Hyperconnected City Logistics for Furniture and Large Appliance Industry: Simulation-based Exploratory Investigation

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Abstract: *In general, the furniture and large appliance industry is currently a disconnected supply chain which forms an interesting area for Physical Internet inspired analysis and intervention. This paper thus aims to provide insights into the effectiveness of the hyperconnected supply chain in serving urban environments through simulation-based scenario analysis. For the studied case, openly sharing storage space of distribution centers reduces travel distance for delivery by 26%, delivery cost by 20% and man-hours by 17% compared to individual operation. Openly sharing delivery assets as well as distribution assets reduces the above measures by 60%, 46%, and 40% respectively. Introducing cross docks and discretizing delivery by utilizing more fuel efficient vehicle in last mile further increases the savings in total cost to 60% and in required man-hours to 58% as well. However, introducing an additional distribution center at city center has little effect. Overall, the results are encouraging, implying that even a small step towards a hyperconnected supply chain can lead to highly significant savings.*

Keywords: *Hyperconnected City Logistics, Furniture and Large Appliance Industry, Physical Internet, Last Mile Delivery, Open Asset Sharing, Open Pooling, Hyperconnected Distribution, Hyperconnected Supply Chain, Hyperconnected Delivery Routing, Simulation*

1 Introduction

The supply chain of furniture and large appliances forms an interesting area of analysis and intervention. Characterized by long lead times of large, bulky, and fragile products, the furniture supply chain is currently in flux due to the emergence of e-commerce. As stated by Terry (2013) "e-commerce has trained consumers to expect fast delivery. Instead of 10- to 21-day delivery time for case goods—the industry term for furniture made from hard materials— consumers expect next-day or two-day delivery." As the majority of manufacturing takes place in Asia (Inbound Logistics, 2007) and customers are demanding products at the earliest, many retailers are asking their manufacturers to increase their inventory at their respective warehouses and DCs (Terry, 2008).

Another notable challenge comes from the fact that last-mile delivery becomes an ever more critical segment of this supply chain as the furniture industry shifts from brick-and-mortar stores to e-commerce. First of all, e-commerce is an important driver of changes in customer behavior. As stated by Terry (2013), instead of buying sturdy sets, customer now prefer cheaper individual pieces of furniture which can be replaced in three to four years or less. Now, retailers must make many small deliveries throughout the day, making each trip more costly. This trend has complicated the last-mile logistics of the industry. Second, the "white glove" service, a term used in furniture industry encompassing a series of services, including set up and clean up, offered upon delivery of furniture and large appliances, distinguishes the last-mile delivery of these products from that of other consumer products. Third, it is becoming increasingly difficult for delivery companies to find drivers during the national driver shortage, especially drivers who can concurrently provide holistic white glove services and positive customer experience. The final stage of furniture supply chain, therefore, becomes a unique and interesting area of innovative intervention.

This study aims to investigate the impact of the Physical Internet (Montreuil, 2011) on the cost and time efficiency of last mile delivery of furniture and large appliances in urban settings. The study uses both quantitative and qualitative analyses to explore the effects of the Physical Internet on the furniture industry's supply chain.

2   Literature Review

Inbound Logistics (2007) provides a detailed qualitative analysis into the underlying costs in furniture logistics, and an examination of the 3PL and last mile delivery services that the furniture industry. Although there were attempts of collaborative logistic operations in furniture industry (Audy et al, 2008), currently most of the furniture companies operate independently.

According to Terry (2013, 2015), logistics operations in the furniture and large appliances industry have been subject to more and more pressure on cost reduction to survive from price competition worsened by economic recession and changed customer behavior with the rise of E-commerce.

In this paper, we devise and analyze *Physical Internet* inspired scenarios for urban last-mile delivery networks for furniture and large appliances. Montreuil (2011) offered the structured introduction of the basic concepts of the *Physical Internet*, including π-containers and open shared supply chain networks, which lie at the basis of the ideas in this paper. We assume the use of π-containers, described in Figure 1 (Montreuil et al., 2016), to enable open asset sharing between retailers. Until now, furniture is usually stored in cardboard boxes, inducing a very high risk of damaging the goods as well as handling and transportation difficulties. The encapsulation in π-containers has they offer anonymity and protect well the furniture, while being easy to transport, for example directly on flatbed trailers, and easily collapsible when unused.

