IMPACT OF RESOURCE SHARING OF FREIGHT TRANSPORTATION

Pedro Furtado, Polytechnique Montréal and CIRRELT - Interuniversity Research Center
Jean-Marc Frayret Polytechnique Montréal and CIRRELT - Interuniversity Research Center

Introduction

In an increasingly global world, optimizing the flow of materials and products is an activity that concerns everyone involved, from industry, consumers, to road users. In this context, companies must provide transportation services for a variety of products, seeking to meet the principles of sustainable development while minimizing operational costs. It is based on these rules and requirements that the emerging concept of Physical Internet (PI, π) was initiated. The Physical Internet is an innovative, ground-breaking transportation philosophy. Its principles are based on the assumption that current logistics networks are unsustainable. Therefore, one of the basic assumptions of a PI network is the sharing of infrastructures, including transportation hubs, warehouse, hauling capacity, containers, among its participating members.

Based on some of those PI assumptions, this paper is founded on the collaborative transportation system between its agents for increasing and optimizing the efficiency of a distribution transportation system. (van Weele 1999, Meller 2012) discovered that the collaborative logistics refers to the practice of two or more organizations collaborating to increase the logistics performance of each organization, within a certain balance of power between them.

This collaborative transportation has as fundamental principle the resource sharing. It means the assets of the network, like the containers, and the trucks and truckers that will be shared between all players (hubs). According to Polenske (2004), in collaborative agreements, the firms tend to gain unique and often unequal access to some of these resources; and this can explain the motivation of firms to collaborate to not only improve performance by reducing costs but also by expanding and controlling the market Ferrer (2010).

Supported by those assumptions, this paper will present a comparison between traditional and shared resource freight transportation. Both models will be implemented in a simulation platform using NetLogo, and tested in various condition and scenario configurations. The results will be analyzed and compared between the models by some social, economic, environmental and operational performance indicators.

The paper is set out as follows. Initially, we present the transportation models, then the concept of agent-based technology and presents further details and parameters of the simulation. In the fourth section it's the experiments, its designs, and the analysis of the results. The last section presents the conclusion.

Transportation models

Both models use same hypotheses, like the hub’s location, the container demand generation, the kind of the truck and the transport fees. Other hypotheses are specifically to each one of the models.

The hubs' locations are based in the Quebec, Ontario and New England major cities. They are therefore located using their latitude and longitude data, and the distances of each arc are determined using the Mercator projection. So the availability of trucks (and truckers) at each hub is also based on the size of population, with the larger cities having more trucks available for hauling.

The container demand generation is based on the population of each city, because every city has a hub. It is understood that the cities with the highest population will demand more products and the origin of such transport is random. Each container has a capacity of 40 tons, and those transportations network only considers Full Truck Load (FTL) transportation. The used truck will be a road train, and it will travel at a speed of 100km/h. The determination of speed is important to calculate the travel time of each arc.

On a different token, transport fees are calculated using two different elements. First, the fee contains a fixed cost and variable costs. The variable cost is a function of the number of kilometers traveled ($/km.container). This is a simplification of reality in which costs in North America are calculated according to complex tables, and a function of the origin and destination states. In this version of the simulation model, the notion of priority is only associated to the delivery date.

One of the general hypothesis of the resource sharing transportation model is that each arc has a distance of no more than 3 hours of transportation in order to allow drivers to make a round-trip in 8 hours (traditionally a day of work), and the truckers have 8-hour shifts distributed randomly within the day, according to the normal distribution. Most truckers have day shifts, although the transportation network operates 24 hours. As we have already said, the hubs' locations are based on the Québec, Ontario and New England major cities. Other hypothesis is the trucks can haul 1 or 2 containers, like a consolidation.

Based on the previous hypothesizes, in the resource sharing model, companies need to send a full container (i.e., container) to their customers. In order to do so, they express their need to the nearest hub (referred to as the origin hub), which is responsible to find a truck willing to transport their container. Transportation needs contain a specific number of containers (i.e., 1 or 2 containers) to transport to a destination (referred to as the destination hub), and a delivery date.

