A SYSTEMIC APPROACH WITH AGENT-BASED MODEL AND DYNAMIC GRAPHS TO UNDERSTAND THE ORGANIZATION OF A LOGISTIC SYSTEM

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Abstract
A logistic system is characterised by a set of actors who interact together to manage coherent flow of goods. The constraints and behaviours of such a system lead it to be structured and organised. The goal of this paper is to provide a model to understand how the macro organisation emerges from the dynamics and the local rules (actors and infrastructures) of the system. We adopted a complex system approach, made of an agent-based model coupled with dynamic graphs, to represent the actors, the logistic infrastructures, and the transportation network. This approach is disaggregated, as opposed to dynamics system for instance. It allows to observe the effects of local parameters on the macro level. An implementation, which uses data about the Seine axis, allows to simulate the evolution of a logistic system. The analysis of the results shows how the simulation can be used to determine the organisation (detection of logistic clusters) and the effects of initial parameters on the territory (systematic adoption of the most efficient strategies to manage the supply networks).

Keywords:
Complex system, agent-based model, dynamic graph, logistic system, simulation

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INTRODUCTION

A logistic system is composed of a set of actors working together to manage the transportation of goods over a territory. This kind of system exists all over the world but they do not provide the same level of quality and efficiency due to their distinct characteristics. Moreover, some of them are very close, which leads to competition. The goal of this article is to provide a model which help to understand how a logistic system is structured and organised.

Actors have to deal with the constraints of the environment: the territory's geography, the transportation networks, the regulations, the local population's needs,... Due to these constraints, actors are specialized to realized specific tasks: the logistics service providers, the transporters, the forwarding agents,... But none of them has a complete decisional power on the transportation of goods. They just manage the goods on a specific part. To create coherent flow of goods, they need to collaborate together, to be organized. These organised communities of actors and structured flow of goods are observable at a macro level. They emerge from the local decisions and constraints of the system. The system has to adapt itself to decisions of each other and to unpredictable events, making it very dynamic. This why we consider the logistic system as complex.

In the literature, the adoption of a complex system approach to the logistics is still recent. Choi *et al.* [1] propose in 2001 to see supply networks as complex adaptive system. Later, in 2003, Henesey *et al.* [2] adopted an agent-based model to the terminals' community. And in 2005, Surana *et al.* [3] use dynamical systems to model a supply network. Our approach here is to describe the local characteristics of the system (such as actors behaviours, or the transportation networks) in order to simulate its evolution. The proposed model will allow to modify the system at a local scale to understand how it is organised, and how these modifications affect its macro properties.

