Organization and optimization of distributed logistics: estimation and patrolling approach based on multi-agent system

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Abstract—**T**his paper proposes a new method to model supply chains. Distributed systems need continuous and up-to-date information about their products, rooting process and consumption, in order to cover customer's needs and to solve problems emerging during the products rooting. The main goal is the satisfaction of every entity constituting the logistics organization. To achieve this goal, we propose a multi-agent based supply chain management. The supply chain studied presents a variable consumption in some areas; we proposed to use two different methods to solve this problem; the need estimation agent and the patrolling method. Patrolling is a complex multi-agent task, which usually requires agents to coordinate their decision-making in order to achieve optimal performance of the group as a whole. The problems encountered in supply chains and the technique to address these problems is first presented. Multi-agent systems and multi-agent patrolling are next used as a potential solution to these problems.

Keywords— Communication problems, multi-agent systems, multi-agent patrolling, need estimation agent, Supply chain management.

I. Introduction

NOWADAYS the industrial world must face strong mutations such as the globalization or customers' rapidly changing needs. Traditional centralized manufacturing systems are not able to face these changes.

Companies face a huge number of problems, such as how to make decision concerning production planning, inventory management and vehicle routing. These three decisions are managed separately in most organizations, because taking each individual decision is very difficult, since many constraints have to be satisfied.

This problem is yet harder in reality because the decisions concerning production planning, inventory management and vehicle routing are interdependent. Hence these three decisions should be taken together which makes the planning problem harder.

In addition companies are not isolated, but impact on and are impacted by their partners. As a result, when a company maximizes its profits, it may disturb other companies, which may result in globally under optimal decisions. The best solution would be to make the decisions together.

The concept of supply chains was proposed to address this problem of minimization of total supply chain cost.

A supply chain can be defined as a network of autonomous or semiautonomous business entities collectively responsible for procurement, manufacturing and distribution activities associated with one or more families of related products.

From the overall system's point of view, the decentralized supply chain may not be as efficient as the centralized one. In practice, alternative performance mechanisms are often used to align the incentives of the different managers in the supply chain.

A supply chain is a set of firms acting to design, engineer, market, manufacture, and distribute products and services to end-consumers [8], [4]. In general this set of firms is structured as a network, as illustrated in Figure 1 in which we can see a supply chain with five levels: raw materiel suppliers, tier suppliers, manufactures, distribution centers and retailers.

The management of a supply chain needs a set of approaches used to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed in the right quantities, to the right locations, and at the right time; in order to minimize system wide costs, while satisfying service level requirements [9].

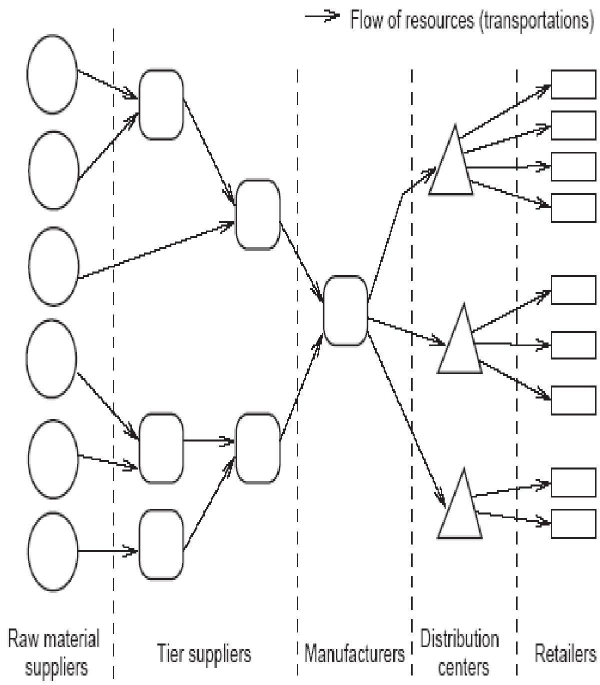

Fig.1. An example of a supply chain

As we can see, supply chains are distributed systems, and thus, issues of stream fluctuations may appear therein.

Supply chain planning is a complex process especially the information sharing that must be considered a crucial point for successful business management. The availability of timely information across the different units of the supply chain, and the need to use the information for improved performance are necessary to optimize the performance of the system as a whole.

