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SIMULATION AND ANALYSIS OF APHYSICAL INTERNET NETWORK THROUGH MULTI-AGENT SYSTEMS

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SIMULATION AND ANALYSIS OF A PHYSICAL INTERNET NETWORK THROUGH MULTI-AGENT SYSTEMS

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ABSTRACT

This article presents a simulation of a transportation network with the concept of Physical Internet and an analysis of their efficiency through indicators of performance. The simulation was done with the software NetLogo using the concept of multi-agent simulation. As it is a new concept, a presentation of the Physical Internet and an explanation of the use of multi-agent simulation in comparison with classical methods had been made.

Keywords: physical internet, multi-agents, simulation, logistics, road transportation, container, consolidation, hub, performance Indicators

1. INTRODUCTION

In an increasingly global world, optimizing the flow of materials and products is an activity that interests everyone involved. Most times, companies must provide transportation 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) was created. The PI is an initiative that offers an innovative and sustainable solution to global problems related to the way we transport, handle, store, produce, deliver and use physical objects in the world (Montreuil 2010). So this is a macroscopic, holistic, and systemic view providing a unifying, provocative, and stimulating framework.

After World War II, the world of business began a movement of dependency towards transportation and logistics. The cost of freight has grown exponentially in Europe, US, and others wealthy countries and regions. For example, in France, according to estimates between the years 2005 and 2025, the growth rate in cost of freight will be 37% and progression is the same for the other OECD countries (OECD/ITF, 2008). It is important to note that there is a direct link between the dependency towards transportation and the increase in emissions of greenhouse gases (GHG). In developing countries the transport is responsible for around 15% of emissions of GHG (OECD/IEA, 2008).

The way physical objects are currently transported, handled, stored, realized, supplied and used throughout the world is not sustainable economically, environmentally and socially. Addressing this global unsustainability is a worldwide grand challenge, hereafter termed the global logistics sustainability grand challenge (Montreuil, 2010). Therefore, the PI seeks to solve this problem by enabling the sustainability of these activities. The challenge is therefore to establish a logistics system based on open physical object and digital interconnection of different networks and operations (Montreuil, Rougès et al., 2011).

The main question of this study, therefore, lies in the performance evaluation of a network with the use of conceptual PI. As the concept of PI is brand new, there are not many studies available in the literature regarding the study of a logistics network. Since a PI logistics network doesn't exist, the proposal of a logistics network close to reality is a major challenge in this research. This challenge can be solved by the simulation of a PI logistics network through a multi-agent software like NetLogo, for example.

The theoretical foundation of this paper (section 2) presents the concept used throughout the article and explains the use of multi-agent simulation technique. In section 3, we describe the simulated logistics network for work, but also the application of the software NetLogo. The discussion and analysis of results from the simulation and the performance indicators used, compose section 4. Finally, in section 5, conclusions are drawn, and limitations on work and suggestions for its future deployment will also been presented.

2. STATE OF ART

2.1. Physical Internet

As shown previously, the PI is based on the assumption that current logistics networks are unsustainable and unviable. Based on this idea, one of the fundamentals assumptions of a PI network is the sharing among its member; you can share information (data) and / or objects such as containers, trucks, hubs, warehouses, and networks.

Therefore, it is understood that the deployment of a PI network will inevitably lead to a deep reorganization of logistics and transport networks as well as their resources. In addition, the PI will have a huge impact on how the goods are purchased by people around the world, how the goods will be designed, produced and distributed to cities and families (Montreuil, Rougès et al., 2011).

Montreuil (2010) proposed the 13 main characteristics of PI to facilitate its development:

- Encapsulate merchandises in world-standard smart green modular containers (π-containers);
- Aiming toward universal interconnectivity;
- Evolve from material to π-container handling and storage systems;
- Exploit smart networked containers embedding smart objects;
- Evolve from point-to-point hub-and-spoke transport to distributed multi-segment intermodal transport (π-nodes);
- Embrace a unified multi-tier conceptual framework;
- Activate and exploit an Open Global Supply Web;
- Design products fitting containers with minimal space waste;

- Minimize physical moves and storages by digitally transmitting knowledge and materializing objects as locally as possible;
- Deploy open performance monitoring and capability certifications;
- Prioritize webbed reliability and resilience of networks;
- Stimulate business model innovation;
- Enable open infrastructural innovation.

Still, according to Ballot, Glardon et al. (2010), the 13 characteristics presented by Montreuil (2010) are divided into founding principles of guidance (tools, accountability, systems, openness and universality) and principles of organization (interconnection, consistency, accessibility to the network, singularity, encapsulation, agents, hiring and certification).

Besides the sharing of physical resources and information, other important items of PI are the modular containers of various sizes, the nodes (local facilities and physical systems) and the vehicles carrying or handling the load (Montreuil, Meller et al. 2010).

2.2. Multi-agents Systems

The multi-agent systems (MAS) involve different technological paradigms and models that are used to create intelligence as an emergent feature of the complex interactions of entities in specialized software (Frayret, 2011). The MAS allow the interaction of various elements (agents) characterized by a range of attributes and governed by rules defined in any environment. The MAS can be useful to reproduce many systems related to economics and social sciences, where the structure can be designed through a network (Conte, Hegselmann & Terna, 1997). Through the MAS, it is possible to implement environments to create, foresee and explore future scenarios, experiment potential alternative decisions, determine different values for the variables of decisions and analyze the effects of these changes (Axelrod, 1997).

At an aggregate level, the use of MAS can help understand the general properties and standards concerning all scenarios (Billari, Fent, Prskawetz, & Scheffran, 2006) that cannot be deduced or provided from observation of each agent due to the complexity of the interactions that occurs between elements of the system.

