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An Agent-based Approach for Controlling Global Logistic Processes

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Abstract

The flow of orders and products along global supply chains gains complexity, on which account the planning and execution of production, storage, and transport operations display great challenges. The use or not of storage services aiming to achieve economies of scale in transport operations is one of the problems to be handled by decision makers within global supply chains. Taking into account this specific decision, this paper proposes an agent-based approach for controlling globally distributed supply-chain processes. The approach model is structured as a group of autonomous agents that act in a coordinated way. To obtain an overview of existing research in the area of agent theory and agent-based systems applied to supply chains the paper begins with a systematic literature review. The proposed approach expands an existing agent-based model that does not allow for intermediary storages. This improvement is justified by the relevance of this kind of storing, which are actually used in real-world global supply chains where transport costs and economies of scale are crucial for decision-making.

Keywords: agents; multi agents systems; supply chains; global operations; logistics.

1 Introduction

In the current global environment, it is common for the raw material resource, the production, and the consumption of a product to be located in different countries and continents. In this context, a global supply chain can be defined as a network of providers, factories, subcontractors, warehouses, distribution centres and retailers which acquire raw material, process it, produce it, and sell it to their costumers (Fox et al., 2000). The flow of merchandise along these chains gains complexity. In fact, the planning and execution of production, storage, and transport operations display great challenges. One of the main problems to be solved in global supply chains is the use or not of storage services aiming to achieve economies of scale in transport operations. To deal with this problem, a new generation of strategies for controlling logistics processes based on autonomous and intelligent agents has gained relevance (Bullinger et al., 2000 apud , Jiao et al., 2006).

In this context, the present article makes use of a theoretic-conceptual approach (Berto and Nakano, 2000), by proposing a model for the control of logistic processes based on intelligent agents in global supply chains. The article formalises the utilisation of distributed agents for the realisation of an integrated transport and production. Such integration is materialised in the coordinated execution of production and transport processes for products and raw materials of each participating company. Through a wide theoretical grounding, this article highlights the impact of autonomous agents in planning and executing complex management activities in global supply chains.

The paper begins by introducing the theoretical grounding in section 2. In this section, fundamental concepts for comprehending the meaning of agents are emphasized. Furthermore, the characteristics of studies whose target is centred in logistics and supply chain are presented. It can be noticed that the use of agents in logistics coordination is a prominent study branch. Section 3 begins by introducing the scenario of the theoretical model application based on distributed agents, i.e., global supply chains. In the sequence, the model is formalised mathematically. It is important to highlight that the proposed approach is an expansion of the model proposed by Lau et al. (Lau et al., 2006). The innovation of the proposed

approach is verifying if the use of storage services to achieve economies of scale would be opportune or not. Finally, the conclusion and final recommendations are stated in section 4.

2 Literature Review

The theoretical ground of the research is the branch of agents applied to logistics (Lang et al., 2008, Moyaux et al., 2006). In the sequence, a systematic literature review is executed. The review attempts to evaluate the use of agents for controlling logistic processes according to the following criteria: application range, coordination type, and approach used.

During the search, a comparison of returned papers for several combinations of different terms was implemented based on the following criterion: application range, coordination type and approach used. Specifically, the "application range" criterion detects if the approached problem is more specifically linked to transportation, or if it pays attention to all processes of the supply chain, such as storage and production. The "coordination type" criterion seeks to observe whether the research is linked to a logistic process in a wide range, or if it is concerned with the automation. At last, with respect to "approach used", the results are directed to the main target of the research, i.e. the terms "agent-based" and "agents". The quantitative results can be identified in Figure 1.