In this synthesis, we worked out the architecture of an information processing system to help in a decentralized way to supply chain management. The two main components of this architecture are the links between the actors of a supply chain, i.e:

- The information and data flows,
- the agents' interactions,
- the actors themselves which are agents of a MAS.

II. Logistics Flow Problems

A. Background and Literature Review

Supply chain problems are generally caused by:

- Supply chain agility reduction;
- higher inventory levels;
- ineffective transportation;
- decrease of customer service levels;
- missed production schedules [Carlson and Fuller, 2000]and;
- Stockpiling due to a high degree of demand uncertainties and variability [Lee et al., 1997b].

Table 1 summarizes the causes and solutions of the supply chain problems proposed in the literature, which are now detailed. Lee and his colleagues [Lee et al., 1997a, Lee et al., 1997b] proposed the first four causes and solutions:

TABLE 1
PROPOSED CAUSES AND SOLUTIONS
OF THE SUPPLY CHAIN PROBLEMS.

Causes	Proposed solutions	Authors
Demand forecast updating	Information sharing(e.g., VMI, CRP…) echelon-based inventory and lead-time reduction	[Lee et al., 1997a, Lee et al., 1997b]
Order batching	EDI (Electronic Data Interchange) and internet technology	[Lee et al., 1997a, Lee et al., 1997b] [Taylor, 1999]
Price fluctuation	EDLP (Every Day Low Pricing)	[Lee et al., 1997a, Lee et al., 1997b]
Rationing and shortage gaming	Allocation based on past sales	[Lee et al., 1997a, Lee et al., 1997b]
Misperception of feedbacks	Giving a better understanding of the supply chain dynamics to managers	[Daganzo, 2003, Dejonckheere et al., 2002] [Forrester, 1958,Forrester, 1961] [Sterman, 1989]
Local optimization without global vision	None	[Chen et al., 2000,Kahn, 1987] [Naish, 1994, Shen, 2001] [Simchi-Levi et al., 2000]
Company processes	None	[Taylor, 1999]

- *Demand Forecast Updating*

Companies base their orders on forecasts, which are themselves based on their incoming orders while such forecasts are not perfectly accurate. Therefore, companies order more or less than what they really require to fulfil their demand.

In other words, forecasting errors amplify the variability of orders. A solution proposed to this cause is information sharing: each client provides more complete information to its supplier in order to allow the supplier to improve its forecasting. Information sharing is already part of industry practices, such as VMI (Vendor-Managed Inventory), CRP (Continuous Replenishment Program), etc.

- *Order Batching (lot sizing in a more general way)*

Companies discretize orders in order to profit from economies of scales, and therefore, place orders for more or less products than what they actually need.

The proposed solution to this cause is electronic transactions (e-commerce, EDI…) to reduce transaction costs and thus make companies' orders more frequent and for smaller quantities. Similarly, the size of production batches may be reduced with SMED (Single Minute Exchange of Die), which may next reduce the quantities ordered.

- *Price Fluctuation*

Every client (company or end-customer) profits from promotions by buying more products than what it really requires, and next, buying nothing when the promotion stops because it has enough products in inventory. The proposed solution by Butman is the EDLP (Every Day Low Pricing) policy, where price is set at the promotion level. However, EDLP also has some drawbacks, e.g., always looking for the lowest price may put a stress on the supply chain that may eventually reduce profits.

- *Rationing and Shortage Gaming*

Since every client has opportunist behaviour, it over orders when its supplier cannot fulfil its entire demand, e.g., in the case where the supplier has a machine breakdown. Through such behaviour, this client does not hope to receive the quantity that it has ordered, but a lower quantity that matches its actual need.

Since this behaviour occurs when the supplier allocates shipping in proportion to the ordered amount, it is preferable to allocate the few available products in proportion with the history of past orders.

- *Misperception of Feedback*

Sterman has noted that players in the Beer Game place orders in a non-optimal way because they do not understand the whole dynamics in their supply chain. For example, they do not correctly interpret their incoming orders, and in consequence, smooth their orders when they should order more, because they do not understand that market consumption has increased.