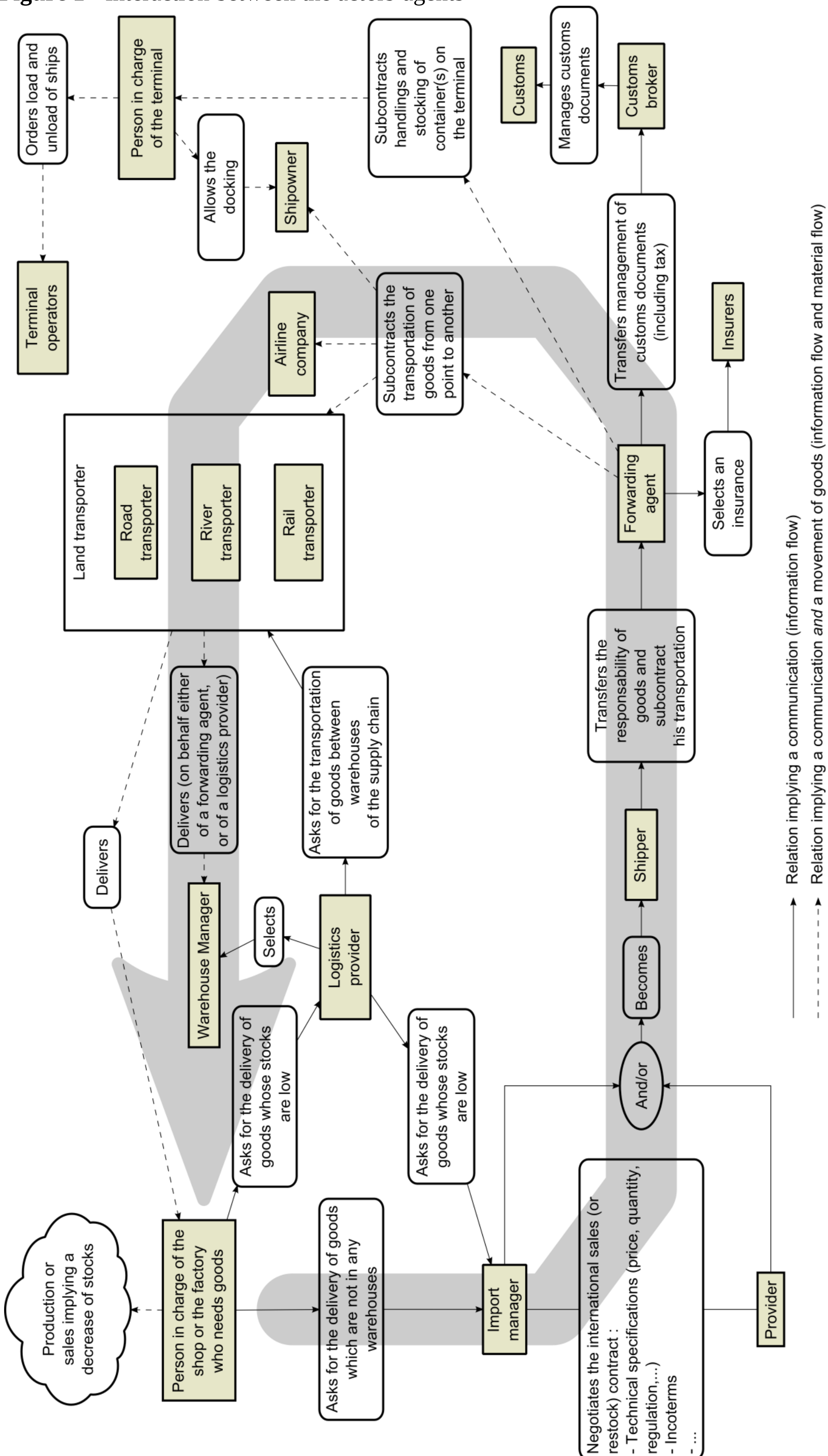
The first section presents an agent-based approach coupled with dynamic graphs to model a logistic system. It allows to represent a territory and each actor and infrastructure in order to simulate its evolution. Since it is a disaggregated approach, it is possible to change a lot of parameters to observe their impact, including the behaviours of the actors, or their position in the space. The second section describe the implementation of the model according to the specific case of the Seine axis. Eventually, the last section comes back on the main results we can get with the simulation, and it also presents how the more efficient strategies adopted by actors are progressively chosen instead of the less efficient ones.

1. MODEL

In this section, we describe a model of a logistic system, centred on the importation of goods. We were looking for a disaggregated model that gives us the capacity to change a maximum number of local parameters. We wanted this model to be dynamic as we wanted to observe the evolution of the system according to the initial parameters. We choose an agent-based approach to represent the actors and nodal infrastructures, and dynamic graphs to represent the transportation networks. These modelling tools allow to represent the spatial dimension of the system and its evolution.

The model is divided in two parts. The first one describes the actors thanks to the agent-based approach. There is a kind of agent associated to each kind of real actor. They take decisions to manage the transportation of goods through a supply network. The second part is the environment which models the transportation network. We use dynamic graphs to represent the different networks (roads, river,...). The nodal infrastructures such as maritime terminals or warehouses are agents, but they also are nodes of the transportation network. It allows to connect two different kinds of network (*e.g.* maritime lines with roads). The actors modelled by agents have access to the information about the network, and they can update in real time their decisions according to the evolution of the environment (*e.g.* traffic jams).

