A Multiagent Systems Approach for Managing Supply-Chain Problems: new tools and results

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Abstract

The main purpose of this paper is to assess if Multi-agent Systems (MAS) technology can be used to model, study and manage Supply Chains (SC). A second objective is to present new tools and results that we have not presented before. In this paper we present multi-agent technology as a sound alternative to classical optimization techniques that can contribute to solve hard problems. To validate this hypothesis it was modelled and implemented a MAS with the following functionalities: simulation of an almost infinite number of agents, heuristics for decision making, possibility to choose among alternative decision strategies and tactics, different evaluation criteria and evaluation functions, different message sequences, and stochastic or deterministic behaviour. Two examples, one SC of the chemistry industry and the Hewlett-Packard SC, are presented to evaluate the usefulness of the MAS technology.

Key words: Agents; Logistics; Multi-agent Systems; Negotiation; Supply Chains.

1 INTRODUCTION[1]

A SC is a network of firms with individual objectives that are useful for the whole network. The main elements are firms and final consumers. During the 90s of the last century, due to globalization, the market became more complex and unstable, a reality that led to the growing awareness of the importance of SC [Handfield99]. Mathematical models, discrete event system models, operational research techniques and MAS are tools used in the study of SC. A MAS is constituted by autonomous agents, cooperative or individualistic, and agent communication and interaction protocols [Huns99].

As for any other technology, the maturity of the MAS technology depends on applications in real situations. Today, this is happening in industry (applications in SC and internal organization of manufacturing systems [Tzafestas94 and Custódio99, among many others]), in internet (for example, e-commerce [Silva99, among many others] and web semantics) and others (for example, robotics and military applications). The success of some of these applications shows that MAS technology is sufficiently mature to allow commercial applications.

Studying the work of some authors and the simulations we performed, allowed the identification and assertion of some advantages and disadvantages of MAS. Among the advantages it is possible to find: i) efficiency and speed of simulation, due to asynchronous functioning; ii) robustness and liability, if one agent fails other agents can perform the same roles; iii) scalability and flexibility, it is possible to adapt the system according to the problem; iv) more cost effective, because implementation can be more simple than using mathematical methods; v) reusability of agents, that can be developed by experts and innovation to develop new technological applications; vi) useful, when information is scarce [Weiss99]. MAS can also be the most suitable method to distributed problems. These problems are complex and multifaceted (e.g., vehicle production) or only solvable if decomposed, or that means an important cost reduction (e.g., monitoring of a wide geographic area) or lead to more efficacy (e.g., product delivery) [Durfee99]. According to this definition, is hard to identify a problem that is inherently distributed; many problems are solvable in both a distributed or centralized way, the choice depends on specific characteristics. This concept appears as a mean to obtain solutions to difficult problems or to those that can be solved using fewer resources.

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[Jennings98] points out three main disadvantages of MAS, i) agents with oversized granularity, ii) few interaction possibilities, and iii) insufficient mechanisms to model the organizational structure. As we were developing our work it became clearer that development time could also be a disadvantage, because it was necessary to define clear boundaries between the building blocks of the system. This difficulty depends on the researcher knowledge of the problem, and of its main characteristics, but it can exist when using other methodologies.

Despite the advantages and disadvantages presented, if there are some modules that are clearly generic that can be reused in other applications, we clearly gain when developing new applications using agent-based technologies. Additionally, there is a problem of complexity and characteristics of the problem to solve. Moreover, MAS can also have an important role when there is no analytical solution or when the problems are mainly distributed, and because of that, MAS are the most natural and understandable solution for users. But quality can also mean more useful results. This can be achieved by using expert knowledge and interesting indicators and measures, to help in the analysis of the obtained results. We believe that it is easier to introduce expert knowledge in MAS than in mathematical tools. In this context, it is clear that we used MAS because we believe they have some important potentialities, useful to solve problems with high complexity.