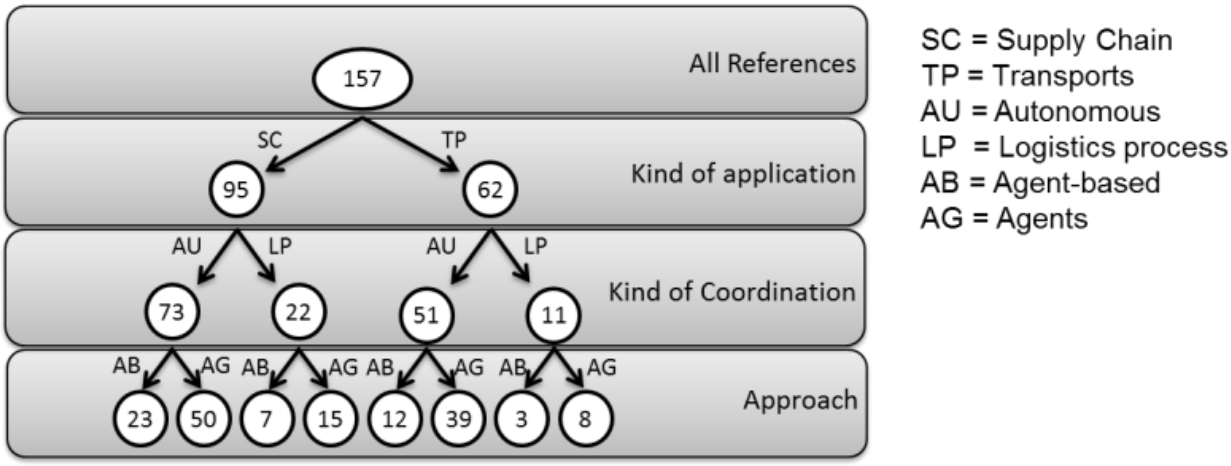

Figure 1: Some quantitative numbers about the references.

Initially 157 (one hundred and fifty-seven) references were identified. It can be verified that the studies regarding the use of agents in logistics approach mostly supply chains and not merely the transport process. Another observation is the recurrence of automation: most applications mention this fact in some manner. After the elimination of duplicated references, 80 (eighty) were listed. Sixty-one of these were published in the last 7 (seven) years. This finding reveals that the study of applications of agents in logistics has recently obtained visibility. The abstract of all 80 articles were analysed with the scope of identifying those which were relevant to the research, i.e., those which approached the theme of autonomous control of logistics processes based on intelligent agents. After this analysis, 7 (seven) papers could be selected which were then used to build the referential basis.

2.1 Agent theory

Agent theory is a field in computer science, more specifically, in artificial intelligence. The definition of the term "agent" is widely disputed, inasmuch as there is yet no consensus as to its formal concept. Parunak (1998) defines agent as a software entity which possesses information and encapsulated programming, thus assuring to the agent the ability of reacting autonomously to achieve its goals. To Fox *et al.* (2000), however, an agent is an autonomous software with the objective of determination that communicates itself asynchronously, communicating itself in a coordinated manner with other agents when necessary.

Wooldridge (2002), in turn, defines agents as software capable of having independent actions according to its user's or to its own interest.

As shown in Figure 2, Nwana (1996) classifies agents according to characteristics as follow: cooperation (other agents are used to run a given activity), learning (historical data is used to decide how a given activity must be run), or autonomy (it acts without waiting for the decision of another agent or person).