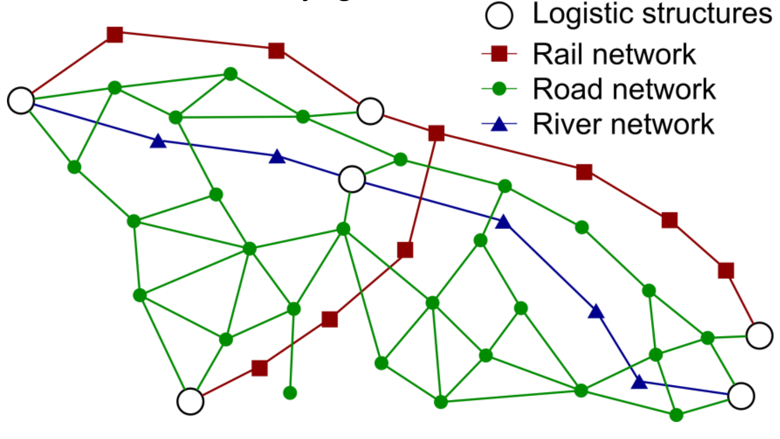
Figure 1 - Interaction between the actors-agents



Each actors of a logistic system, such as the providers or the logistics service providers, is represented by an agents (see figure 1). The persons in charge of a shop or a factory are the final consignees of the system. They have local stocks which decrease regularly. Each of them selects a logistics service provider who must manage the outsourced stocks, stored in warehouses of a supply network. The goal of this supply network is to restock quickly the final consignees. One logistics service provider might have many customers. Therefore, the supply network also allows to share the different costs of storage and transport between its customers. The way to create the supply network depends on the strategy adopted by the logistics service provider. For instance, some of them might be specialised in short circuit, implying few intermediary warehouses between the provider and the final consignee. However, the topology of the network, or the characteristics of the chosen warehouses, have a major effect on the efficiency of the supply chain: the costs (financial or ecological), but also the ability to react quickly,... When the stocks are too low, the Provider agent have to send goods. This agent is outside the territory delimited by the system and he is connected to it through access nodes like a port. A forwarding agent is contacted to organised the transportation between the provider and the first warehouse of the supply network. The transportation can be multi-modal according to the decisions made by the forwarding agent. These decisions depends on the costs but also on the work habits of the agent.

Some measures about the efficiency of each agent are made. It includes, for instance, the costs of transportation or storage, the delays to deliver the goods,... These measures are used by the agents to decide if their collaborators are efficient enough. If they are not, they can decide to change of collaborator. It leads the agents to choose the more efficient strategies according to the current state of the system. If the system evolves to another state, other strategies could emerge.

Figure 2 - The transportation network is made of different sub-graphs connected with each other by agents



The environment is modelled by different dynamic graphs: each kind of sub-transportation network (*e.g.* road, river, rail networks) becomes a graph with its own characteristics (speed, capacity,...). They are interconnected with each other thanks to specific agents : the nodal infrastructures (maritime or river terminals, warehouses,...). The goods can travel trough these nodes to reach another kind of network, but they are slow down due to the bulk breaking. Indeed, each of these agents has a capacity to process a quantity of goods per time unit. Therefore, some traffic jams might happen inside the nodal infrastructures. The graphs are dynamic because it is possible to update in real time the topology: we can add or delete some roads. Moreover, when the goods move along an edge of a graph, it increases the traffic, and if it exceeds the capacity of the edge, the goods is slowed down. Therefore, according to these modifications of the environment, the actors-agents can update in real time their decisions and choose other paths for the goods. This is a retro-action mechanism.