2 LITERATURE REVIEW

MAS are a technology used to study SC, specially during and after the 90s of the last century. It is possible to identify four main paths in the study of SC: efficiency, coordination, negotiation and utility evaluation of SC. Efficiency is the first one, in which the work of Vulkan and Jennings is included [Vulkan98], among other authors. For [Karimi02] logistics is the glue that holds together the different entities of a SC. Any chemical company is a good example of this thought and a good example of possible agent-based SC management, with the objective of reaching efficient results [Julka02]. Intelligent systems can be the most useful tools to solve problems of process engineering [Stephanopoulos96] or to make the portrait of complex information in a SC [Shaw98]. The second research path, coordination, studies the mechanisms that agents use to support the consistent behaviour of an agent community. The study of the model of distributed problem solving is here fundamental.

For some authors, responsibility is a cohourt of conditions that must be fulfilled before cooperation takes place. The solution could be the joint responsibility concept, defined by [Cohen92], using the Theory of Joint Intentions. There are four coordination mechanisms: Structural Organization, Contracting, Multi-agent Planning and Negotiation. The last one is the third research path. Negotiation can be viewed as the communication process among agents, through which they try to achieve a certain agreement for a specific issue. It can also be seen as a type of distributed search through the space of admissible agreements [Jennings98]. Finally, the fourth research path is utility evaluation of SC through MAS. As an example, Fox and Grunninger identified a number of questions that should be answered by MAS when a SC is simulated [Fox97].

A closer look to the work of some management science authors, led to the conclusion that to model small firms emotion modelling would be necessary [Baranger93]. In these firms, the procedures and liaisons between departments are loosely formal, the roles of main elements being very badly defined. This idea does not mean that firms should have emotions, but that emotions can be included in the decision capabilities of specific firm elements. Emotion decision making involves the inclusion of new decision parameters, not considered in the classical management and professional methodologies. Going even further, some authors believe that there can not exist any rational behaviour without emotions [Damásio94]. For [Minsky88], the question is not if machines can have emotions, but if they can be intelligent without emotions. In our MAS emotions are not modelled.

3 PROPOSED MAS MODEL

The MAS proposed here was implemented using LISP and had as first source of inspiration the agent creation language named RUBA [Ventura97]. The system has as main blocks i) an environment agent, in charge of the meaningful functioning of the system and event execution simulation [Michael90], ii) client agents, with needs to be satisfied and iii) firm agents, that have also needs but are capable of product manufacturing. The system also includes a blackboard, where agents can post their messages, and a set of communication rules (a communication protocol inspired on the *Contract Net* protocol

[Smith80; Smith81]), common to all agents and that makes possible message exchange. KQML [Finin94], a standard message format, and KIF [Genesereth94], a message content specification, served as the basis for the communication protocol of our MAS [Huns99]. The following message types were implemented: *ask-one*, *ask-all*, *reply*, *sorry*, *recruit-one*, *standby*, *ready*, *next*, *tell* and *confirm*.

The code of our MAS is not used in other applications and it does not use code of other applications. Nevertheless, it has some characteristics that permit reusability, for example, the utilization of standard specifications for agent based applications, the KQML and KIF. It is fundamental the application in different contexts to assess its reusability potentialities.

Demand can be stochastic, according to normal or exponential distributions, or deterministic. When a factory receives an order, checks bill of materials and available inventory to evaluate if it is possible an on-time deliver or, on the contrary, an additional negotiation is needed for intermediate product acquisition. This information is essential to begin the relevant negotiations to satisfy the received orders. To accomplish this agents use their fundamental elements: i) memory for knowledge about the world (static or dynamic), ii) memory for own identification and goals, and finally iii) rules to interact with the world. Firms save more information than client agents, because they calculate specific indicators related to their activity: financial indicators (described at [Baranger93]) and capability indexes (described at [Garg02]). All agents calculate indicators of negotiation performance (described at [Jennings et al. 1997]). Our MAS computes indicators for its functioning and for the SC.

The main elements of the system, agents, blackboard and a communication protocol, are essential for functioning. These agents are intelligent, because they are able to present successful behaviour [Albus91]. Figure 1 shows the system behaviour.

