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Agent-Based Approach and Dynamic Graphs to Model Logistic Corridor

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Abstract

This paper presents the modelling of a logistic corridor. It integrates the port and the metropolitan logistics connected by an interface. Such a system can be seen as complex. A multi-scale point of view is adopted thanks to an agent-based approach which is coupled with dynamic graphs in order to represent in the one hand the actors involved in the transportation of goods, and in the other hand, the structured environment. The model is implemented in an agent-based simulation platform. Results about the impacts of parameters on the demand generating the flows of goods are finally discussed.

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Keywords: agent-based model, dynamic graph, logistic system, modelling, complex system, geographical information system

Introduction

The modelling of a logistic corridor can provide information about the mechanisms at the origin of the organisation and of the structure of such a complex system. They are mostly described in the literature as two separated components: for instance, De Langen et al. [1] or Hesse and Rodrigue [2] worked on the freight transportation but only over the hinterland; Carlo et al. [3] described numerous works about operations in container terminals. The port and its hinterland are often seen as distinguished systems. Both form strong clusters of highly connected actors with specific needs and ways of working. But despite a lot of papers on the modelling of logistics [4], there is a lack in the literature since too few papers try to model these interconnections in order to simulate the working of the whole system. This paper shows, through the model, how these two sub-systems are connected thanks to a logistic interface.

The first section explains the context of this work while the second section describes the modelling of a logistic corridor seen as a complex system. A multi-scale approach has been chosen thanks to the use of a multi-agent system and dynamic graphs. These concepts can model the spatial constraints but also the functional rules of the actors of

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such a system. The last section provides the results from the implementation on a simulation platform, using data about the Seine axis: a logistic corridor.

1. Context

A logistic corridor is defined as a spatial environment on which goods are transported to reach final customers. But the transportation is compelled by numerous limitations of different kinds (economical, spatial or political). Actors must organise themselves to push back these restrictions in order to improve global performance of the corridor and increase the size of the hinterland in order to deliver goods in further urban areas. It leads to a competition between corridors who shares some metropolis such as Paris whose the freight mostly comes from the ports of Le Havre and Antwerp.

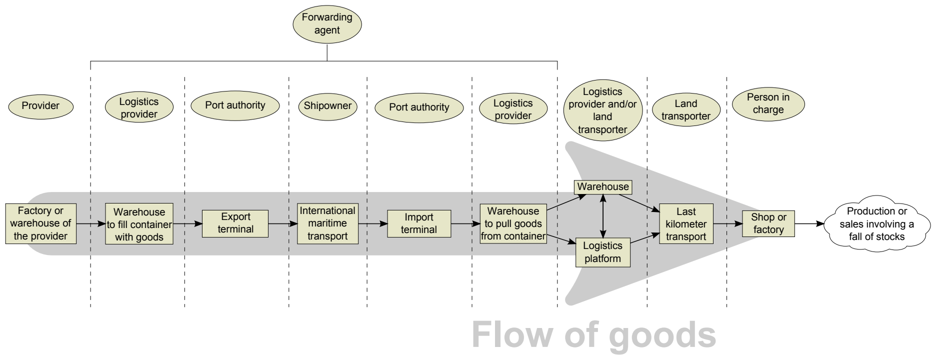

Fig. 1: Each actor manage a part of the flow

As on figure 1, the main actors of the logistics[1] manage the flows of goods. They have personal and collective goals: financial profits and to satisfy their customers. These goals are achieved thanks to the local functional rules of the micro level: their behaviours (their business strategies) and the interactions with other actors. But actors in competition must sometimes collaborate together in order to avoid the constraints of the environment (politics, spatial restrictions,...). At a macro level, it results in the auto-organisation of clusters, or local communities such as on the port or in an urban area. It reveals the complexity of a logistic system.