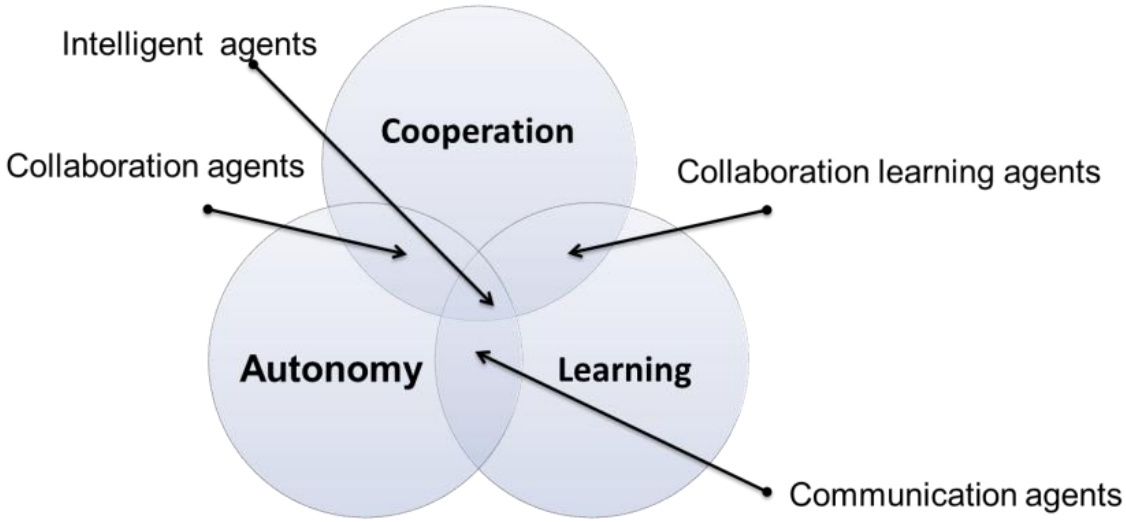

Figure 2: Agents Typology (Nwana, 1996).

Using a combination of these concepts, collaborative learning agents may be defined, which must withhold cooperation and learning, but must not necessarily be autonomous. From this way onward, collaborative agents (without learning), communication agents (without cooperation), and intelligent agents (which possess all three characteristics) are presented.

The use of agents in transportation may be organized according to two main goals: Decision-Support System (DSS), and automation systems. According to the coordination perspective, each agent utilisation proposal may be classified according to its control: centralised and decentralised; to its structure: static or dynamic; and to its attitude: cooperation, competition, or both (Davidsson et al., 2005).

Parunak (Parunak, 2000) has proposed a maturity level of agent-based applications, at an increasing maturity level, classifying the agent applications by: conceptual proposals, computational environment simulations, prototyping through adequate hardware and software, test phase in commercial environment or in case studies, being used by a given company in the market, and commercialization, where the developed application is robust enough to be used by other clients.

Another trend is the use of multi-agent systems (MAS) concept. These systems distribute the power of decision between agents as a means of becoming more assertive in their decisions, as well as sharing the computational cost of the decision making [9]. These multi-agent systems are naturally distributed.

In spite of these systems being generally less efficient than centralised solutions [9] (since normally the decision making is done without the complete knowledge of the available information), its implementation is more feasible, inasmuch as the information is scattered in the network. Distributed applications have the advantage of attending to applications with the following characteristics: geographically distributed, many interacting components, large informational content, and a large scope of coverage in the domain (Huhns and Stephens, 1999).

2.2 Agent-based systems applied to supply chains

A new tendency for decision distribution at the level of a global supply chain has its results in the development of agent-based planning systems (Forget et al., 2008). This technology has been pointed out as appropriate for the deployment of autonomous logistics (Schuldt, 2010, Lau et al., 2006). The

centralized management of supply chains causes a significant raise in its complexity due to the increasing number of: transactions, differentiated objects, involved entities, and distributed processes.

In an increasingly dynamic market, this entire complex system needs to be constantly supervised, so that the observation of opportunities for improving its efficiency might be permitted (Julka et al., 2002). Agent-based distributed systems are more adequate to meet increasingly dynamic markets, since they do not depend on available computational resources which are located in the nodes of the web.

It has been verified that agents may represent processes (planning, purchase, dispatches, etc.) as well as physical objects which they manage (load, vehicles, machines, etc.). These agents are run in different industries, related logistics operators; and may even be in computers boarded in vehicles or loads. Table 1 shows some details of entities which are normally related to supply chains. The Table also references the concepts identified in the systematic literature review.

Table 1: Agents frequently cited in the literature.

Agent	Location	Reference
Planning	Industry	(Jiao et al., 2006, Fox et al., 2000, Nilsson and Darley, 2006, Lau et al., 2006)
Raw material purchase	Industry	(Jiao et al., 2006, Fox et al., 2000, Chai et al., 2010, Lau et al., 2006)
Production or scheduling	Industry	(Jiao et al., 2006, Fox et al., 2000, Chai et al., 2010)
Dispatch	Industry	(Jiao et al., 2006, Fox et al., 2000)
Configuration	Industry	(Jiao et al., 2006, Fox et al., 2000)
Acquisition	Retailer	(Jiao et al., 2006, Lau et al., 2006, Fox et al., 2000, Nilsson and Darley, 2006, Chai et al., 2010)
Transportation	Operator	(Fox et al., 2000, Schuldt, 2010)
Warehouse	Operator	(Fox et al., 2000, Schuldt, 2010)
Resources	Load/Vehicle	(Schuldt, 2010, Nilsson and Darley, 2006)
Machines	Industry	(Nilsson and Darley, 2006)

Based on this theoretical grounding, an autonomous control model for logistics processes run by intelligent agents will be proposed in section 3.