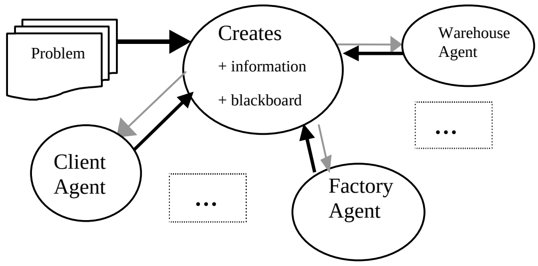


Figure 1. Environment Agent and Agent Behaviour

Among the firm agents we can find logistic firms, warehouse firms, head office firms and factory firms. The simulation begins due to the initiative of the environment agent that reads data from files and uses some of it to create the necessary agents, asks firm agents for information related to inventory policies and asks client agents for demand patterns. After answering to these questions the simulation starts, always by the client agents that put some orders. The gray arrows represent information queries of the environment agent, and the black arrows show information transmission from other agents. The environment agent just collects to itself the information strictly necessary for its roles.

The internal structure of the modelled agents has as building blocks: sensors, that react to stimuli of the external world, tools (for example, tactics), specific memory and world knowledge. Tactics are linear combinations of strategies used to generate an offer, or counter offer, for a single component of the negotiation object using a single criterion (time, resources and opponent behaviour). The tactics used in this paper are the following: time dependent *boulware* (exponential or polynomial), behaviour-dependent *random absolute tit-for-tat* (ratft) and behaviour-dependent *relative tit-for-tat* (rtft). In time dependent tactics, the predominant factor used to decide which value to offer next, is time, $\boldsymbol{t}$. Behaviour-dependent tactics compute the next offer based on the previous attitude of the negotiation opponent. Both the message types implemented and the tactics applied make possible and meaningful some message sequences. There are the following main message sequences: i) production line breakdown and recovery; ii) order and deliver of a product (demand transmission process), iii) proposal negotiation, iv) environment agent queries, v) advertisement and vi) head office firm queries.

The time to the next failure and to the next repair are exponencially distributed and computed using the following expression:

$x_i = - MT * \ln(1 - r_i)$, for: $\boldsymbol{i} = 1, 2, \ldots, n$;

where $\boldsymbol{r_i}$ is a random exponential number generated by uniform distribution; $\boldsymbol{x_i}$ is a random observation and MT – mean time (for failure or reparation). Figure 2 illustrates sequence i) and Figure 3 shows sequence iii).

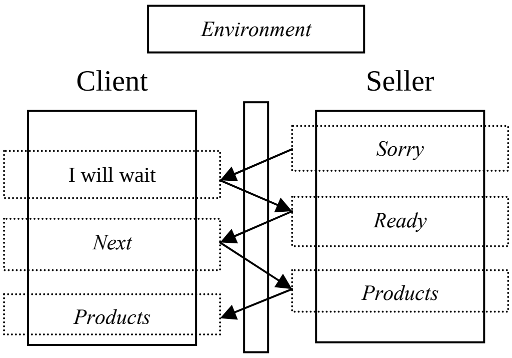


Figure 2. Production line breakdown

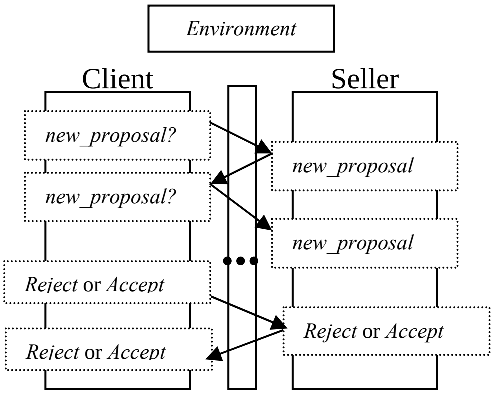


Figure 3. Negotiation sequence

The dashed boxes are messages sent by the agents. The message *Sorry* announces a production line breakdown, which occurs with Poisson distribution and add more complexity to the problem that the researcher wants to model and study. The first message *new_proposal?* starts a new negotiation. This sequence occurs when firms exchange information in order to reach an agreement. If an agreement is obtained, the next sequences will be the ones of product acquisition and delivery. The scoring function for evaluation of proposals is the following [Jennings et al. 98]:

$$V^i(x) = \sum_{1 <= j <= n} w^i_j \, V^i_j(x_j) \quad \text{where} \quad \sum_{j=1}^{n} w^i_j = 1$$

the parameter $\mathbf{V^i(x)}$ is a value (between 0 and 1) that agent ***i*** associates to parameter ***x*** and $\boldsymbol{w^i_j}$ is the importance that agent *i* gives to $\boldsymbol{x_j}$. The decision function is the following:

$$I^a(t', x^t_{b\to a}) = \begin{cases} reject & If \quad t' > t^a_{\max} \\ accept & If \quad V^a(x^t_{b\to a}) \geq V^a(x^{t'}_{b\to a}) \\ x^{t'}_{a\to b} & If \quad not \end{cases}$$

where: $x^{t'}_{a\to b}$ proposal of ***a*** to ***b***;

