AN AGENT-BASED COLLABORATIVE MODEL FOR SUPPLY CHAIN MANAGEMENT SIMULATION

C. M. Vieira
Centre for Management Studies
Technical University of Lisbon
1049-001, Lisbon, Portugal
ESTG
Polytechnic Institute of Leiria
2411-901 Leiria, Portugal
E-mail: carlos.vieira@ipleiria.pt

A. P. Barbosa-Póvoa
Centre for Management Studies
Technical University of Lisbon
1049-001, Lisbon, Portugal
E-mail: apovoa@ist.utl.pt

C. Martinho
Dep. of Computer Science
Technical University of Lisbon
1049-001, Lisbon, Portugal
Email:carlos.martinho@ist.utl.pt

KEYWORDS
Supply Chain Management, Multi-Agent System, Simulation.

ABSTRACT

In traditional supply chain (SC), planning problems are usually considered individually at each SC entity. However, such decisions often influence the other members in the chain and thus an integrated approach should be considered. By modelling system-wide SC networks, different SC problems, like production planning, coordination, order distribution, among others, can be integrated and solved simultaneously so that the solution is beneficial to all entities in a long-term base. In an attempt to make progress in this area, researchers use various methods for modelling the dynamics of SCs. In the literature review, due to their distinctive characteristics, multi-agent-based systems have emerged as one of the most adequate modelling tools for tackling various aspects of SC problems. In this work, a multi-agent supply chain system (MASCS) model that integrates different SC processes is presented. The proposed model allows modelling different SCs with multi-products and different operational policies considering information asymmetry and distributed/decentralized mode of control.
In this article the details of the MASCS model development and implementation are presented. Furthermore, the applicability of the proposed MASCS is briefly demonstrated through the solution of a SC example. The obtained results are discussed and research extensions are outlined.

INTRODUCTION

A supply chain (SC) is a network of trading partners linked through upstream and downstream connections where the main aim is to produce and deliver products/services to the ultimate consumers so as to provide global SC profit. Traditionally, managers have been focusing on the management of their internal operations to improve profitability and thus an internal concern has been the main objective. However, supply chain management (SCM) calls for the integration of the SC operational activities in order to organize/manage the flows between entities as if they form a single organization. Moreover, with the businesses globalization, inter-organizational coordination is becoming strategically important for companies to augment responsiveness while maintaining SC efficiency.
Numerous studies have demonstrated that substantial benefits can be obtained from an integrated SCM. Such integration provides tremendous challenges to managers (Arshinder 2008). Although a completely integrated solution may exist with an optimal system performance, such solution is not always in the best interest of every individual member. As a result, each SC member attempts to optimize a part of the system without giving full consideration to the impact of their myopic decisions on the total system performance. Optimizing the portions of the system yields sub-optimal performance, resulting in an inefficient allocation of scarce resources, higher system costs, compromised customer service, and a weakened strategic position. A key issue in SCM is then how to coordinate the independent players to work together as a whole so as to pursue the common goal of chain profitability.
In an attempt to make progress in this area, researchers use various methods for modelling the dynamics of SCs. The multi-agent system (MAS) approach has appeared as one of the most adequate modelling tool for tackling various aspects of SC coordination problems (Santa-Eulalia et al. 2011). Indeed, considering the fact that most of the SCs involve enterprises with independent ownerships (requiring the ability to model information asymmetry and distributed/decentralized mode of controls), applicability of traditional modelling approaches is limited and unrealistic (Govindu and Chinnam 2010). Additionally, a holistic model is required to explore different coordination mechanisms and their value in SC where different set of combinations of coordination mechanisms can be tried with the help of simulation. Moreover, most of the models describing coordination mechanisms are dealt in two-level SC, which needs to be extended to multi-level SCs (Arshinder 2008).

Proceedings 26th European Conference on Modelling and Simulation ©ECMS Klaus G. Troitzsch, Michael Möhring, Ulf Lotzmann (Editors)
ISBN: 978-0-9564944-4-3 / ISBN: 978-0-9564944-5-0 (CD)

From these considerations, a MASCS model that integrates different SC processes is here presented. The proposed model allows simulating different SCs with multi-products, multi-entity and information asymmetry where different types of decisions are accounted for.
This paper is structured as follows. The first sections describe the proposed MASCS model and the corresponding implementation. Then a SC example is introduced in order to validate the MASCS model. The results are presented and discussed. Finally, the last section summarizes research contributions and identifies some possible extensions.