3 An Agent-Based Model for the Control of Logistics Processes

The model developed must support the logistics process for all production activities required for building a product; to this set of activities we define a project, and the model would be able to handle multiple projects. The model is structured with three classes of agents: planning agents, production agents and middle agents. Planning agents are entities responsible for managing the collaboration and controlling the distribution of the production activities to production agents. These agents have two objectives: the first one is to achieve a feasible schedule and the second one is to minimize the total cost, taking into consideration all the costs for the production activities required. The production agents represent the companies manufacturing the products; the objectives are to find a feasible schedule of the activities agreed with the planning companies and to maximize the revenues with these activities. Finally, the middle agents, which coordinate the scheduling process, register the resources for planning agents, the

capabilities of producing agents for performing activities, and allow planning agents to search for production agents with specific capabilities. It is argued that the proposed agent-based model for controlling production and logistic processes in global supply chains could contribute to the dynamic balancing of different interests.

The model herein suggested is an evolution of the model proposed by Lau *et al.* (2006). These authors propose that a supply chain be managed in a distributed way by $n \subset N$ planning companies (which seek the making of operations and carriers necessary) and by $m \subset M$ production companies (the final or intermediate industries of the supply chain). In this article, the model will be extended to the observation of the impact of storage costs along the global supply chain. Each production company m of the model holds a demand for some sort of product, regardless of it being in a final or intermediate stage of production, and thus it sends products onward in the supply chain after some sort of performed activity. The time horizon for planning is T, with a cyclical rate of t which varies from 1 to T. The granularity of time may be adequate according to the interest of whoever needs to apply the model; it may represent minutes, hours, days, or even broader units.

A request may be represented by the graph $P := < J, E >$, where J is a set of operations (nodes) in a project, and is a set of edges. An edge may be represented by $(i, j) \in E$, and yields that the operation i precedes the operation j. The information of a request P which is being controlled by a carrier n may be described by J_n and E_n. The order must be complete before deadline D_n, which is established by the project client. Each operation i may be initiated only after a waiting time known as rp_i. This deadline may represent the time necessary to make the transactional procedures, or even the time to solve financial issues. Operation i must also meet the production company's requirements which define the setup time necessary for initiating the operation.

The set of production companies that are able of making operation i is defined by AC_i. The capacity of each company m in a period t is defined by CP_{mt}, knowing that the company may run more than one operation at the same time. Information such as processing time, resource and cost demand for running, and operation i may be defined as l_{im}, q_{im}, and c_{im}, respectively. Delivery time, in turn, as well as transportation cost and the transportation cost in a product scale obtained with operation i made from company h to company k may be represented as lt_{ihk}, lc_{ihk}, and lc'_{ihk}, respectively. The economies of scale in transportation happen when the merchandise is directed firstly to a warehouse so that it may afterwards be sent to its destination, which will always be another warehouse in the case of trips between more distant regions.

A production planning for the entire supply chain may be defined as $S := \{S_1, \dots, S_n\}$. A planning for each company n may be defined as $S_n := < X_n, Z_n >$, where X_n represents a vector containing the beginning time of the operations, and $Z_n = \{Z_{im}\}$ represents the selection of production companies for the operation. The entire planning for this company n must also meet the limits established by company D_n.

The mathematical formulation of the global supply chain scheduling problem (see equations 1-4) may be seen as a minimization of the total cost (TO) , which consists of three major components, the first of which takes into account the production costs within the chain, being important for the definition of the configuration of the supply chain network. The second component ($\mathcal{CIS}\mathcal{A}$) is that of internal transportation costs within each country. The third component is that of external transportation costs, i.e., the flows which begin in a country and reach another; such costs may be in no possession ($\mathcal{CES}\mathcal{A}$ Errr)) or in possession ($\mathcal{CEC}\mathcal{A}$ Errr) of intermediate warehouses, the smaller of which is chosen, reminding that $\mathcal{DF}_a$ intermediate warehouses have a fixed cost. The use of intermediate warehouses hired in different countries may allow economies of scale in the transport making in great distances.

