simulations are widely used in supply chain management as decision support tools (Cimino et al. 2010). In particular, multi-agent simulation platforms are suitable to model and mimic complex system dynamics (Jennings, 2000; Govindu and Chinnam, 2007). Thus we choose to adopt a multi-agent simulation based analysis approach in order to contrast between actual and alternative E-Commerce distribution systems.

3 The open distribution web simulation model

We propose two simulation models for modeling and analyzing integrated and interconnected B2C e-commerce distribution systems. The first model considers the specificities of integrated distribution where supplier private distribution systems interact with 3PL hub-and-spoke networks to analyze resulting supplier performances in current e-commerce distribution scenarios. The second model takes into consideration the exploitation of an open Logistics Web with its Distribution and Mobility Web constituents (Montreuil et al. 2013) as enablers for an interconnected B2C distribution, in order to analyze supplier's resulting performances from scenarios of PI-enabled distribution as a logistics alternative in the context of B2C e-commerce.

3.1 Integrated B2C e-commerce distribution simulation model

In order to contrast actual e-commerce distribution performances with potential performances resulting from interconnected distribution scenarios, we use the agent-based simulation model we proposed in Naccache et al. (2014). In our previous work, we presented the main components from a B2C integrated distribution network simulation model, i.e., the agents, the agent behaviors and the simulation parameters. The agents are the autonomous software components that are responsible for reproducing a given distribution process, i.e. Shipment, Inventory, Production, Product deployment and Consumer orders. *Shipment agent* is responsible for executing product deployment orders communicated by the *Distribution agent*. Also, *Shipment agent* is responsible for consumer order routing and shipments. It is associated with the factories, distribution centers (DCs) and 3PL hubs. *Inventory agent* adjusts inventory levels according to received and shipped products and is associated to (DCs). *Production agent* plans and executes production calendars in factory nodes. *Distribution agent* is responsible for product deployment decisions which are executed by the factory and DC *Shipment agents*. Finally, *Consumer agents* order products from their respective locations.

Each agent implements a set of behaviors according to its responsibility and to the simulated distribution scenario. An agent behavior object may notably reproduce the historic behavior of a process (based on an operational log) or an operational logic. In addition to agent behavior, a simulation scenario is set up through simulation parameter values. Simulation parameters that are shared among all simulation scenarios can be assigned to one of four categories concerning, distribution network structure (supplier's side and 3PL side), agent behavior class for each simulation agent, transport parameters and deployment plan parameters (Table 1).

Table 1: Simulation parameters

Parameter Category	Parameter	Description
Distribution network structure	NMv	Supplier v's distribution network: refers to a set of a supplier's factory and distribution center nodes in addition to their links.
	NTt	3PL t's transportation network: refers to a set of node for a given 3PL (hubs, terminals) in addition to their links.
Agent Behavior	CBv	v's consumer agent behavior identifier.
	PBv	v's production agent behavior identifier.
	SBv	v's stock agent behavior identifier.
	DBv	v's distribution agent behavior identifier.
	ShBv	v's shipment agent behavior identifier.
	TSB	Transportation schedule for 3PLs: the daily frequency of consolidations made by the 3PL shipment agents
	TST	Time of the first daily consolidation of 3PLs
Transport Parameters	TWH	Trucker maximum working hours per day.
	TRH	Trucker resting hours per day.
	DSr	Driving speed on a route from type r.
	AFPab	Average 3PL truck filling percentage of vehicle traveling from node of type a to node of type b.
	FPDab	3PL truck filling standard deviation of vehicle traveling from node of type a to node of type b.
	MWCab	Maximum weight capacity of vehicle traveling from node of type a to node of type b.
	MVCab	Maximum volume capacity of vehicle traveling from node of type a to node of type b.
Deployment Plan Parameters	α	Smoothing factor for demand forecast
	covDaysNb	Number of target days of coverage
	Xmin	Lower bound of deviation of product shortage in a DC from its actual coverage, to define first priority shortages to be fulfilled when a deployment plan is executed.
	Ymax	Upper bound of the number of actual days of coverage over the target number of days of coverage of a product in a DC, to define first priority shortages to be fulfilled when a deployment plan is executed.

The resulting integrated distribution simulation models current B2C e-commerce logistics scenarios and can be adapted to model as well alternative B2C distribution scenarios. In order to assess the potential of adopting PI enabled interconnected distribution in the B2C distribution contexts, we extended the previous model to take into account the special characteristics of the interconnected distribution to obtain the PI-Enabled interconnected distribution simulation model.