$t^a_{\max}$ maximum negotiation time

The next expression computes the value of the negotiated parameter for time dependent tactics [Jennings98].

$$x^t_{a\to b}[j] = \begin{cases} \min^a_j + \alpha^a_j(t)\left(\max^a_j - \min^a_j\right) & \text{a)} \\ \min^a_j + \left(1 - \alpha^a_j(t)\right)\left(\max^a_j - \min^a_j\right) & \text{b)} \end{cases}$$

a) If V^a_j is decreasing

b) If V^a_j is increasing

In this expression we find:

$x^t_{a\to b}[j] =$ value to be uttered by agent ***a*** to agent ***b*** for issue ***j*** as the offer at time ***t***, with 0 <= ***t*** <= $\boldsymbol{t_{max}}$

$\min^a_j =$ minimum value of issue ***j***, acceptable by agent ***a***.

$\max^a_j =$ maximum value of issue ***j***, acceptable by agent ***a***.

The β parameter used in $\alpha^a_j(t)$ permits some distinct tactics.

$\alpha^a_j(t)$ is defined as follows:

Polinomial

$$\alpha^a_j(t) = k^a_j + \left(1 - k^a_j\right)\left(\frac{\min(t, t_{\max})}{t_{\max}}\right)^{\frac{1}{\beta}}$$

Exponential

$$\alpha^a_j(t) = e^{\left(1 - \frac{\min(t, t_{\max})}{t_{\max}}\right)^{\beta} \ln k^a_j}$$

Tactics *ratft* and *rtft* are defined by [Jennings et al. 98]. In this paper we just use Intrinsic Utility (IU), that represents the final utility of a negotiation, for an agent that uses a family of tactics in a certain environment, independently of the resources and time spent. The financial indicators applied in this paper are: Unit Margin (UM) and the Unitary Profitability Tax (UPT). UM is the difference between the unit selling price and the unit buying price. The UPT makes a percentage comparison between the UM and the selling price [Baranger93]. Process capability indices C_p, C_{pk}, and C_{pm} have been applied extensively by industries for the purpose of capability analysis of manufacturing processes where variability is an inherent effect. In our MAS we implemented several capability indices. For some of them, such as Potential and Actual Yield, we used integral calculus using functions implemented through the notion of Rieman integral [Ferreira94].

Only the most common capability indices, C_{pk}, C_p and C_{pm}, are used in this paper, and are defined by [Garg et al. 02]. Tolerance is used to calculate these indicators and reflects the admissible variability, starting from the mean point of the specified interval. C_p measures the potential of a process to produce acceptable products, in other words, the probability to produce one unit within specification limits, when the process distribution has mean value at the mean acceptance point. The index C_{pk} reflects the effect of the variation of μ, at the capacity to produce within the wanted interval. It takes into account the minimum possible variation starting from the mean of the process to reach one of the possible limits. With the purpose of measuring the probability to produce within the specification limits (actual yield), it was idealised the C_{pm} index, which is the probability to produce with defect.

The variability of certain production parameters, for example, the time length of the production cycle or the availability a raw material, can be decisive for the manufactured products. Quality is a measure of proximity of a product relatively to certain standard characteristics. Quality control is the group of policies, action rules and procedures that establish and maintain certain quality levels [Monks87]. This is the context in which capability indices are crucial. When C_p and C_{pk} achieve higher values, the manufacturing process quality is higher, variability is smaller and the production defects are reduced or eliminated [Bastos01]. In our MAS we also calculate the following indicators:

i.) Indicators for the environment agent (number of iterations, number of sent messages, and others);

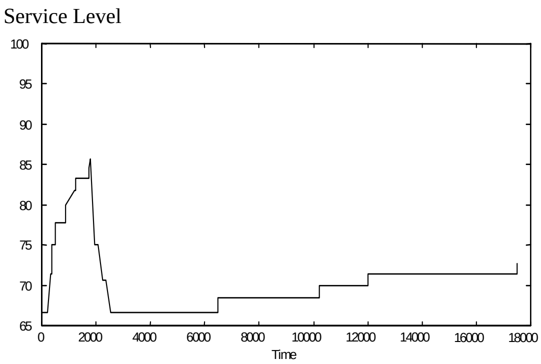
ii.) Firms calculate several indicators (business volume, mean revenue, demand rate, production rate, levels of inventory, unit profit and economic order quantity);

iii.) Both firms and clients record information related to identification of opponent negotiation agents, quantities, prices and instants of action.