- *Local Optimization without Global Vision*

Several authors “Kahn, Naish and Shen, have noted that companies maximize their own profit without taking into account the effect of their decisions on the rest of the supply chain. In particular, some companies use an ordering scheme.

- *Company Processes*

Taylor and his colleagues propose two causes of supply chain problems: variability in machine reliability and output, and variability in process capability and subsequent product quality. In these two causes, which are summarized as Company processes" in Table 1, production problems at each workstation are amplified from one workstation to another. This cause recalls that intra company problems and uncertainties may affect each company's behaviour, which in turn may make them change the way they place orders.

B. Supply chain studied

We studied a supply chain composed of different cities: Figure 2.

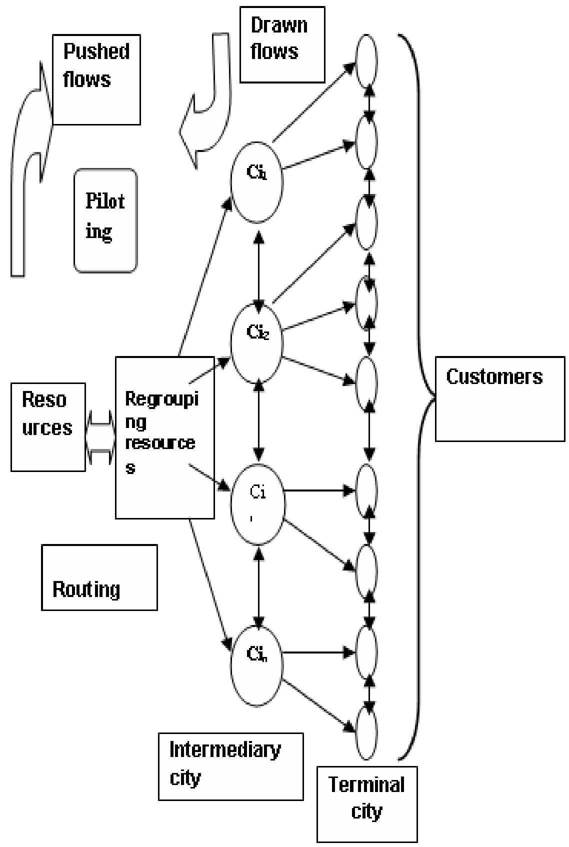

Fig.2. Supply chain studied

The idea is to route the flows from one city to another. Knowing that the needs in every city are different, and the consumption in the terminal cities is variable. This is due to several criteria such as: features of the geographic city, the nature of the stocks, the existing customers in every city. We want to optimize the routing of these flows in order to satisfy the needs in every city.

An optimal routing requires communications between the different units of the system as a whole. Every city is so strongly related with one other, all should collaborate in our supply chain model. As we can see, this system is distributed, and thus, many problems of coordination may appear. This is caused by several reasons, such as:

- *Collaboration reason*: an amplification of demand variability in the different units of the supply chain;

- *Collecting information reason*: on each product from the regrouping resources area to the customers or purchase point;
- *Accessing data reason*: from a single point of contact to the city information system ;
- *Analyzing data*: planning activities and making trade-offs based on information from the entire supply chain.

III. Problem solution: A multi-agent architecture for supply chain management.

A. Multi-Agent Systems

Autonomous Agents and Multi-Agent Systems are, in the judgment of many observers, the most significant new paradigm for software modelling and development to emerge from Computer Science in the last two decades.

Autonomous Agents are computer programs that are able to decide between different methods of achieving their programmed goals. This is in contrast to the scripted, predefined behaviour that a traditional program, for example a Unix Daemon, would exhibit, and means that Autonomous Agents can cope with dynamic environments, can be developed as a quick solution to complex problems, and can tailor their behaviour to individual users in a way that traditional software cannot.

Multi-Agent Systems are computational environments in which different programs, possibly developed in isolation, can co-ordinate their behaviours to achieve their goals. The technology of Multi-Agent Systems is, therefore, particularly applicable to modern operational environments like e-business, ubiquitous computing, the Internet, and, of course, the supply chain.

These two topics of research are tightly coupled. For a Multi-Agent System to be fully implemented, it is often necessary to utilize the technology of Autonomous Agents. For an Agent to act with true autonomy in a realistic, modern setting, it must often be able to reason about other Agents and co-ordinate its behaviour with them.