3.2 PI-Enabled interconnected distribution simulation model

In order to highlight the e-supplier performance improvements when adopting an interconnected distribution system in B2C versus a conventional integrated distribution, we developed a simulation model inspired from the one presented in section 3.1. This second simulation model takes into consideration the special features of interconnected distribution, namely the open Distribution and Mobility Webs.

A supplier's preferred interconnected distribution network is a set of open DCs selected from the set of all available open DC operating the interconnected distribution system. During strategic planning, the preferred open DCs of a supplier are located so as to minimize the total logistics cost including DC exploitation cost, inventory holding and transportation costs, as well as business-specific environmental and social goals. In comparison with an integrated e-commerce distribution system, the number of open DCs in the resulting preferred interconnected network exceeds DCs within a supplier's private distribution network. Meanwhile, no leasing or acquisition cost is incurred to suppliers while "virtually implementing" their preferred interconnected distribution network. The preferred open DC network is generated previously to simulation scenario instantiation thanks to a network design heuristic or exact optimization model. The resulting preferred DC network is set as a simulation parameter input. Furthermore, assuming the use of the Mobility Web, the *Distribution agent behavior* and the *Shipment agent behavior* in an interconnected simulation model, differ from their equivalent in the integrated distribution simulation model. We provide more details about the differences between these agent behaviors in section 3.3.

In order to model the integration of the Mobility Web into the interconnected distribution simulation model, we do no longer take into account the explicit participation of each 3PL in the distribution system, rather assuming that all transportation services are provided by the Mobility Web in which numerous 3PLs are to contribute. In the integrated distribution system, products are usually transported in a truckload (TL) mode between private supplier DCs (*Deployment* stage), where vehicles only contain this e-supplier's products. In addition, consumer orders shipped to their final consumers from their e-supplier's closest private DCs (*Order Delivery* stage) are transported by the parcel delivery service providers in a Less-Than-Truckload (LTL) mode, where vehicles contain the consumer orders of the e-supplier mixed in with parcels from other heterogeneous sources.

Assuming the use of a fully functional Mobility Web, product transportation across an interconnected distribution system is made in a LTL-like service in both *Deployment* and *Order Delivery* stages, where vehicles transporting an e-supplier's products also contain products from other sources. The transportation cost of a vehicle in a Mobility Web is modeled as being proportional to the distance traveled and to the total weight of transported products over the total weight load capacity of the truck. In the *Deployment stage,* the e-supplier's product deployment transportation cost is modeled as being proportional to the total weight of supplier's products over the total weight load of the vehicle (E-Supplier contribution to the vehicle cost), where we assume that a vehicle in this stage is in average fully loaded at a predetermined level (such as 90% in this study). In the *Order Delivery* stage, the e-supplier's consumer order transportation cost is composed from the contribution of the e-supplier to the vehicle cost plus a handling cost proportional to the weight of each consumer order. At the *Order Delivery* stage, we assume that a vehicle is in average fully loaded at an average predetermined level (here 50%).

Finally, the simulation parameters in this simulation model are kept the same as presented in Table 1, while discarding the ones attached to a specific 3PL's activities (i.e: *TSB*, TST, AFP_{ab} and FPD_{ab}).

3.3 Agent behaviors

Each software agent in our simulation models is responsible for one distribution process, while their associated behaviors can be changed to model different distribution scenarios, i.e. integrated and interconnected distribution scenarios. For the extent of the current research, we used the same *Consumer*, *Production* and *Inventory agent behaviors* in both the integrated and interconnected distribution simulation models, while we developed for each simulation model a specific *Distribution agent behavior* and a *Shipment agent behavior*.

Shared agent behaviors

The Consumer agent behavior is implemented by the *Consumer* agent. It consists of a historic behavior reproducing the log of consumer orders from our industrial partner, saved in the *HistoricConsumerOrder* database table. *The Production agent behavior* is implemented by the *Production* agent. It consists of a historic behavior playing back E-Supplier's production orders calendar saved in the *HistoricProduction* database Table. The *Inventory agent behavior* is implemented by the *Inventory* agent. It adjusts the on hand inventory level of products at each DC according to received and shipped products.

The Shipment agent behavior

The *Shipment agent behavior* that is implemented by the *Shipment* agent consists in shipping product quantities between DCs, as ordered by the *Distribution* agent, at the *Deployment stage*. At the *Order Delivery* stage, the *Shipment agent behavior* routes consumer orders from their closest DC having the ordered product in inventory and located within a maximum distance distance (*MaxDistance*) that allows it to fulfill the consumer order within the promised delay. *MaxDistance* parameter is specific to the *Shipment agent* behaviors we developed within the scope of this paper. In the integrated distribution simulation model the *Shipment agent behavior* routes the consumer orders from their respective private DCs to their final consumer locations, across the hubs of their client assigned 3PL, using a shortest path algorithm. In the interconnected distribution simulation model, the *Shipment agent behavior* directly ships orders from their respective open DCs directly to their final consumer locations, assuming the existence of PI-hubs from the Mobility Web.

