Agent-based model and networks : the modelling of the maritime and metropolitan interfaces of the Seine axis

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Abstract This contribution concerns the modelling of the freight flows on the Seine axis and the processes which are behind these flows. The issue is the difficulty to understand and analyse such an environment. Indeed, the freight transport implies an important number of different actors (such as importers, exporters, transporters, logistics providers,...) which are connected with each other by different kinds of interactions (collaboration, negotiation or competition). Moreover, on the physical world, the freight itself can take part in several, different and multi-modal supply chains. Thus, we can see this environment and its actors as a complex system.

Thanks to a knowledge base which describes the Seine axis logistic (his environment, his actors and its infrastructures), we explain how we model this complex system. The methodological context, with concepts of graph theory and of agent-based models, help us to achieve our goal. We come back on the main interactions between agents and their behaviours. We study their physical world (including the retro-action mechanisms) and how the different kinds of flows (information, communication and freight) are integrated. We also describe the implementation on an agent-based simulation platform named GAMA [1] and the analysis tools developed. Some first results are finally discussed.

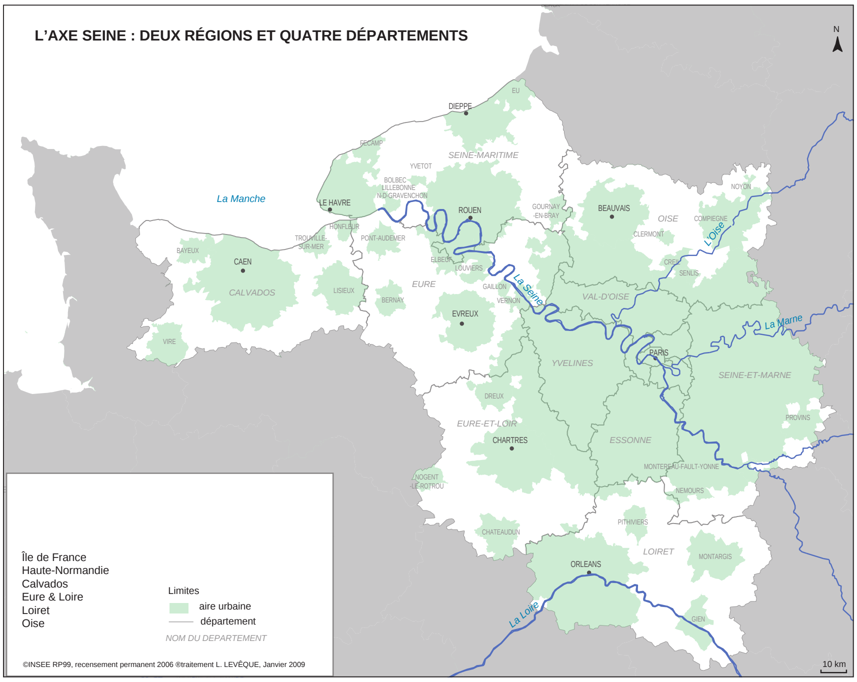
Contents

Introduction

The Seine axis is a geographical space, economically important. It is composed of an international trade port, thanks to Le Havre, and of a large hinterland with the Parisian metropolis. Furthermore, the cities of Paris and Rouen provide a port activity thanks to the Seine. The prominent consumers market of around 15 millions of inhabitants, mainly from Paris, must be regularly supplied. In order to answer to this need, some logistics actors organise themselves to order and transport goods to these consumers.

The complexity of this particular system comes from the important number of actors (such as importers, exporters, transporters, logistics providers, port authorities, forwarding agents, customs officers,...) and their numerous local interactions (collaboration, cooperation and/or competition). Once on the hinterland, the goods can take part of various supply chains and follow paths composed of different transportation modes thanks to road, river or rail networks. However, we can observe a similar pattern in these many supply chains at the macro level. Thus, the local processes and interactions of the entities (the actors), at the micro level, build this mechanism of flows of goods at the macro level, and it is

Figure 1: The Seine axis territory



one more reason of why we can see it as a complex system. So, the problematic justly comes from this complexity, and we will provide a way to model this geographical and economical space.

This research is a collaboration between the LITIS[1] and members of the Devport project[2]. The latter regroups researchers from different fields such as geography, economy, mathematics, and computer science. They work on the analysis of port organisation models and are looking for a best comprehension of maritime economy, and of port and logistics actors. The final goal is to optimise the transportation of goods on the Seine Axis thanks to theses models. The LITIS is a computer science laboratory located in Université de Rouen, the INSA and the Université du Havre. One of these teams (RI2C[3]) works on the morphodynamic of dynamic interactions networks and in particular the ones who structure the territories such as road networks. These ones are often considered as complex system. Thus, members of the LITIS have developed some tools, as the Graphstream platform [2], in order to model and analyse these networks. For instance, thanks to these tools, some previous works of LITIS' members [3] have showed some retro-action mechanisms between the structure (morphology and topology) and the dynamics of the system.

In the first part, we will describe the Seine axis logistic with the main actors and how they interact with each other. Then, we will see how the environment is composed and structured.

The complex systems theory is often used to model this kind of problematic and within this field, the agents models, associated to networks, provide an interesting way to model

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[2] Site Internet du projet Devport : http://www.projet-devport.fr/
[3] Réseaux d'Interactions et Intelligence Collective

this environment. So, in the second part, we will explain what is the agent-based approach; what is, in particular, the individuals-based approach; and why this is very modular. Finally, we will talk about the graph theory and show that it offers many analysis tools.

In the third part, we will describe our agents/individuals-based models coupled to some networks. The agents model mainly the actors while the networks represent the environment or the interactions between the actors.

Afterwards, we will talk about the first implementation of this model on the Gama platform [1]. It will be the time to explain a bit more some technical details, and to present some analysis tools used to provide some information on the model.

Finally, the last part will present the first results of the simulation. We get charts of measures (quantity of goods,...) and graphs (interaction network, neighbourhood graphs,...) while the simulation is running. These tools allow us to have a best understanding of the simulation and will help us to make new analysis tools.

1 The Seine axis logistic

In the following parts, we will explain the logistic of the Seine axis. In the first section, we present the actors who make the flows of goods thanks to their decisions. In the second one, we study the infrastructures and the physical network who carry these flows.

1.1 The actors

The flows of goods are managed by actors and more particularly they are initiated by the final consignee who decides to take orders in function of some parameters such as :

- The current stock of the product.
- The current date : indeed, the rate of consumption of a particular product could be correlated with the time of the year. For instance, toys are better sold in November and December than the other months.
- The size of the consumer market.

The final consignees are mostly either a wholesale trader or a retailer or a manufacturer. In each case, a contact is made, directly or not, between the provider and the final consignee in order that they negotiate the conditions of the order [4] : mainly the quantity, the price, and the Incoterms[4]. If the provider makes the contact according to sales previsions, the flow of goods is said *pushed*. By opposition, if the final consignee asks for the order, the flow is said *pulled*. For instance, for his next launch, an important smartphones manufacturer will probably push his next smartphones to the biggest retailers, while small retailers will probably need to pull this same product.

[4]The Incoterms are a series of commercial terms intended to provide the tasks, costs and risks associated with the transportation of goods. It defines where the responsibilities are transferred from the exporter to the importer.