MASCS MODEL DESCRIPTION

The MASCS model developed is based on a generic process-centered methodological framework (Govindu and Chinnam 2007) Multi-Agent Supply Chain Framework (MASCF), which is a generic methodology that simplifies the SCs modelling through MAS development. MASCF uses the notion of process-centered organization metaphor, and adopts Supply Chain Operations Reference Model (SCOR) (SCC 2010) with Gaia methodology (Zambonelli et al. 2003) focusing on the system analysis and design phases of the MAS development. Given the characteristics to account in our MASCS model, MASCF analysis identifies the number (single/multiple), and the scope of sub organizations that a SC system would comprise along with the services that they have to offer according to the SCOR process definitions. The entire logic of the system dynamics is then split among these SC entities, and is projected into process level logic while determining the role and interaction between these entities. Subsequent analysis and design steps of MASCF resulted in the identification and specification of the agents and services listed in table 1.
The proposed MASCS model is constructed through the definition of five different types of agents (market, sales, inventory, procurement and production). The existence of multiple geographically disperse markets, representing the aggregate demand pattern of customers for different products, are modelled through the creation of Market Agents (MA). The other four agents represent the principal functions that any SC entity possesses that allows them to participate in different SC processes and activities so as to produce value in the form of products/services delivered to the final consumers.
Each MA will be responsible to generate the market demand for each product, send market orders requests to available SC entities, and receive the corresponding products. The market orders can be filled from any SC entity (retailers, manufacturers and suppliers) and will be received by the corresponding sales function. After receiving orders, and in order to fill them, the requested Sales Agent (SA) needs to query the inventory position for the requested items. Based on the inventory position and on the quantity ordered, the SA decides to send all, partial or none of the quantity required.
In case of a total or partial filled order occurrence, the SA depletes inventory and sends the corresponding information to the Inventory Agent (IA). If one or more orders need to be delivered, the SA plans shipment load and delivery, and sends the corresponding shipments to customers.

Table 1: Agents and Services

Agents	Services
Market Agent (MA)	Generate market demand
	Place order
	Receive shipment
Sales Agent (SA)	Receive order
	Query inventory position
	Fill order
	Send deplete inventory information
	Plan shipment load and delivery
	Send shipment
	Compute sales forecast
	Send forecast information
	Receive replenishment information
Inventory Agent (IA)	Receive deplete inventory information
	Receive replenish inventory information
	Update inventory
	Send inventory information
Procurement Agent (PA)	Receive forecast information
	Receive inventory information
	Define order request
	Send order requests
	Receive proposals and refusals
	Analyse proposals
	Send accept/reject proposal notifications
	Receive shipment
	Send replenishment inventory information
	Receive shipment
	Send replenishment inventory information
Production Agent (PrA)	Receive forecast information
	Receive inventory information
	Plan production
	Production
	Send deplete inventory information
	Send replenishment inventory information

Since the Procurement Agent (PA) needs sell forecast information to source products/parts/raw-materials, the SA forecasts sales and sends this information to the PA periodically. Also, whenever there is a product replenishment, the SA receives the corresponding information in order to plan and send a shipment with backorders (BO) that can be satisfied based on the new inventory position.
The IA is responsible to update the stock movements due to deplete and replenish actions performed by the SA and the PA, respectively. Additionally, the IA must inform periodically or continuously the PA on the inventory position of each item based on a periodic or continuous inventory review systems. Based on a

replenishment action, the IA must also inform the SA on new products availability.

The PA is responsible to procure all items required by the SC entity that it represents. As so, the PA must have access to sales forecast and inventory position for each item. The replenishment decision will then be based on a particular replenishment policy method associated. At some instant, if a replenishment quantity is needed then the PA will set an order and send several order requests to potential suppliers of the item under analyse, initiating a negotiation process with the corresponding SAs.