2. IMPLEMENTATION

In this section, we present the implementation of the model into in a simulation platform. This implementation is centred on the transportation of goods, and does not include the notion of costs. According to different surveys on agent-based simulation platform [4, 5, 6], we eventually choose the GAMA platform because it allows us to easily integrate geographical data. We use data on the Seine axis coming from the Devport project. This axis is a French territory with a natural corridor from the port of Le Havre to Paris thanks to the Seine river. It also integrates the cities of Rouen, Caen and Orleans. The road is mostly used instead of the other modes of transport. The region of Paris is the most important urban areas of the territory, and also the place where there are the most numerous logistic activities.

2.1 THE AGENTS

We implemented three kinds of actors-agents: the final consignees, the logistics service providers and the providers. The latter represent the access nodes of the territory. We have as much providers as access nodes. Most of our analysis only consider one provider connected to the territory through the port of Le Havre. We assume that these agents can deliver any kind of goods in any quantity.

The final consignees have local stocks of different products identified by a number. Each day, a part of the stocks is remove based on the estimated number of customers computed thanks to the Huff's model [7]. We assume that the more the final consignee has customers, the quicker his stocks decrease (it is a probability to decrease). Each final consignee selects a logistics service provider to manage the outsourced stocks. This agent manages a network of warehouses between the provider and his customers. There are two intermediary warehouses between the provider and a final consignee. The goods leave the provider to go to a warehouse of regional level, then to a warehouse of local level, and finally to the final consignee. This kind of topology for the supply network is the most common over the Seine axis. The logistics service provider checks each day the stocks he manages, and he orders to a warehouse of higher level or to the provider, to deliver the missing quantity of goods.

A logistics service provider selects a warehouse according to the strategy he adopted at the beginning of the simulation. Once he choose a strategy he cannot change it during the simulation. There are four strategies :

- First strategy: the warehouses are selected randomly.
- Second strategy: the warehouse of regional level is the one providing the largest available storage surface; and the warehouse of local level is the closest one to the final consignee.
- Third strategy: it is barely the same as the second strategy but there is a logarithmic probability to choose instead a smaller (for regional level) or a further (for local level) warehouse.
- Fourth and last strategy: for the warehouses of regional level, the agent selects the 15 warehouses providing the largest available storage surface, and then selects the most accessible (according to the Shimbel's index [8]). For the warehouses of local level, the agent selects the 15 warehouses closest to the new

final consignee, and then selects the most accessible (according to the Shimbel's index).

At every step, we update, for each logistics service provider, a value measuring his effectiveness. Here, we consider the effectiveness as the capacity to react quickly. So, we measure the time taken to deliver the final consignees. However, it is also possible to measure the distance travelled by the goods if we want to consider the costs of transportation as a measure of effectiveness instead. Then, a final consignee can compare the score reached by his own logistics service provider with the average score. If the score is under the average value, then the final consignee decides to change of logistics service provider. This mechanism contributes to make emerge the most efficient strategy.

2.2 THE NETWORK

The transportation network is not multi-modal yet. Only the roads are integrated. The goods moving on the network are modelled by an agent called "Batch". It represents one or many vehicle(s). Indeed, this agent aggregates all the goods of the orders whose the source and the destination are the same. When the Batch agents are created, they compute a shortest path from their initial location to their destination. They can move along the edges of the network according to the speed limits. In the same time of their trip, they leave a trace on the edges equal to the quantity of goods they carry. We can use this trace to observe the traffic over the network. Moreover, at each step, we use a coefficient which makes decrease every traces on every edges. As the pheromones used in ant colony optimization algorithms [9, 10], this mechanism allows to make evaporate the trace in order to follow the dynamics of the traffic. For instance, if an edge is particularly used, its trace has a high value. But if for some reasons, the edge is not used any more, then the trace will disappear.