The transportation network is also source of complexity. It must be structured because each kind of logistics has specific characteristics. The multi-modality of the transportation network implies that sub-networks have different constraints (size of vehicles, speed,...). The maritime or port logistics allows to carry more goods by vehicles. Ships and terminals must have the capacity to process such amount of freight. But the flows is subject to hazards, such as natural events, making the flows irregular. Concerning the metropolitan logistics, the expected flows must be regular due to the final customers needs. And they must be atomised because the urban areas are spread over the territory. It is made possible thanks to the interface logistics composed of: the logistic buildings (warehouses and logistic platforms[5,6,7]) which compensate the irregularity with outsourced stocks; and the other sub-networks which allow the atomisation. A river barge carries more goods than one train which carries itself more goods than one truck. But trucks are more flexible because they can deliver everywhere on the territory and they are often used to make the last kilometre. There is a real hierarchy between sub-networks according to the needs (regularity, speed, quantity). The path followed by goods defines a particular structure chosen by the logistics providers from an infrastructure to another; in fact, from a logistic of mass to a logistic of unity. The transportation network has therefore two goals: to atomise the flows of goods, and to compensate the irregularity of the international transportation. Its complex structure makes emerge from local movement of goods, overall patterns at the macro level: local constraints of the network force the flows of goods to take particular itineraries observable at the macro level.

2. Modelling of a logistic corridor

The model described here has the goals to help to understand how a logistic system is structured, and to help to make decisions about spatial planning or strategies to adopt. An agent-based approach[8] coupled with dynamic graph[9,10] has been chosen because they are well-suited to model complex systems. The graph theory and its numerous measures can provide data about a system to help the decision making. For instance, it is possible to observe the traffic, the time of transportation, the costs (financial or environmental)... The agent-based approach can describes the spatial dimension of a system. Moreover, both can be configured thanks to parameters, and thus provide adaptability.

The agent-based approach gives the capacity to the model to adapt itself to different logistic system. Even if the different corridors share some characteristics, the spatial constraints, or the laws are not always the same everywhere. Thus, actors do not have necessarily the same exact behaviours from a corridor to another.

The transportation network is made of sub-networks (maritime lines, river, road and rail networks). It is a dynamic graph where flows evolve in time over the edges. If the traffic increase too much, the flows can be slowed down due to congestion, or stopped temporarily if there is a traffic jam. The agents can perceive these issues and update their decision in real-time. The buildings, such as logistic platform or terminal, are also agents. They can transfer goods from a sub-network to another according to their connections to the network. They are also integrated in a higher level of network: the supply chain. This one is organised by the logistics provider according to predefined rules described in the figure 2.

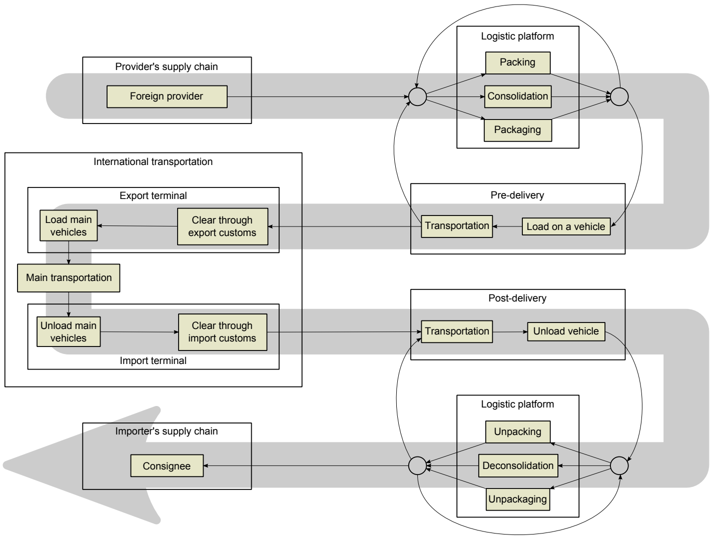

Fig. 2: Simplified representation of the different steps followed by containerized goods during the international transportation