Based on these requests, the PA receives proposals and refusals (one proposal or refusal for each order request) and identifies the proposal that better suits some given criteria. The SA with the winner proposal will then receive an accept proposal information. As for the others, the PA sends a reject proposal notification. Finally, the PA must also receive shipments from their suppliers and send corresponding replenishment inventory information to the IA on the items received.

Due to the negotiation process previously discussed, the SA will additionally need to, in response to a particular order request, send a proposal with his best commercial offer or a refusal signal if the requested item is not available. In case of an accepted proposal the SA performs the services previously discussed.

Finally, the Production Agent (PrA) is responsible to plan production and accordingly produce finished products. In order to perform these actions the PrA must have access to sales forecasts, bill of materials and product/part/raw-material inventory information. The order production will be based on a particular production policy and any production initiation leads PrA to inform IA on parts and raw-materials inventory depletion. Similarly, the PrA must inform the corresponding IA on product inventory replenishment whenever a production order is concluded.

For implementation purposes, the MASCS model will use the notion of reusable and extensible components defined in a software agent-component based framework (Govindu and Chinnam 2010). This framework defines two types of agents – supply chain agents (SCAs) and organizational agents (OAs). Any real-world SC network consists of multiple interacting entities (independent enterprises) at different levels/tiers (e.g., retailer, supplier, manufacturer, and so on). The set of agents representing all such entities constitute the library of SCAs. Also, each of the SC entities in turn consists of multiple functions. The set of all agents representing organizational functions (within the SC entities) constitute the OAs library. The framework by design conceives OAs to be reused in multiple SC entities. Indeed, at a conceptual level the basic functionalities of the sales agent remains the same irrespective of which SC entity it belongs to. Additionally, by design, both SCAs and OAs are only generic shells with communication abilities providing both direct (peer-to-peer between SCAs or between OAs belonging to a particular SCA), and indirect (routed through the corresponding SCAs) modes of communication. As an important feature, the model allows the generation of different SC models and helps the explicit study of SC dynamics (both intra- and inter-organizational) involving Bullwhip-effect and coordination issues in any SC considering information asymmetry. This MAS structures will allow the development of different analysis on any SC network. The MASCS model additionally, as already mentioned, incorporates multiple geographically disperse market entities representing the aggregate demand behaviour of all possible customers for different products through the usage of MAs.

Further additional features have been also added to the MASCS model. SCM spans all movements and storage of raw materials, work-in-process inventory, and finished goods from point of origin to point of consumption. These different products are referenced in the current model with the notion of Stock-Keeping Unit (SKU) in which, different SKU identifications are assigned for each product based on product variants (product form, fit or function) or even package sizes (boxes, pallets or other load unit). As a result, as for real SC, the MASCS model and consequently all the decisions (replenishment, transportation, production and so on) will be based on the SKU notion.

The proposed MASCS model allows to incorporate appropriate operational policies which will support the decision making of the OAs associated with replenishment, procurement, production and distribution processes. Indeed, these policies are defined as generic reusable objects that can be referenced inside agent's behaviours. This model feature allows to conduct studies that will help to understand the impact of such policies in the SC performance.

As a result from the previous model features, it results that the MASCS model will allow to deal simultaneously with multi-products, multi-SKUs and multi-entity SCs where different types of decisions are accounted for. Indeed, the inclusion of any procurement negotiation scheme will support the dynamic formation of SCs over time. Additionally, the MASCS model will provide a way to conduct studies of different information sharing and operational policies scenarios.

MASCS MODEL IMPLEMENTATION

The MASCS model was implemented using the Java Agent Development Framework (JADE™) (Bellifemine et al. 2007). JADE™ is a software development framework aimed at developing MAS and applications conforming to the Foundation for Intelligent Physical Agents (FIPA) standards, which are intended to promote the interoperation of heterogeneous agents and the services that they can represent. The list of services (table 1) that the defined agents have to provide in the proposed MASCS model, are then carried out extending behaviours classes and establishing proper communication schemas between agents.

The JADE™ behaviours classes (Bellifemine et al. 2007) range from simple to composite behaviours with several types within each category. Each behaviour type class has a particular method to insert execution thread within the tasks queue of a specific agent during simulation. The behaviour classes in use are the following: one-shot behaviour that executes only one particular event-based task normally after receiving a given type of message; cyclic behaviour that executes a given task forever during simulation, which is normally associated with the received message service for each agent; waker behaviour that allows to execute a given task only once, just after a given elapsed timeout; and finally ticker behaviour for tasks that must be executed periodically.