Regarding the nodal infrastructures, they are modelled by Warehouse agents. Each order received from a logistics service provider is stored inside a First-in First-out list. Each time a warehouse is selected to be part of a supply chain, it increases its capacity to process some orders per time unit. In parallel, when a Batch agent enters in a warehouse, the goods are also stored temporarily inside another First-in First-out list. Therefore, at each step, the warehouses can process a part of the orders and of the entering goods according to their own capacity to process the orders and to process the goods. This mechanism models the break bulking of each infrastructures. If the traffic inside a warehouse is too high for its capacity, it could lead to traffic jams.

3. RESULTS

In this section we will present the possible measures offered by the implementation. It allows to show how this model can be used to get information about the system. Most of these measures are computed from the disaggregated data, and are then aggregated in order to be analysed. Firstly, we will come back on static measures which do not depend on the execution of the simulation. Then, we will tackle dynamic measures which change with the evolution of the simulation.

3.1 STATIC MEASURES

In previous researches [11, 12], we used neighbourhood graphs to detect logistic clusters: each warehouse was a node and we add an edge between two nodes if the Euclidean distance was smaller than a given value. The numerous connected components of this kind of graph shows the existence of logistic clusters spread over the territory. Moreover, the large size of few connected components highlights that some region have a higher probability to welcome logistic activities. More particularly, the study of the traffic [11] shows that these regions are connected by corridors where the traffic is more important. The interest to use neighbourhood graph is to detect the clusters and to know how big they are.

A way to have information about these clusters is to create a grid over the territory and to colour each cell of the grid according to a value. On the figure 3, a cell is coloured according the sum of the storage surface of every warehouses within the cell. On the figure 4, we computed the average accessibility (the Shimbel's index [8]) of the warehouses within each cell. Both results show that some particular regions are more highlighted. The regions where there are the largest storage surfaces are the main logistic clusters. And the environment provides a better network where the accessibility values are better. It appears that the storage surfaces of the cells are correlated with the average accessibility. Indeed the Spearman's coefficient between these two variables is equal to 0.77, meaning a strong correlation. The p-value of 2e-90 indicates that the correlation is significant. It means that the logistic clusters are more likely located near accessible places.

Figure 3 - The territory of the Seine axis divided into cells to highlight the storage surface