To the extent of authors' knowledge, there has been no paper providing advanced analysis on the impact of shared logistics assets, by incorporating the framework of *Physical Internet*, on home delivery of furniture and large appliances.
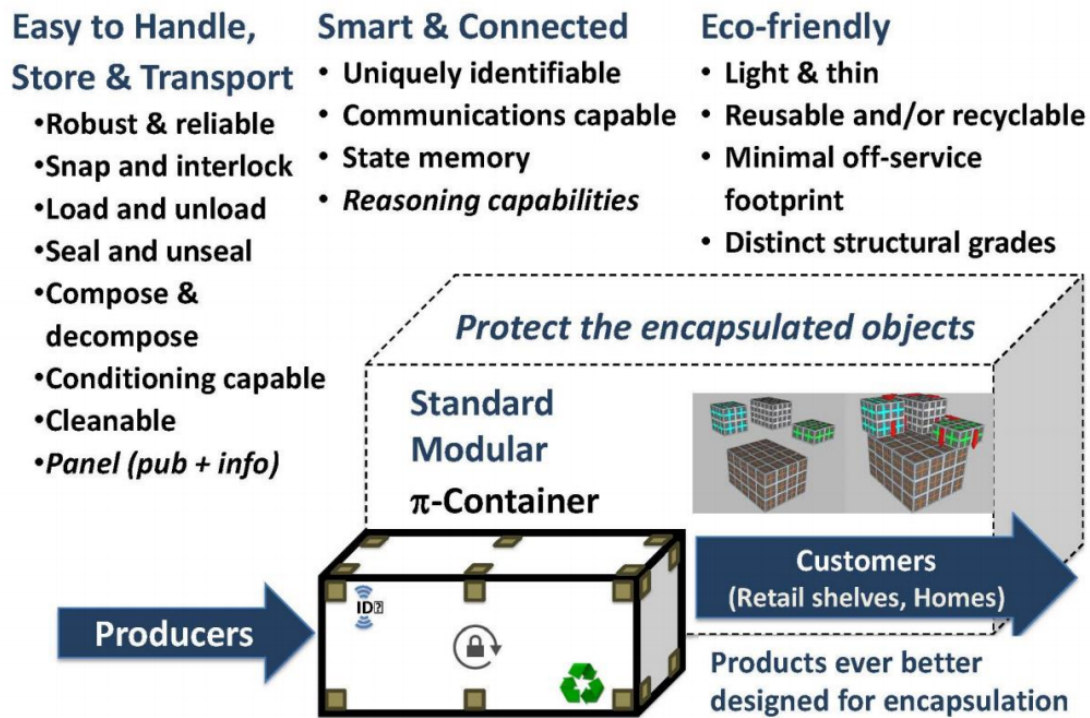
Figure 1: π-Containers (Montreuil at el., 2015)

This study focuses on home delivery restricted in urban area, thus city logistics is at its core focus. City logistics has drawn attention from many scholars and practitioners in diverse sectors. Although not all can be listed, there are plethora of studies and project movements in city logistics. Key examples include Taniguchi et al., 2005; BESTUFS, 2007; Benjelloun et al, 2008; Marcharis et al., 2011; and Savelsbergh et al., 2016. These include new models and case studies where solutions such as road pricing, truck ban, night deliveries, and city distribution center (a.k.a. urban consolidation center) are suggested or implemented. Naturally, last-mile delivery is central to urban logistics as it comprises the most logistics activities in a city and is impacted the most by customer behavior changes due to e-commerce. Visser et al. (2014) specifically address the impact of e-commerce on home delivery and urban logistics. Furthermore, last-mile delivery is "one of the most expensive, least efficient and the most polluting part of entire logistics chain" according to Gevaers et al. (2011). That is, the potentials to reduce cost and negative environmental impact are substantial.

Aiming to enable improving the economical, environmental and social efficiency and sustainability of city logistics, Crainic et al. (2016) have proposed a Physical Internet inspired comprehensive conceptual framework for hyperconnected city logistics that is at the source of the investigations performed in this study.

Although furniture and large appliances are one of the products moving in a city, however, unique aspects of these products must be noted. For example, white glove service at customer site is accompanied in many cases and customers tend to ask home delivery when buying at a physical retail site due to the large size of the products. Also, unlike other parcel deliveries, volume and weight of these large products highly constrain the number of deliveries per route, so the delivery density of these products is relatively low. We focus on delivery of this particular products in urban area in this study and seek for improvement through exploiting the *Physical Internet*.

3   Methodology

Simulation based scenario analysis is used to analyze the impact of *Physical Internet* inspired changes on logistic networks for home delivery.

As a simulation playground, we assume four virtual retailers who serve a fictitious square shaped city. Retailers have a single distribution center (DC), located along a city border, with a single DC per city side border. The location of the DC along its assigned outer border is generated randomly in each simulation run. Every day during a simulation, each retailer has to serve 20 clients whose location is randomly specified within the city.

Daily delivery routes are constructed using nearest neighbor heuristics, respecting the route duration constraints. The duration of the route is determined by the summation of the driving time, delivery time, and if necessary the installation time. Driving time is calculated based on the assumption that the delivery vehicles travel at 40 km/h. Delivery time and installation time, measured in minutes, are randomly generated from $N(15, 5^2)$ and $N(30, 10^2)$ respectively. Installation time is assigned to only a determined percentage of the customers.