In this proposed model, routes are planned both in a centralized and decentralized manner. In other word, when a container arrives at a hub, this hub calculates the fastest routes towards the final hubs. To do so, it considers all possible routes through the entire network. However, only the road segment to the next hub are actually planned and implemented. When the container arrives at the next hub, the route is similarly planned again, and so on and so forth until the container reaches the final destination hub. In order to calculate the fastest routes towards the destination, hubs use the Dijkstra algorithm (i.e., shortest path) based on the total transportation time, which includes the travel time and the processing time for handling containers in the hubs along the routes. The processing time for handling containers is dynamically estimated by each hub taking into account the handling capacity of the hub and the number of container to process. This estimated waiting time is regularly updated and communicated to all hubs in order to let them know dynamically the processing time containers have to wait. In other words, instead of calculating the shortest route to destination, routes are calculated based on the shortest time to achieve the final destination taking into account the actual congestion in the different hubs.

Along the same token, in order to model the natural ability of a resource sharing transportation network to improve truck efficiency, instead of returning with no container to their origin hub, trucks have the possibility to wait for an opportunity to haul another container on their way back. More specifically, truckers have two levels of willingness to wait for another container for backhauling. At the first level, they return as soon as the initial container is delivered, and general, they return hauling no container (referred to as empty return). At the second level, trucks wait for another container to haul up to 1 hour, thereby increase the probability of returning to their origin hauling a container.

When a container arrives at its destination, if there is enough time left in the work shift of the trucker, the truck can be assigned to another trip to transport another container to the origin hub of the truck. In other words, when a container is delivered, its management is not tackled in this model. This aspect of the model will eventually take into account a more detailed description of the last miles delivery of containers. This will include the option of leaving the containers at its final destination, which will be different of the destination hub.

In the business model proposed in this simulation model, the origin hub, to which demand is expressed, is paid by the client, and it gives a portion of its revenue to the intermediate hubs used to transport the container. The payment to the intermediate hub is based on fixed transit costs (i.e., cost of processing the trailer/container). This transit cost is calculated as an average cost per container carried to an intermediate hub, which includes the cost of handling containers, the cost of storing containers, and the cost of planning (i.e., administrative cost).

The first difference between the two models is the creation of trucks. Indeed, first of all, the amount per hub depends only of the size of the city and of its position in the network. It will of course keep the same total of trucks across the network to enable a comparison of the results of the two models.

In the traditional model, we consider that the trips are associated with a single container. A container will be transported by the same truck from its origin to its destination. The truck doesn't stop in the intermediate hubs and may do the backhauling to not return empty.

Unlike resource sharing model, trucks do not belong to a single hub, but belong to a zone that has several hubs. These are actually hubs lying within "Zone_km". So when looking for containers, trucks can fetch containers in other hubs of their area. The trucks cannot do the consolidation.

Transportation planning is fully centralized. That is, the original hub plans the full trip until the load reaches the final hub.

Simulation Model

This section first introduces the notion of agent-based technology, which is the technology used to implement this transportation model.

Next, the general architecture of the agent-base simulation is presented. Finally, a last sub-section is dedicated to parameters definition

According to Frayret (2012), Multi-Agent Systems (MAS) technology involves different technological paradigms and models used to create intelligence as an emergent feature of the complex interactions of, often simple, entities referred to as software agents. MAS technology is useful for simulating different systems related to economics, social sciences, as well as biological and engineering sciences. Conte (1997) affirms that it is particularly useful where the structure of a system of simulation can be modeled as a network. With MAS technology, it is possible to implement and simulate systems and environments in order to explore future scenarios, explore potential alternative decisions, and determine probable outcome and trends (Axelrod 1997). It is also possible to model entities with simple behavior with predefined responses to stimuli, or entities with much more complex behavior capable of intelligently apply rules or goal-oriented actions according to non-programmed situations. This general modeling philosophy is used in the specific modeling of this transportation system. Consequently, MAS technology is appropriate for modeling supply chain management problems, which are naturally distributed and complex (Ahn and Lee 2004).