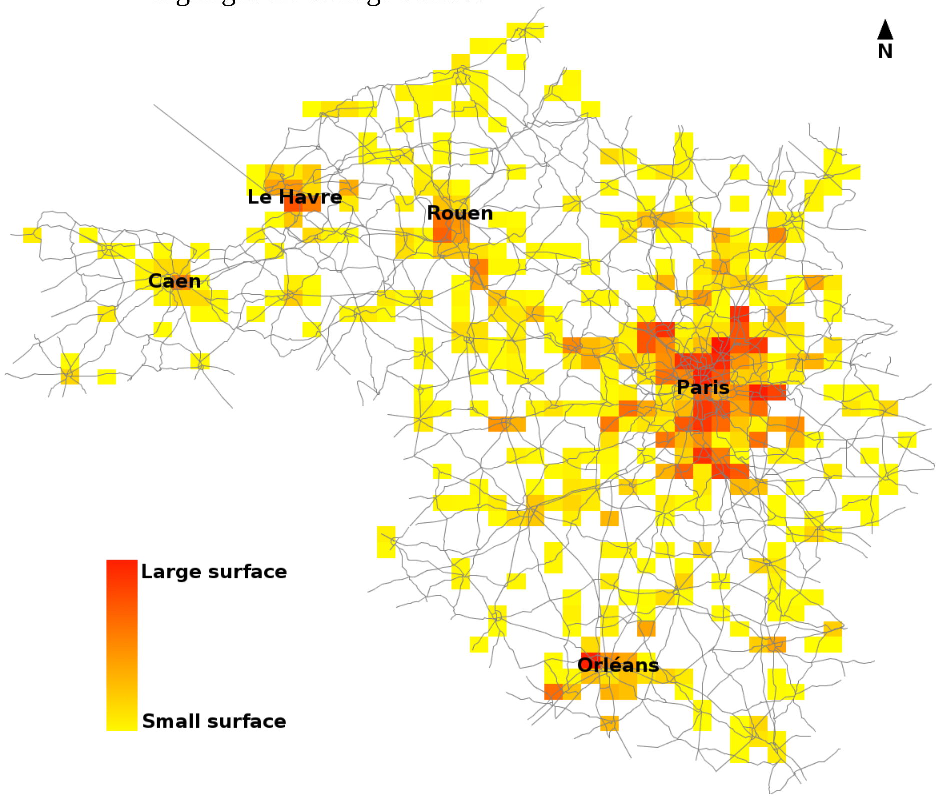
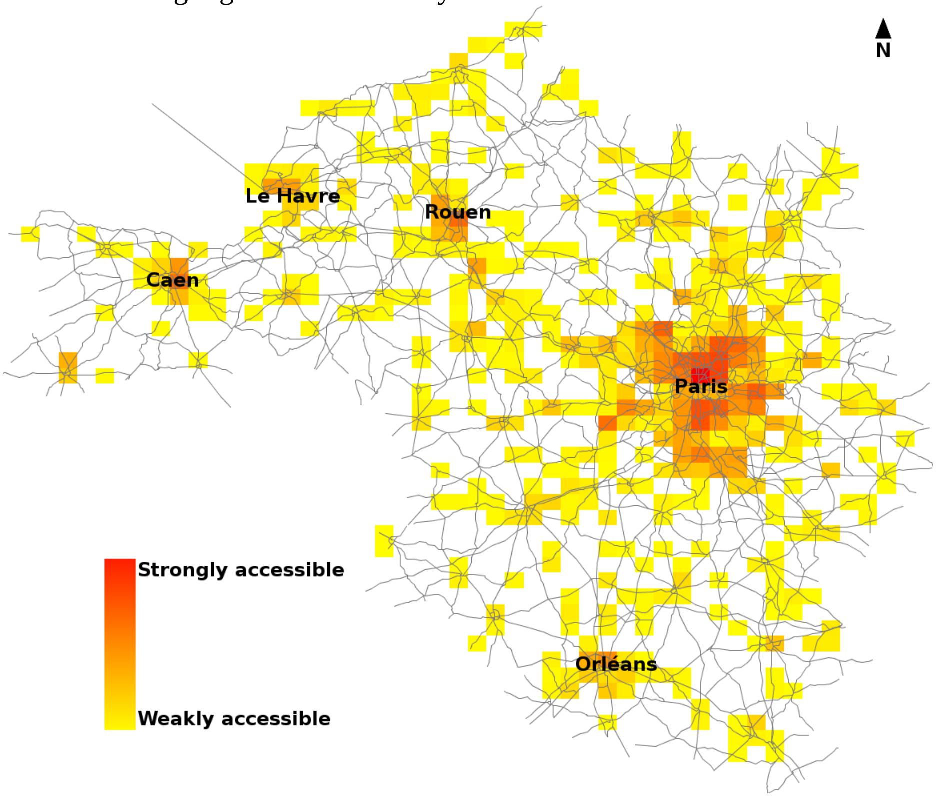


Figure 4 - The territory of the Seine axis divided into cells to highlight the accessibility