As for communication, the messages exchanged by MASCS agents were specified using the Agent Communication Language (ACL) format (FIPA 2001).

In this format, a performative parameter indicates the type of the communicative act which can be among others: REQUEST, if the sender wants the receiver to perform an action as in the query inventory service that the SA must perform; INFORM, if the sender wants the receiver to be aware of a fact as for the send inventory or send forecast information services or; CFP (call for proposal), PROPOSE, ACCEPT PROPOSAL, REJECT PROPOSAL, if the sender and receiver are engaged in a negotiation, which is the case of the procurement negotiation process between SC entities.

The content of the message can be established in JADE™ through the usage of ontology objects. Ontology represents a common vocabulary to share information in a specific domain and includes its terms, their properties and interrelationships. In MASs, the use of an ontology facilitates interaction, coordination, and negotiation among agents. Ontology objects can be transferred as extensions of predefined classes that JADE™ agents can automatically use to encode and decode messages in a standard FIPA format ensuring agent interactions at a semantic-level rather than just pure syntactic-level.

At this point, and before describing the SC ontology adopted, it is important to highlight the messages type needed to be exchanged between agents in the proposed MASCS model. Because the material, money and information flows throughout the entire chain and must be managed in an integrated and holistic manner for the SC to achieve its maximum level of effectiveness and efficiency, it is assumed that the message exchange between MASCS agents represent all the possible material (shipment deliveries, inventory replenishments and so on), money and information (order requests, production orders, order proposals/refusals, inventory and forecast information and so on) exchanges throughout the entire SC.

In technical terms, FIPA/JADE™-compliant ontology (Bellifemine et al. 2007) consists of a set of schemas defining the structure of the predicates, agent's actions, and concepts that are relevant to a domain of interest (Bellifemine et al. 2007). To provide a better idea for the ontology developed, the version of our SC domain ontology includes about 30 concepts and independent slots (in which the mains are: Deplete, Forecast, Inventory, Load, Order, Period, Proposal, Replenish, Ship and SKU) and 10 predicates (Deplete inventory, Inform forecast, Inform inventory, replenish inventory, Send order, send proposal, send accept proposal, send reject proposal, send refusal and send shipment).

At instantiation, the model communication configuration is defined through a MySQL™ table (OAs table in table 2) (Oracle 2011) that allows the establishment of all the acquaintances needed.

At this point, along with JADE™, several toolkits were integrated into the integrated development environment platform: OpenForecast©, Colt© project and Java database connectivity (JDBC). OpenForecast© (Gould 2003) is a package of forecasting models written in Java that can be applied to any data series. It includes a variety of different forecasting models and provides a module for best time series fitting. The provided classes allow to reference any available forecast model into the SA class in order to periodically produce sales forecast. On the other hand, the Colt© project (CERN 2004) provides a set of open source libraries for high performance scientific and technical computing in Java. The Colt library provides fundamental general-purpose data structures optimized for numerical data, such as random number generators and distributions useful for (event) simulations. On the other hand, JDBC (Oracle 2012) is a standard application programming interface that allows Java programs to access database management systems. The need for a database for MASCS variable definitions, parameters initialization and simulation output data is straightforward. For that purpose, MySQL™ database (Oracle 2011) as an open source database was chosen. Diverse tables, see table 2, were created in order to store all the required MASCS information.

Table 2: List of MySQL™ tables

Designation	Description
Behaviour periodicity	Periodicity parameter definition for ticker behaviours for each agent.
Bill of Materials	Materials/parts and quantities of each needed to produce an end product.
Demand	Demand generation process definition between each MA/SCA pair and SKU item.
Inventory	Inventory position /replenishment method definition for each SKU item and SCA.
Inventory details	Inventory movements registered for each SCA and SKU.
OAs	OAs list and interactions needed between each OAs during simulation.
Orders	Registered orders between SCAs.
Procurement	Procurement decisions made by the PAs per simulation period and SKU item.
Production	Production parameters definition for each

parameters	production resource and SKU item.
Production resources	Production resources available for each MfA and availability status.
Proposals	Registered proposals/refusals and output variables between each SCA pair.
Sales	Sales, lost sales and forecasts for each SCA, SKU item and period.
SCAs	SCAs type and number needed for SC structure configuration.
Shipments	Shipments registered and variable values for each SCA pair per simulation period.
Suppliers	SKU supplier entities available.
Timer	Time interval simulation period definition.
Transportation resources	Available resources and associated parameters for each SCA pair and SKU.
Transportation time	Transportation time distribution for each SCA pair and transportation resource.