In order to focus the study strictly on delivery, inventory is assumed never to be a constraint and is therefore not modeled explicitly. Specific parameters used in the research, such as the gas price, salary of drivers, can be found in Appendix.

Six scenarios are modeled and analyzed. Scenario 1 exemplifies the typical operations of current furniture industry representing disconnected supply chain, serving as a baseline for the remainder of the scenarios. All other models, from Scenario 2 through Scenario 6 represent the gradual move towards a hyperconnected supply chain. In scenario 2, retailers share the storage space, and in scenario 3, delivery fleets are shared as well. In scenario 4, mobile cross docks throughout the city are utilized. In scenario 5, one additional shared DC is introduced. Finally, in scenario 6, the DC locations are optimized. The scenarios are compared by the average travel distances and cost.

To obtain reliable results from simulation, average performance measures from 1,000 independent simulation runs for each scenario were used to evaluate and compare each model.

4   Scenario Analysis

The five scenarios subject to simulation based experimentation are hereafter analyzed.

4.1   Scenario 1 – Solo Storage, Solo Distribution

The first scenario models typical operations of the current furniture supply chain where each company independently operates its own warehouses and distribution channels. Total travel distances and times for the four retailers are calculated by summing up the individual travel distances and times of each retailer. As previously mentioned, the results of scenario 1 form a logistic performance baseline to evaluate other scenarios. Figure 4 shows a graphical display of a set of daily routes from one retailer DC in Scenario 1.
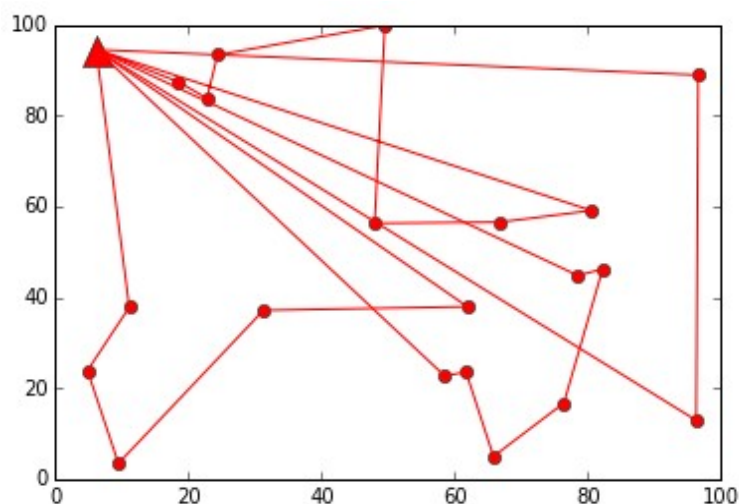

Figure 2: Daily Routes of a Retailer from its dedicated DC in Scenario 1

4.2   Scenario 2 – Shared Storage, Solo Distribution

In Scenario 2, retailers utilize shared storage at each DC, but continue to use solo distribution from those DC's. To be specific, retailers are allowed to store inventory in any of the four retailers' DC, which can potentially increase proximity to customer locations, and, therefore, routes are originated from the best location in regards to travel distance. However, the products still need to be handled and delivered by their retailer-dedicated workers and trucks. This is a first step toward a hyperconnected supply chain. Figure 5 shows a graphical display of a daily delivery route for one retailer in Scenario 2. Note that Figure 5, which only plots the Red routes, visually shows how Scenario 2 takes advantage of shared distribution, as one of the Red routes is more effectively served from the Yellow DC of another retailer.
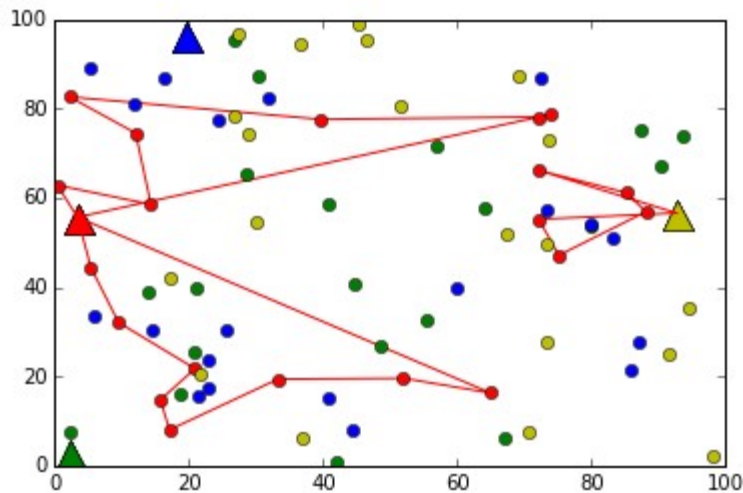