The agent paradigm is a natural metaphor for network organizations, since companies prefer maximizing their own profit than the profit of the supply chain [10]. Moreover, multi-agent systems offer a way to elaborate supply chain that are decentralized rather than centralized, emergent rather than planned, and concurrent rather than sequential. Therefore, they allow relaxing the constraints of centralized, planned, sequential control [7].

In this work we use the agent concept which has the same characteristics as a supply chain. The use of such a concept facilitates the conception of the distributed system and makes more flexible the different system's tasks:

- *Autonomy:* a city in the supply chain carries out tasks by itself without external intervention and has some kind of control over its action and internal states;

- *Social ability:* a city in the supply chain interacts with other cities, by placing orders for product routing or services;

- *Reactivity:* a city perceives its environment and the other cities. Each city modifies its behaviour to adapt to the environment changes and the evolution of the consumption;

- *Pro-activeness*: a city not only simply acts in response to its environment; it can also initiate new activities.

B. Supply chain Modeling

We proposed in a previous work [11] to model the supply chain as seen in the Figure 3. The Multi-Agent System proposed is composed of four types of agents: piloting Agent Agp, regrouping resources agent AgR, intermediary city agent Agi, and terminal city agent AgT [12].

- Agp: this agent is the manager; it supervises the different cities in the supply chain. It can cooperate in conflict case with AgR, AgI and AgT.
- AgR: responsible of the storage of the resources and flows ready to be routed; it interacts with Agp and AgI.
- AgI: This agent receives resources and flows of the regrouping area and distributes them to the final city, it cooperates interacts with Agp, AgT, AgI.
- AgT: the terminal city agent receives resources from the intermediary city. The terminal city distributes products to the customers.

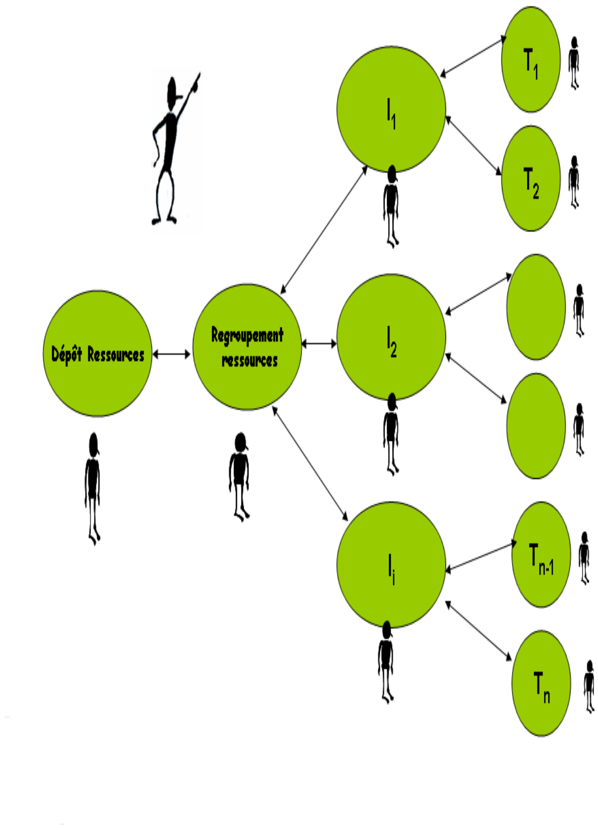

Fig.3. Supply chain modeling

Our focus now is how to control the variable consumption in the terminal city. To achieve this goal, two methods will be proposed, Need Estimation Agent and multi-agent patrolling. In a first time we proposed an estimation agent in the terminal city.

C. *Need Estimation Agent NEA*

In a supply chain, it is important to maintain stocks above a certain critical value. Usually, it is possible to have an idea of the consumption. But in case of modifications of some parameters, this consumption can vary a lot.

The Need Estimation Agent is a multi agent system; it provides an evaluation of the consumption coming from a city.

The NEA is an interface for a whole system; it indicates to a city agent what it will need using all the data provided by this agent.

To evaluate consumption, we achieved an expert system. The idea of this conception is to determine a law of calculation of the consumption, then to optimize it according to the statistical data in our possession.