An optimization problem is to find the best solution, according to a given criteria, among a set of feasible solutions. The optimization algorithms are usually step-by-step instructions for troubleshooting. In other words, an optimization algorithm is created to address a problem that can be applied to any other case, the problem to produce a viable solution. Optimization algorithms meeting the exact optimal solution or heuristics to find the best solution is not necessarily the ideal. The heuristics are particularly useful for difficult problems, that is, problems that belong to the class of NP-hard (Burke and Kendall, 2005).

Due to its characteristics, the MAS has recently been used as a promising heuristic technique to solve problems for which domains are distributed, complex, and heterogeneous. As pointed out by Madejski (2007), for the purposes of optimization, MAS can be designed according to a "physical" or a decomposition "functional." In the first case, the agents represent physical entities (e.g., workers, machine tools, resources, vehicles) involved in a specific problem to be solved. The second case is the functional decomposition approach, where there is no relationship between agents and physical entities.

According to Barbati, et al. (2011), in terms of computational time, agent-based approaches may offer some advantages due to their ability to divide problems into sub-problems. However, the computational advantages may be offset by the need of frequent interaction, in order to coordinate the activities in accordance with a given paradigm. Classical approaches have higher computational complexity, but not the costs of communication, as they are characterized by high centralization.

According to Ahn & Lee (2004), based on these characteristics, the MAS could be an interesting approach when the size of the problem is large, when the domain is modular in nature, and when the changes in that domain structure are common. Moreover, the potential of the MAS is also suitable for modeling problems of supply chain management practice, where the analysis and / or optimization results cannot be easily applied, as it is the case of this paper.

3. SIMULATION

3.1. Proposed Model

The proposed model is based on the interaction of various components (agents and objects) composed of several interdependent levels of autonomy and perception of the environment. Agents are divided into external (customers) and internal agents (hubs and trucks/truckers) and the objects are the containers, as well as the routes. Objects are entities that enable the organization of data to be analyzed and unlike agents, they cannot make a decision.

To explain how the interaction takes place between agents and objects, first one needs to determine what the attributes of each agent and object are. The attributes of the hubs are hubs neighbors (intermediated or final), theirs names, populations, demands, and inventories. The truck attributes are the hub for which the trucker works the original hub and the destination hub. The containers have, as attributes; their original and final destination, their delivery time, as well as their route.

It’s also important to mention that transportation planning is fully decentralized; that is, the hub only plans the trip to the next hub, which plans to the next, until the load reaches the final hub.

Figure 1 presents the relationship between the clients, the hubs (Original, Intermediate (s) and Final), and the truckers. This work considers that each trucker has only one truck and vice versa.

The relationship between agents occurs through an open web, like intranet. The client accesses the intranet and requests transportation, informing the amount of containers, destination and the delivery date of each container. With this information, the Hub close to the client, called Original Hub, hires one or more truckers to transport the containers to an Intermediate Hub. Upon receipt of the containers, the Original Hub communicates to the

Intermediate Hub and the Final Hub, through the intranet, the transport characteristics like the quantity of containers (1 or 2), their Final Hub, and their delivery date.

After being informed of the shipping container, the Intermediate Hub plans the sequence path, hiring the trucker who will transport the container to the next hub, following and checking if there is a container to be sent to the previous hub to take advantage of the presence of the trucker and who comes and should return to his Original Hub. This sequence is performed until the arrival of the container to the Final Hub.

The intranet serves as a blackboard, where all information, such as customer location, location of trucks and containers, containers stock level in each Hub, and delivery time of the containers, is available. Thus, hubs can better plan the receipt and the distribution of containers within their clients.

According to Barthes (2007), there are three main advantages to use a blackboard architecture: (1) separate, independent knowledge sources; (2) shared memory; and (3) possibilities of parallel asynchronous processing. Gathering knowledge into separate, independent knowledge sources allows for replacement of knowledge sources or extension by simple addition of new knowledge sources. The shared memory contains all the data, hypotheses, and contextual information used to solve the problem at hand. Inspecting the memory yields an overview of the state of the computation. Finally, knowledge sources can be distributed over several independent processors sharing a common memory, allowing for a simple form of parallel processing which may increase the efficiency of the overall process.

The network is based on cities, on their populations and on their real connections (roads). Those data are imported into OpenJUMP (GIS software) to keep the same ratio of distance between cities using latitude and longitude positions. The shapefiles created by OpenJump are imported into NetLogo.

NetLogo is a free software simulation for MAS, allowing for quick and easy creation of models. It is particularly well suited for modeling complex systems under development over time.