The Distribution agent behavior

The *Distribution agent behavior* implemented by the *Distribution* agent aims at dynamically deploying product excesses in DCs to balance inventory levels all over the distribution network in order to respond smartly to forecasted demand, according to the needs of each DC for each product. At each simulation day, the main agent behavior routine proceeds in a sequence of four main subroutines SR1, SR2, SR3 and SR4, as illustrated in Figure 2. Two *Distribution* agent behaviors are inherited from the basic *Distribution agent behavior*, namely the *Integrated Distribution agent behavior* and the *Interconnected Distribution agent behavior* implemented respectively in integrated and interconnected distribution simulation model.

The first Subroutine SR1 assigns each consumer order to its closest DC having inventory for the ordered product, and which is located within a maximum distance equal to *MaxDistance* parameter. In SR2, inventory excesses and shortages are computed as following: first a target coverage stock level is computed. This security stock of a product *p* at a given DC *x* is computed through the estimation of the target inventory coverage to be held expressed in equation (1), where $\hat{d}(p,x)$ is the daily demand forecast of *p* at *x* (computed through the exponential smoothing with a factor α=0.03) and covDaysNb(*e*) is the target number of coverage days of *x*'s echelon *e*.

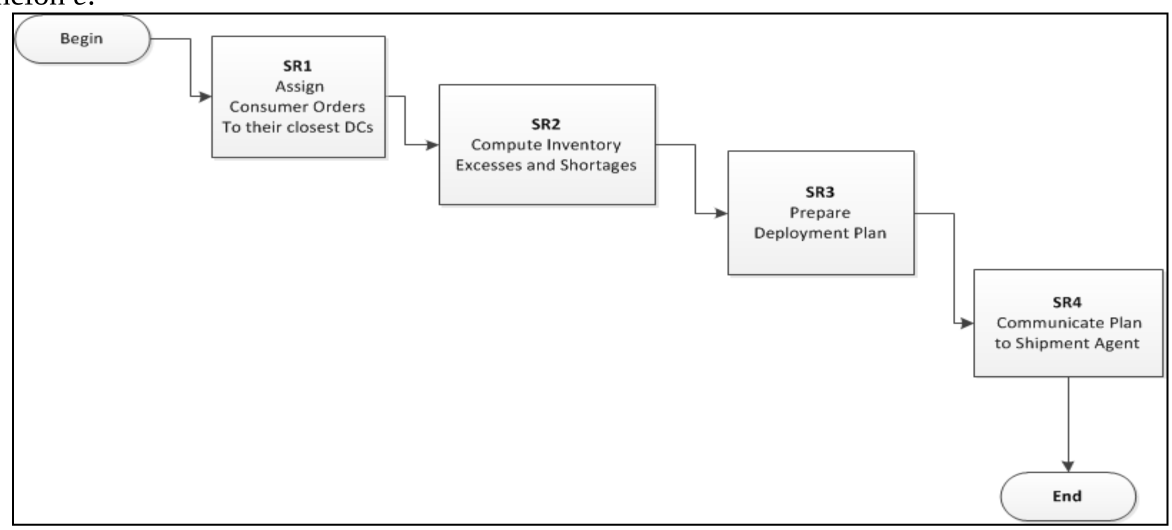

Figure 2: Distribution agent behavior subroutines

Then SR2 computes the set of gaps as expressed through equation (2) where $NetInventory(p,x)$ is composed from quantities of product *p* in stock at node *x* summed to quantities of in-transit product *p* being shipped to *x*, from which assigned consumer order quantities are deduced. Estimated inventory excesses and shortages correspond respectively to positive and negative gaps (*gap(p,x)*).

$$TargetCoverage(p,x) = \hat{d}(p,x)covDaysNb(e) \quad (1)$$

$$gap(p,x) = NetInventory(p,x) - TargetCoverage(p,x) \quad (2)$$

SR 3 is divided into four steps (Figure 3), namely SR3.1, SR3.2, SR3.3 and SR3.4, where SR3.3 is implemented differently according to the desired simulation model (integrated and interconnected). SR3.1 sorts shortages according to their priority of fulfillment, the most urgent shortage being the one with the greatest value of the estimated deviation of product shortage in the DC of concern from its actual coverage and with the lowest number of actual days of coverage over the target number of days of coverage of a product in the DC of concern. Then, SR3.1 detects emergency shortages to be fulfilled based on X_{min} and Y_{max} parameters presented in Table 1.