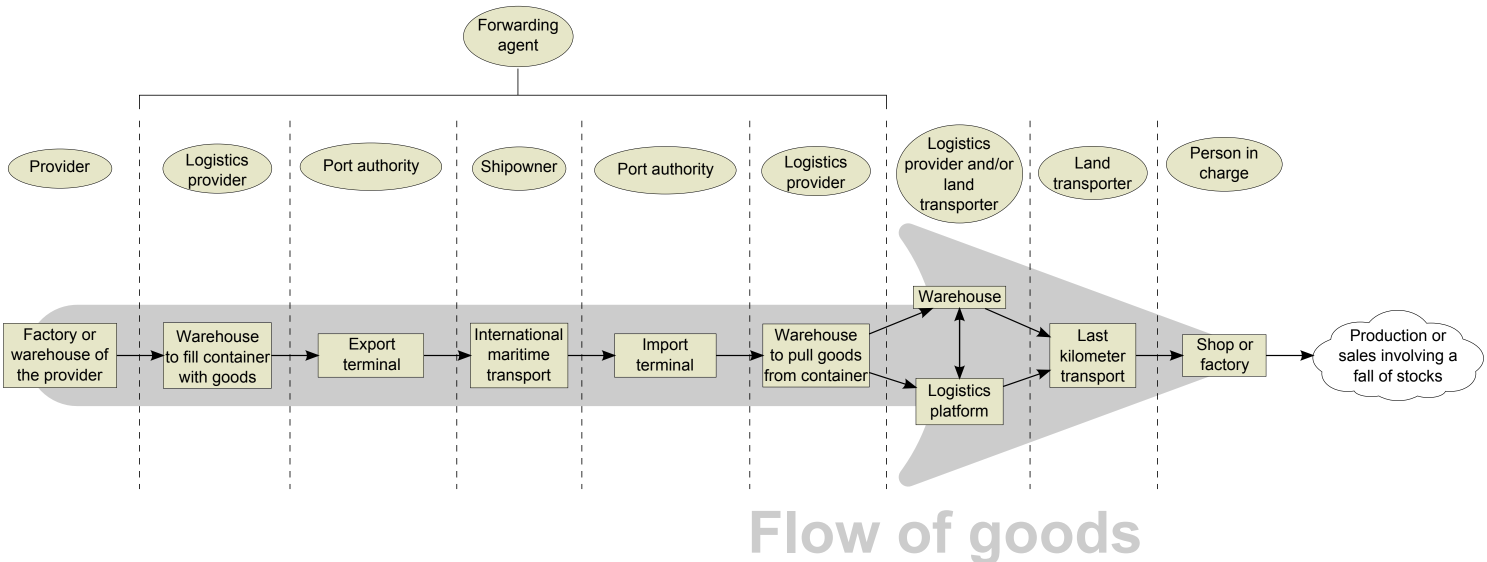
According to the Incoterms, the exporter and the importer are responsible of the goods on their respective parts. In most cases, they subcontract this complex work to a forwarding agent. The latter contacts the shipowner so as to select a proper shipping line, he deals with the import and export customs duties, and finally manages (directly or not) the land transport just before the export port and just after the import port.

Once on the hinterland, the management of the goods are often transferred to a logistic provider. This one operates goods within warehouses of the supply chain. Some of them (called Fourth Party Logistics or 4PL) provides softwares to do that while others (called Third Party Logistics) physically handles the goods. Furthermore, if the stocks of one or many warehouse(s) are not well-balanced, the logistics provider can also order to a land transporter to move goods from the larger warehouses to the smaller one.

We can notice that each transport operators (shipowner, road transporter, river transporter and rail transporter) and forwarding agents are freight forwarders. It is a legal status involving that they are responsible of the transported goods. They organise the transport of goods and choose a path on behalf of his customer.

All of these actors interact therefore with each others in order to control the physical flow of goods. For each part of the path followed by the goods, there is an actor who is able to manage it on this particular part (as on figure 2). The path followed by this flow is therefore the result of a collective collaboration and of personal decision-makings. However, the flow is also under the influence of hazards from the reality of the physical world. Thus, we are going to describe in the next part, the characteristics of the real world that we tackle as a network.

Figure 2: Each actor manage a part of the flow



1.2 The physical environment

The physical world is composed of linear and nodal infrastructures with particular characteristics according to which sub-network they belong to. Indeed, the shipping lines, the roads and rivers *etc.* form interconnected subnetworks and each of them have particular characteristics. For instance, on shipping lines, a container ship is more likely to suffer of hazards (and thus, of delays) than a truck or a river barge on the hinterland. It is one of the reasons why the land transports is known to compensate the delays of maritime transports thanks to precise time limit. Indeed, the traffic, the speeds, and others parameters are very well known on land transport, so it is easy to compute the exact date of arrival. However, the volume carried by a container ship (up to around 18,000 TEU[5]) is really huge compared to the volume carried by a truck (one container) or a river barge (about one hundred). So, these high volumes make the costs of this transportation mode very attractive. Also, we can notice that a truck can go wherever he wants or nearly. It is clearly not the case to others transportation mode. So, for the last kilometre, it is almost guaranteed to use this mode.

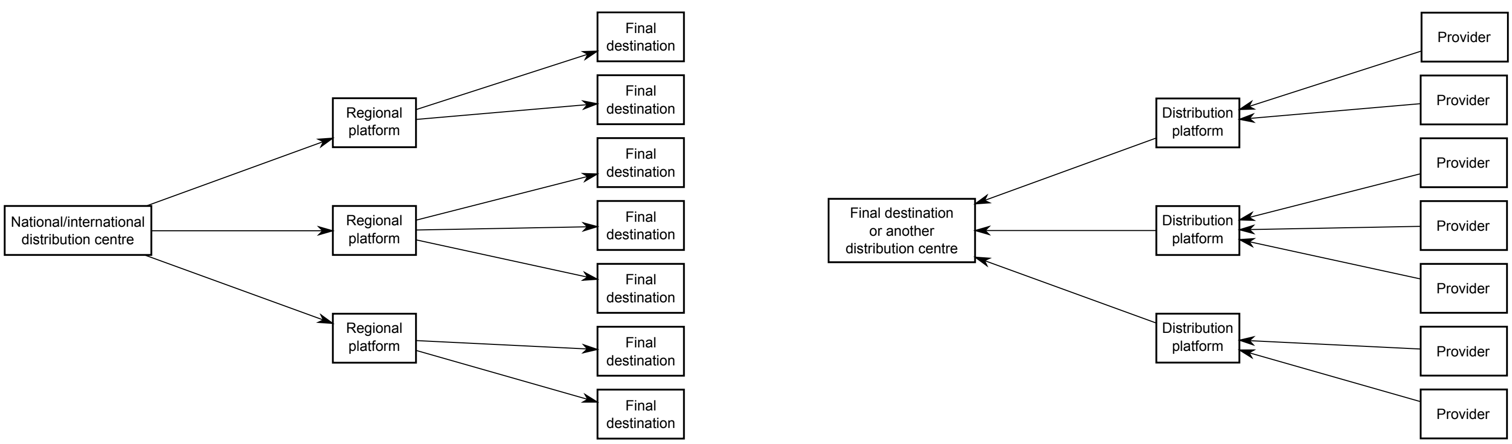
Beyond the linear infrastructures, the nodal ones must be studied too. Firstly, the maritime and river terminals allow to load (resp. unload) goods on (resp. from) a ship (a container one or a river barge). They provide a goods handling area where goods could be stocked temporarily. By definition, a terminal is a multi-modal infrastructure. The goods come in on a particular kind of vehicle, and come out on another kind.