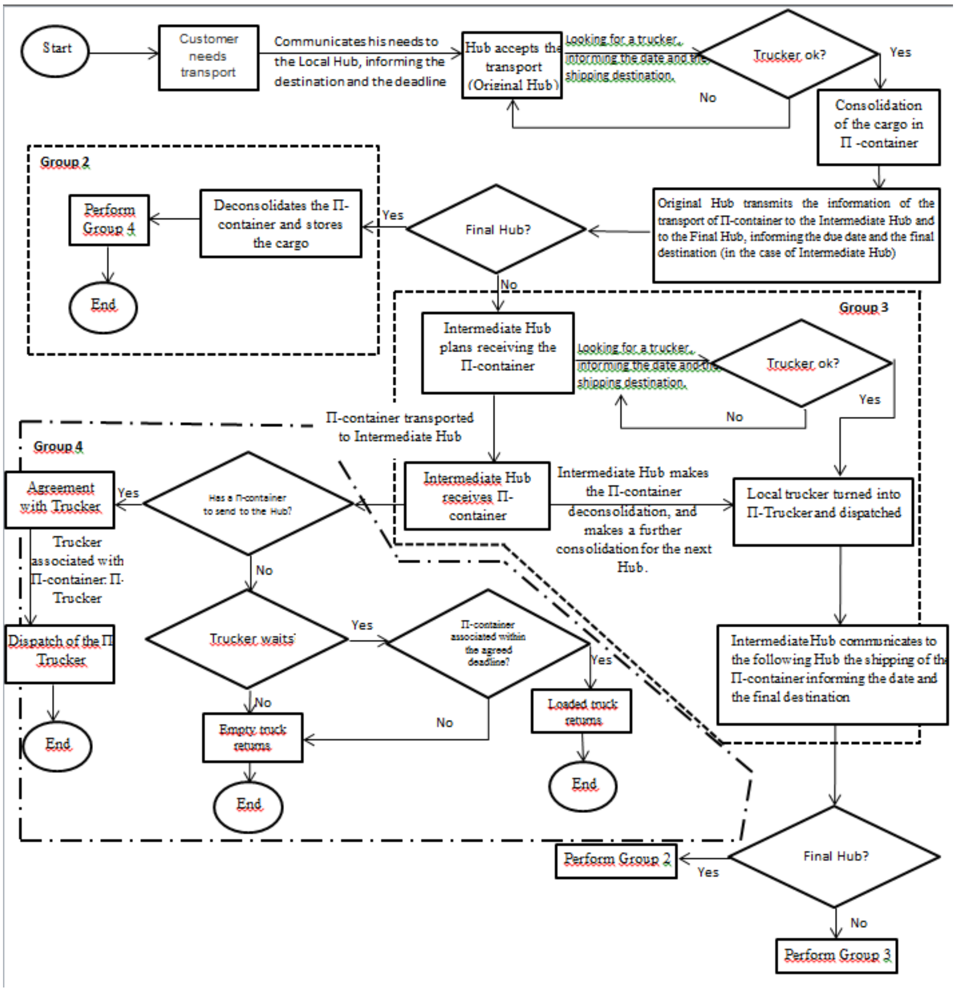

Figure 1 – Flowchart of interactions

3.2. Features of the Model

3.2.1. Transportation Planning

Focusing on the delivery date and the location of the Final Hub, the Original and Intermediate Hubs plan an optimal route based on Dijkstra’s algorithm (shortest path). However, as the transportation planning is decentralized to each Hub, each Hub plans the transportation until the next Hub.

Then, for transporting containers, there are two possible cases. As the truckers are connected to a hub, they can perform the transport of the containers from their Original Hub to the Intermediated Hub and return immediately; they can also choose to wait and join the list of truckers available to transport from this Intermediated Hub back to their Original Hub, thus allowing a loaded truck return.

As previously presented, the truckers are attached to one hub; thus, after delivery, they are required to return to their Original Hub. In an Intermediate Hub, truckers are considered as a potential carrier for their Original Hub. They can wait a while for a container and thus return to their Original Hub, carrying a load.

The management of the contract with the customer is the responsibility of the Original Hub. It is responsible for monitoring the container via blackboard to the Final Hub, interacting with Intermediate Hubs to meet the needs of transportation. This allows every client to follow his transport.

3.2.2. Parameters definition

In order to analyze the feasibility and performance of the proposed transportation model, a virtual model was implemented and simulated using an agent-based simulation tool. More specifically, although there is no PI transportation network actually implemented from which we could draw data, to create a model with realistic parameters, 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 (2010), these states and provinces accounted for 16.13% of the value of the trade between the two countries in 2010. Similarly, the Canadians highways transported 82.7 million tonnes in exports and imports in 2009 (Canada, 2011), 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 millions tonnes of goods are moved by truck in this region. Considering that a trailer has a capacity of 40 tonnes, this region moved almost 28 million trailers. 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 millions trailers proportionally. Therefore, larger cities generate higher demand for transportation.

After demand was estimated for each hub, we similarly estimated the fleet size (supply). In order to follow the same logic, the number of trucks at a hub is directly proportional to the population size. The specific values described in Table I. The next section presents the various scenarios that were simulated, and discuss the general results obtained.

Table I – Demand and Supply Calcul

City	Population	%	Annual Demand	Weekly Demand	Per 3h Period	1% of Demand 3h period (Medium Demand)	Quantity of Trucks - Suply (Medium Fleet)
Quebec	765 706	1,59%	435 270	8 371	149	1	28
Montreal	3 824 221	7,95%	2 173 901	41 806	747	7	142
Ottawa	1 236 324	2,57%	702 796	13 515	241	2	46
Kingston	159 561	0,33%	90 703	1 744	31	1	6
Toronto	5 583 064	11,60%	3 173 726	61 033	1 090	11	207
Buffalo	1 135 509	2,36%	645 487	12 413	222	2	42
Pittsburgh	2 356 285	4,90%	1 339 444	25 759	460	5	87
Altoona	127 089	0,26%	72 244	1 389	25	1	5
Harrisburg	528 892	1,10%	300 652	5 782	103	1	20
Philadelphia	5 965 343	12,40%	3 391 034	65 212	1 165	12	221
New York	18 897 109	39,28%	10 742 173	206 580	3 689	37	699
Albany	870 716	1,81%	494 964	9 519	170	2	32
Plattsburgh	19 989	0,04%	11 363	219	4	1	1
Portland	516 826	1,07%	293 793	5 650	101	1	19
Wilkes-Barre	563 631	1,17%	320 399	6 162	110	1	21
Binghamton	251 725	0,52%	143 095	2 752	49	1	9
Syracuse	662 577	1,38%	376 646	7 243	129	1	25
Boston	4 522 858	9,40%	2 571 045	49 443	883	9	167
Warwick	82 672	0,17%	46 995	904	16	1	3
Concord	42 695	0,09%	24 270	467	8	1	2
Total	**48 112 792**	**100,00%**	**27 350 000**	**525 962**	**9 392**	**98**	**1781**

3.3. Experiences

The first parameter to vary was the consolidation, to allow the truck to transport 1 or 2 containers per trip. The second parameter was to establish the levels of waiting time for truckers in Intermediated Hubs awaiting the determination of the container to transport to their Original Hubs: 0 period, random [0,1] periods and random [0,1,2] periods.