$$\min(TC) = \sum_{n \in N} \left[\sum_{i \in J_n} \left(\sum_{m \in AC_i} Z_{im} c_{im} \right) + \mathcal{CIS}\mathcal{A} + \min(\mathcal{CES}\mathcal{A}, \mathcal{CEC}\mathcal{A}) \right] \qquad (1)$$

$$\mathcal{CISA} := \sum_{(i,j)\in E_n} \sum_{h\in AC_i, k\in AC_j} Z_{ih} Z_{jk} lc_{ihk}$$
$$\forall (h,k) \in E_n, C_h = C_k \tag{2}$$

$$\mathcal{CESA} := \sum_{(i,j)\in E_n} \sum_{h\in AC_i, k\in AC_j} Z_{ih} Z_{jk} lc_{ihk}$$
$$\forall (h,k) \in E_n, C_h \neq C_k \tag{3}$$

$$\mathcal{CECA} := \mathcal{DF}_a + \sum_{(i,j)\in E_n} \sum_{h\in AC_i, k\in AC_j} Z_{ih} Z_{jk} lc_{ihA_a} + Z_{ih} Z_{jk} lc'_{ihk}$$
$$\forall a \in C, \forall (h,k) \in E_n, C_h \neq C_k \tag{4}$$

The negotiation among the agents is started by the middle agent, and is finished by the planning agent when all activities are assigned to production companies. The transition state diagram (Figure 3) presents the message exchange between planning and production agents, and how they interact in order to achieve the schedule of all supply chain.