4 ONE SC OF THE CHEMISTRY INDUSTRY

Garg, Narahari and Viswanadham studied plastic industry's SC as an example of linear SC that can be studied using the concept of "Six Sigma" SC [Garg et al. 02]. Their SC has as main elements: Raw Materials Procurement; Sheet Fabrication; Transportation; Manufacturing; Assembly and Distribution. The time between new orders follows an exponential distribution. Every client defines acceptance windows for delivery period, nevertheless his satisfaction relies on cycle time and queue dimensions, managed with a FIFO policy at manufacturing. The hypothesis of total availability of logistics can limit cycle time variability and firms apply a continuous review policy for inventory management. As at the examples of HP's SC, all agents use a *boulware* tactics with $\beta = 0.1$. From the simulation developed it was possible to understand that clients are the most successful at the negotiation process. This fact was also identified and explained by [Jennings98]. The authors consider that that happens because clients are the first ones to present their proposals.

It was the plastic sheet factory that presented the better financial results, with a UPT approximately equal to 230.8 %. The manufacturing plant reached the lowest profit, a UPT equal to 64.8 %. These results are not surprising, because it is the plastic sheet factory the one that adds more value to products. The manufacturing plant also adds an important value to products but has to buy more expensive intermediate products and it has a more complex activity. The service level reached in the mean and long term, results from variation of the target inventory level and of the reorder level, for the final product that is determined by heuristic use. It was simulated the evolution of the real service level, for a target service level of 80 %. After a certain time point, it is possible to see a strong delay in the convergence movement towards the target level, which results in higher waiting time at waiting lines. Graphic 1. presents the convergence process of the real service level.



Graphic 1. Service level convergence (80% objective)

The heuristic used to obtain Graphic 1 is defined through the use of two parameters, the reorder level defined as about 30 % of the actual demand, and the number of times which is needed to multiply the actual demand (X), in order to reach the inventory between the reorder level and the target/objective level, that permits to obtain the desired service level.

The number to multiply by the actual demand is given by the following equation:

$$X = \frac{1}{(1 - (objective\ \ service\ \ level / 100)} - 1$$

For example, if 80 % is the desired service level and the actual order is 20 units, the value of X will be 4 and the inventory between the reorder level and the target inventory level is 80 (4 * 20). The target inventory level is equal to the addition of the reorder level, 6.6 units plus 80, which equals 86.6 units.

For capability indices calculus, it was possible to reach results very similar to those presented at [Garg et al. 02]. The results were not completely equal, because we wanted to verify the impact of some differences in the transport time, which lead to very high values of C_{pk}. From the data obtained, we can conclude that this SC should improve performance. The usage of different means of transport, plane for example, can be a feasible solution. In order to increase our confidence in the modelled entities, we tried to reduce the differences at certain parameters, and tried to compare the results with the values presented by the authors. We only did this for the external logistics, and the values obtained (1.30 for C_p, 0.60 for C_{pk} and 0.20 for C_{pm}) were very similar to the desired ones 1.3(3) for C_p, 0.6(6) for C_{pk}, and 0.60 for C_{pm}.

5 PRODUCT INNOVATION AT HEWLETT-PACKARD

The objective of Lee, Billington and Carter when they started the study of HP's SC was the optimisation of that SC, applying the concept of *design for manufacturability*. This concept was used for design process that take into account the operational and delivery service considerations for the multiple market segments [Lee et al. 93]. Figure 4. presents the Deskjet printer Bill Of Materials (BOM) and Figure 5. the SC of the Maxim printer.