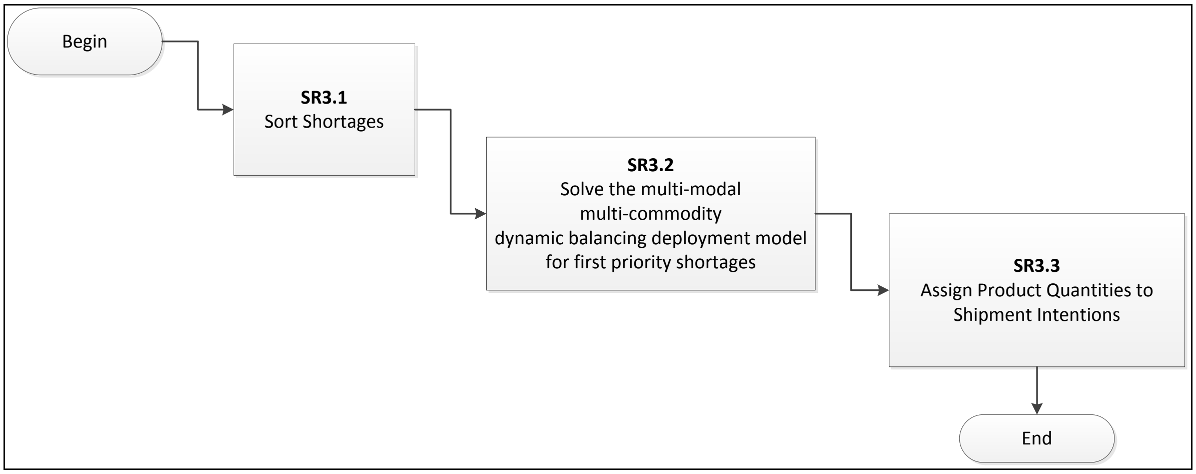

Figure 3: Subroutine SR3 details

Based on available product excesses and emergency shortages, SR3.2 finds a near optimal solution of the *Multimodal multi-commodity dynamic balancing deployment model* to deploy the emergency shortages (equations (3) - (8)). This linear program aims at minimizing shipment costs to cover inventory redeployment targets (reducing and increasing inventories of specific products at specific DCs), with respect to used vehicle capacities.

$$Minimize\ Z = \sum_i \sum_j C_{mij} S_{mij} \qquad (3)$$

Subject To

$$\sum_{j,m} X_{mpij} \leq a_{pi}\ ; \quad \forall p, j \qquad (4)$$

$$\sum_{i,m} X_{mpij} = d_{pj}\ ; \quad \forall p, i \qquad (5)$$

$$\sum_p v_p X_{mpij} \leq v_m S_{mij}\ ; \quad \forall m, i, j \qquad (6)$$

$$\sum_p w_p X_{mpij} \leq w_m S_{mij}\ ; \quad \forall m, i, j \qquad (7)$$

$$X_{mpij} \geq 0\ ;\ \ S_{mij} \geq 0;\ X_{mpij} \in \mathbb{N};\ S_{mij} \in \mathbb{N} \qquad (8)$$

Where

i: Source node.
j: Destination node.
p : A product to be deployed.

m : Vehicle type (Ex.: 53' truck, van).
a_{pi}: Quantity of product p available to be deployed from source node i.
d_{pj}: Quantity of product p to be fulfilled at destination node j.
w_p: Weight of product p.
v_p: Volume of product p.
w_m: Weight capacity of vehicle of type m.
v_m: Volume capacity of vehicle of type m.
C_{mij}: Cost of a vehicle of type m shipping from i to j.
X_{mpij}: Decision variable of the quantities of p to be deployed from i to j using vehicles from type m.
S_{mij}: Decision variable for the target number of vehicles of type m to be used to ship products from i to j.

Then, SR3.3 computes plans for product movements (shipment intentions) to be considered later on by the Shipment Agent in order to assign product quantities in vehicles from sources to destinations of concern. SR3.3 in the *Integrated Distribution agent behavior* is different from SR3.3 in the *Interconnected Distribution agent behavior*, through their respective consolidation logics detailed in Table 2.