Then, there are the logistics buildings including warehouses and logistics platforms. Their goal is to outsource the stock of another building (a shop, a factory, *etc.*). We distinguish them mainly by the time of stocking goods : if it is less than 24 hours, we talk about warehouses, else, we talk about logistics platforms[5]. Moreover, a logistics building could have a speciality : *i.e.* stocked only foods, textile, chemicals, *etc.*. The logistics buildings are categorised according to their sizes : for instance there is, from the larger to the smaller, the national, regional and local warehouses. It allows to build supply chains organised in the form of "trumpet" and "funnel" networks [5] (see figure 3). As well, these logistics buildings can be spatially grouped together (it is called the polarised logistic) or on the contrary be spread (it is called the distributed logistic)[6].

Figure 3: The two main network topologies of logistics buildings

(a) Logistics buildings in a "trumpet" network

(b) Logistics buildings in a "funnel" network



In addition to their stocking activity, a logistic building could also provide one of these logistics activities [5, 6, 7] (it is not an exhaustive list) :

[5] Twenty-foot Equivalent Unit.

- consolidation/deconsolidation : the consolidation process consists to build an higher flow from many smaller flows of distinct origins but of identical destination. The deconsolidation is the inverse process.
- the cross-docking : it is a routing process. The inflows are constituted of batches of distinct destinations. However, it is possible to build outflows composed of batches, from the whole inflows, of similar destinations.
- container packing/unpacking : it consists to take in (packing) or take out (unpacking) goods of a container.
- quality control : it consists to check if the goods are in good condition.
- repackaging : it consists to make a particular process to the goods including : packaging, labelling, smoothing out,...
- picking : it consists to go find the right items in the right quantities before sending.
- sending : it consists to place the order in the right vehicle at the right time.

2 Graphs and agents

Now, we will study two methodological concepts that we use in our model : first, the graph theory and its properties and vocabulary, and then the agent-based approach.

2.1 Graph theory

The graph theory is a field of the mathematics and the computer science. The paper on the seven bridges of Königsberg written by Euler [8] is often considered as the first paper talking about graph. A graph defines the relations (the edges) between entities (the nodes or vertices). These edges can be directed or not.

Formally, let G be a graph such as $G = (V, E)$, with $V = \{u, v, ...\}$, a set of *vertices* (or *nodes*), and $E = \{(u, v), ...\}$ a set of *edges* (a pair of vertices). The properties of graphs and the vocabulary used are numerous but this is some of them :

- If the vertices of a pair are ordered, the graph is *directed*.
- Two edges are called *adjacent* if they share one vertex.
- If there is an edge such as $e \in E$ and $e = (u, v)$, then u and v are *adjacent*.
- The *degree of a vertex* v (written $d(v)$), is the number of edges going in or leaving v.
- G is said *complete* if all vertices are connected with each other.
- A graph is said *weighted* if its nodes or its edges are labelled, and more particularly with values. For instance, if an edge represents a road, the weight could be the euclidean length of this road.
- $G_s = (V_s, E_s)$ is a *subgraph* of the *super-graph* G if $V_s \subseteq V$ and $\forall e \in E_s$, we have $e \in E$.
- A *path* is an ordered set whose we alternate distinct vertices and edges. We start a path with an initial vertex, then we had successively edges and vertices such as the edges comes from the previous vertex and goes to the next one. We continue until we reach the terminal vertex. Each edges and each nodes are traversed at most once.

- A *circuit* is a path where the initial node and the terminal one are the same.
- A graph is said *connected* if there is at least one path between each of its vertices.
- A *connected component* is a connected subgraph with no vertex connected to any other vertex of the super-graph. A connected graph has only one connected component.
- *etc.*.

Beyond this strong mathematical formalisation, the graph theory provides a large collection of analysis tools. They help to get information about the structure and the topology of the graph as well as on its weaknesses and its strengths. This is a non-exhaustive list of these measures : the number of nodes or edges, the average degree, the density, the diameter, the degree average deviation, the degree distribution, the distribution of the size of connected components, the average clustering coefficients, or the betweenness centrality. It is mainly why the graph theory is used in so many fields to model systems : in social science to model friendship network, in biology to model protein interactions, in computer science to model connections between machines like in Internet, in geography to model transportation networks, *etc.*.

2.2 Agent-based approach

The cellular automaton of John Von Neumann has been probably the first step toward the agent-based approach. Later, researches on distributed artificial intelligence, and particularly on swarm intelligence, like boids in 1987 [9] or ant colony optimisation algorithms in 1991 [10, 11] had contributed to build the agent-based approach.

Indeed, many problems seem naturally distributed : for instance, a set of autonomous vehicles moving on a network must reach their destination without accident; the design and the construction of a viaduct needs many kind of expertises... These systems are not just the sum of applied knowledge (*e.g.* drive a car and follow a defined path), but they are also the results of interactions between their entities (*e.g.* take care of others cars and adapt his speed).

There is not a real formalism of the agent-based approach because it is still a recent field, but nevertheless we can deduce the main concepts from the literature. Ferber [12] defines an agent as a physical or virtual autonomous entity ables to perceive his environment and to manipulate it. It has internal properties and behaviours and, has also the capacity to interact with others agents. The entity or agent can model everything without limitations : a whole sub-system, a community, a city... However, if the entities represent members of a population, we said that the model is an individual-based approach. The agent paradigm is used in many fields but some previous works [13, 14] show that it is possible and effective to use it in a logistic context.

A multi-agent system (or MAS) is composed of many agents within an environment. The environment has a topology and is itself constituted of objects. The agents could be heterogeneous, *i.e.* they can make part of different species (as Treuil *et al.* explain it [15]) and have *different* behaviours and properties. Thus, agents must collaborate, cooperate or be competing with each others. Moreover, new agents could be created while the system is running and other agents could be deleted, therefore they must adapt permanently their behaviours.

These non-deterministic mechanisms make the multi-agent system sensible to chaotic phenomenons. Even if, all behaviours of agents are clearly specified by a human, there is still non-predictable behaviours due to random value. Moreover, the output of a simulation could significantly change as the result of different values of initial parameters.

3 Conceptual model

In this section, we will study our agent-based model extracted from the previous knowledge base (see 1). We use an individual-based approach in order to build our agents from the actors and the infrastructures. The model is made up of two agents networks. The first one describes the interactions between the actors while the second models the physical environment with the logistics infrastructures (road, warehouses, terminals,...).

3.1 The actors-agents

The figure 4 describes the possible main interactions between the actors who take decisions. It can be noticed that it is not a linear flow.

The final destination is where the stock is consumed because of sales or because the goods are used for the manufacture of other products. The person in charge must restock regularly with the help of the logistics provider. The latter must balance the stock between each warehouses of the supply chain. He orders to a transporter to move goods from a warehouse to the next one until the goods reach the final destination. When the stocks are too low, an order is made to the provider. The person in charge of importation and the provider contact their respective forwarding agent. This one manages the goods on the right part of the route by choosing the transporters, the customs broker,...