To create demand, two scenarios are possible: medium demand and high demand (110% of the medium demand). In addition, for the creation of supply three scenarios were tested: medium fleet, low fleet (85% of the medium fleet) and high fleet (115% of the medium fleet).

These parameters allow the creation of 27 scenarios, according to Table 2.

Table II -27 Scenarios

	Supply	High			Medium			Low (-15%)		
Consolidation	**Waiting Time \ Demand**	[0]	[0,1]	[0,1,2]	[0]	[0,1]	[0,1,2]	[0]	[0,1]	[0,1,2]
ON	High (+10%)	1	2	3	4	5	6	7	8	9
	Medium	X	X	X	10	11	12	13	14	15
OFF	High (+10%)	16	17	18	19	20	21	X	X	X
	Medium	22	23	24	25	26	27	X	X	X

3.4. NetLogo

As previously shown, NetLogo is a free software which specializes in multi-agent simulation. Figure 2 shows the simulation interface.

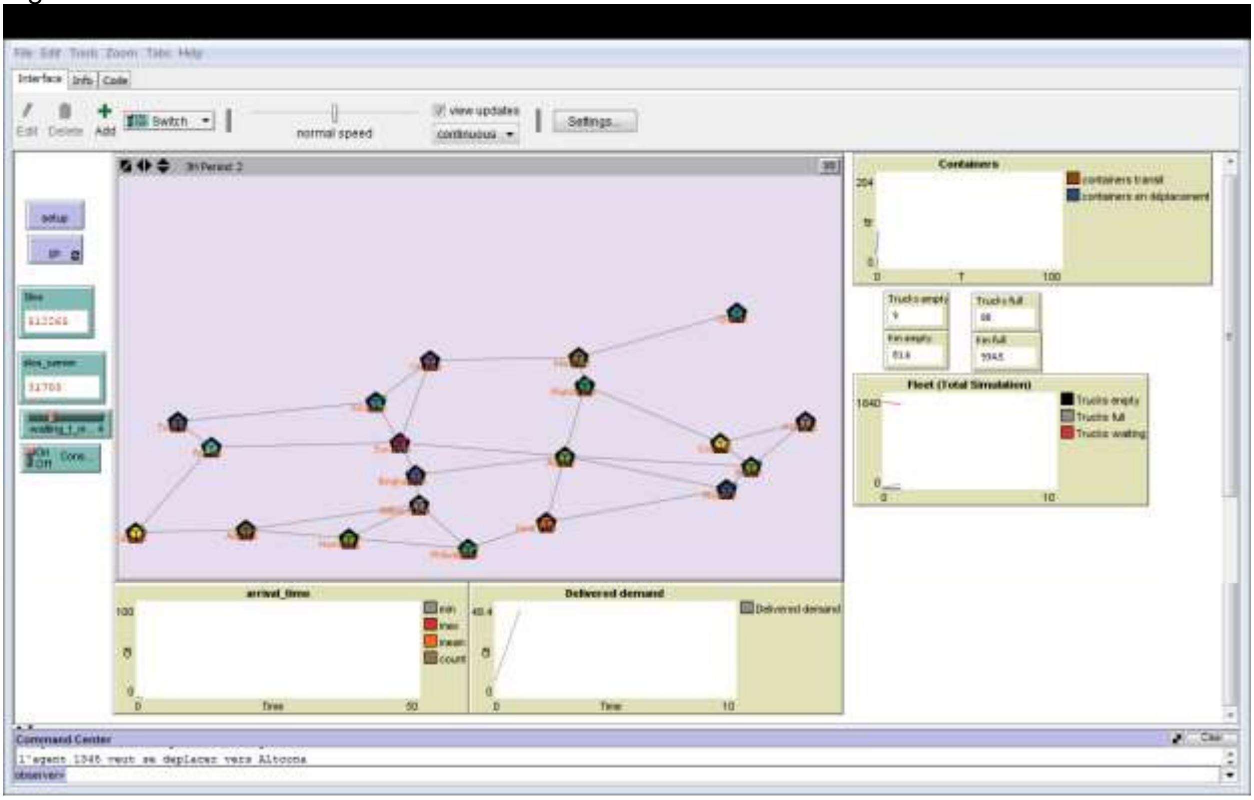

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Figure 2 – NetLogo´s Simulation Screen

The results for each simulation are presented and analyzed in the next section.

4. ANALYSIS OF THE RESULTS

4.1. Performance Indicators

Before presenting the analysis of the results, it is important to specify the measures and the performance indicators used to analyze the various scenarios. Several variables have been set in NetLogo allowing to measure certain data and to contribute to the validation of network performance. Thus, for each simulated scenario and each period, the following variables were accounted: containers in transit (in standby in the Intermediates Hubs) and containers traveling; amount of empty and loaded trucks (whether or not they were in consolidation); distance per empty and loaded truck (km); demand delivered on delay and maximum, minimum, and average delay times.

Several authors estimate that to measure and to compare costs constitute a way to understand and determine the efficiency of transport (Pels and Rietveld, 2000), (Novaes, 2007), (Bowersox, Closs et al., 2008). However, according to Alvarenga and Novaes (2000) it is also necessary to compare the times of services, the rate of goods which were damaged during transportation and delivery errors. Still according to Ballot and Fontane (2008), the cost of downtime caused by a rupture of stock should be considered.

Taking all points of view into account, this paper presents four performance indicators.

4.1.1. Network Total Cost

The calculation was done as follows: Σ (Fixed transportation cost + variable transportation cost + transit cost). The fixed cost is allocated to each transport demand, covering the costs of the trucks (fleet maintenance, depreciation, insurance) and administrative costs. The variable cost is calculated as a rate $ / km traveled per container, including fuel costs per km and the remuneration of the trucker. Finally, the transit cost is calculated as an average cost per container carried to an Intermediate Hub, including the cost of maintenance and storage of containers in Intermediate Hubs and the planning cost (administrative cost).