Table 2: SR3.3 details in Integrated versus Interconnected Distribution agent behavior

Integrated Distribution agent behavior	Interconnected Distribution agent behavior
1. Assign X_{mpij} (emergency shortages) to shipment intention. 2. Sort remaining unassigned shortages in decreasing order of product shortage deviation from actual coverage, and increasing order of actual days of coverage over the target number of days of coverage. 3. Progressively fill resulting trucks being loaded less than the loading threshold with one day of estimated demand coverage from the first element in the sorted non-urgent shortage list, while products can be assigned and the truck filling has not reached the *AFPab* threshold parameter.	1. Assign X_{mpij} (emergency shortages) to shipment intentions.

In the integrated system, the supplier has to consolidate efficiently its products into full trucks. Filling trucks with only first priority shortages may result into partially filled trucks, which may be delayed to the next deployment planning and increase the inventory shortage of the product at the corresponding DC. Thus, the *Integrated Distribution agent behavior* has to check whether it is possible to fill trucks until reaching the filling threshold with remaining unassigned shortages. The second simulation model assumes using the Mobility Web, thus the *Interconnected Distribution agent behavior* considers only assigning first priority shortages, having the confidence that the Web of mobility system would achieve full trucks including not only the supplier's product, but also other items of other organizations, stored in the source open DC and heading toward the same next destination.

Finally, in SR3.4, the *Distribution* agent communicates each shipment intention corresponds to truck filled beyond *AFPab* threshold parameter, as shipment orders.

4 Experiment and results

The experiments presented in this paper are based on a case study of *Southshore Industries* (*SI*), a leading North-American e-commerce furniture manufacturer serving flagship clients such as Amazon.com and Walmart.com that sell *SI*'s products all across Canada and the United States markets. *SI* currently makes its products in three plants, stores them in its DCs nearby its plants, and ships daily consumer orders in truckloads from these DCs to the closest dropping locations their e-clients' 3PLs in Champlain, NY, USA or El Paso, TX, USA. Then, the 3PL delivery service provider *T1*, *T2* or *T3* specified by the e-commerce client, collect *SI*'s drop-shipped consumer orders. These providers are responsible to move the products ordered online through their respective hub-and-spoke networks to their purchasing consumer. Figures 4 to 6 display modeled networks for these delivery service providers. *SI* is actually able to promise a delivery within an average delay of four days to e-consumers in Canada and a delivery within an average delay of five days to e-consumers in the United States.