This model is based on the interaction of various components (i.e., agents and objects), each having various levels of autonomy (i.e., control over its own actions) and different perception (i.e., ability to perceive certain information) of the environment. Agents are divided into external (i.e., customers) and internal (i.e., hubs, trucks/trucker) agents. The routes, routes segments and containers are simple objects with no behavior, but they represent the structure of the data to be used by the agents, and they do not make decisions. They are created dynamically as needed. The agents and objects communicate with each other through shared global data and variables.

In order to analyze the feasibility and the performance of the proposed transportation models (resource sharing and traditional), two virtual models were implemented and simulated using an agent-based simulation tool. More specifically, we designed a virtual network based on general shipping data between the Canadian provinces of Quebec and Ontario, and the U.S. states of Rhode Island, Massachusetts, New Hampshire, Pennsylvania, Vermont, Maine, and New York. According to RITA (2012), these states and provinces accounted for 16.13% of the value of the trade between the two countries in 2010. Similarly, Canada (2012) presents that the Canadians highways transported 82.7 million tonnes in exports and imports in 2009, which represent 82% of the 2010 road's trade between the two countries. Therefore, we estimated that 82% x 82.700.000 x 16.13% = 10.94 million tonnes of goods are moved by truck in this region. Considering that a container has a capacity of 40 tonnes, this region moved almost 28 million containers. Therefore, based on the hypothesis presented earlier, which states that demand for container transportation is based on population, we extrapolate the average demand for each city/hub, by splitting the 28 million containers proportionally. Therefore, larger cities generate higher demand for transportation.

After demand was estimated for each hub, we similarly estimated the fleet size and the hubs' capacity to process containers. In order to follow the same logic, the number of trucks at a hub is directly proportional to the population size. As the trips in traditional transport are directs, without stops at the intermediate hubs, the hubs' capacity are only considered for the resource sharing transportation model. Concerning the hubs' capacity to process container, the problem is rather different, and as important as defining fleet size. Indeed, if there is not enough capacity to process containers, performance will be artificially low. Therefore, in order to make sure that each hub possesses enough, although reasonable, process capacity, a different approach was used. More specifically, due to the characteristics of a resource sharing network, the number of containers/container passing through any hub depends on both the size of global demand and the centrality of its position in the network. In order to take this into account, we estimated the centrality of each hub using the number of road leading to them. Therefore, both capacities were chosen in order to represent a realistic transportation network with a capacity that is in a state of equilibrium with demand. The capacity is fixed during each simulation runs.

We use different measures and performance indicators used to analyze the scenarios. These variables were directly programmed in the NetLogo platform and accumulated during the entire simulation horizon. These measures include logistic performance indicators, cost indicators, social indicators, as well as environmental indicator.

Several authors (Pels and Rietveld (2000); Novaes (2007); Bowersox, Closs et al. (2008)) consider that cost comparison constitutes a way to understand and determine transport efficiency. However, according to Alvarenga and Novaes (2000), it is also necessary to compare service times, damaged good rate, as well as delivery errors. Still, Ballot and Fontane (2008) affirms that it should considered the cost of downtime caused by a rupture of stock. Taking this into account, this paper presents four other performance indicators. First, total cost is calculated as the sum of the fixed transportation cost, the variable transportation cost and the processing cost in hubs. The fixed cost is allocated to each transport demands. The variable cost is calculated as a rate $/km traveled per container, including fuel costs per km and the remuneration of truck drivers. Finally, the transit cost is calculated as an average cost per container, including the cost of maintenance and storage of container and administrative costs.

Beyond the total cost indicator, the other indicators include logistic performance indicators, social indicators, as well as environmental indicator. Logistic performance indicators include: the number of containers in transit (e.g., containers in driving and waiting states at any given time); the number of empty and loaded trucks (whether or not containers are consolidated); the total distance traveled empty and loaded (km); the on-time delivery (Fill rate); the fleet efficiency (ratio of the number of loaded trips vs. the number of trips); and the average delay (hours).