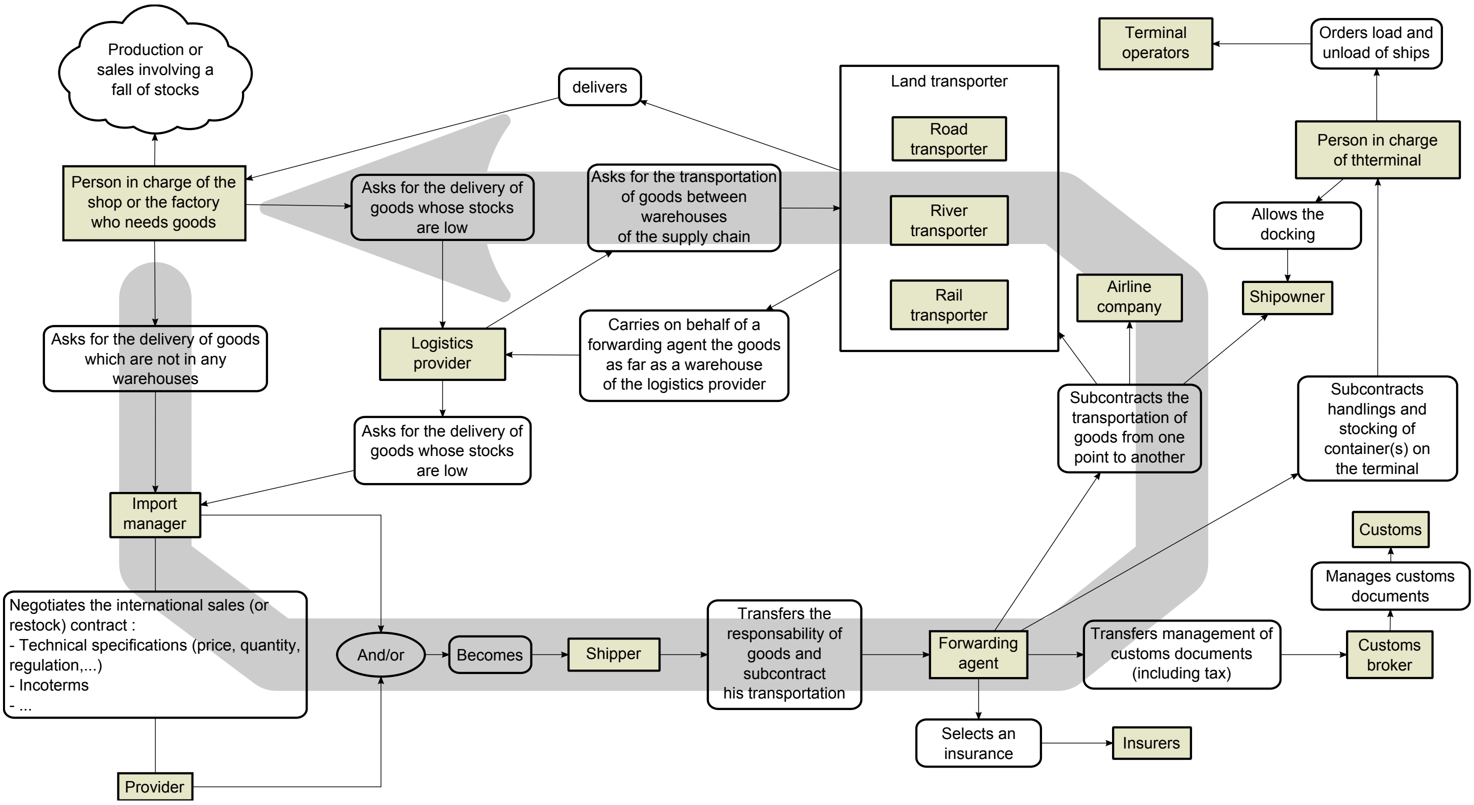
The agent-based model allows to reproduce the interactions system of the actors. It gives us the possibility to get a dynamic and auto-organised system with a sufficient modularity to make evolve the model. Each actor of this network is built as an entity able to communicate with others in function of its possible interactions detailed in the figure 4.

Moreover, each entity has a capacity to interact with his environment according to the kind of agent it represents. For instance, transporters are able to order to a vehicle to move goods from a point to another (which set the current traffic on roads). The person in charge of the final destination and the logistics provider are able to check the evolution of stock within their logistics buildings.

3.2 The infrastructures-agents and the supply chains

The modelling of the physical world is in two parts. Firstly, there are the agents representing the linear (roads, river and maritime lines) and nodal (logistics buildings and terminals) infrastructures. They make part of the environment and they form a network on which the

Figure 4: Network representation of possible interactions between agents



vehicles move and where the physical goods are stocked. This physical network is in fact made of many sub-interconnected-networks, thus, goods can reach their destination using different kinds of transportation modes. This multimodality is possible thanks to nodal infrastructures, like terminals, which allow to the goods to go from a sub-network to another one. A vehicle is associated to a particular sub-network and can only move on this one. The nodal agents could have a behaviour, and have some characteristics as a break bulk time, an occupied and a free surface. The linear ones have got a maximal speed, a maximal traffic capacity,...

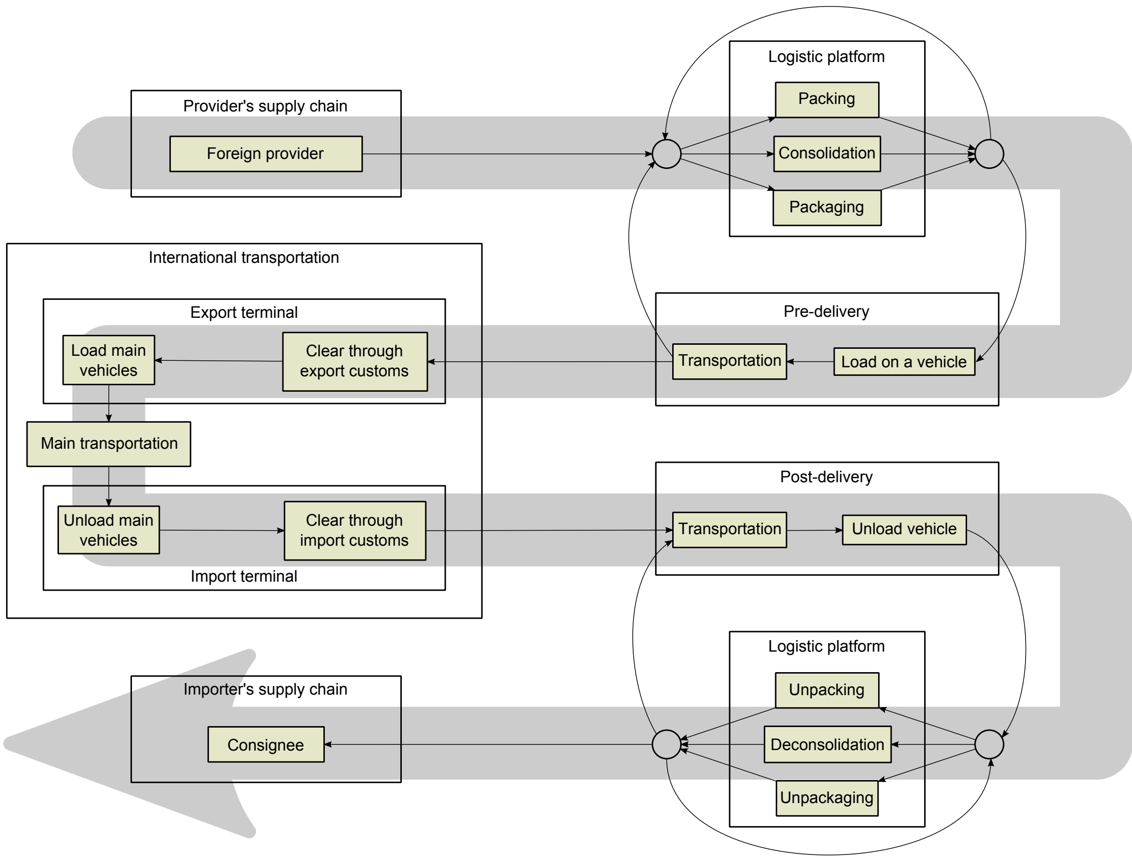
Secondly, the goods which move within a supply chain must go through ordered and precise nodal infrastructures. So, we need to model the possible supply chains associated to a particular industry as on figure 5. Each sector can have his own supply chain and obeys to its own rules. Moreover, each part of the transport can be made by any kind of transport mode. Thus, it is voluntary simplified on the figure 5 in order to be more clear.