MASCS APPLICABILITY

The applicability of the proposed MASCS was tested through the resolution of a SC example that will be briefly described (figure 1). The example is composed of two different entities in each SC tier (markets: M1 and M2; retailers: R1 and R2; manufacturers: Mf1 and Mf2; and suppliers: S1 and S2). Products (Products Code (PC): PC111, PC112 and PC232) and parts (PC1111, PC1112, PC2221, PC2222, and PC2321) are handled through several sized function SKUs. For example, PC111 has associated with him 3 different SKU items, each having a different number of units (SKU1: 1 unit; SKU2: 50 units and; SKU3: 20 units).
M1 is responsible for generating the demand for PC111 and PC112 for R1 and the demand of PC232 for R2. M2 is only responsible for generating the demand of PC111 for R1. All market order requests are generated in SKU1 terms and defined through the demand parameters (mean demand: μd [SKU units/period]: demand standard deviation: σd [SKU units/period] and; number of demand events per period NDEP [demand events/period]).
Each time there is an inventory replenishment need, R1 will acquire PC111 according to the best offer received from Mf1 and Mf2. PC112 is only supplied from Mf1, and R2 only procures PC232 from Mf2. Additionally, Mf1 is responsible to produce PC111 and PC112 in SKU2 and SKU3 terms with two dedicated production resources according to a bill of materials. Based on the production needs and on the inventory level Mf1, for example, will procure PC1111 and PC1112 for PC111, and PC2221 and PC2222 for PC112. Finally, the parts needed from Mf1 and Mf2 are procured in 10 PC units SKU size from two suppliers according to figure 1.
Different replenishment policies (RC=1: Periodic Review, Reorder-Up-To-Level System; RC=2: Reorder-Point, Reorder-Quantity (s, Q) System; and RC=3: Reorder-Point, Reorder-Up-To-Level (s, S) System) are associated to each SC entity, PC and SKU item. The on-hand (OH [SKU units]) inventory value for each PC, SKU and SC entity is defined at the beginning of the simulation. The other inventory parameters values (on-order quantity (OO) and BO) are assumed null.
R1 sends Full Truck Load (FTL) shipments for PC111 (18 m^3 and 1 ton truck) and Lot for Lot (LFL) shipments for PC112 (other dispatch rules are illustrated in figure 1). In order to compute a random production time to produce a specified quantity in a specified allocated resource, a normal capacity variable with a mean capacity (μcap[units/time period]) and a standard deviation capacity (σcap[units/time period]) are used. An additional constant setup time parameter (Setup [time period/10]) is used to compute the production order starting time. The corresponding values are shown in figure 1. Other input parameters are used, but are not presented due to space limitation, to allow the full characterization of the SC structure, material and information flows and behaviour periodicity of the SC case study. Finally, it is assumed that sales are known for the ten past simulation period for each PC at each SC entity in order to perform sales forecast.
The current SC example was simulated during 250 periods (each period corresponds to 10 seconds long) and the corresponding results are partially presented in figure 2. Due to the large amount of output data and this paper space limitation, the full example characterization is not possible in this paper. Some illustrative results are discussed, further details are expected to be oulished in an extended paper. Figure 2 shows the decisions and actions made by the OAs from R1 and R2 and by the PAs from the manufacturers in order to respond to the PCs order generation process during the 30 first seconds. Additionally, the PCs inventory level (IL) evolution at the retailers during the entire simulation is also illustrated.
The results show that M1 generates 9 PC111 orders and M2 generates 5 PC111 orders to R1. Additionally, M1 generates 3 PC112 and 3 PC232 orders to R1 and R2 respectively. The PC111 orders are then almost totally sent in two FTL shipments with departure time at 18 and 26 seconds, shipments number 2 and 5 from R1. The first shipment has two different destinations (M1 and M2) in which M1 is the first route destination. PC111 orders 1, 3 and 6, which were requested by M1 at instant time 11, 14 and 17 seconds respectively, were received at instant time 19s. The PC111 order request 1, 2 and 3 from M2 are received one second later. The PC111 orders sent in the first shipment are exclusively filled through PC111 availability in stock. The second PC111 shipment is only sent after a replenishment process due to a procurement need at 20s. Indeed, PC111 orders 11, 14 and 15 from M1 and order 5 from M2 are firstly backordered and then sent in the second shipment due to the FTL shipment condition. As a result from this operational constraint the PC111 order request number 7 which were requested at time instant 18s from M1 is only received at time instant 31s. As illustrated, the retailers IAs identified two PC111, two PC112 and one PC232 inventory replenishment need.