Figure 3: Graphical Display of a Daily Routes of a Retailer in Scenario 2

4.3   Scenario 3 – Shared Storage, Shared Delivery

The third scenario is a second step toward a hyperconnected supply chain. In this scenario, the retailers share delivery assets such as trucks and drivers in addition to the distribution assets, i.e. storage space of DCs. In other words, customers of different retailers can be served in a shared route departing from the closest DC. Each customer destination is assigned to the closest DC. Routes from each DC are constructed based on a group of customer destinations assigned to the DC. The travel distance for delivery can be drastically reduced by sharing delivery assets. Figure 6 shows a graphical display of a daily routes of Scenario 3 in its entirety.
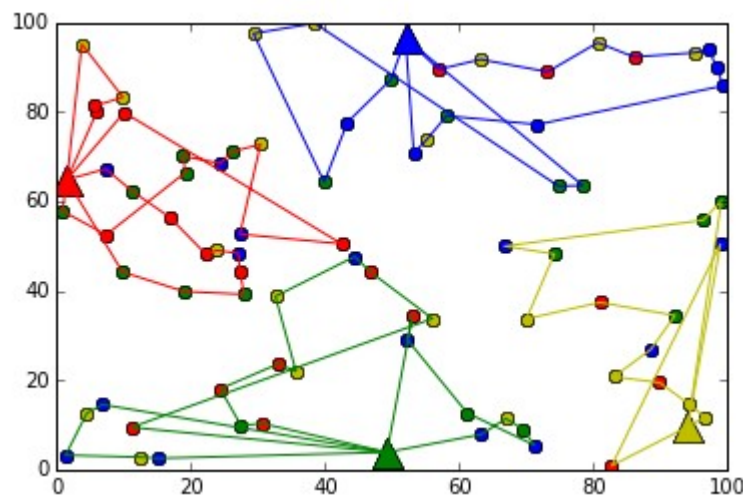

Figure 4: Graphical Display of a Daily Routes of in Scenario 3

4.4 Scenario 4 – Mobile Cross Docks

Scenario 4 introduces 16 possible mobile crossdock locations in addition to the four DCs. These crossdock locations can be large vacant areas, such as parking lots, in the city. The locations of the crossdocks are preassigned and fixed. In this scenario, the daily 80 customer destinations are each assigned to one of the mobile crossdocks based on proximity and then grouped into routes. Once the assignment is done, full size trucks departing from DCs deliver products to the mobile cross docks in the morning to prepare daily deliveries. The last-mile deliveries are made by smaller and more fuel efficient trucks from the mobile crossdocks. Typically, one full-size truck is required per DC and it is assumed that these trucks have been contracted as they would be used for approximately one hour each day in the morning. The maximum travel time of one route for small trucks is limited to 3 hours. In addition, small trucks are allowed to serve multiple routes per day if the total travel time is no more than 8 hours.

Figure 7 and Figure 8 show a graphical display of Scenario 4 delivery, respectively from DC to mobile cross dock and delivery from mobile cross dock to customer destination.
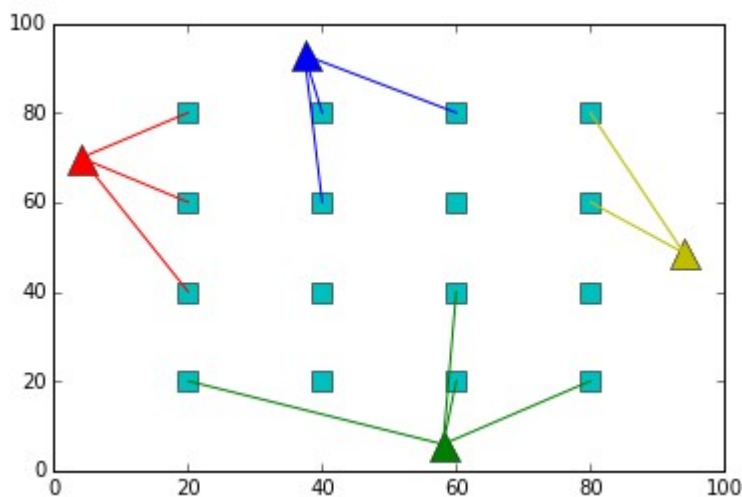

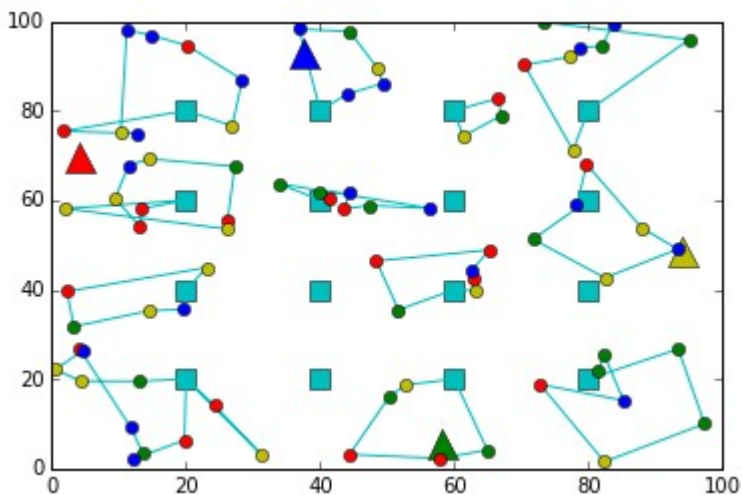*Figure 5: Graphical Display of Deliveries from DCs to Mobile Cross Docks in Scenario 4*