3.3 Networks interconnected

The actors-agents are directly connected to the infrastructures-agents. For instance, the logistic provider can access to the stocks of its warehouses; the forwarding agent can know the current traffic on route and determine the best path took by goods (best in term of financial costs, duration,...);...

Yet, these communication skills are not reserved to the actors. Indeed, the logistics

Figure 5: Simplified representation of the international flow of containerized goods



buildings and vehicles can transmit issues encountered, like delays due to break bulk, low stocks, or hazards (in particular on maritime lines).

Thus, the actors network can act on the physical world because their choices will modify the flows and the traffic on particular area of the physical world. In the opposite, the congestion, the hazards, the technical issues on these axes will release some retro-mechanisms and the actors will must update their decisions.

4 The simulation

We will now explain how we have implemented our model in a simulation platform. Then we will study the tools developed in order to analyse the output data.

4.1 How it works

In order to implement our model, we were looking for an agent-simulation platform which could integrates geographical data like Shapefile. Different articles [16, 17] provide some comparisons of well-known platforms like Netlogo or Repast. However, it appears that the GAMA platform [1], that we have selected, is more appropriate to ours needs.

There are three mains kinds of agents in this implementation : the infrastructures, the actors and the agents representing the goods at different steps. We can also notice that most of the rules presented below could be configured thanks to parameters defined by the user.

The infrastructures In this first category, there is three agents : "Building", "Warehouse" and "Road".

"Building" can stock goods. He owns a function "receive_batch" which allow him to receive the entering batch of goods and to integrate the quantity of goods within its own stocks.

"Warehouse" derives from "Building". In addition, he has the capacity to receive restock order from the logistics provider. This action will have as consequences to update the stocks quantity of the warehouse and to create a "Batch" agent (see below) representing the order. These agents are sorted out according to their surfaces : there are national warehouses (large surface), regional warehouses (average surface), and finally the local warehouses (the smallest ones).

The road network is modelled by agents "Road" representing edges of this network. The whole forms an oriented and valued graph on which we can move, we can compute shortest path,...

The actors This second category contains the Provider, the LogisticProvider and the FinalDestinationManager.

The "Provider" agent is unique. Even if in the reality there are a lot of providers, we have no data on foreign providers, so, we have decided to model a unique super provider. We assume that he is able to satisfy all kind of requests (any quantities, any kind of goods). For each received order, he creates and sends a Batch agent.

The "FinalDestinationManager" is always associated to a "Building" whose the stocks fall regularly because of sales or uses. We can notice that we use the Huff model [18] which allows to compute the number of customer of a shop according to his sales surface and the distance which separates him from the consumers. However, we use it to determine a decreasing rate of stocks : the more there are customers, the more the stocks run out. The goal of the agent is to prevent an out of stock by ordering some restocks to his associated logistic provider. The restock is made from the warehouses of the supply chain associated to this agent. The LogisticProvider is chosen according to a probability depending of his proximity : the more the logistic provider is close, the more he have a chance to be chosen. Moreover, the person in charge of the final destination could have the possibility to change of logistic provider while the simulation is running. To do that, he must wait between one and three years. When his tolerance threshold is exceeded, the agent has got a probability to change or not of logistic provider : the more the collaboration has been long, the more the probability to change is high. However, only 90% of the FinalDestinationManager can change of LogisticProvider while the simulation is running.

The "LogisticProvider" determines a supply chain for each of his customers. One chain is constituted of exactly three levels of warehouses[6] (so, the whole supply chains form a trumpet network). These warehouses are shared between all the logistics providers. The goal of this agent is to externalise the stocks of his customers and to well-balance these stocks between the warehouses. When he receives an order from a customer to restock, he must transfer the right quantity from the local warehouse to the building of this customer. And when the stocks are too low in a warehouse, he restocks it by moving goods from the warehouse of the upper level. The last level is restocked from the Provider. The national warehouses are chosen according to their free surface; the local warehouses are chosen according to their proximity to the customer; and finally the regional warehouse must be the more possible on the middle of the axis between these two previous warehouses.

Agents modelling goods In this last category, there is "Stock", "Order" and "Batch".

The "Stock" represents a quantity of a particular kind of goods within a Building. It occupies a surface subtracted to the free surface.

The "Order" agent is the abstract form of goods. It models an information shared by actor of which kind of goods and in which quantity that must be moved.

Finally, the "Batch" agent represents the goods which move on the network. It contains a path to follow (at the present time, computed by GAMA according to the euclidean distance) and it is subjected to break bulks (between 2 and 24 hours) when it comes in or comes out a logistics building.

Origins of data sets At the present time, the FinalDestinationManager are generated from a Shapefile including only the wholesale trader. In the future, it could also include classic retailers and factories. The road network comes from the main roads of the Seine axis, such as highways or national roads. The warehouses are stemming from a database of building permissions between 1980 and 2011 of logistics buildings whose the surface is higher than 2000m^2. Finally, in France, the logistic providers often have the status of freight forwarder, so, these agents come from a database including the freight forwarder of the Seine axis.

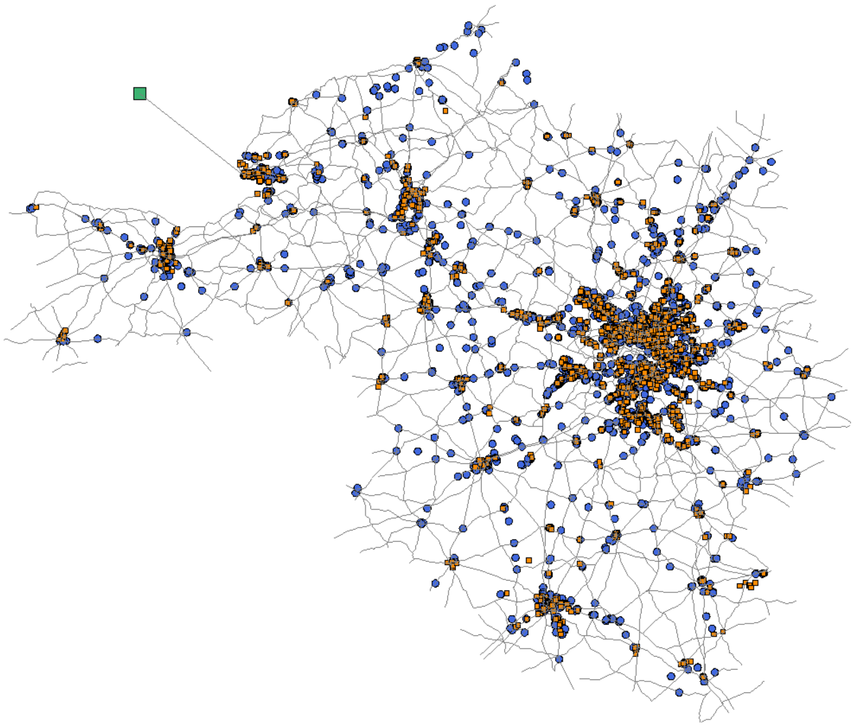
4.2 Analysis tools

In order to analyse data generated by the simulation, we have developed a GAMA plug-in called "gs-gama". It allows us to build graphs within an external program using the Graphstream library [2], and from GAMA's outputs. Thus, these graphs can be analysed thanks to algorithms of the graph theory.