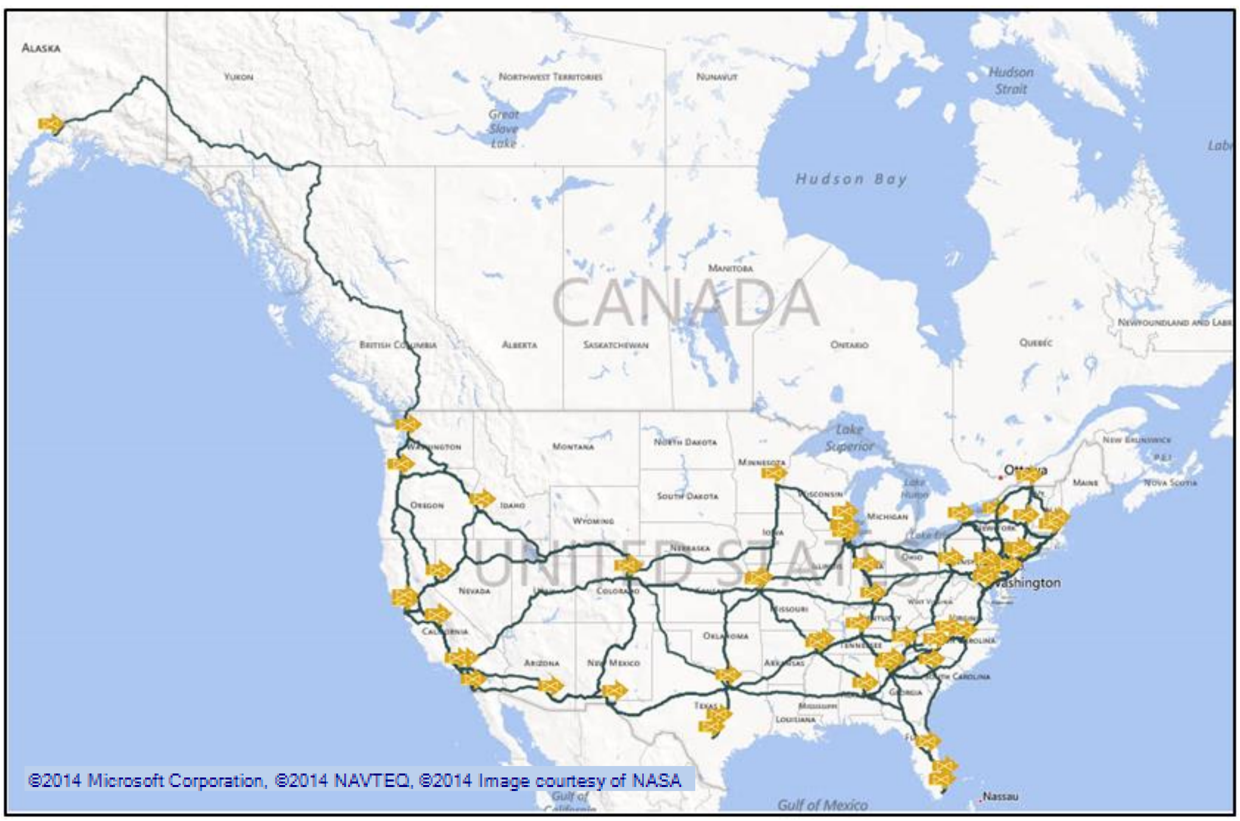

Figure 4: T1's hub-and-spoke network (hubs in orange)

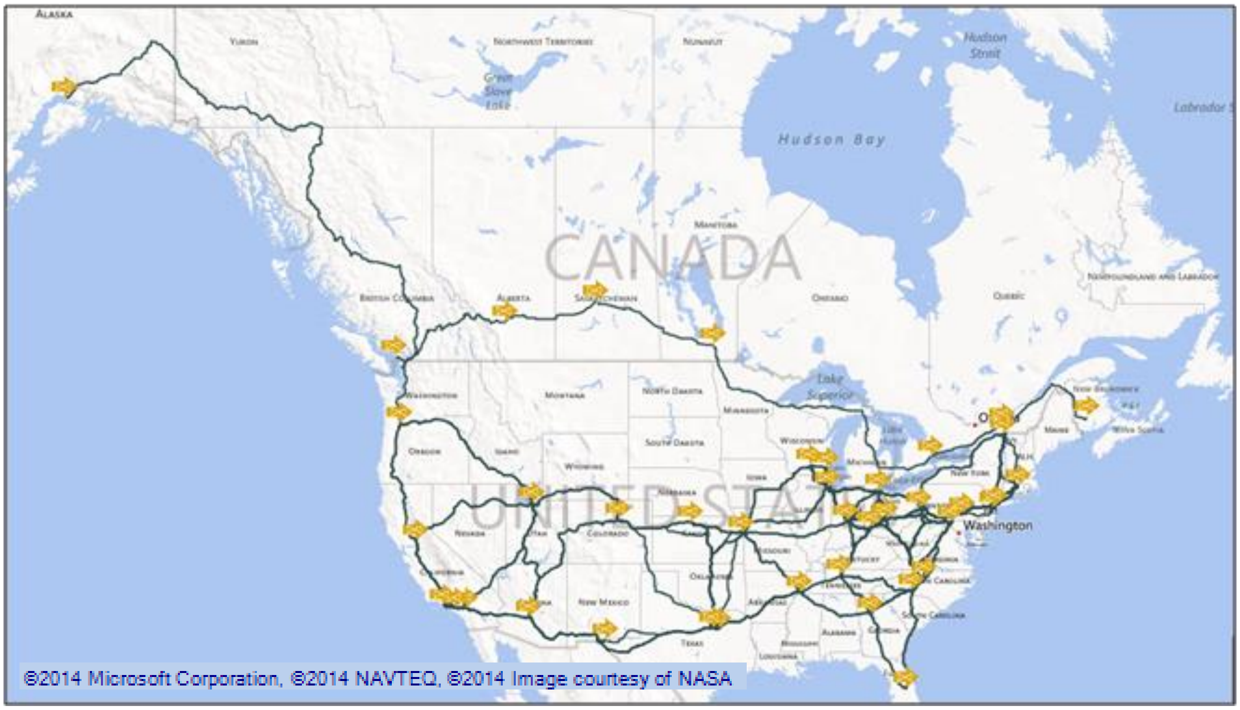

Figure 5: T2's hub-and-spoke network (hubs in orange)

Figure 6: T3's hub-and-spoke network (hubs in orange)

Based on SI's production and consumer order log, we aim to assess its performances in both integrated and interconnected B2C distribution systems with increasing consumer delivery speed requirements, shrinking *SI*'s actual delivery promise down to 3 days to both Canadian and United States' E-Consumers. To assess the economic, social and environmental performances of SI in an integrated distribution scenario, we used our simulation model presented in section 3.1, using the network presented in Figure 7 that illustrates integrated distribution network proposed for SI under a 3-day delivery policy. Then, in order to investigate the performance improvements for SI when adopting interconnected *B2C* distribution, we modeled a 3-day-delivery interconnected distribution scenario through the simulation model presented in section 3.2, using the preferred open DC network illustrated in Figure 8.