Figure 6: Graphical Display of Deliveries from Mobile Cross Docks to Customer Destinations in Scenario 4

4.5 Scenario 5 – City Distribution Center

The fifth scenario is a variation on the third scenario. All that is changed is the addition of a fifth open DC, located at the center of the city. Deliveries are assigned to routes starting from the nearest DC to the customer location, as depicted in Figure 8.
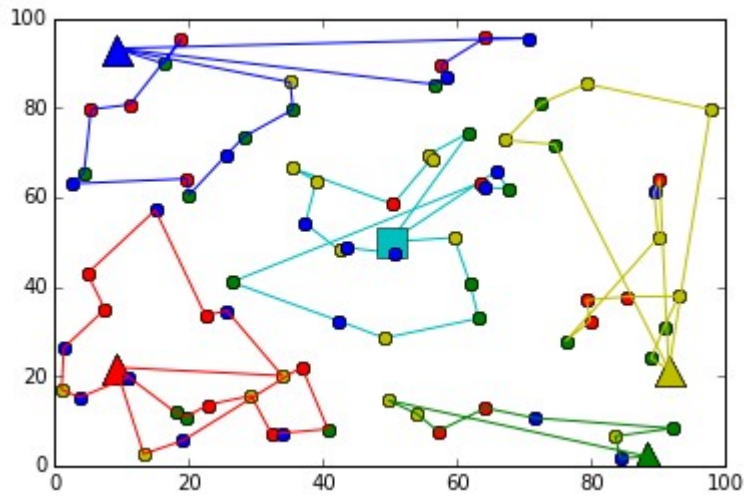
Figure 7: Graphical Display of Daily Routes in Scenario 5

4.6   Results

The simulation results of the scenarios are hereafter compared in terms of selected performance measures. The two main performance measures of focus are total cost and total distance.

Figure 10 shows total distance traveled by different types of vehicles in each scenario. The total travel distance is reduced by about a third in scenario 3, 4, and 5 compared to the highest travel distance in Scenario 1.
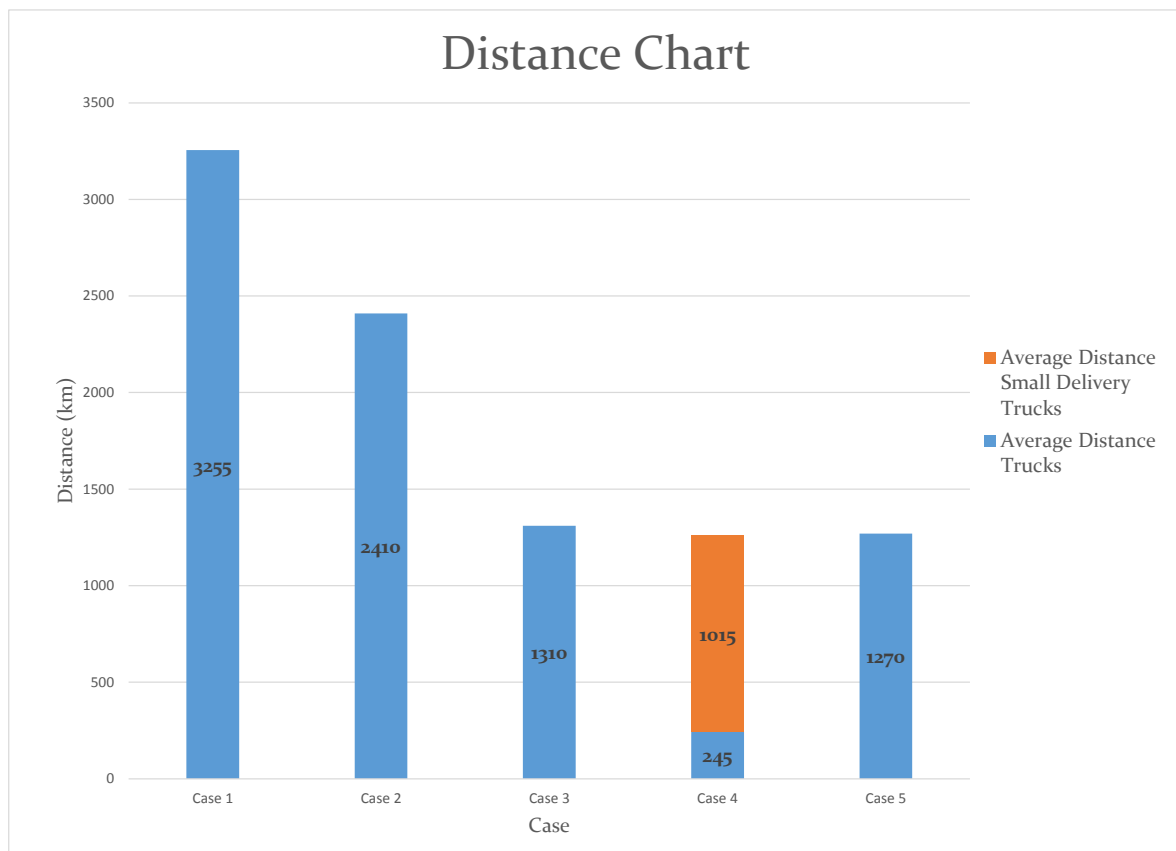