We decided to treat the case of a demand of clothes. Than a certain number of parameters, that can influence the consumption of clothes, can be determinate. The two parameters used for this simulation are: The ambient temperature and the ambient humidity.

The NEA use fuzzy logic calculation. The city agent provides, to the NEA, the needed data in order to complete the calculation. A human expert is in charge to estimate these data. He has to provide the real data acquired on the city and some estimation in order to create the membership functions and the rule matrix. An optimization process will be able to correct these estimations.

We achieved a test for two linear estimators: Linear regression and Point to point.

TABLE 2.
ESTIMATION VALUES

week	**1**	**2**	**3**	**4**	**5**	**6**
Humidity	90	90	90	90	90	90
Temperature	20	20	20	20	20	20
Number of persons	5000	15000	20000	30000	25000	25000
Non optimized value	4862,64	14587,93	19450,57	29175	24313	24313
Agent estimator 1	4862,64	14587,93	21995,39	27854	22325	22793
Agent estimator 2	4862,64	14587,93	21000	23000	19000	19000
Optimized value	4862,64	14587,93	21497,7	24618	19831	19758
Corrected value	4500	15500	18000	20000	19000	19000
Weighting agent 1	1	1	1	1	1	1
Weighting agent 2	1	1	2	3	4	5
Non optimized Error	8,06%	5,88%	8,06%	45,88%	27,96%	27,96 %
Error Agent 1	8,06%	5,88%	22,20%	39,27%	17,50%	19,96 %
Error Agent 2	8,06%	5,88%	16,67%	15,00%	0,00%	0,00%
Total Error	8,06%	5,88%	19,43%	23,09%	4,37%	3,99%

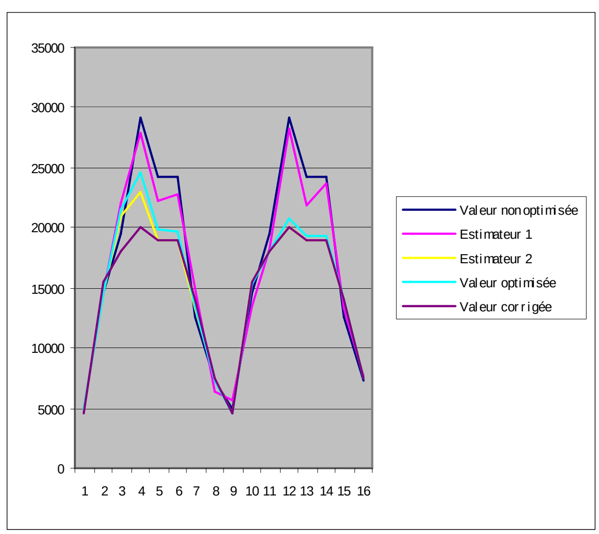

Fig.4. Estimation evolution

We can see in the figure 4, the estimation evolution in time. The estimator 2, point to point estimator, improves between the first and the second period. In the second period, values given by the estimator 2 are equal to real values that are means that we can determine the exact needs in these areas.

This method is very efficient in the case of a limited consumption. But it has some restrictions; if the consumption increases in a random way, we will see an overstock. This can affect all the supply chain management.

For this reason we propose another approach, the multi-agent patrolling, this method is recommended in the case of abrupt consumption.

D. *Multi-agent patrolling*

Patrolling is a complex multi-agent task, which usually requires agents to coordinate their decision-making in order to achieve optimal performance of the group as a whole. In previous work, many patrolling strategies have been developed, based on different approaches: heuristic agents, negotiation mechanisms, reinforcement learning techniques, techniques based on graph-theory and others.

To patrol is literally "the act of walking or traveling around an area, at regular intervals, in order to protect or supervise it" [7]. This task is by nature a multi-agent task and there are a wide variety of problems that may reformulate as particular patrol task [8]. A good patrolling strategy is one that minimizes the time lag between two visits to the same location [1]. Patrolling can be useful for domains where distributed surveillance, inspection or control is required. For instance, patrolling agents can help administrators in the surveillance of failures or specific situations in an Intranet [9] or detect recently modified or new web pages to be indexed by search engines [10].