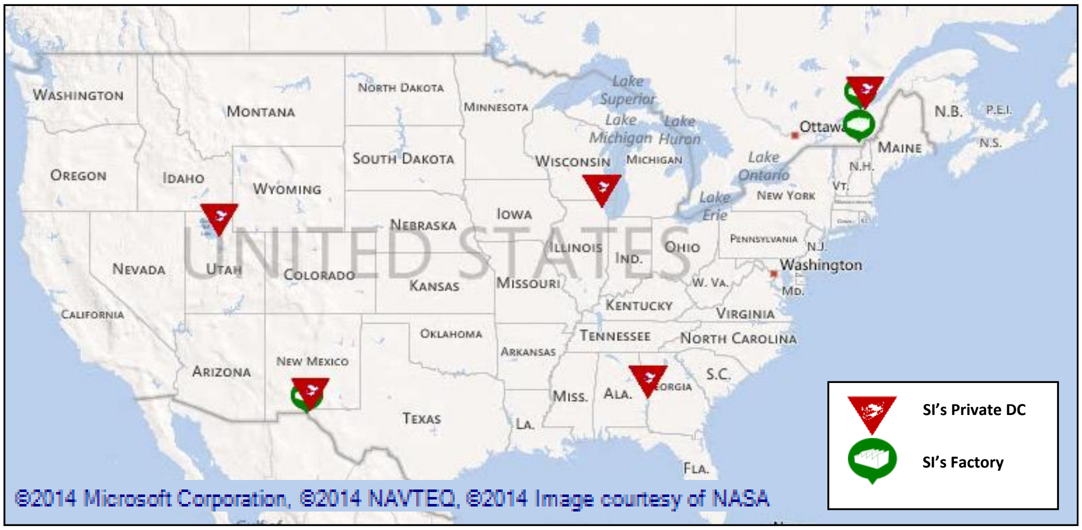

Figure 7: Private DCs in SI's 3-day delivery network under an integrated distribution scenario

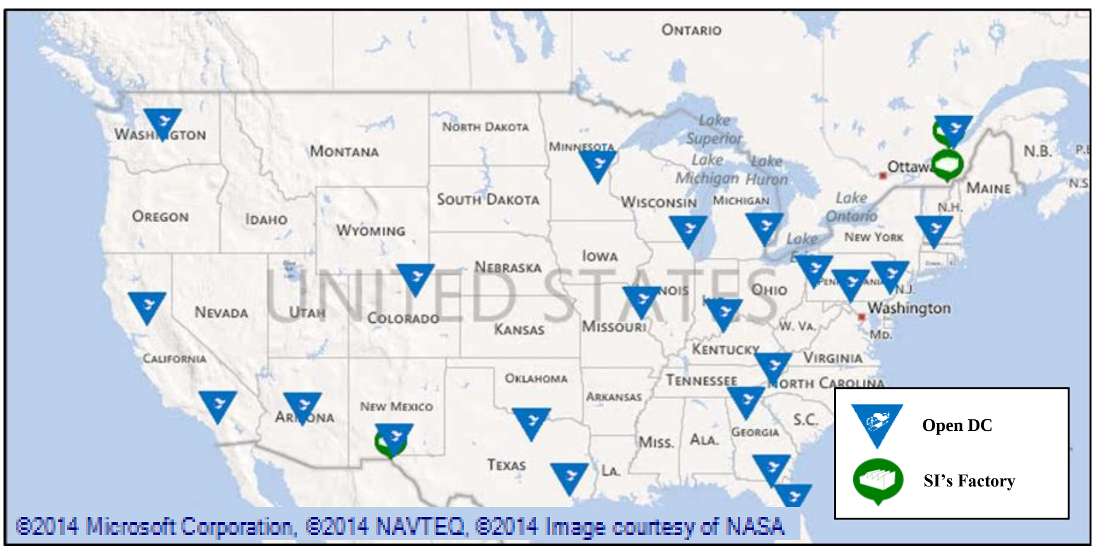

Figure 8: Preferred open DCs in SI's Network under an interconnected distribution scenario

For each simulation scenario we computed economic, social and environmental performances according to a set of Key Performance Indicators (KPI). Economic performances are quantified in Table 3, environmental performances are quantified in Table 4 and social performances are quantified in Table 5.