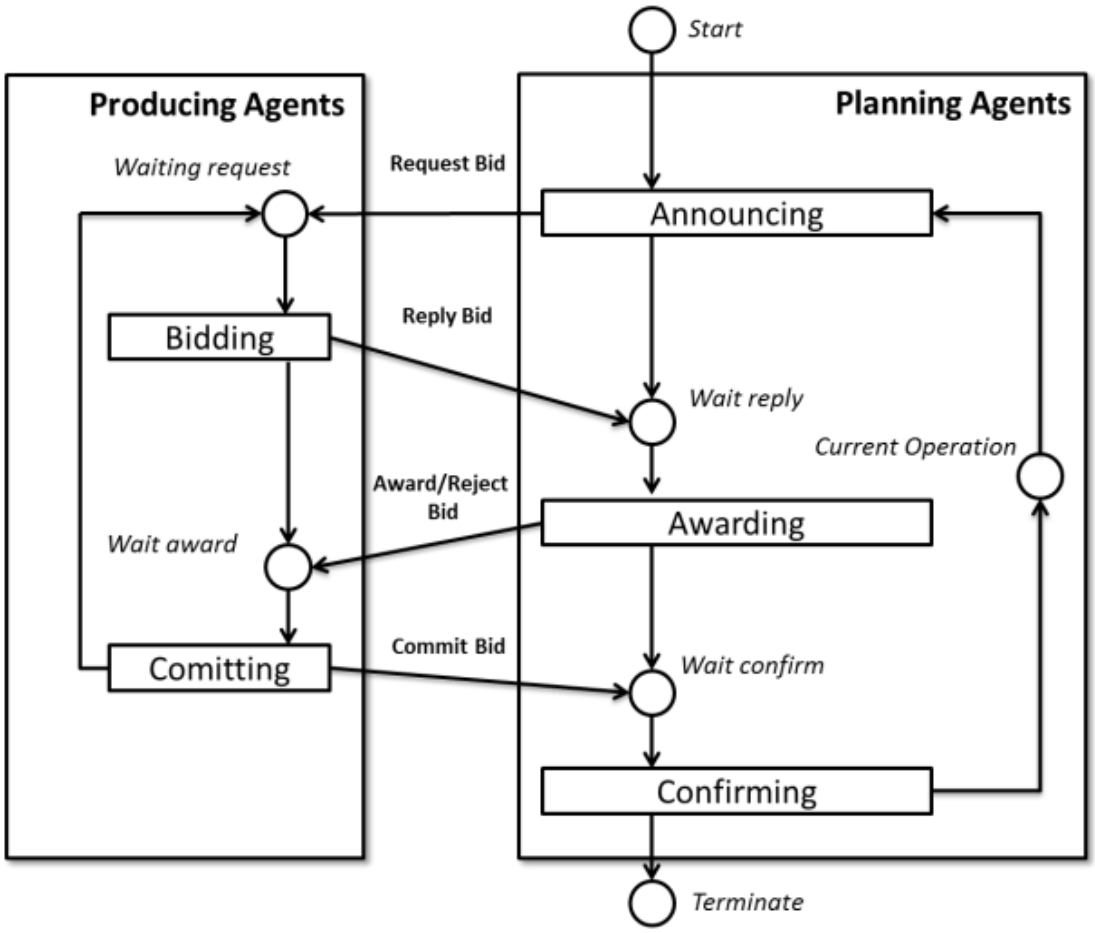

Figure 3: State transition diagram (Lau et al., 2006)

Figure 4 illustrates a sample of a supply chain network, where there are 10 operations, 2 planning agents and 9 producing agents.

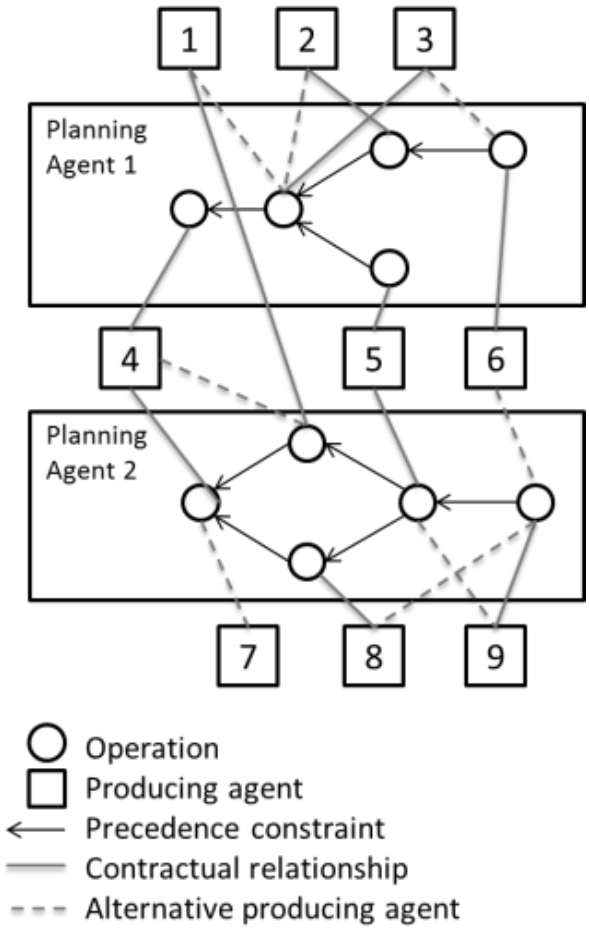

Figure 4: Instance of a supply chain.

In order to achieve the objective of minimizing the operating cost, the planning agents take into account: the price of the bid from the producing agents (bid_{im}), the transportation costs of immediate preceding operations (BC_{im}), and transportation costs of immediate succeeding operations (FC_{im}). By the time, producing agents maximize the revenues by better scheduling their own activities, whenever it is possible to relocate the operations to an earlier time, and thus gaining time to fulfil more activities.

$$BC_{im} := \sum_{(j,i)\in E_n} \begin{cases} lc_{j,z(j),m}\,, C_{z(j)} = C_m \\ \min\left(lc_{j,z(j),m}, lc_{j,z(j),A_a} + lc'_{j,z(j),m}\right), C_{z(j)} \neq C_m \end{cases} \quad \forall (k,m) \in E_n \tag{5}$$

$$FC_{im} := \sum_{(i,g)\in E_n} \begin{cases} \min(\, lc_{i,m,k}\,), \forall k \in AC_g, C_m = C_k \\ \min\left(lc_{i,m,k}, lc_{i,m,A_a} + lc'_{i,m,k}\right), \forall k \in AC_g, C_m \neq C_{mk} \end{cases} \quad \forall (m,k) \in E_n \tag{6}$$

The test scenario for the model might be characterised by a company which acts with emphasis on a specific country, this country being the location of the main warehouse (A_0). The country C_a is defined where a productive operation a must be realized. The supply chain displays networks in each country. This way, there can be a warehouse used to consolidate loads, before they are shipped to other countries.