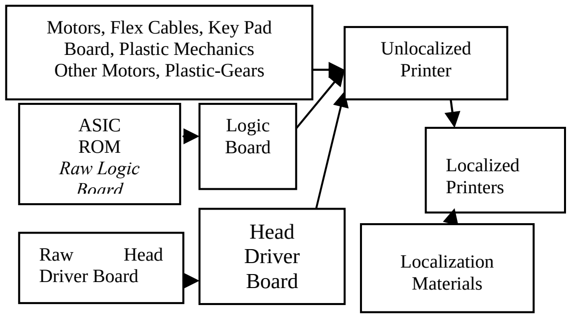
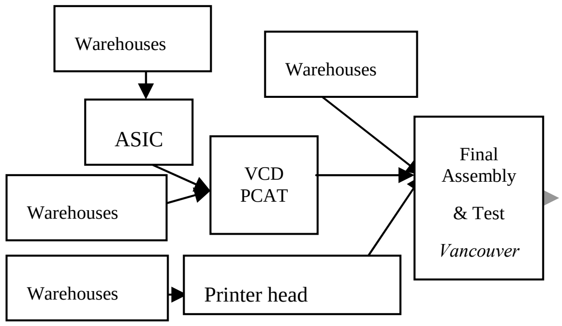
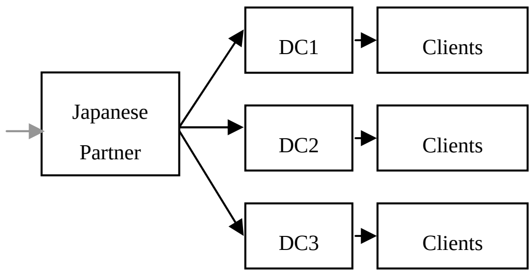


Figure 4. Deskjet Bill of Materials (BOM)

Vancouver produces the main motor and sends it to a Japanese partner, that uses it in the manufacturing of the final product and uses its own specific distribution channels. Figure 5. presents Maxim's SC, which is equal to the Deskjet SC, with additional liaisons to a Japanese partner, which does not exist in the Deskjet's SC.



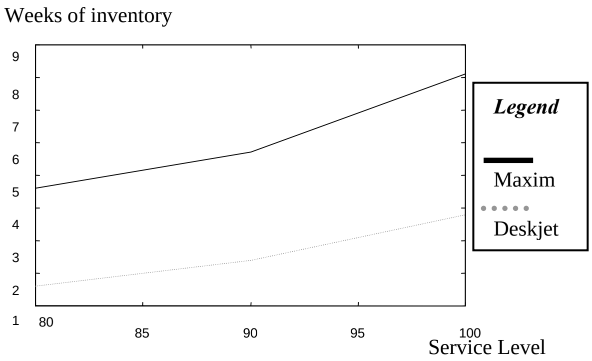
5.a) Procurement



5.b) Distribution

Figure 5. Maxim SC's

We simulated a SC were firms satisfy client orders that occur with normal distribution and apply a periodic review policy to manage inventory. Graphic 2. presents some trade-off solutions for different service levels, for Maxim and Deskjet SC. The performance of Deskjet's SC is clearly better than the performance of the Maxim's SC. The Deskjet SC permits the same service level during a longer period of time.



Graphic 2. Trade-off solutions for different service levels

In the simulations, for the same service levels in the Deskjet SC printer, it was needed less inventory than at the Maxim SC. We can see this in Graphic 2.

In this example, there were also calculated financial and negotiation quality indicators for the Deskjet printer SC. Clients present the best negotiation results, with IU equal to 0.685, much higher than that of the distribution agents, only 0.315. These last agents present a very poor performance when compared with that of the client agents, but the performance of the other firms is even worse, always with IU equal or inferior to 0.1. The Vancouver plant presents the best financial results with UPT equal to 149.6 %. Nevertheless, it obtained a IU equal to 0.078. Distribution agents obtained an IU of 99%, less than the Vancouver factory, a fact that can be partially explained by their negotiation with client agents, as we have just seen, those with the better results. The Maxim's SC results were very similar, but it was verified a strong reduction of profitability at the Vancouver plant. The Japanese partner and the Vancouver partner obtained a UPT equal to 68 %.

