Multi-Agent Modelling for Simulation of Customer-Centric Supply Chain

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Abstract: The analysis of coordination among the supply chain is a key factor for improving its performance. The highly dynamic demand induced by the volatility of customers requires defining tools to improve the performance. This paper presents an agent-based modelling concept for simulation of customer-centric supply chain. We describe the specificities of such supply chains at the enterprise modelling domain level and propose an approach permitting to explicitly take into account the customers and their behaviours. The approach uses three levels of modelling, successively leading to a domain model, a conceptual agent model and an operational agent model. A case study from the personalized golf club industry illustrates the proposed approach.

Keywords: Customer-Centric Supply Chain, Multi Agents Systems, Agent-Oriented Simulation

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1 Introduction

In the increasingly competitive context of globalization, it is becoming more and more difficult for companies to preserve and conquer market shares. Strategically it is important for them to insure that their Supply Chain [1] becomes an integrated networked organization capable of responding to the volatility of customers needs. To grasp these needs, the structure of their Supply Chain (SC) has to be adapted to targeted product/market segments and the overall management of the SC has to become demand driven and customer centric (growing variability of products adapted to numerous differentiated categories of customers). Such a customer-centric SC becomes characterized by a highly dynamic demand.

This context requires companies to develop flexible capabilities enabling them fast reactivity to dynamic changes in the environment. To deliver customizable products shorter delays it is necessary for them to develop adaptive strategies for resources allocation and flow management (relationships involving combinations of Make-To-Order and Make-To-Stock). Overall this has a significant impact on both the structure and dynamics of the SC.

Estimating the future key performance indicators of a client centric SC in a highly dynamic context is important to insure that client expectations are to be met profitably. It is key when a SC transformation project is proposed and implemented. It is also key to help determine up to which conditions the current SC is to be adequate, and then which elements should be improved or altered. Classic forecasting models turn out to have limited applicability [2] for such performance estimation. In order to estimate the key performance indices of a customer-centric SC, it is necessary to develop elaborate tools such as a SC simulator. However building a tool to simulate the behaviour of the SC in a customer-centric context is not a trivial matter. It requires the elaboration of a representative model and the execution of this model according to a set of hypotheses [3].

Due to their properties, Multi-Agent Systems, having developed in the field of Distributed Artificial Intelligence, seem particularly well suited for the modelling and the simulation of SC. This leads us to suggest an agent-based modelling and simulation approach to facilitate the management of Customer-Centric SC.

In section two, we present a review of previous research on agent-based modelling and simulation of SC. In section three, we define at the enterprise modelling level the specificities of customer-centric SC. In order to explicitly take into account the customers and their behaviours we propose a domain representation of such networks. A case study from the golf club industry illustrating this approach is then presented. Section four presents an agent-based modelling of customer-centric SC, derived from the previous domain modelling and composed of two models: a conceptual agent model and an operational agent model. We emphasize the modelling and the simulation of the customer actor, central actor of the SC. Finally, section five presents conclusive remarks and avenues for further research.

2 Agent-Based Modelling and Simulation of Supply Chains

Parunak et al. [4] contrast three main modelling approaches: (i) the Control Theory approach, based on differential equations, (ii) the Operational Research approach, which relies on optimization theories, and (iii) the Simulation approach. Simulation, which relies on experimentation through executable models, is a well-known technique for understanding and predicting the behaviour of systems [5]. It has been recognized for its capability to allow more realistic observation of the SC behaviours and dynamics over time. This allows to understand the organizational decision-making processes, to analyze the dynamic interdependencies between actors and the consistency of coordination modes through the SC.

When using the Simulation approach the literature distinguishes between two main types of modelling [4]: equation-based modelling and agent-based modelling. The former sets observables as quantifiable characteristics of one or more individuals. It expresses the relations between the observables through equations. The model is executed by iteratively evaluating these equations and observing the evolution of the observables. The latter approach encapsulates in individuals (agents) the behaviour of each actor of the system. The execution of the model is a behavioural simulation, letting the agents interact with each other and the environment, and monitoring their behaviour and the observables which are impacted agent actions. Several research studies in the correlated manufacturing and SC domains [6-9] point to the fact that the agent-based modelling approach may be well suited for realizing models enabling the analysis of the SC behaviour.