The first graph models the interactions between the FinalDestinationManager and the LogisticProvider : the agents are the nodes, and if they had worked together, then they are connected by an edge. The next one represents the whole supply chains : if two buildings

[6] We are aware that in the reality, each supply chain can be different, but we have voluntary simplified this part of the simulation. In the future we want to improve the mechanisms of selection of supply chain and make it more realistic.

Figure 6: The road network and the position of agents on the Gama platform
In orange : the FinalDestinationManagers; in blue : the Warehouses; and in green : the Provider



are side by side in a supply chain, then they are connected by an edge. And finally, we also can generate a set of neighbourhood graphs : the nodes of the same graph could be of any kind of agents, and if they are within a predefined distance from each others, then they are connected by an edge.

For each of these graphs we can get different measures which help us to determine particular properties of these graphs, and in the future to detect communities within these graphs. Thus, the goal is to get a best view of the reality. Furthermore, in the future, we want to study if the flows of goods follow paths of high betweenness centrality. It will be possible thanks to new measure got in real-time while the simulation is running : we will transmit to Graphstream the quantity of goods on the roads and we will compare these values to the betweenness centrality of the edges.

Others tools have been developed where we can observe the evolution of variables of the simulation, among the overall stock within warehouses or final destination, the number of batches on roads and the quantity of goods on roads.

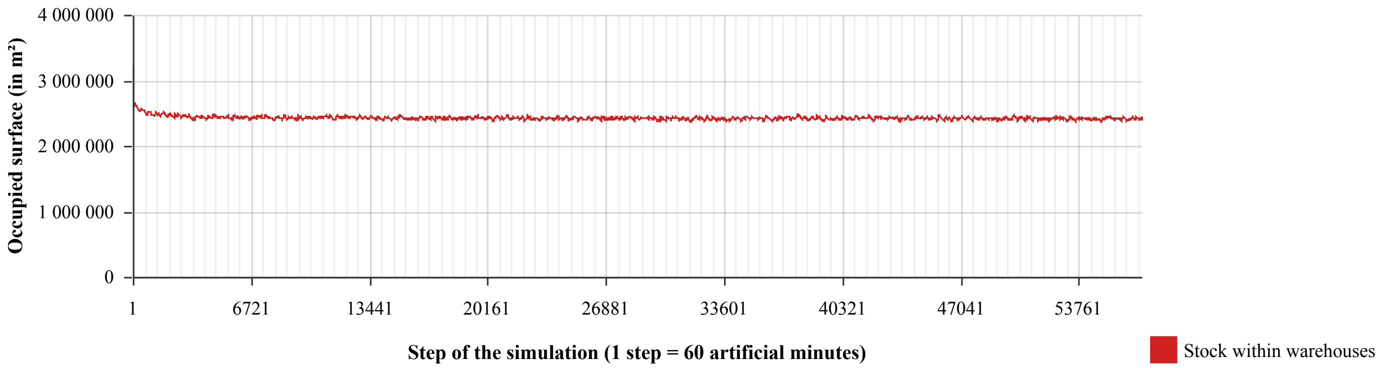
5 The results

In this following part, we will discuss about the first results of the simulation. It is a first step in order to better understand the model and in the future to develop new analysis tools.

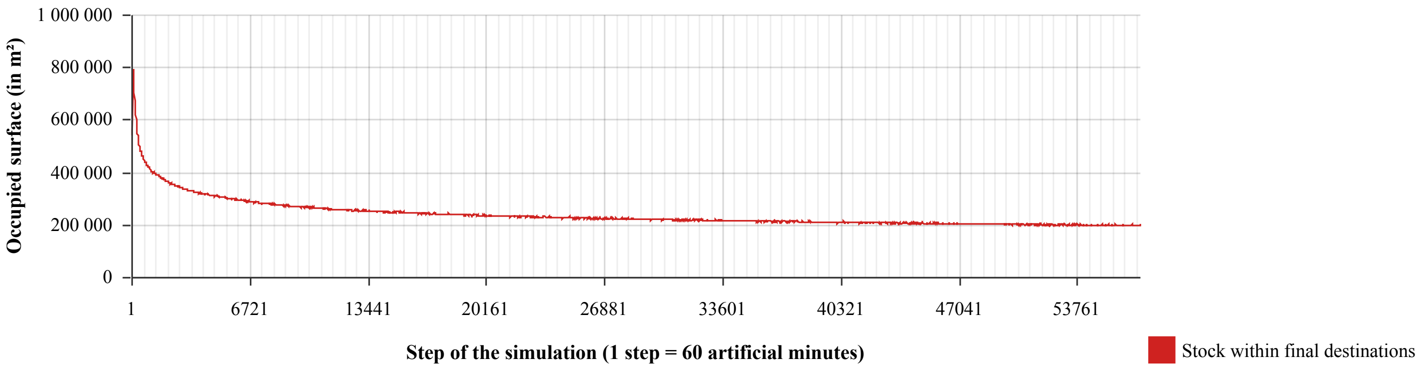
On the figure 7, we can observe the evolution of the amount of stock in warehouses and in final consignees. Our unit measure of the quantity is the occupied surface in m^2. Indeed, at the present time, the goods are artificial so we can not define another proper unit measure like the volume. On the first chart, we see that the quantity is very stable while, in the second chart, the quantity decreases progressively before reach an asymptote near the 15,000th step (one step equals one artificial hour). This phenomenon indicates us when the simulation is completely stable. We could probably make faster the stabilisation if we adjust the method of initialisation of the stocks.

Figure 7: The quantity of goods within logistics buildings

(a) The quantity of goods within warehouses



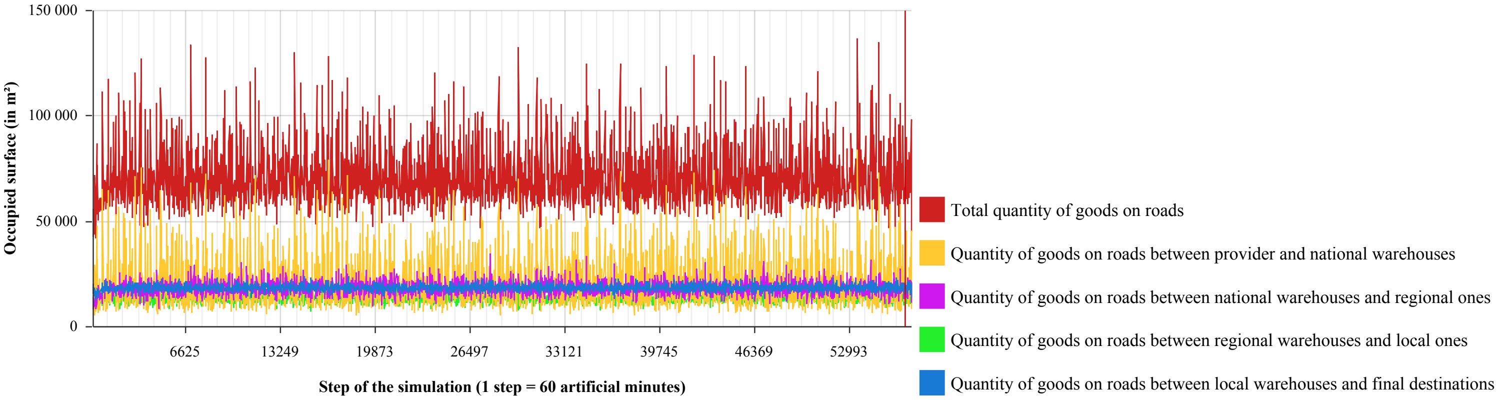
(b) The quantity of goods within final destinations