Patrolling can be performed by multiple agents, requiring coordinated behaviour and decision-making in order to achieve optimal global performance. Despite its high potential utility and scientific interest, only recently multi-agent patrolling has been rigorously studied.
The current approaches for multi-agent patrolling are based on three different techniques:

- Operations research algorithms, in particular those used for the Travelling Salesman Problem (TSP);
- Non-learning Multi-Agent Systems (MAS), involving classic techniques for agent Coordination and design; and
- Multi-Agent learning, which uses Reinforcement learning, allows the agents to continuously adapt their patrolling strategies.

- *The patrolling task*

To define the patrolling task, researchers represent the terrain being patrolled as a graph, where the nodes correspond to specific locations and the edges to possible paths, as illustrated in Fig.5.

The main advantage of adopting this abstract representation is that it can be easily mapped to many different domains, from terrains to computer networks. Given a graph, the patrolling task studied in the remainder of this paper consists in continuously visiting its nodes.

There are some variations in the patrolling task. For instance, the terrain may contain mobile obstacles or assign different priorities to some regions. In some cases, typically military simulations, agent communication is forbidden.

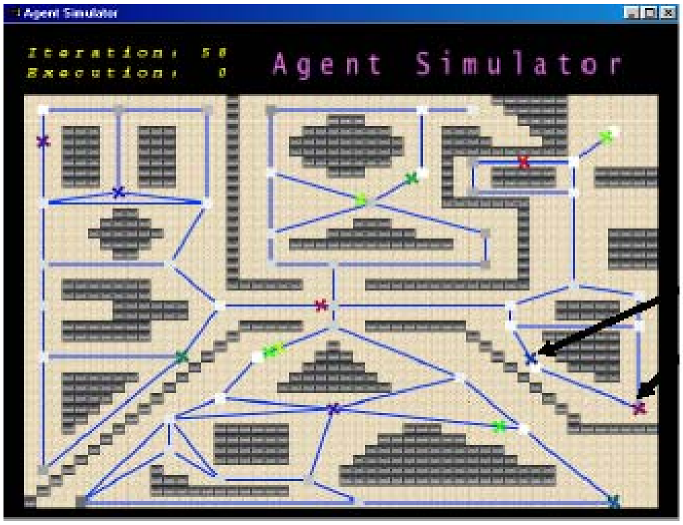

Fig.5. Example of patrolling graph

The graph representing the city will be referred to as G (V, E), where V = {1 . . . m} is the set of nodes and E the set of edges of G. To each edge (i, j) will correspond a weight cij representing the distance between nodes. The time taken by an agent to move across an edge (i, j) will be exactly cij. At time 0, r agents will be positioned on nodes of G. When the patrolling task starts, agents will move simultaneously around the nodes and edges of the graph according to a predetermined strategy [2], [3].

- *Patrolling strategies*

The concept we propose is to apply the patrolling task in the terminal cities, these cities had different criteria, Figure 6. In order to have precious values of the Consumption in These areas, we need to choose the best patrolling strategy.

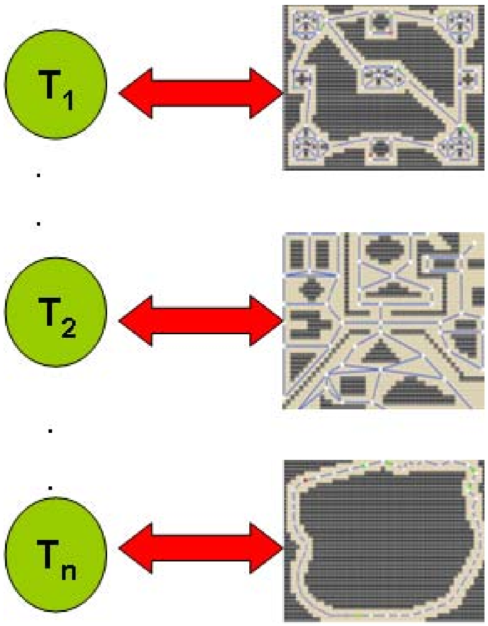

Fig.6. Terminal cites zoom.