The fixed costs are:
(cost_tires($646) + maintenance_cost($0,13) + fixed_charges($981) + depreciation($260)) x total fleet Equation1

The cost of tires was calculated considering a road train uses 16 tires, every 130.000 km, and it makes three tire setups during the simulation. Each new tire costs $ 700 (Logistics Solutions Builders, 2005). The maintenance cost is estimated at $ 2,500 each 20,000 km [34]. The fixed costs are $ 51,000 per truck per year. They are composed of the sum of the license / insurance / rent ($ 35,000), plus administrative costs ($ 26,000) (Freightmetrics, 2012). Depreciation is calculated on the purchase price of a main unit truck ($ 135,000) depreciated over 10 years. (Logistics Solutions Builders, 2005)

The variables costs (Equation 2) are the sum of the fuel costs (Equations 3 et 4) plus the trucker salary:

$fuel + (total_km_traveled_empty-full x trucker salary($0,31)) Équation2

The trucker salary is calculated using the average salary in Quebec and Ontario in 2005, increased by an annual growth rate estimated at 2% (Logistics Solutions Builders, 2005). The cost of fuel is the sum of the cost without consolidation (Equation 3) and the cost with consolidation (Equation 4). The fuel consumption values are based on (Canada E, 2012; Canada, 2011; Canada T, 2012)

(total_km_travelled_full x consumption per km without consolidation (40)) + (total_km_travelled_empty x consolidation per km empty(30)) x fuel($1,4) Equation 3

(total_km_travelled_full x consumption per km with consolidation (43)) + (total_km_travelled_empty x consolidation per km empty(30)) x fuel($1,4) Equation 4

In the proposed business model, the Original Hub to which the request is sent is paid by customers. And he pays the Intermediate Hubs to planning the transport until the Final Hub, it is called the cost of transit. Payment the Intermediate Hub is based on the fixed costs of transportation (ie the cost of treating container) (Equation 5). The transportation cost is calculated as an average cost per container transported to an Intermediate Hub including the cost of container handling, the storage cost of the container and the cost of planning (administrative costs, for example).

The transit costs are:
Total_container_transit x storage-maintenance_cost ($108) Equation 5

The storage and maintenance cost is based on the fixed charges of monitoring related to the presence of an inspector to a fire prevention at the container by the Montreal Authority Port (Montreal, 2013).

4.1.2. Container Average Cost per Km

The calculation was done as follows: the network total cost divided by the number of containers transported and by the total kilometers traveled. Thus there is the average cost of a container per km, considering the transportation and the transit costs.

4.1.3. Percentage of Empty-Return Trips

The calculation was done as follows: total kilometers traveled empty divided by total kilometers traveled (empty and loaded). Thus it is known the impact of empty-return trips on the network total cost. The idea is the lower percentage, the better.

4.1.4. Percentage of Delays

The calculation was done as follows: total number of containers delivered on delay over the total number of containers carried. The delay calculation is done based on the actual date of delivery minus the scheduled date for delivery. The idea is the lower percentage, the better.

4.2. Results Obtained

The presentation of the results will be done in three steps. The first will be presenting an overview of the results. The second is the comparative analysis between scenarios with and without consolidation and flexibility of the truckers (i.e., their level of waiting time to return to their Original Hub). It is important to detect if there was an impact on the amount of empty-return trips.

Finally, a comparative analysis of scenarios based on the Percentage of Container Delivery on Time and the Total Cost will be presented.

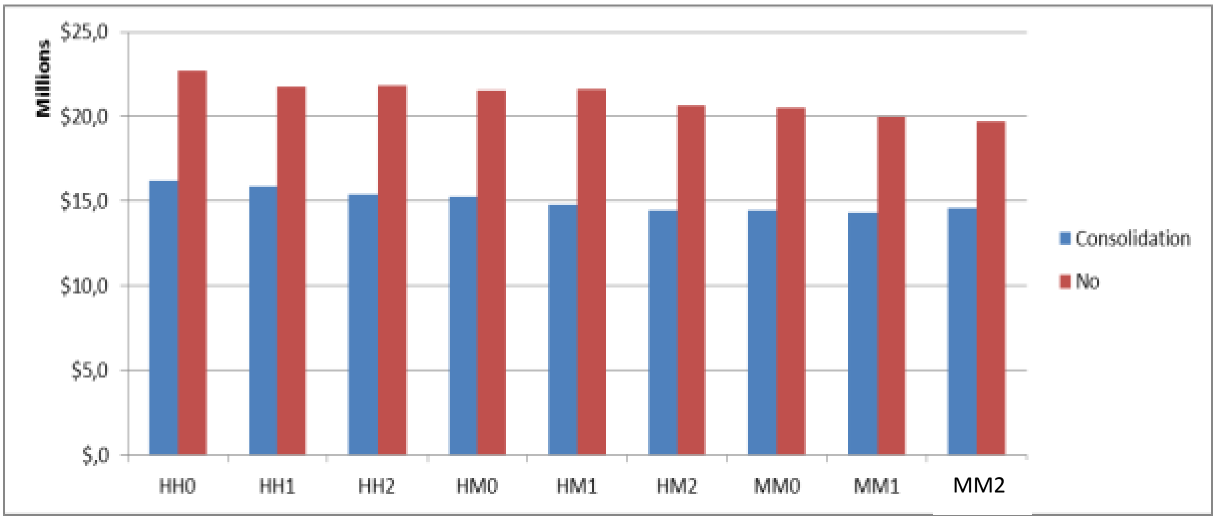
4.2.1. Overall Results

Some overall results are highlighted: fuel costs represent 60% of variable costs. Variable costs represent at least the double of the fixed costs, and transit costs are insignificant compared to the other two types of costs.