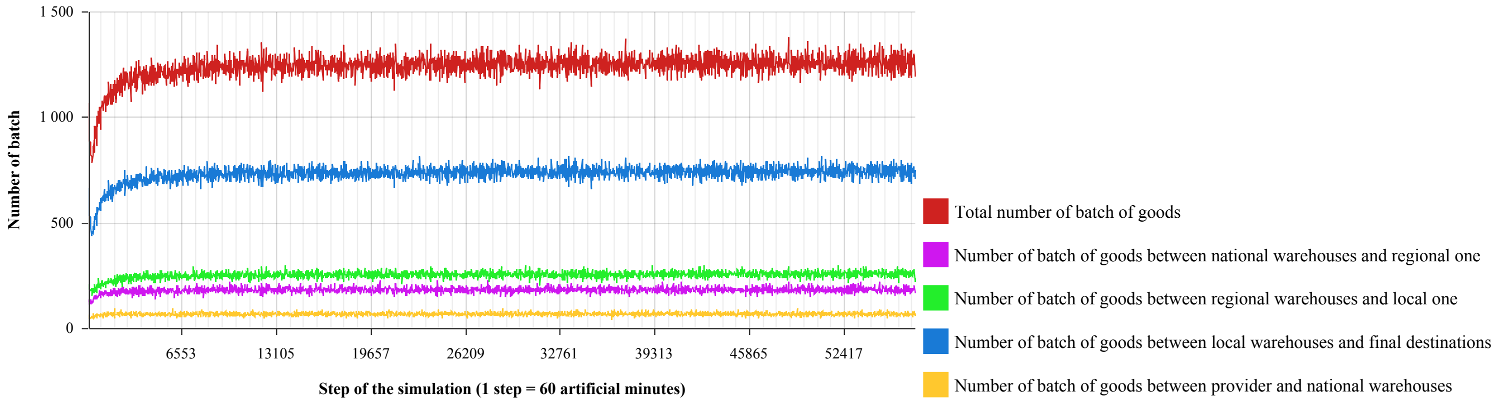
The figure 8 shows two linked charts. The quantity of goods on road is in fact the quantity of goods within moving batches. We have separated the set of batches in four subsets according to their destination, thus, we are able to compute the quantity of goods which are moving from a kind of logistic building to another one; for instance, from the provider to a national warehouse. For each of these charts, the stabilisation starts around the 2,000th step. However, even if the curves are both more or less horizontal lines, we can not observe the same hierarchy of the curves between the quantity of goods and the number of batches. Indeed, the number of batches is clearly ordered : there is less batches going from the provider to the national warehouses than batches going from the regional warehouses to the local ones. Nevertheless, we can not find this hierarchy on the first chart of this figure, even if we zoom in a smaller range. Therefore, we can assume that although some kind of batch are less numerous, the quantity they carry are more important. The batches going from the provider to the national warehouses carry more goods than the batches going from the local warehouses to the final consignee. Thus, this characteristic is the principle of atomisation of flows and it is a well-known phenomenon of the real world.

Figure 8: The quantity of goods on road

(a) The quantity of goods on road



(b) The number of batches of goods



Now, we will develop the analysis tools based on graph theory. The first kind of graph is a neighbourhood network as on figure 9. We can view many connected components of different sizes. The chart associated to this figure 9 shows that there is many little components but quickly, the number of taller components decreases. Indeed, the curve draws a power law distribution. It appears that some geographical spaces regroup more or less warehouses. These groupings can be seen as geographical clusters or communities. Moreover, we can note that on the others neighbourhood networks (not shown here), we observe similar results.

On the last figure 10, we see that the supply chain network is mainly a star. However, some particular warehouses have been chosen several times to take part of a supply chain. It models a phenomenon of preference in the selection process of which warehouse will take part of the supply chain. Indeed, the more a node have a high degree in this network, the more we can deduce that it is rightly located or has a large surface and that the agents prefer to chose this one than another.

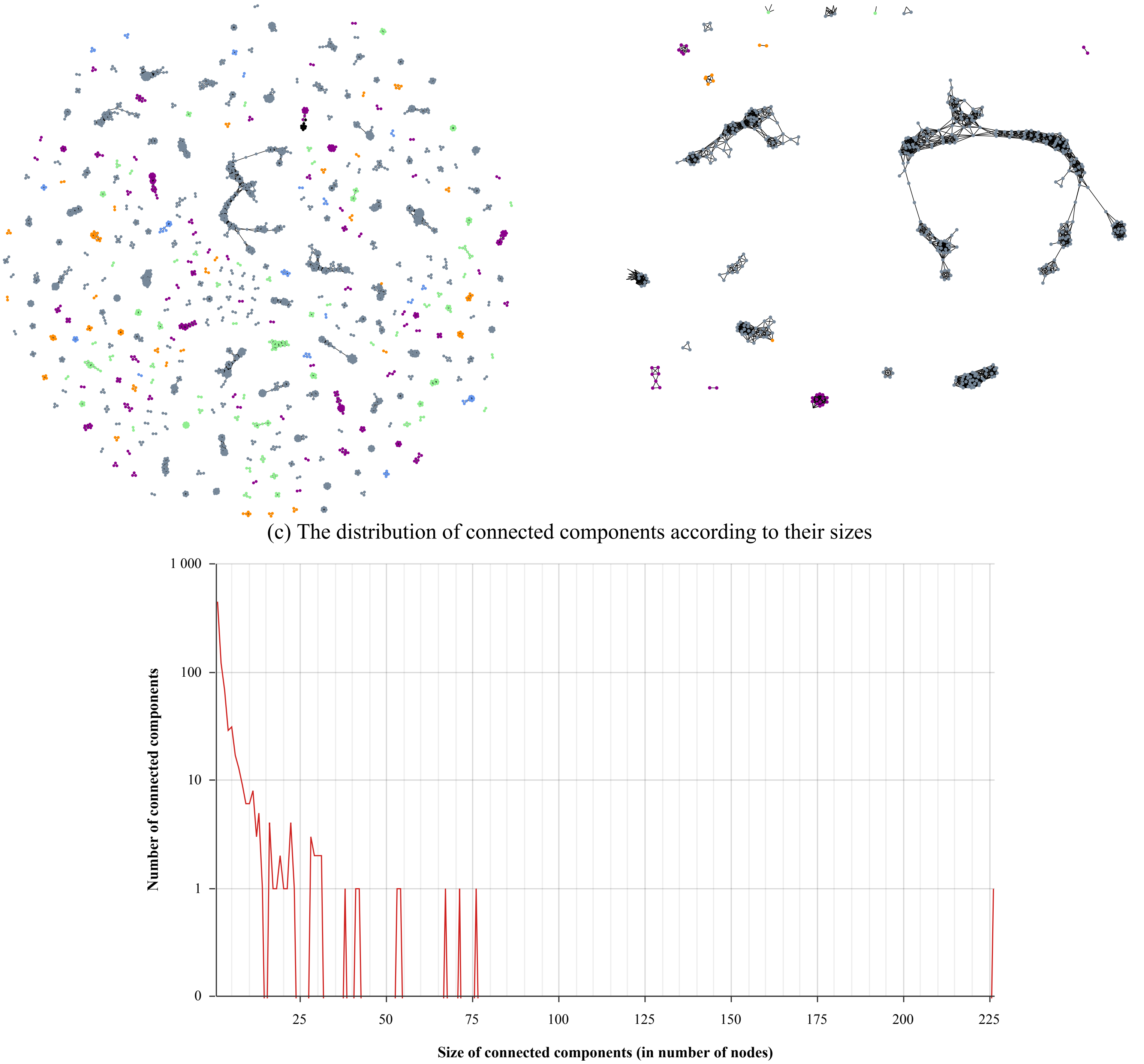
These first results are a first step to get a better understanding of the simulation and the model. For instance, we want to use some algorithms of community detection (as from a survey of Santo Fortunato [19]) in order to reveal clusters in term of their geographical positions but also in term of a functional organisation. Indeed, we can assume that it exists some agents who work together and form a community which can be more or less stable according to the strategic behaviours of its agents and their functional performances within