With the goal of improving de performance of the Maxim SC, the authors tested four design alternatives: motor inventory at Vancouver; the possibility of sending the motors by plane; motor production at Singapore and, finally, producing Maxim in Japan (co-localization) [Lee et al. 93]. The performed simulations did not allow to obtain the same results due to the lack of information about the real problem. The results do not confirm the hypothesis that the place where the products are adapted to the market can clearly influence the level of inventory of the firm and the trade-off decisions for the inventory and service levels [Lee93]. The options "motors by plane" and "motor at Singapore", with 1.12 and 4.5 weeks of inventory, respectively, are the most effective. Nevertheless, the study of different opportunities of SC optimization, using tools such as MAS, can be a very useful help and at a cost-effective price. The simulated examples were more complex than those proposed by [Lee et al. 93]. We considered backorder possibilities for all products of the BOM, and not just for one of those products, as they assumed for the sake of simplicity. In these examples of HP's SC, the problem could be simulated using a queuing line model of the type N/N/3. In other words, the time between the arrival of new orders and the service time presents a normal distribution, and there exist three servers and three distribution centres.

The study of the SixSigma and HP SC also allowed to conclude that:

- The simulation of non linear SCs is more complex and time consuming than simulation of linear SCs,
- The convergence for steady-state (at the *SixSigma* example the target inventory level) is more slow when the SC complexity is more important,
- Specially, at the HP's example, it is clear the advantage of MAS over mathematical methodologies, because it makes possible the simulation of examples with higher complexity in this case the backorder of all products that take part of the BOM.

Other advantages of the MAS technology are the easiness to add (or remove) complexity, creating new problems without extreme time usage, and the possibility to use tools that permit an easier modelling of some problems even if there is insufficient information about some detail of a certain problem. The use of heuristics and knowledge of specialists is an obvious example that can help in the modelling of a wide variety of experiments in a short period of time.

6 FINDING IMPROVEMENT OPPORTUNITIES FOR SC

The examples presented here were used to demonstrate the MAS capacity to solve SC problems with some complexity. In order to understand some phenomena at the SC, some tests were made considering an example with one client, a factory and a warehouse. We found that if the number of clients increases, the simulation time increases exponentially and that the maximum negotiation time variation is very important to determine the final outcome of the negotiation. With the objective of testing the possibilities of the MAS implemented as a useful tool in the study of solutions to improve the performance of SC it were made some simulations for: i) different options between alternative evaluation functions; ii) different inventory levels; iii) different options between alternative tactics/strategies; iv) to include or not firms from different groups; v) usage of the Herfindal-Hirshman (HH) index and vi) results with equal acceptance intervals. We found that different evaluation criteria lead to different outcomes and backordering for all products of the BOM imply an important raise in simulation time.

We used the following rule to give the agents the capability to choose among different tactics: first, a number of tactics to test is defined (***X***) and a list of tactics to test, then if ***X*** tactics are tested, the one with best IU is chosen. If ***X*** tactics are not tested, is selected the next to test, according to the order of the list defined a priori. Using this rule we found that *boulware* tactics are the most competitive ones, specially the polynomial *boulware* tactics with β = 0.1 (IU = 0.55). We also found that testing several tactics can lead to an average performance (IU = 0.21) inferior to that obtained in the situation when it is always used the tactic with the best result.

To illustrate the outcome of the firms we compute the HH index [Cabral94]. When all firm have the same market share, HH is equal to 1/***n***, where ***n*** is the number of firms. If only one firm satisfies all the demand, HH is equal to 1. An example with one product demanded by five client agents and five alternative sellers, was simulated. Table 1 presents the obtained results.

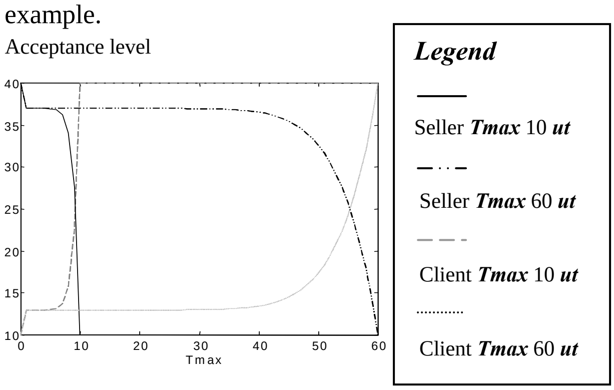
Example 0		Example 1		Example 2	
Firm id	Share	Firm id	Share	Firm id	Share
5	20 %	5	20 %	5	0 %
6	20 %	6	0 %	6	0 %
7	20 %	7	20 %	7	0 %
8	20 %	8	40 %	8	0 %
9	20 %	9	20 %	9	100 %
HH	0.20	HH	0.28	HH	1