2.1 The Agent approach

An agent can be defined as an entity, theoretical, virtual or physical, capable of acting on itself and on the environment in which it evolves and to communicate with other agents. Its behaviour is the consequence of its observations, knowledge and interactions. An agent is defined by Jennings et al. [10] as a: "*computer system, situated in some environment, that is capable of flexible autonomous action in order to meet its design objectives*". Wooldridge and Jennings [11] propose the following properties of an agent:

- *Autonomy*: an agent operates without human being or other direct intervention and neither the actions it realizes nor its internal state are submitted to any control.

- *Reactivity*: an agent perceives its environment and reacts in an appropriate way.
- *Pro-activity*: an agent must be able to develop behaviours directed by internal goals.
- *Sociability*: the agents interact with each other using communication languages and common sociability rules

Two kinds of agents are distinguished according to their degree of intelligence and knowledge: the reactive and cognitive agents. The reactive agents follow the stimulus/action law and use reduced communication languages. The cognitive agents have reasoning capabilities and have an explicit representation of the environment in which they evolve [12].

2.2 Relevance of the agent approach

Multi-Agent Systems (MAS) and SC can both be seen as networks of entities which cooperate in order to solve problems that are beyond their individual abilities or knowledge [13]. The analogical thread between MAS and SC relates to the coordination needs and capabilities, between agents in a MAS and between actors in a SC. Table 1 summarizes important analogies between MAS and SC.

Table 1 Analogies between SC and MAS, adapted from [14]

Nature	*Supply Chains*	*Multi-Agent Systems*
Multiplicity of active entities	Multiple actors involved to realize common tasks	Multiple agents with different roles and abilities
Properties of entities	Goals and skills needed for task execution / management rules	Goals, roles, reasoning abilities to perform decisional activities
Social abilities of entities	Decisions through coordination / negotiation methods	Autonomous social capabilities, proactive and/or reactive
Decision-making capabilities of entities	Learning and reasoning in order to take decisions	Reasoning, knowledge acquisition /modification through interactions
Coordination between entities	Material, informational, decisional, financial interactions	Through agents' activities interaction
Information sharing among entities	Incomplete information accessed and shared in the SC	Incomplete information and knowledge exchanged by message
The task distribution	Tasks delegable to other actors	Tasks delegable to other agents
Structure flexibility of the system	Flexible structure organized by actors' strategies	Flexible MAS with organizational structures
Evolution abilities of the system	Dynamic SC allowing actors to join, quit or change roles	MAS in which agents can be added, deleted, or be made to change roles

Both MAS and SC are composed of entities which interact according to their roles and abilities within organizational structures. Agents and SC actors have means, resources and capabilities allowing them to carry out various functions, tasks or activities in an individual or collective way. These analogies naturally lead to the use of the Multi-Agent approach to represent SC. Empirical evidence shows that MAS make the study by simulation of the SC more realistic, as reported through many projects of agent-based modelling and simulation [15, 7, 8, 9, and 16]. The agent based approach allows to easily taking into account:

- The distributed nature of SC and the non linearity of their behaviours;
- The modifications of the environments, since the agent autonomy allows the model to change by updating through addition and removal of agents;
- The decision complexity and variety, through the MAS capability to solve problems by cooperation in a distributed way;
- The presence of cooperative, yet not altruist, behaviour by actors, thanks to the definition of the agents' properties through interaction modes.