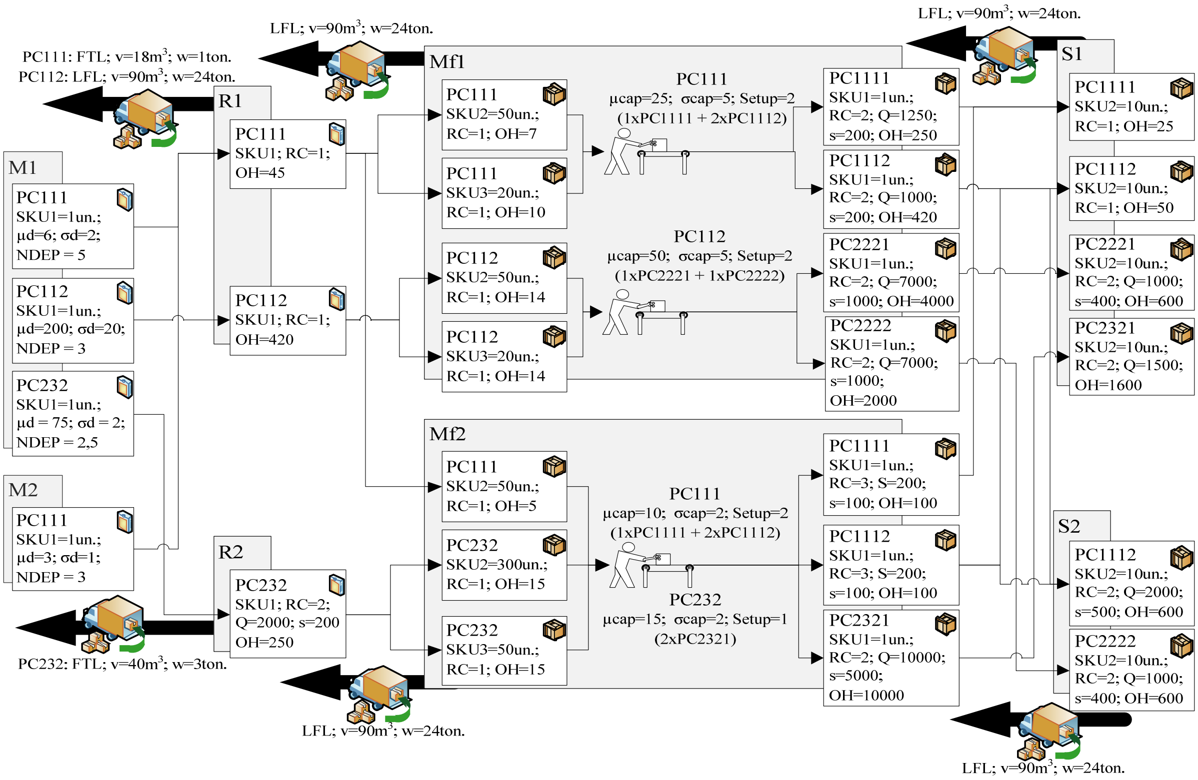

Figure 1: Supply Chain example

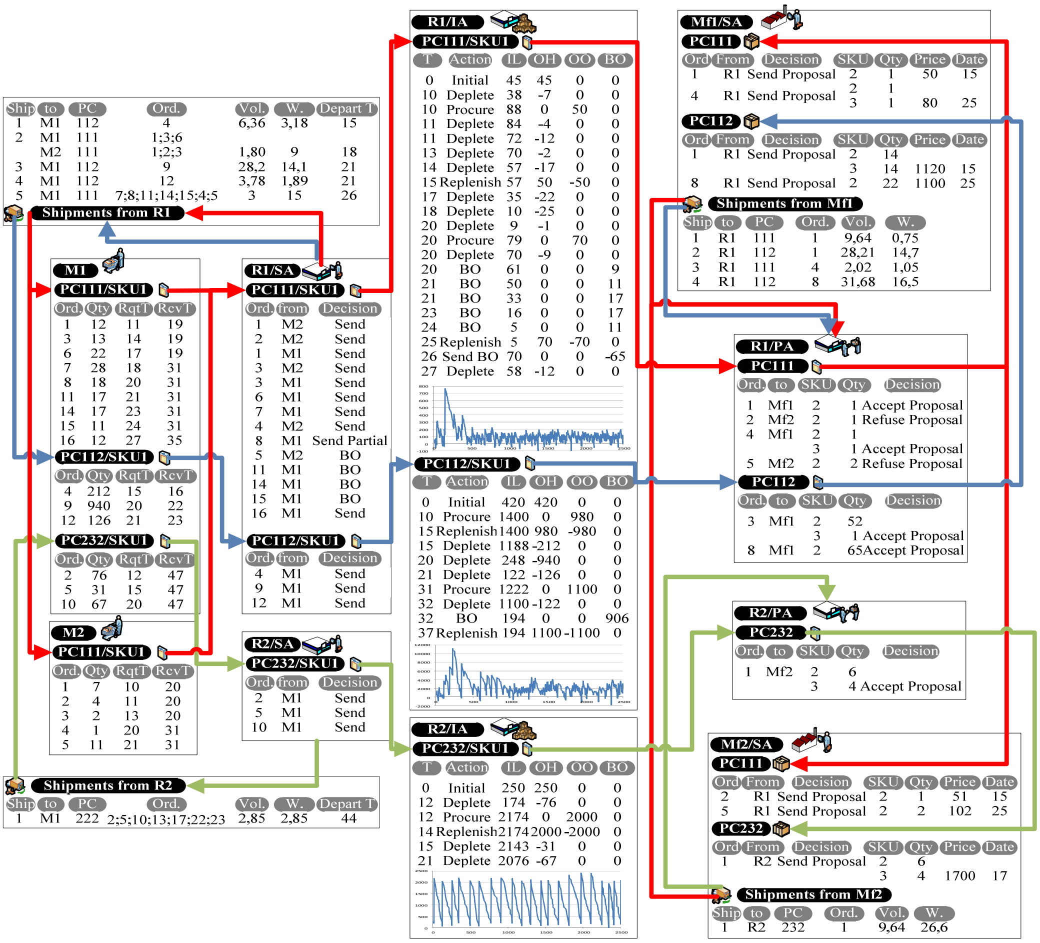

Figure 2: Example results

From these signals, different negotiation process were initialized between the Retailers' PA and the manufacturers. As an example, the first PC111 procurement negotiation, in order to request one SKU2 unit of PC111 at time instant 10s, is initialized from R1'PA sending two order requests (order 1 and 2) to the available suppliers (Mf1 and Mf2). The manufacturers sent back one order proposal with the quantity requested but with different prices. The Mf1 order proposal was then accepted since it presents a lower price (50 against 51 monetary units). The corresponding shipment (ship 1 from Mf1) was then received at time instant 15s allowing the replenishment of 50 units of PC111. Further procurement negotiation process result in the acceptance of a lower quantity then the one requested.

Much more can be said on the obtained results but the most important result is that the current MASCS model act according to the advocated objectives. Indeed, the actions and decisions made by the diverse agents are coherent with the SC example scenario and the MASCS model shows a relative stable behaviour during simulation. This later statement can be highlighted through the inventory level evolution graph illustrated in figure 2 and which were replicated throughout the SC entities of the proposed example.