The social performance indicator is mainly represented by the percentage of time spent at home per truck driver, which the ratio between the amount of hours at home and the amount of hours in 1 week (192 hours).

Finally, the environmental performance indicator is represented by the amount of greenhouse gas (GHG) emissions. It is calculated according to Equation (1) as a quantity of CO2 per useful traveled distance in km.container equivalent (i.e., a hauling of one container over one km). It was calculated according to statistics corresponding that an average road train emission, which is 2.7 KgCO2 GHG per liter (Canada 2012). Furthermore, a truck hauling two containers uses 17% more gas than an empty truck, and 14% more than a truck hauling one container ((Canada 2011, Canada 2012, Canada 2012).

$$kg\ CO_2\ per\ km.container = \frac{CO_2(empty) + CO_2(non_{consolidated}) + CO_2(consolidated)}{((1 - \%consolidated) + 2 * \%consoli\ dated) * Distance\ (loaded)} \quad (1)$$

Experiments

In order to study the performance of various configurations of such a transportation network, we selected two configuration parameters that are the same between the models: demand level and fleet size. The first parameter is fixed at 10% of the total demand and the second is fixed at 100% of the total fleet.

The following parameters belong exclusively to the resource sharing model. The first parameter concerns the notion of consolidation. Based on Meller (2012), the level of consolidation is 57%. The second parameter studies the impact of the trucker’s willingness to wait before he comes back hauling a container at a hub. We established two levels of willingness to wait: no willingness to wait and willingness to wait between 0 and 1 hour.

The traditional model’s exclusive parameter is linked to the backhauling; the Zone_Km. It means that each trucker can search for a container before returning to his original area. The first zone is 100km, the second 150km, and the last one 200km.

Those five scenarios, 2 for the resource sharing model and 3 scenarios for the traditional model, were simulated 100 times for a total of 500 simulation runs and we used the average results. We simulated an eight days experience, including one day as warm-up. So, we have one week experience for each scenario. To validate the results, we did the variable analyze test, and all the results were accepted.

The first step to compare the results was to validate the traditional model. So, based on Meller (2012), 75% of the fleet (randomly generated) that can do the backhauling, we compare the percentages of empty trips by distance and by paths (Table 1), and it’s logical to accept the traditional model, because comparing the KPI results with the literature, we see that all the results are around 25%.

Table 1: Processing capacity and fleet size of each Hub

KPI/Scenario	*100km*	*150km*	*200km*
% Empty Trip (per km)	*26.62%*	*29.45%*	*29.47%*
% Empty Trip (per path)	*29.75%*	*28.98%*	*28.39%*

After validate the traditional model, we compare those three scenarios with the resource sharing scenarios.

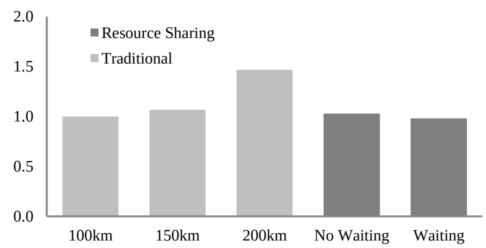
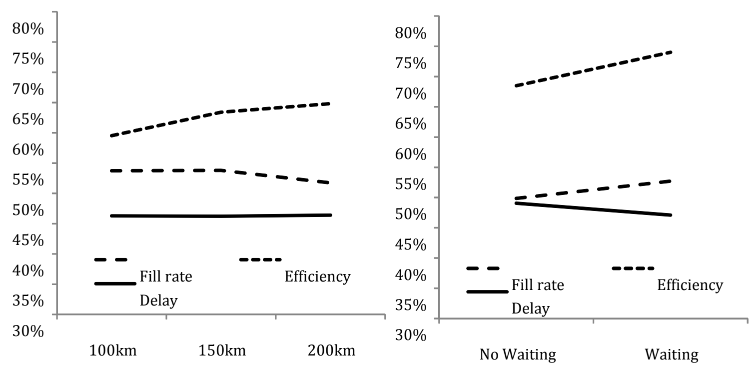