Figure 9: The neighbourhood graph of warehouses with a maximal distance of 1km
In grey : warehouses from Ile-de-France; in orange : warehouses from Picardie; in green : warehouse from Centre; in violet : warehouses from Haute-Normandie; in blue : warehouses from Basse-Normandie

(a) The whole graph

(b) A zoomed zone of the same graph

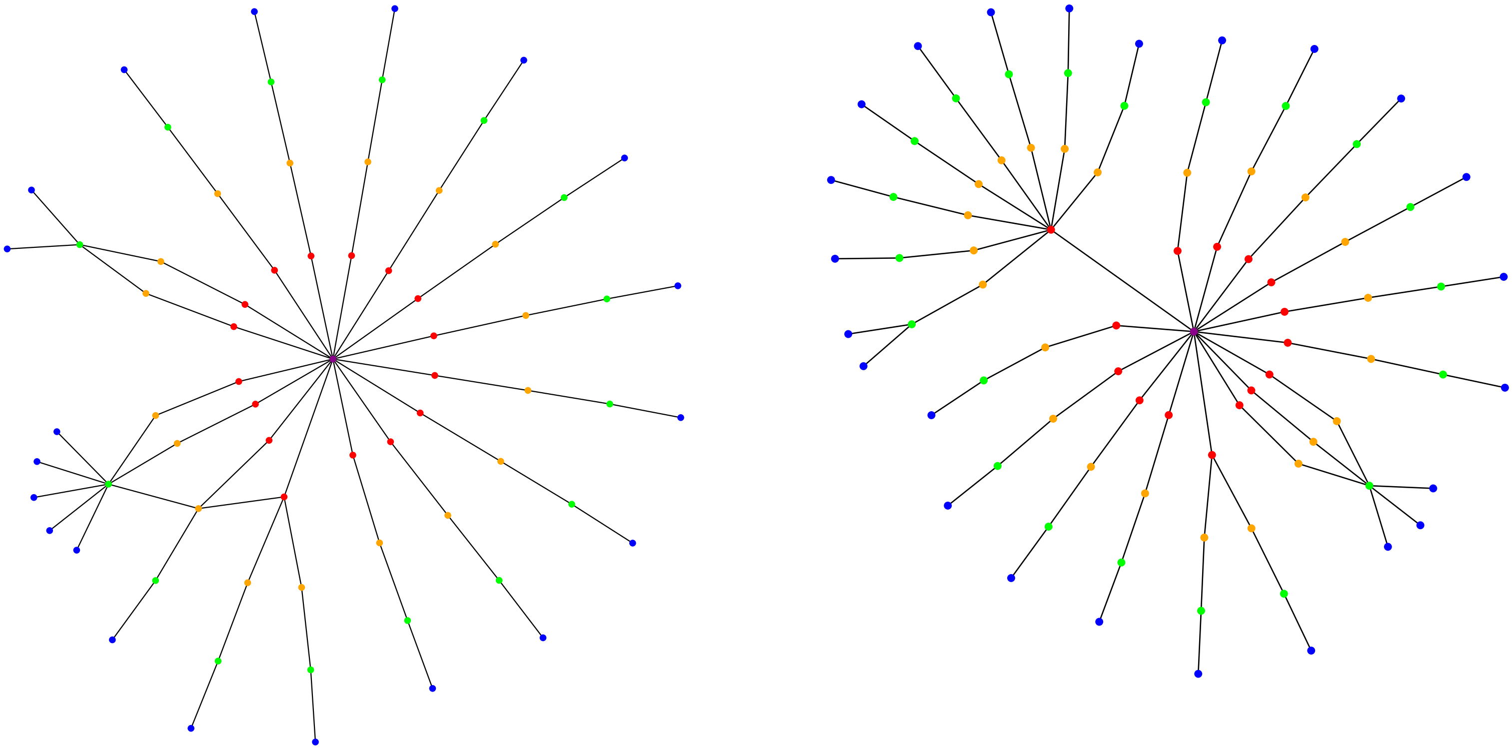
(c) The distribution of connected components according to their sizes



the community. It is very interesting to identify the properties of these clusters in order to highlight how a successful cluster is build and works.

Figure 10: Two partial graphs of all supply chains
In blue : the FinalDestinationManagers; in green : the local warehouses; in orange : the regional warehouses; in red : the national warehouses; in violet : the Provider

(a) First partial graph (b) Second one



Conclusion

So, in order to build a model of the Seine axis logistic, we have developed a knowledge base of the actors and the infrastructures of this geographical space. Among the main actors, we have highlighted the final consignees, the providers, the logistic providers, the forwarding agents and the transport operators. They cooperate and collaborate together in order to carry goods over the physical infrastructures. The latter are divided in two sets : the first contains maritime lines, road, river and rail networks; while the second contains terminals, warehouses and logistic platforms.

Thanks to methodological concepts described in the second part, we have developed a conceptual representation of actors and infrastructures with an agent-based approach. The roads, the maritime lines, the river and the rail network are modelled by graphs and each edges are an agent. Some retro-action mechanisms exist between the actors and the infrastructures : agents, like logistic provider or transport operators, know about congestions, bottlenecks or low stocks and delays due to break bulk. Therefore, agents can update in real-time their choices.

We have also implemented the model in an agent-based simulation platform named Gama. Since it is a work in progress, there is only a subset of the main actors : the logistic provider, the provider and the final consignee. Moreover, the linear infrastructures are restricted to the road network. In parallel, we have developed analysis tools in order to get information on the model thanks to measures on charts and graphs.

The first results indicate when the simulation is stabilised. Then, we have highlighted the atomisation process of the goods thanks to charts on figure 8. Finally, neighbourhood graphs allow to detect geographical clusters, while the supply chain graph describes that some warehouses are more likely chosen due to a better localisation or a larger free surface.

This whole work is a first step to get more information on the Seine axis logistic. We have planned to use some algorithms of community detection in order to reveal functional organisations (a stable clusters of collaborating agents in interactions). Moreover, we will bring together the simulation with the conceptual model. Indeed, there is still some actors and infrastructures which need to be implemented (like the forwarding agent).

Finally, we want to confront these results to real data in order to validate our model.

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