CONCLUSIONS

A MASCS model has been developed and implemented in JADE™ in order to analyse simultaneously different SC problems, like production planning, inventory management, procurement negotiation, and order distribution. Also it was considered coordination among SC entities considering information asymmetry and distributed/decentralized mode of controls. The proposed model allows to deal additionally with multi-products, multi-SKUs, multi-entity SCs for different SC network configurations. The results show that the MASCS is adequate to analyse coordination issues and the global performance of SC systems under different inventory, production, procurement and shipments policies scenarios. Furthermore it is shown that the developed model can be used as a relevant coordination decision-making tool for SCM.

Further features on the constructed MASCS model can be added to tackle coordination decisions at the interface of the SC. Indeed, the future direction of our work intend to add additional coordination mechanism (SC contracts, information sharing and joint decision making) along as more SC operational and constraints details in order to identify, for different SC scenarios, which set of coordination mechanisms can lead to a better SC performance.

REFERENCES

Arshinder, Arun Kanda and Deshmukh, S.G. 2008. "Supply Chain Coordination: Perspectives, Empirical studies and Research Directions". *International Journal of Production Economics*, 115(2), 316-335.

Bellifemine, F. L., Caire, G., and Greenwood, D. 2007. Developing Multi-Agent Systems with JADE. Wiley.

CERN - European Organization for Nuclear Research. 2004. The Colt© project, version 1.2.0.

FIPA - Foundation for Intelligent Physical Agents. 2001. "*FIPA ACL message structure specification*". Technical report XC00061.

Gould, S. R. 2003. OpenForecast©, version 0.5. "*The OpenForecast User Guide*".

Govindu, R. and R. B. Chinnam. 2007. "MASCF: A Generic Process-Centered Methodological Framework for Analysis and Design of Multi-Agent Supply Chain Systems." *Computers & Industrial Engineering*, 53(4), 584-609.

Govindu, R. and R. B. Chinnam. 2010. "A Software Agent-Component Based Framework for Multi-Agent Supply Chain Modelling and Simulation." *International Journal of Modelling and Simulation*, 584-609.

Oracle. 2011. MySQL™, version 5.0. "*MySQL 5.0 Reference Manual*".

Oracle. 2012. JDBC, version 4.0 "MySQL Connector/J".

Santa-Eulalia, L.A., Halladjian, G., D'Amours, S., and Frayret, J.M. 2011. "Integrated Methodological Frameworks for Modeling Agent-Based Advanced Supply Chain Planning Systems: A Systematic Literature Review. *Journal of Industrial Engineering and Management*, 4(4), 624-668.

SCC – The Supply-Chain Council. 2010. *SCOR: Supply Chain Operations Reference Model – Version 10.0*. The Supply Chain Council. August 2010, version 10.0.

Zambonelli, F., Jennings N. R. and Wooldridge M. 2003. "Developing Multiagent Systems: The Gaia Methodology." *ACM Transactions on Software Engineering and Methodology*, 12(3), 317-370.

AUTHOR BIOGRAPHIES

C. M. VIEIRA obtained his Master degree in Technological Innovation and Industrial Engineering from Instituto Superior Técnico (IST), Technical University of Lisbon (UTL). Actually, as a PhD student in Industrial Engineering, his research interests are in the field of SCM/MAS. He is a Professor of Operations and Logistics at the Polytechnic Institute of Leiria.

ANA P. BARBOSA-PÓVOA obtained her PhD in Engineering from Imperial College of Science Technology and Medicine. She is currently a Full Professor of Operations and Logistics at the Department of Management and Engineering of IST, UTL. Ana's research interests are on the SCM, and on the design, planning and scheduling of flexible systems where sustainability is a main topic. Ana has published widely in these areas and supervised several Master and PhD students.

CARLOS MARTINHO received the PhD degree in Computer Science and Engineering from IST, UTL, in 2007. He is an Assistant Professor at the Computer Science and Engineering Department of IST and a Senior Researcher in the Intelligent Agents and Synthetic Character Group (GAIPS) at INESC-ID. His main research interests are in the field of autonomous agents, synthetic characters and social robotics, merging subfields from artificial intelligence into agent based simulation of believable behaviour.