Figure 1: Normalized unit operation Cost

In Figure 1, we used the cost of the traditional model for a backhauling zone size of 100km as a reference. First, the graph shows that unit cost increases for the traditional model as the backhauling zone size increases. This is normal because the increased distance to pick-up a container for backhauling impacts directly the unit cost. Next, the unit cost of the resource-sharing scenario without waiting time is higher by 3%. However this cost is lower by 2% when truck drivers are willing to wait, which increases backhauling opportunity. Furthermore, the average cost of resource-sharing scenarios represents respectively 94% and 68% of the cost of the traditional scenarios with a backhauling zone respectively 150km and 200km. The main economic benefit of resource-sharing occurs because in the traditional model, the total distance traveled is on average 23% higher for an equivalent number of containers.



(a) Traditional transportation model (b) Resource sharing transportation model

Figure 2: Delay, Fill rate and Efficiency as a function of backhauling zone size and willingness to wait.

Concerning the fill rate, the average for the traditional transportation model is slightly better (53%) than the average for the resource-sharing transportation (51%), although it is not really significant. This is consistent with the previous results. This result can be attributed to the container processing time and the wait at intermediate hubs, which slightly increase the total travel time. These extra operations do not exist in the traditional model.

Finally, concerning efficiency, which is a quality performance indicator connected to truck utilization, resource-sharing have, as expected, better results than the traditional transportation model. Scenarios when drivers are willing to wait have an even better efficiency (>70%), because it significantly increases backhauling opportunity. Again, the traditional transportation model with a larger backhauling zone size has better results (65%) for the same reason. However, increasing the backhauling size does not increase efficiency linearly. The further the truck must go to pick-up a container, the less efficient the route is.

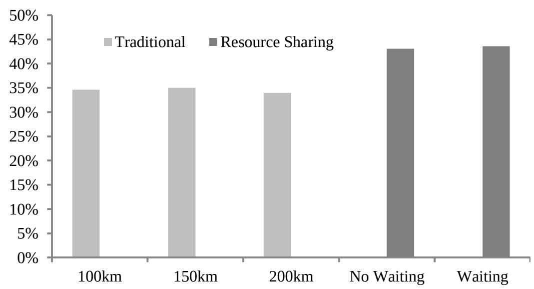


Figure 3: Time spent at home as a function of backhauling zone size and willingness to wait.

As far as the social indicator is concerned (Figure 3), the percentage of time spent at home per truck driver is significantly higher (25%) with the resource-sharing model. Because truck drivers make shorter trips in the resource-sharing model, this latter is more socially friendly than the traditional transport.

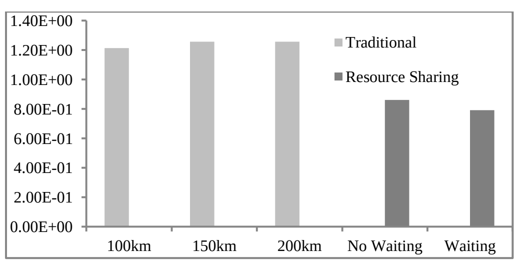


Figure 4: GHG Emission (kgCo2/truck) as a function of backhauling zone size and willingness to wait.

Finally, the environmental indicator (Figure 4), the resource-sharing models generate significantly less GHG per km.container than the traditional model with an average of 33% reduction. GHG emission calculation is based on gas consumption and the total distance traveled (empty and loaded). On average, the distance traveled in the resource-sharing model is 21% lower. Therefore, increased efficiency and consolidation leads to significantly lower GHG emissions.