The percentage of the demand delivered varies between 75% and 89%. The peak of delivery delay was 36 periods, 4.5 days, while the average delays ranged between 4 and 13 periods, or 0.5 and 1.5 days. The empty-return trips ranged between 31% and 38% of the total distance.

4.2.1. Comparing with and without Consolidation

Figure 3 presents a comparison of the total costs between the scenarios with and without consolidation. The scenarios without consolidation have a higher total cost than the one with consolidation; the large gap is between 34% and 58%. Another information is that transit costs are highest between 34% and 52% in scenarios without consolidation. This means, that consolidation reduces costs of logistics network.

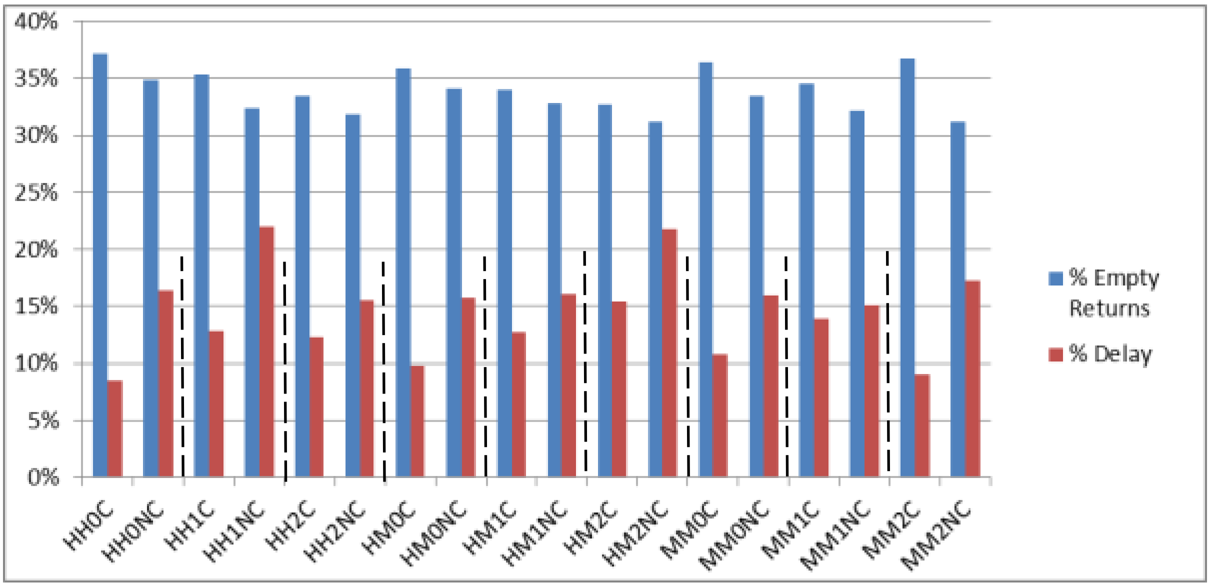


Subtitle: each scenario consists of 3 items (two letters and a number). The first letter refers to the level of demand (high-H and M-medium), the second to the supply (H-high and M-medium). The number refers to the maximum waiting time of the trucker before returning to the Original Hub.

Figure 3 – Comparative analysis of total costs between the scenarios with and without consolidation

Figure 4 presents a comparative analysis between the Percentage of Empty-Returns Trips and the Percentage of Delays. The consolidation scenarios have a greater Percentage of Empty-Returns Trips, between 1.2 % and 5.5 %.

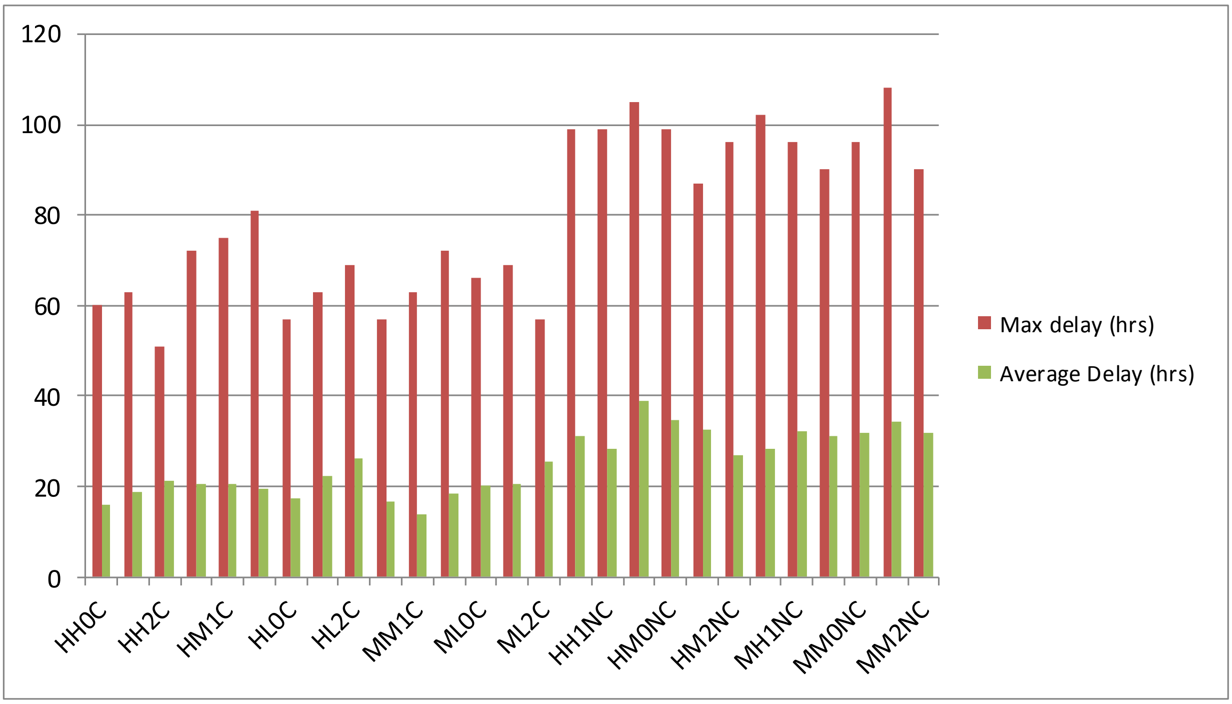
Therefore, the Percentage of Delays is lower in consolidated scenarios, between 1.14% and 9.12%, ensuring an increase in efficiency with consolidation.