Each actor and infrastructure are modelled with an agent who takes autonomous decisions according to its perception of the environment, the kind of agent it is, and to its interactions with other agents. The figure 3 represents the modelled actors and describes their possible interactions. The person in charge of the shop is the final consignee. He has a stock of goods which decreases progressively, and he also have an outsourced stock managed by a logistics provider. This one is selected according to his performances (time to deliver the goods, costs,...) but also the distance which separate the two actors. Indeed, it is more common to work with a person spatially close. The local stock decreases according to the size of the local population and the accessibility of the final consignee (the Huff's model[11] can be used to determine that). The logistics provider manages a supply chain whose the goal is to deliver quickly and regularly the goods of his customers. He must order to transfer goods from a warehouse to another in order to well-balance the stocks. The order to transfer depends on a threshold under which the logistics provider orders the delivery. The supply chain is designed as a fork network and can have many levels depending either of the strategy adopted by the agent, but also by the kind of logistic corridor. For instance, on the Seine axis the number of levels is mostly of 2: a regional or national level, and a local level; for the hinterland of Antwerp, the number of levels is mostly of three: an international or national level, a regional one and a local one. They choose the warehouses according to their surface for the warehouses of higher level in the supply chain, and according to their position with regards to their customers for warehouses of lower level. This structure allows the atomisation of the flows because there is less warehouses of high level. It means that goods of different customers can be stocked within the same warehouse. The topology of the supply chain and the characteristics of the warehouses which compose it (position, surface, accessibility) determine the performances of the agent. It is a characteristic of the logistics provider agents which is public to other agents. If the stocks are too low within the supply chain, an order is made to a provider. The forwarding agent has the role to select an appropriate path over the transportation network from the provider to a high level warehouse of the supply chain. This path can be multi-modal and its selection is made according to the financial costs but also the time of transportation, the carbon footprint, or a preference among the different modes. The adopted strategy, shaped as percentages, defines the importance of one of these parameters over the others. The forwarding agent must work with the transporters. These agent can provide a path on a specialized network to each quadruplet origin, destination, kind and quantity of goods. This path has a cost (financial, time of transportation, carbon footprint,...), a departure date, and an indication if the transportation will be shared with the goods of other customers.

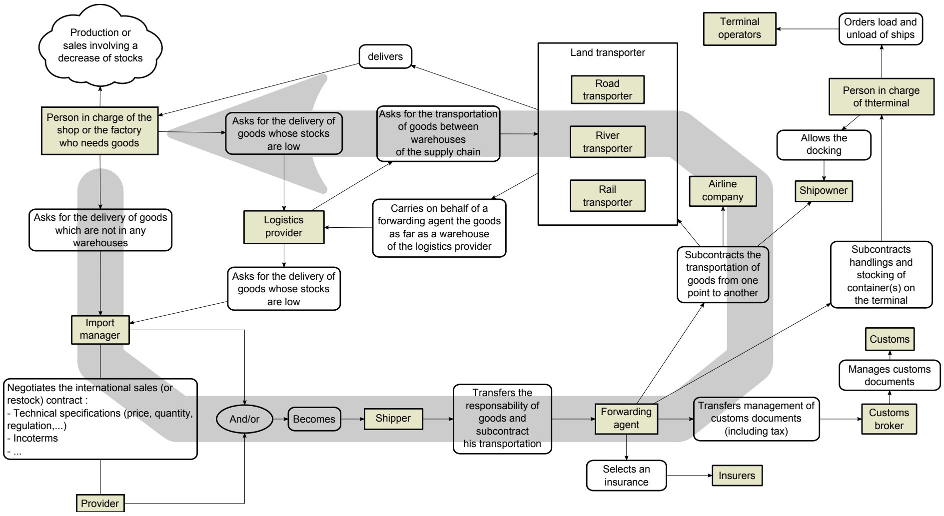

Fig. 3: Graph representation of possible interactions between agents

Therefore, the providers, the forwarding agents and the international transporters are included in the maritime or port logistics. The final consignees corresponds to the metropolitan logistics. And the logistics providers and the land transporters plays the role of the interface.

Such a model is independent of the input data, such as the topology of the transportation network or the position and the number of warehouses. A decision maker can modify a real network, for instance adding a new highway, and can test the effects of this new configuration on the performances of the system. He can also add or delete some warehouses with a better position, for instance in term of a high value of an accessibility measure such as the Shimbel index [12], and again tests the effect on the logistic performances.

3. Results

This section describes the implementation of the previous model in a simulation platform. The goals are to check the validity of the model but also to provides first measures to help to the decision making. The data used here comes from a geographic database using Shapefiles. They are provided by the Devport project[1], a research team who

[1] Its website: http://www.projet-devport.fr/en/

works on the Seine axis. The Shapefiles provides the position of the agents over the territory of the Seine axis. It is possible to execute the simulation with another set of data of another corridor. The agent-based simulation platform GAMA [13] is suitable for the implementation thanks to its capacity to integrate easily geographical data compare to other platforms [14,15].