Consequently, for an equivalent logistic performance and cost, the proposed resource-sharing transportation model has significantly better results with respect to environmental and social performance than the traditional transportation model. The next section analyzes the specific impact of various parameters of resource-sharing on performance.

Conclusion

The Physical Internet (PI) is a ground-breaking transportation philosophy. It provides a very innovative way to redesign and operate the transportation industry all around the world. Its principles are based on the assumption that current logistics networks are unsustainable.

The study presented in this paper provides an analysis of various performance indicators of a simple implementation of the PI philosophy. To do so, this article presents a freight transportation model based on the resource sharing methodology. As suggested by the PI general principles, this model is based on the distribution of road transportation services. Based on this idea, instead of hauling containers from origin to destination using a single tractor, freight is hauled from hub-to-hub, using different tractors allocated to one specific hub. This model also considers the possibility to consolidate two containers into a road train. The impact of the resource sharing and distribution transport on drivers' working conditions is significant, as they only offer their service within a limited area. This model also offers the ability to adjust transportation flows according to hubs' waiting time to process containers. This model was implemented into a simulation platform using NetLogo, and tested in various conditions of demand and design configurations.

The results indicate that resource sharing transportation improve the financial, operational, social and environmental performance of a transport operation, more than the traditional model, so it’s important to the following developments of physical internet methodology.

References

Ahn, H. J. and H. Lee (2004). "An Agent-Based Dynamic Information Network for Supply Chain Management." BT Technology Journal **22**(2): 18-27.

Alvarenga, A. C. and A. G. Novaes (2000). Logística Aplicada: Suprimentos e Distribuição Física. Brésil, 3ième éd., Edgard Blücher.

Axelrod, R. (1997). The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration Princeton, N.J, Princeton University Press

Ballot, E. and F. Fontane (2008). "Rendement et efficience du transport: un nouvel indicateur de performance." Revue Française de Gestion Industrielle(27).

Bowersox, D., et al. (2008). Gestão da Cadeia de Suprimentos. Brésil, 2ième éd, Campus.

Canada, E. (2012). National Inventory Report - GREENHOUSE GAS SOURCES AND SINKS IN CANADA. Gatineau(Canada), Environment Canada**:** 16.

Canada, T. (2011). Transportation in Canada 2011 - Statistical Addendum. Ottawa**:** 194.

Canada, T. (2012). Auxiliary Power Units (APU) Calculator User Guide. T. Canada. Ottawa, Transport Canada.

Conte, R. H., R. Terna, P. (1997). Simulating social phenomena. Berlin, Springer-Verlag.

Ferrer, M. S., Ricardo; Hyland, Paul W.; Bretherto, Phil (2010). "Relational factors that explain supply chain relationships." Asia Pacific Journal of Marketing and Logistics **22**(3): 22.

Frayret, J. M. (2012) Multi-Agent System applications in the forest products industry. Journal of Science & Technology for Forest Products and Processes. **1**,

Meller, R. D. E., K. P. & Loftis, B. (2012). From Horizontal Collaboration to the Physical Internet: Quantifying the Effects on Sustainability and Profits When Shifting to Interconnected Logistics Systems. Final Research Report of the CELDi Physical Internet Project, Phase I, CELDI. **1**.

Novaes, A. G. (2007). Logística e Gerenciamento da Cadeia de Distribuição: Estratégia, Operação e Avaliação. Brésil, 3ième éd., Campus.

Pels, E. and P. Rietveld (2000). Cost Functions in Transport. Handbook of Transportation Modeling, Permagon**:** 321-333.

Polenske, K. (2004). "Competition, Collaboration and Cooperation: An Uneasy Triangle in Networks of Firms and Regions." Regional Studies **38**(9): 15.

RITA (2012). North American Transborder Freight Data: Main Search Page. Washington, Research and Innovative Technology Administration - Bureau of Transportation Statistics.

van Weele, A. a. R., F.A. (1999). The role of power in partnership relationships: An empirical investigation of current body of knowledge. Proceedings of the 8th International Annual IPSERA Conference, Belfast-Dublin.