Figure 8: . Distance based performance of each simulated scenario

Figure 11 shows the fuel, labor and total cost of each scenario. Both labor and fuel costs are reduced dramatically in Physical internet scenarios. Interestingly, although labor cost is more than twice the fuel cost in all scenarios and therefore the size of reduction is larger in labor cost, the percentage reduction is larger in fuel cost. Most of the cost reductions are owing to the reduced

travel distance. However, in scenario 4, although the total travel distance is similar to that of scenario 3 and 5, the total cost is smaller as more fuel efficient small delivery trucks are utilized.

Another interesting development, especially for firms who wish to be environmentally friendly, is the strong correlation between the dropping of fuel costs as the scenarios become more and more hyperconnected. Clearly, the less money spent on fuel mean the less greenhouse gas emitted, and in today's environmentally aware society carries more and more weight.
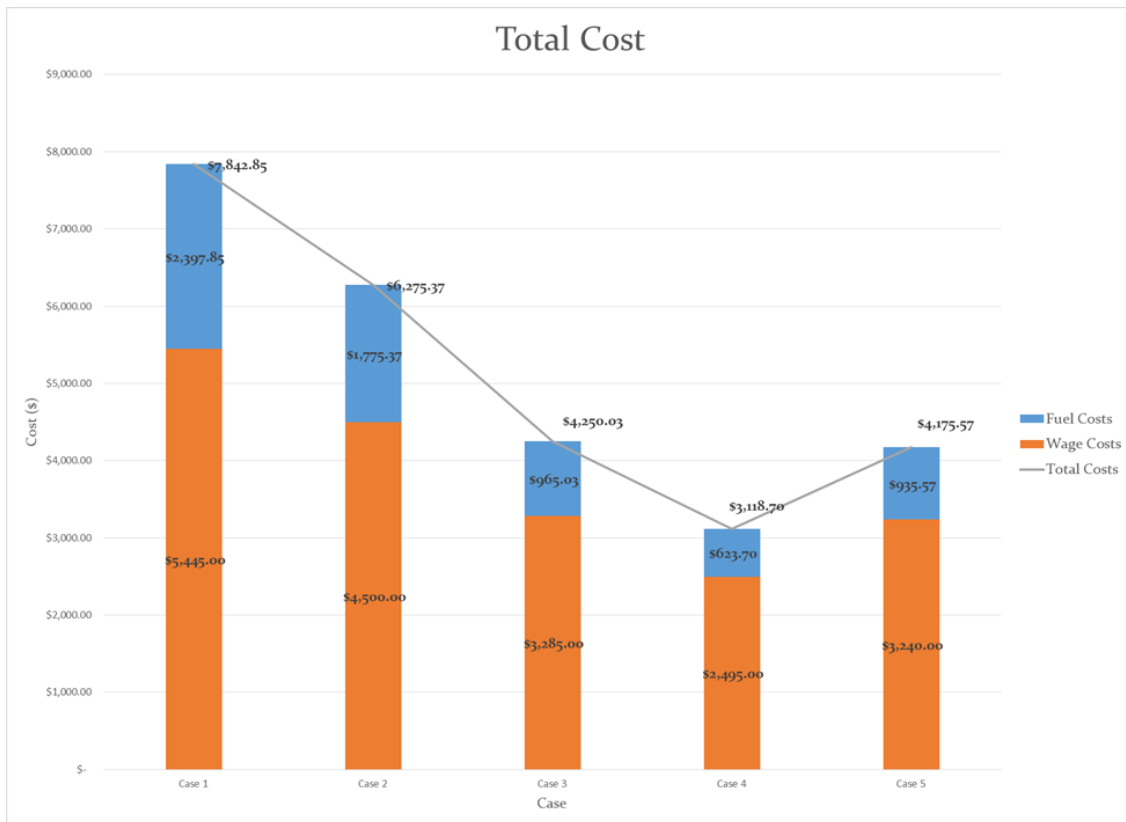

Figure 9: The Total Cost Broken Down into Wage and Fuel Cost by Scenario

Scenario 1 is the most expensive and the least efficient in regards to the total cost and total distance. On the other hand, the progression of savings increases as the supply chain becomes more and more hyperconnected. Even by taking a small step towards a hyperconnected supply chain as in Scenario 2, the cost, travel distance and truck time are reduced by 20%, 26%, and 17% on average respectively. The savings mainly come from fuel cost as delivery assets are not shared.