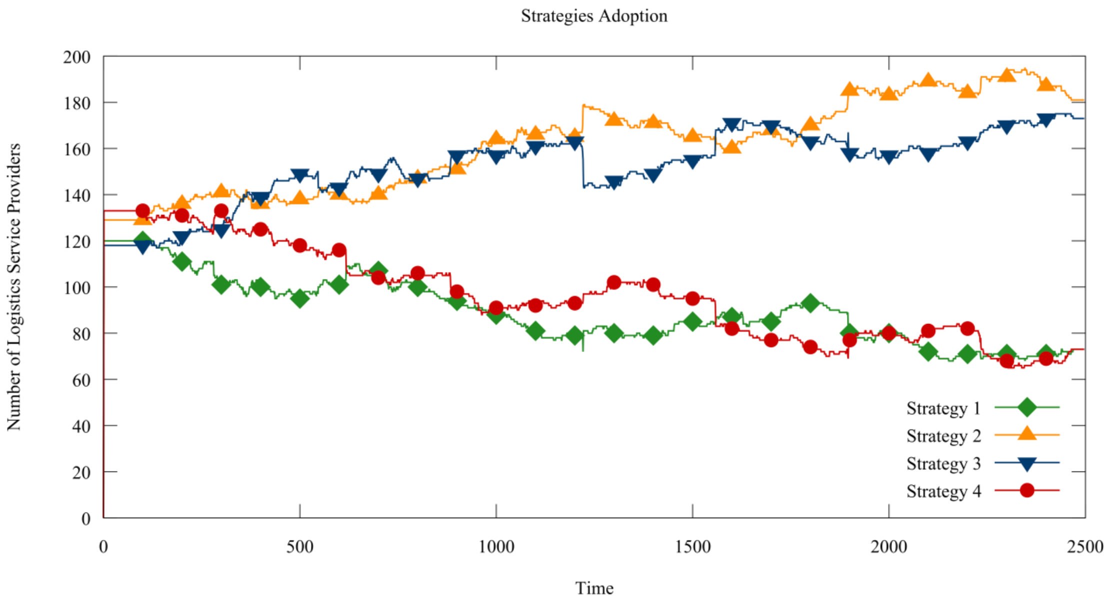
3.2 DYNAMIC MEASURES

Among the different dynamic measures, we made observations of the atomisation process [12]. We separated the set of Batch agents into different groups according to their destination: a group for the Batch agents leaving the provider, another with the Batch agents leaving the regional warehouses, and a last one with the agents going to the final consignees. Then, we compare the cumulated quantity of goods inside each group, with the number of agents making part of these groups. It appears that there is a hierarchy in the number of Batch agents. There are more agents going to final consignees than agents leaving the provider. However, the cumulated quantity of goods associated to a group of Batch agent is always the same. It proves that the simulation provides an atomisation mechanism of the flow of goods, as in the reality. Before the goods enter the territory, they are transported by container ships, and the closer they come to the final consignees, the smaller are the vehicles.

We also study the evolution of the stocks shortages according to different initial parameters [11, 13]. The first parameter models how much and how quick the local population consumes the goods. The second parameter describes the capacity of the logistics service providers to anticipate the stocks shortages by ordering the restock before it is too late. It appears that according to the quantity of goods consumed, the logistics service providers should order the restocks really soon. We show that the simulation could be used to determine which strategy adopt in order to maximise the satisfaction of the customers (and avoid stocks shortages) and in the same time, minimize the number of transportation (and increase the costs).

Now, the figure 5 presents the evolution of the adoption of different strategies. There is no evolution in the first steps of the simulation in order to let each actor generates enough data to compute the measure of effectiveness. We can observe on this figure that after the first 100 steps, two similar strategies emerge: the second and the third ones. The strategy 2 is a bit more adopted, but it is not truly significant. And since the simulation is not deterministic, it can appear, with other executions, that the strategy 3 is the more adopted one. The strategy 4, which includes the accessibility, is always the less adopted. The strategy 1 allows a pure random selection of the warehouses. It means that it allows to explores every possible supply network. Therefore, the simulation could lead to an optimal solution. This is why, it already appears that this strategy is sometimes more adopted, even if, in this case, the strategies 1 and 4 have similar results. The measure we used is really simple: it only consider the time to deliver the final consignee from the step when an order is made to the delivery of the goods. Therefore, it is logical that the best strategies are the ones who select the closest warehouse when they are looking for a local one. But this result learns us that we could use the simulation to determine which strategy is more efficient. The strategies implemented here are simple but we could implement some more sophisticated strategies to compare them. The only requirement is to develop an adapted measure to determine the effectiveness of a solution.