Table 1 - Observed behaviour of the HH Indice

In example 2, only one seller, the agent 9, is responsible for all the orders and has a 100 % market share, or HH equal to 1. In example 1, agent 8 satisfies 2 orders, which correspond to a 40 % market share or HH equal to 0.28. To obtain these results the acceptance intervals of the sellers were manipulated.

The evaluation of the negotiation performance, with similar acceptance intervals, permitted to conclude that a raise in the negotiation time leads to similar results for all the negotiating agents. Conversely, if an agent has less time to negotiate, it obtains an inferior performance. Finally, we consider that the introduction of proactive message types, such as *active_ask* and *proactive_tell*, can be a source of simulation and problem solving efficiency [Yen00]. If an agent informs other that a new possible seller has arrived, using a *proactive_tell*, then all the interested agents do not need to ask periodically if there is a new seller, they just wait for that information and act efficiently using fewer communication resources.

All the presented tools can help in the simulation of more complex and realistic SC. They can also help in the simulation of different problems, because there are several phenomena at SC which can be found at computer networks, such as the time span between the instant an order is placed and the answer, and the impact of different SC (or network) configuration. In the domain of social sciences the use of MAS (as a tool to solve real and complex problems) can be a decisive help to model and simulate experiments that could never be made in reality, due to ethical impediments. By realistic model we mean one that can be used to extract useful conclusions about the world [Chalmers94]. In fact, our model permits negotiation, as in the first two groups of negotiation contexts identified by [Raiffa82], two parties that negotiate one item, several parties that negotiate several items and multiple parties that negotiate several items. For example, it is possible to eliminate the decision making condition that stops the negotiation, and look at various patterns of negotiation between two agents. Graph 3 is an example.



Graphic 3. Buyer and seller agents negotiate using *Boulware* tactics β = 0.1, and maximum negotiation time (Tmax) of 10 or 60 time units

According to the observation of Graphic 3, it is possible to conclude that the implemented MAS permits the same results obtained by [Faratin97]. If the negotiation decision rule presented at Section 3 is applied, there are agreements when there are intersections between the lines of clients and sellers. When clients and sellers compute their proposals according to the same tactic they reach an agreement at the same acceptance level (at the graph 25 units) independently of the ***Tmax*** value. In reality, this is very unusual.

Using a *Boulware* tactics with β = 0.1, agents will concede higher values as the time limit gets closer. In this context, when a client has a ***Tmax*** value equal to 10 ***tu*** and a seller has a ***Tmax*** value equal to 60 ***tu***, the acceptance level is equal to 37 units. When studying the consequences of a real negotiation, if these patterns are known it is possible to envision the possible outputs of the process, before it starts. These evaluations can be very important, to determine more valuable tactics and strategies to negotiate certain products or services with certain agents.

According to our experiments, comparison of results with those obtained through other techniques and knowledge of part of the decision making process of some firms we believe that the implemented MAS has some commercial potential. We would like to test it in an actual, real and unexplored SC problem.

7 CONCLUSIONS

The examples *SixSigma* and HP allowed to evaluate and demonstrate the capability of the proposed MAS to solve real SC problems and the relevance of the information used in the simulation. Considering the obtained results, it is clear that we decided to build our application as a multi-agent system because it permits satisfactory results for problems with higher complexity than that we find in simulated examples were classical mathematical tools are used. For example, when we applied our MAS to a problem of SC management at HP, we obtained results with stockouts for every product of the bill of materials. On the contrary, some authors using mathematical tools only simulated the stockout of only one product of the bill of materials. Some of the possible future research paths can be i) the modelling of the departments that are part of the internal structure of a firm, ii) inference mechanisms, using knowledge that could make possible decision tacking with quality as if a specialist was in charge of those decisions, iii) learning in MAS and iv) the ecological consequences of internalising the costs of environmental damage [Tietenberg03].

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