Scenario 3, which induces sizable savings, improves upon Scenario 2 by allowing shared distribution. This next step toward the hyperconnected supply chain substantially improves the performance and savings presented by Scenario 2. Although the routing algorithm remains the same, deliveries made per driving mile increase dramatically due to increased demand density. This is in line with the results of Boyer et al. (2009). However, the impact of higher demand density can be more significant in furniture and large appliances industry as there is less delivery for these items compared to small parcels. As displayed in Figure 12, the percentages of savings for truck time and total cost increased to over 40%, and the distance saved is 60% when compared to Scenario 1. This result is very encouraging, especially considering the fact the scenario just changed how to utilize existing resources, not adding or rebuilding any infrastructure. However, with a few tweaks to Scenario 3 there are even more potential savings.
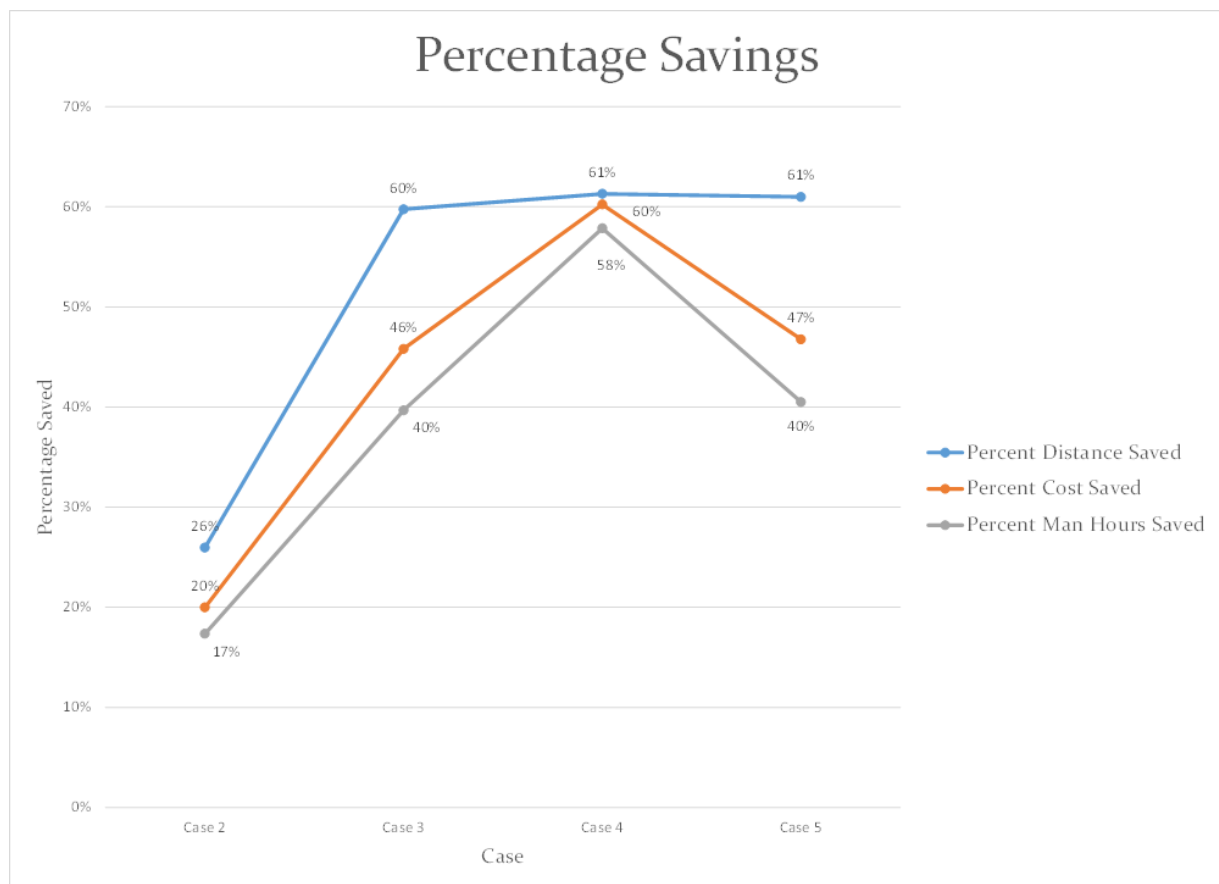
Figure 10: Percentage Savings of Scenarios 2-5 Compared to Scenario 1

Scenario 5 is targeted to examine the effect of introducing an extra DC. Interestingly enough, the centrally located DC improves the total cost of the current method of operation by around 47%, but only improved Scenario 3 by 1-2%. This marginal improvement would not be worth the investment of constructing a new DC in the middle of a major city. It is believed that the reason there is only a slight improvement from Scenario 3 to Scenario 5 is because the customer destinations that are taken by the new DC would not create that much more distance and cost to be absorbed into the current routes from the original DC. This model proves that it is not necessary to invest millions of dollars into the supply chain to make it more efficient.