Figure 5 - The evolution of the adoption of four different strategies by the logistics service providers



CONCLUSION

The model presented here used a complex system approach to describe a logistic system. The actors are modelled by agents. Their behaviours and interactions are at the origin of the flow of goods. The transportation network is represented by sub-graphs: one for each kind of network. These graphs are connected together thanks to nodal infrastructures, also modelled by agents.

The implementation of the model to the Seine axis allowed us to simulate the evolution of this system. We implemented four simple strategy that the logistics service provider could use. The analysis of the simulation showed us that we can use the model to get information on the structure and the organisation of the territory, but also to understand to evolution of system's dynamics according to different initial conditions.

However, the model may still be improved. We would like to explore the competition that could happen between two access nodes. Indeed, in the reality, a large part of the goods going to Paris's region, come from the port of Antwerp and not from Le Havre. We could use the mechanism of adoption of different strategies to observe the evolution of the share between these two ports. Moreover, we also would like to integrate a Disruptive agent in order to test the capacity of the system to absorb some issues (accidents on roads, stock shortage from a provider,...)

REFERENCES

[1] T. Y. Choi, K. J. Dooley, and M. Rungtusanatham, "Supply networks and complex adaptive systems : control versus emergence", Journal of Operations Management, vol. 19, no. 3, pp. 351-366, 2001.

[2] L. E. Henesey, T. E. Notteboom, and P. Davidsson, "Agent-based simulation of stakeholders relations : An approach to sustainable port and terminal management", in International Association of Maritime Economists Annual Conference, 2003(a), pp. 314-331, 2003.

[3] A. Surana, S. Kumara, M. Greaves, and U. N. Raghavan, "Supply-chain networks : a complex adaptive systems perspective", International Journal of Production Research, vol. 43, no. 20, pp. 4235-4265, 2005.

[4] S. F. Railsback, S. L. Lytinen, and S. K. Jackson, "Agent-based simulation platforms : Review and development recommendations", SIMULATION, vol. 82, pp. 609-623, Jan. 2006.

[5] R. Allan, "Survey of agent based modelling and simulation tools", 2010.

[6] K. Kravari and N. Bassiliades, "A survey of agent platforms", Journal of Artificial Societies and Social Simulation, vol. 18, no. 1, 2015.

[7] D. L. Huff, "Defining and estimating a trading area", Journal of Marketing, vol. 28, no. 3, pp. pp. 34-38, 1964.

[8] A. Shimbel, "Structural parameters of communication networks", The bulletin of mathematical biophysics, vol. 15, no. 4, pp. 501-507, 1953.

[9] A. Colorni, M. Dorigo, and V. Maniezzo, "Distributed optimization by ant colonies", in Towards a Practice of Autonomous Systems : Proceedings of the First European Conference on Artificial Life (F. J. Varela and P. Bourgine,eds.), pp. 134-142, Cambridge, MA : MIT Press, 1992.

[10] M. Dorigo, "Optimization, Learning and Natural Algorithms". PhD thesis, Politecnico di Milano, Italy, 1992.

[11] T. Démare, C. Bertelle, A. Dutot, and L. Lévêque, "Logistic corridors modelled with agent-based approach and dynamic graphs", in 4th International Conference on Advanced Logistics and Transport (ICALT), pp. 199-204, May 2015.

[12] T. Démare, C. Bertelle, A. Dutot, and L. Lévêque, "Agent-based model and networks : the modelling of the maritime and metropolitan interfaces of the seine axis" in Devport international conference for ports, maritime transport and regional development : Adaptation of maritime, port and logistics actors to hazards of globalization, June 2014.

[13] T. Démare, C. Bertelle, A. Dutot, and L. Lévêque, "Agent-based approach and dynamic graphs to model logistic corridor", Procedia Computer Science, vol. 52, no. 0, pp. 968- 973, 2015. The 6th International Conference on Ambient Systems, Networks and Technologies (ANT-2015), the 5th International Conference on Sustainable Energy Information Technology (SEIT-2015).