To study this approach, we define:

- r: number of agents patrolling the graph nodes of the graph G (V, E);
- Π : N➔V ; Π(j) : j[th] patrolled node;
- Π = {Π_1, Π_2, Π_3,…,Π_r} : multi-agent patrolling strategy;
- Π_i (0) : agent i strategy at t = 0;
- Π_i (j)= Π_i (0) Π_i (1)…Π_i (j) (1)

The goal of this study is to define the best patrolling strategy of the graph. In order to evaluate the used strategies, we introduce the idleness notion (Idle).The idleness of a city means this city is not patrolled.

- $Idle_t(i)$ = Idleness of the node i at the instant t ;
- t=0 , Idle=0.

Considering that a cycle is a simulation step, the instantaneous node idleness for a node n at a cycle t is the number of cycles elapsed since the last visit before t.
The instantaneous graph idleness is the average instantaneous idleness over all nodes in a given cycle. Finally, the average idleness is the mean of the instantaneous graph idleness over a t-cycle simulation. In the same
Context.

Another interesting measure is the worst idleness: the highest value of the instantaneous node idleness encountered during the whole simulation. In order to better evaluate the contribution of each agent when the population size varies, the idleness can be normalized by multiplying the absolute value by the number of agents divided the number of nodes in the graph.

From the nodes idleness we can deduce the graph idleness:

- Max $Idle_t(G)$= $max_{i\in V}dle_t(i)$ (2)

The best patrolling strategy, Π={Π_1,Π_2, …,Π_r}, is the strategy minimising Max $Idle_t(G)$

The idleness of all nodes at the beginning of the patrolling task is set to 0. The worst idleness is the biggest value of the idleness occurred during the entire patrolling process for all nodes.

Figure 7.Illustrates the calculation of the idleness and worst idleness for a single agent and a very simple graph.

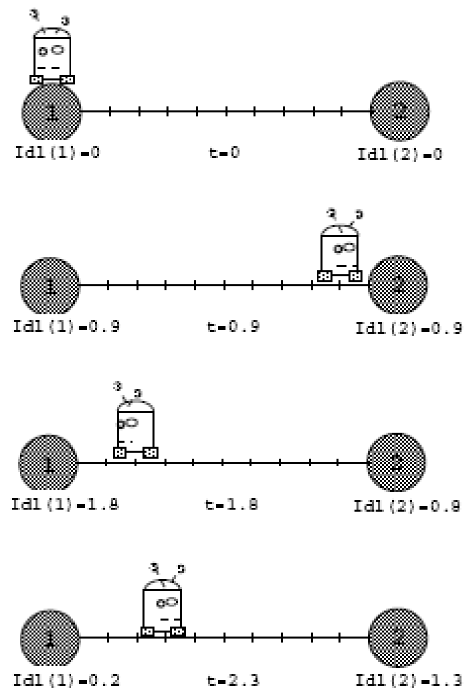

Figure 7. Agent patrolling

The Figure 7 present an agent patrolling graph made of two nodes and an edge of weight 1. Its strategy is Π = 1, 2, 1, 2, 1,…

Procedure patroll(x, i, patrolledcity, Ag_{Tn})

1. Let $\{AgT1 \ldots AgTn\}$ be a set of n terminal agent
3. Let E be a tree joining all graph regions between them
2. Let $s^i_1 \ldots s^i_{mi}$, a cycle that browses all graph nodes G_i
   $s^i_1 = s^i_{mi} = x$
3. PatrolledCity🡐 PatrolledCity $\cup \{i\}$
4. **For** k=1…m_i-1 **do**
5. **For** all (s_k^i,y) ∈ E such us a region j of y ∉ PatrolledCity **do**
6. **return** (s_k^i,y)
7. patroll(y, j, patrolledcity, Ag_{Tn})
8. **return** (y, s_k^i)

9. **end for**
10. **return** (s_k^i, s_k^{i+1})
11. **end for**

IV. Conclusion

This work presents some original contributions to the problem of supply chain management. The application of multi-agent techniques makes the system more flexible. According to the consumption variation in the city (fluid variation or abrupt and frequent variation), we can use one of the two methods proposed, Need Estimation Agent or multi-agent patrolling. The hybridization of those two approaches is possible too. It permits to have an open system answering to the requirements of its environment and evolving with every change or possible disruption that can affect it.

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