The transport on the Seine axis is mostly represented by the road. So, the implemented transportation network is not multi-modal yet. Only three actors are implemented: a unique provider who aggregates every foreign providers (the simulation is focused on the Seine axis and not on its outside); the logistics providers who organise the outsourced stocks thanks to a supply chain that they determine; and the final consignees who play the role of manufacturer or retailer and see their stocks fall regularly. At each step of the simulation (one step of the simulation equals to one artificial hour), each agent can take decisions. The Huff's model [11] is used to compute the number of customer of the final consignees and therefore to define a hierarchy among them. This hierarchy allow to determine a coefficient of diminution of stocks. One time per day, this coefficient is used to decrease the quantity of stock: the more the coefficient is low, the more the stock can decrease. It is nevertheless a probability and sometimes, the stock can not decrease at all.

The final consignees choose also a logistics provider. His probability to be chosen depends on the distance to his customer: the closers have a higher probability. When he is chosen, the logistics provider must determine a supply chain of two levels: a large warehouse and a warehouse close to his customer. Since he has potentially many customers, he can already have a supply chain and can decide to reuse one warehouse of his supply chain (if there is a sufficient free surface). His goal is to well-balance the stocks over the warehouses of its supply chain in order to avoid the stock shortages of his customers, and to minimize the number of movement of goods. Therefore, an order to move some goods is made only if the stock of a product is under a predefined threshold. This movement is represented by an agent called Batch which moves along the edges of the network according to the maximum speed allowed by the roads. It leaves a trace along its followed path and corresponding to its generated traffic. The trace disappears progressively in time, bringing a dynamic to the network.

The threshold under which the logistics provider orders the delivery and the coefficient of diminution of the stocks have a direct impact on the performance of the logistic corridor. The coefficient defines the consumption of the population over the territory. The more the coefficient is low, the more the consumption is high and the more the stock decrease quickly. The table 1 corresponds to six different simulations. Every final consignees of a same simulation are configured to have the same coefficient, and the logistics providers have the same threshold. When final consignees have a low coefficient (and therefore a high consumption) the number of stock shortages is higher than the simulation executed with a higher coefficient. When the consumption increases, the logistic corridor must provide a higher performance to satisfy the demand.

Table 1: Evolution of the average number of stock shortage according to different values of coefficient of diminution and of threshold

Coefficient of diminution	3		4		5	
Threshold under which the logistics provider orders the delivery (in percentage)	20%	30%	20%	30%	20%	30%
Average number of stock shortages after 2000 steps (1 step equals 1 artificial hour)	654	114	234	35	91	31

The table 1 focuses also on the effect of the threshold under which the logistics provider orders the delivery. For each simulation made, there are less stock shortages when the percentage is higher. It means that the logistics provider adopt a more secure behaviour to avoid the stock shortages. There is less time between two orders and the logistics provider has more easier his stock with a sufficient amount of goods to satisfy the demand. However, a lower threshold means that the quantity of transported goods per order is also more important. Therefore, in that case, there is potentially less movement of goods which is economical. A logistics provider must optimise the ratio between a risky but thrifty behaviour, and a secure but expensive behaviour. The simulation can be used to approximate this ratio and help a decision maker to optimise a strategy of stock management between many warehouses.

Conclusion

This paper presented a way to model a logistic system. Such a model can provide the necessary information about the system in order to understand its structure and its organisation. A logistic system can be seen as complex thanks to a multi-scale point of view. The agent-based approach and the dynamic graphs can integrate the spatial constraints and the functional rules of a logistic corridor. Thanks to these concepts, the model gets the capacity to adapt itself and is therefore compatible with most of the known logistic corridor. Moreover, it can help to the decision making of spatial planning.

The implementation has been made on the simulation platform GAMA and the data used comes from the Seine axis, a logistic corridor of the Northern European range. Only a subset of the agent from the model has been implemented but there are interesting results showing the effects of the consumption and of behaviours about the management of stocks. The simulation is still a work in progress, and more measures and results will be studied in the future. For instance, the logistic performance could be investigate through the measure of the average time delivery or the average distance covered by goods.

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