The decision of using a consolidation warehouse or not in a country depends on the country's volume of purchasing. Each producing company m has its own internal inventory for its production. When the country does not hold a volume of purchasing which might justify a consolidation warehouse, inventory costs of the products remain in the hands of each producer, i.e., embedded in the production cost, which causes a higher production cost in that country. When such a consolidation warehouse does exist, the final products are sent directly to this importing company's intermediate warehouse.

Figure 5 illustrates the business scenario which served as a basis for the current article, wherein the company owns the Brazilian consumer market, but commercializes product from other countries, taking China for example. The agents to be modelled in this proposal are: Suppliers, Retailers, Warehouses, and Carriers.

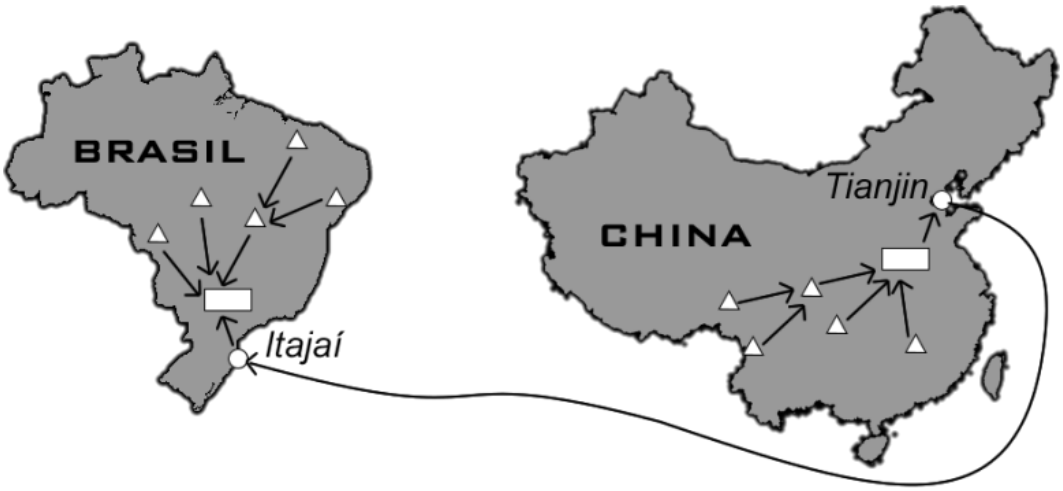

Figure 5: Example of a provision flow to be modeled

Looking for the *planning* companies there are two objectives: the first one is to achieve a feasible schedule and the second is minimizing the total cost, taking in consideration all the cost for the activities required during the projects. However, the interest of the producing companies is to find a feasible schedule of the activities agreed with the planning companies and maximize the revenues with these activities. It is argued that the proposed agent-based model for controlling production and transport process in global supply chains could contribute to the dynamic balancing of different interests.

4 Final Considerations

The use of agents in logistics is no longer a new concept, since much has been studied and developed regarding the theme. However, it is still a challenge to create models closer to the dynamic reality in which companies are inserted. The proposed model focused on the global supply chain schedule problem, due to the wide proportion of models which take into consideration more geographically limited scenarios. Another limitation of current models, which is neglecting the necessity of obtaining economies of scale in long-distance transportation, was also partially addressed here.

Agent-based distributed systems are adequate to handle increasingly dynamic situation, since they could adapt rapidly to local changes. So, considering that such distributed systems need an elevated degree of autonomy, we argue that the proposed agent-based model for controlling global supply chains could contribute to overcoming existing challenges. It is also noticed that the use of these systems in Brazil and abroad is still a challenge. A *sine qua non* condition is that the supply chains are structured and the information systems are ready to exchange data properly. This will permit possible substantiation of the longed-for automation of the agent-based intelligent logistics processes.

The next step in this research would be the implementation of the proposed test scenario for analysing the behaviour of the system. This research activity should take advantage of already existing multi-agent systems (MAS) simulation platforms. Finally, based on data collected from firms acting in global supply chains, a real-world test case would support the assessment of practical implications.

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