Subtitle: each scenario consists of four items (three letters and a number). The first letter refers to the level of demand (H-high and M-medium), the second to the supply and third letter is regarding the consolidation (C or NC) and the number for the maximum waiting time of the trucker before returning to the Original Hub.

Figure 4 – Comparing the scenarios with and without consolidation for Percentage of Empty-Returns Trips and Percentage of Delay

Figure 5 presents a comparative analysis between scenarios with and without consolidation, for indicators of Maximum Delay and Average Delay. The scenarios without consolidation have a higher Maximum Delay, between 12 % and 54 %. Thus scenarios without consolidation have a higher Average Delay, between 8% and 20%. All this has an impact on the inefficiency of scenarios without consolidation. Consequently, so their total costs are higher.



Subtitle: like Figure 4
Figure 5 – Comparing the scenarios with and without consolidation for Maximum Delay and the Average Delay.

4.2.2. Comparing the Trucker's level of flexibility

Figure 6 shows a comparison of the transit costs between the scenarios with and without consolidation, varying the flexibility of trucker waiting time before he can return to his Original Hub. It is observed that the scenarios without consolidation have a higher transit cost, between 48% and 65%.

It also appears that transit costs increase as the flexibility increases too. In scenarios with consolidation, for a waiting time between [0,1], the costs increase by 23%, and by 9 % on waiting time between [0,1,2]. In scenarios without consolidation, for a waiting time between [0,1] the costs increase by 10%, and by 16% for a waiting time between [0,1,2].

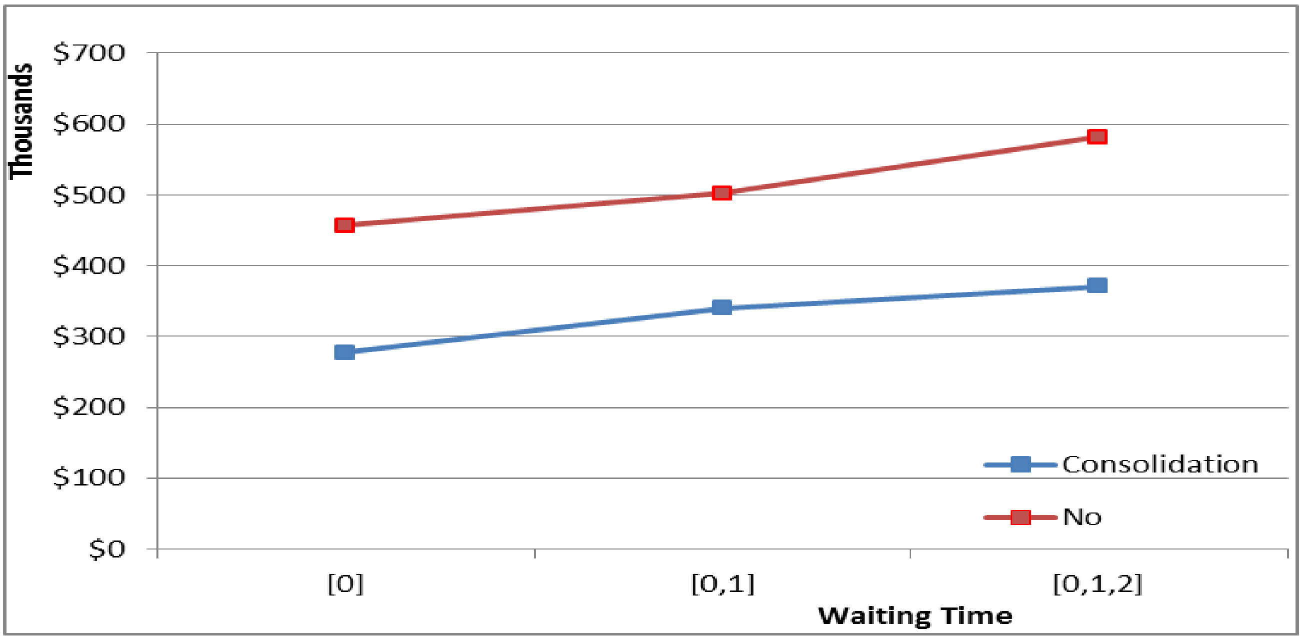


Figure 6 – Comparing the Transit Costs by king of Consolidation to the Waiting Time

Figure 7 presents a comparative analysis between the Percentage of Containers Delivered on Time and the Percentage of Empty-Returns Trips. It is observed that the scenarios with a high Percentage of Empty-Returns Trips have a higher Percentage of Containers Delivered on Time. There is a correlation of 0.75 for these results, which guarantees a strong relationship between them.