As illustrated in Table 3, thanks to the use of the Mobility Web, the interconnected distribution system caused a decrease of 29% in the *SI*'s transportation costs in the *Deployment* stage acrossDCs in comparison with the integrated distribution system. Also, a decrease of 31.4% is observed in *SI*'s e-clients' costs during the *Order Delivery* stage. Both transportation costs from *SI* and its e-clients resulted in a total overall decrease of 31%. This total decrease improved the transportation part in the selling price of a product to E-Consumers, as it resulted in a decrease of 31.5%.

Table 3: Economic Performance improvements in interconnected system versus integrated system

Indicators	Performance Improvements
STC = *SI*'s Supplier Transportation Cost (*Deployment* stage)	-29%
CTC = Total Clients' Transportation Cost (*Order Delivery* stage)	-31.4%
TCT = **STC** + **CTC** = Total Transportation Cost	-31.0%
TCT/Revenues =Transportation Cost from the Consumer's Perspective	-31.5%

Table 4: SI's Environmental Performance

B2C Distribution Scenario	KPI	Integrated	Interconnected
Deployment stage	Fuel (10^3 L)	669	466
	Energy (MJ)	25 881	18 025
	CO_2 (T)	1 782	1 241
	CH_4 (T)	0.09	0.06
	N_2H (T)	0.27	0.19
Order Delivery stage	Fuel (10^3 L)	1214	617
	Energy (MJ)	46 953	23 869
	CO_2 (T)	3 233	1 643
	CH_4 (T)	0.16	0.08
	N_2H (T)	0.49	0.25
Total	Fuel (10^3 L)	1 883	1 083
	Energy (MJ)	72 834	41 893
	CO_2 (T)	5 014	2 884
	CH_4 (T)	0.25	0.14
	N_2H (T)	0.75	0.43

According to Table 4, if *SI* adopts an interconnected distribution system, the environmental performances are improved at all distribution stages, in comparison with environmental performances in the integrated system. At the *Deployment* stage, a decrease of 30% in *SI*'s contribution to vehicles' fuel consumption and gas emissions is observed. At the *Order Delivery* stage a decrease of 49% is observed in *SI*'s contribution to vehicles' fuel consumption. The overall contribution of *SI* in vehicle fuel consumption drops by 42% in the interconnected distribution system when compared with the integrated distribution system. The important decrease of fuel consumption in the delivery stage is due to the use of the openly pooled Mobility Web.

Finally, as presented in Table 5, from a social performance perspective, an increase of 9% in *SI*'s on-time order delivery is obtained through the interconnected distribution system as well as an improvement in SI's average truck load rate versus the average used truck capacity ratio, where we observed a decrease of 85% at the *Deployment* stage and a decrease of 59% at the *Order Delivery* stage. The social performance improvement does not only include *SI*'s performance, but also the driver work condition: the ratio between rest cycle count and driving cycle count is reduced from 66% to zero when shifting from integrated to interconnected distribution, due to significantly shorter driving routes.

Through the reported results, we proved through simulation, and based on real operational data from *SI*, that the PI-Enabled interconnected B2C distribution system improves economic, environmental and social performances at all stages of product distribution, compared with a conventional B2C integrated distribution system.

Table 5: Social Performance

B2C Distribution Scenario	KPI	Integrated	Interconnected
SI's Service Level	On time Delivery	85%	93%
SI's Average Truck Load Rate VS. Average Used Truck Capacity Ratio	*Deployment* stage	100%	15%
	Order Delivery stage	1%	1%
Rest Vs. Drive Cycle ratio	*Deployment* stage	69%	0%
	Order Delivery stage	66%	0%
	Total	66%	0%

5 Conclusion

The adoption of an interconnected open distribution in the context of B2C is an interesting alternative to be considered not only by suppliers, but also by e-clients. In fact, we reported performance improvement at the different stages of the distribution, i.e. *Deployment* and *Order Delivery*.

The current study focused on distribution, assuming production decisions out of its scope. This has lead to results having the system fulfilling only 96% from total e-consumer order intentions in the tight three-day delivery policy. In further studies, this scoping constraint has to be unlocked, allowing production decisions to be dynamic, in order to help improve product deployment in face of stochastic demand.

As another research avenue, the interconnected B2C distribution system robustness has to be tested in more variable conditions, for example taking into account regional characteristics of consumers as well as demand seasonality creating huge peaks and valleys of demand.

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