The most conceptually advanced scenario is Scenario 4. This scenario, starting from the setting of Scenario 3, introduces 16 possible mobile cross dock locations. Scenario 4 achieves savings in cost due to the use of small delivery trucks as opposed to the fuel inefficient larger trucks. The distance traveled for Scenario 4 and Scenario 3 is extremely close, but with the smaller and more fuel efficient delivery trucks, Scenario 4 is not only a more cost effective option, but also a more environmentally friendly. The limitation to even further gains in Scenario 4 is the small delivery truck's ability to fit a substantial amount of customer destinations within their routes, which limits the capability to take advantage of economies of scale.

Overall, the conceptual sophistication of scenario 4 enables it to achieve the greatest percentage of savings in Total Cost when compared to Scenario 1 (60%), and is the more environmentally friendly option.

5   Conclusion

The exploratory work and results presented in this paper can potentially act as a foundation for further research on hyperconnected supply chains and a catalyzer for innovation toward the implementation of the Physical Internet and its exploitation, notably in the furniture and appliance industry.

The results are stimulating as the percentage savings increased with a strong positive correlation with every step that was taken towards a hyperconnected supply chain. There is potential to reduce traffic in the city and negative environmental impact caused by last mile deliveries. Even with the smallest effort to share storage caused the travel distance and cost savings to meet or exceed 20%. Going a step further and sharing distribution created even larger savings in all three of the savings areas.

The scenarios presented are the simplest and most implementable ones theorized in the path to becoming fully hyperconnected, and they already show highly significant gains for each and every party involved. The savings projected in these scenarios are obtainable, and the path to realizing these savings is becoming clearer every day. Moreover, although the study is focused on the specific furniture and appliance industry, it is conjectures that the results can be easily expanded to other industries. Even the results itself can provide good insight to all types of home deliveries.

Every model outlined in this paper constitutes a thorough and precise depiction of real life scenarios. There are, however, a few avenues that should be revisited by future works.

First is the development of more real life constraints. These constraints should include but not be limited to the volume, weight and time capacity of trucks and DC's, integrating electric vehicles once the range is respectable enough to be viable, and using a simulated road system instead of direct path from destination to destination. Most importantly, inventories are not considered in this delivery focused study. In subsequent studies, it would be highly pertinent to explicitly treat inventory and its availability, affecting the feasibility of routing products from DCs, testing whether high routing efficiency can be achieved without requiring significant increases in inventory levels.

Second is the betterment of the vehicle routing heuristic. Another heuristic or exact vehicle routing model can be used to generate better solutions than that from local neighborhood search with a greedy nearest neighbor heuristic. Also, advanced analytic methodologies such as data mining can be used, for example, as suggested by Ehmke et al. (2012).

Third, the generation of demand can better represent real world by generating stochastic demand based on probabilistic distributions, rather than imposing a fixed number of customers per day as was simply done here.. Time windows for deliveries could be added to the model as well.

Fourth is the addition of new scenarios exploring novel improvement avenues. For example, a scenario where delivery and installation are split can be examined.

Fifth is to expand the scope of the project from just focusing on home delivery to implementing a hyperconnected supply chain throughout the entire network, from manufacturers to last mile.

Finally, sixth is to rigorously assess the impact of Physical Internet to home deliveries in a specific real city. This requires to deal with the specific characteristics of the city, such as its demand pattern, its geography and its infrastructure..

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Appendix

Table 1 shows cost parameters used in the model.

Table 1: Cost parameters

Category	Subcategory	Cost	Source
Wage	Local Truck Driver	20 $/hr	http://www.theglobeandmail.com/report-on-business/careers/career-advice/i-want-to-be-a-truck-driver-what-will-my-salary-be/article22752104/
	Truck Driver Assistant	10 $/hr	
	Furniture Installer	15 $/hr	http://www.wowjobs.ca/salary-office+furniture+installer
	Furniture Installer Assistant	10 $/hr	
Fuel Efficiency	Truck	6 mpg	https://www.fueleconomy.gov/feg/noframes/33148.shtml
	Small Delivery Truck	13.1 mpg	http://www.nrel.gov/docs/fy10osti/44134.pdf
	Small Vehicle	39 mpg	http://www.edf.org/blog/2014/05/07/trucks-delivering-six-miles-gallon-wont-work-long-haul
Fuel Price	Diesel	4.40 CAD/Gallon	http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/econ154b-eng.htm
	Gasoline	4.65 CAD/Gallon	http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/econ154a-eng.htm