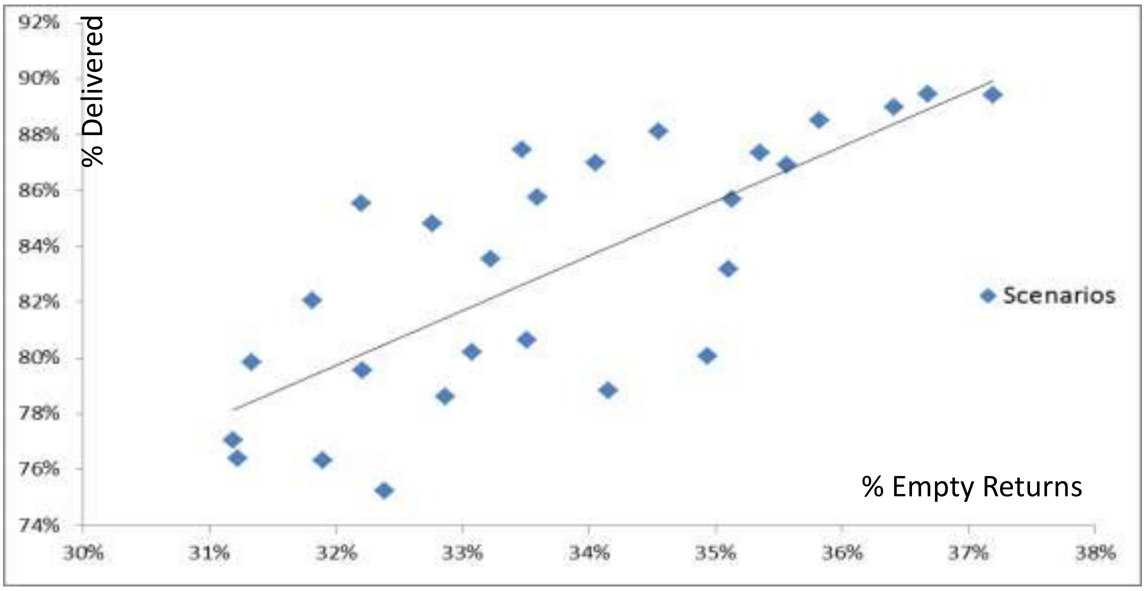


Figure 7 – Comparing the % Delivered and the % Empty Returns

Figure 8 presents a comparative analysis between the Percentage of Containers Delivered on Time and the Total Cost. In effect, the most efficient scenarios have the lowest total cost. The negative correlation of -0.8 confirms this statement.

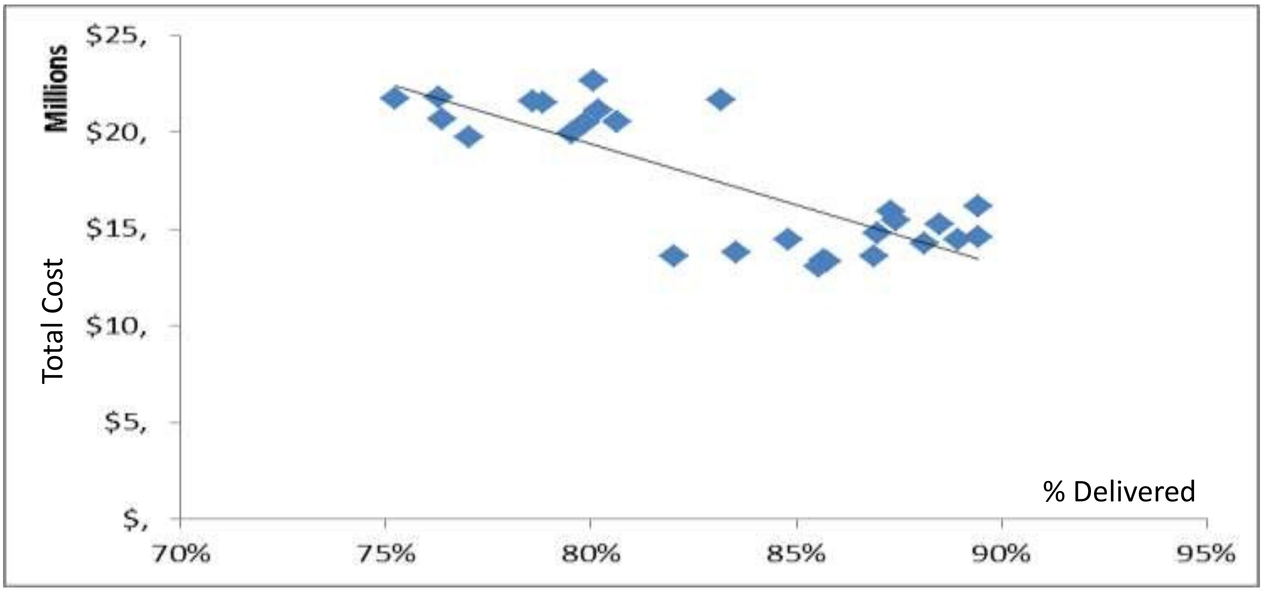


Figure 8 – Comparing the scenarios between the % Delivered and the Total Cost

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Despite the fact that the adaptation of the model faced some technical restrictions and limited knowledge about programming, the simulations do reflect the scenarios applied to the real world. The use of real data statistics of population and transport in Canada and US allowed evaluating the effectiveness of PI network realistically. However, a different time scale, a supply and a different demand generation, setting another configuration of the waiting time, and a non-discrete simulation, can generate different results.

An important conclusion is that it is unclear which would be the perfect scenario. In relation to the variation of multiple parameters and the study of multiple goals, there are several contradictions. Despite those several contradictions, allow the conclusion that the 27 studied scenarios and objectives can attest to the realism of the PI transportation network is real.

Another conclusion is that the use of empty-return trips are a great asset for the network, because it allows a decrease of the trips, reducing the number of trucks on the roads and the emission of GHG, bringing a great value to the environment.

From a social point of view, the truckers of a PI network work as well as the truckers of a traditional network. However, with PI network's arch of work, the distance traveled per trip is shorter, and the truckers are guaranteed to return to home every night.

5.2. Recommendations

Future work in PI theory should improve the following points.

1. Developing other transportation models to solve the technical difficulties and knowledge of simulation;
2. Comparing on a real network to identify the potential problems of a PI network and the potential solutions for traditional network of the transport;
3. Quantifying the environmental impacts to know if the use of a PI network will benefit the environment;
4. Developing and studying different business models to identify the financial and the economic potential of the PI network.

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