2.3 Using multi-agent systems for modelling supply chains

MAS offer a behavioural representation in a modular way and allow simulation models to have evolutionary transformation capabilities due to their ability to adapt themselves to changes and to structural modifications (without an entire alteration of the system). Agent-based modelling of SC allows the actors' behaviours and the interactions to be represented, this approach is especially well suited to this kind of problem [12]. Previous research based on the agent paradigm has been mainly focused on SC Management. Some noteworthy examples of this focus are found in the works of Strader et al [7], Swaminathan et al [17], Gjerdrum et al. [18], the MASCOT [9] and the DASCh [4] project.

In these projects, the scope of the study, the simulation objectives and the abstraction level influence the multi-agent organization design which represents the SC. As revealed in [18] and [17], the representation has not been systematically isomorphic. For example, each plant site or manufacturing resource is not necessarily represented by an agent. The DASCh project [4] and the MASCOT project [9] and several other works rely on different combination of agents by company modelled. The abstraction level influences the number of agents evolving in the multi-agent organization and the granularity of their behaviours.

Depending on the project, an agent in the model has behaviours, communicational and decisional capabilities, which range from the management of a resource to the planning of a company [18]. For example, the agents attempt to locally optimize their schedule or estimate various scheduling policies by using negotiation processes or protocols. The DASCh project [4] defines a Company agent which interacts with the Production Planning and Inventory Control agent when a problem occurs in order to compute a new plan.

2.4 Current limits of Agent-Based Supply Chain Modelling

At the modelling level, the analysis of previous research works highlights the fact that the agents are used to model the existing actors and / or decisional processes. However, these works differ relative to the approaches applied for the design of the simulation model. They do not offer modelling frameworks based on domain modelling which take enough into account the variety of SC configurations, and more generally the physical characteristics of the real systems.

At the model design level, the works of [17] are centred on the modularity and the re-use of conceptual models using a library of SC components. This library is made of components: structural which define the actors of the SC, and functional which describe the behaviour of each actor by specifying the decision processes and the actions to realize. The use of such a library can be restrictive if the elements needed for designing a new model do not match the library components (for example, customers do not belong to the structural components). Moreover, actors can play multiple roles defines by supplier/client relationships. So, the number of roles playing appears to be limited in response of the multiple relationships which influence the SC structure and the actors' behaviour.

Finally, in the analyzed projects, demand estimates are specified as fixed input parameters of the simulation model. To take into account the dynamic of this demand in customer centric SC, a representation of the customer behaviour is needed. This is especially true in a product personalization context, where demand is difficult to predict by classical forecasting methods, due to the lack of data or of history, or due to the lack of adequate granularity.

2.5 Conclusion

The analysis of the coordination and the synchronization of the SC actors is a key step towards improving SC performance. It is difficult to realize such an analytical study directly on the real system, paving the way for using a simulation model.

The agent-oriented approach is both relevant and applicable for SC modelling and simulation. Each analyzed research project had its own aims in modelling and simulation and consequently supplied specific decision support to the improvement of the SC performance.

Our research is concerned with a specific kind of SC: customer-centric SC. None of the research works studied in this section has covered this kind of SC. Such SC have specific characteristics due to the role that the customer plays in the chain. The agent approach appears to be relevant to model and simulate these SC.

As a first step to the introduction of our proposed approach to the agent based modelling and simulation of customer-centric SC, the next section introduces the key features of domain modelling of such chains.

3 Modelling Customer-Centric Supply Chains

In customer-centric SC, the customers have to be considered as the "prime contractors" actors. These SC may have to face an erratic and highly dynamic demand induced by the volatility of the customers needs. Consequently, a relevant modelling has to explicitly take into account the customer, its demands, its interactions with the other actors of the chain. It also has to consider various multiple supplier/client relationships between these actors. If the agent-oriented approach is relevant for SC representation, it appears to be necessary for the customer-centric SC description.

This section starts by defining the specificities of such chain at the enterprise modelling domain level, in order to propose an agent representation of customer-centric SC, permitting an agent simulation. Then we propose a specific domain modelling, based on two different models: a "Structural Model" and a "Dynamic Model". This approach allows in particular to explicitly take into account the customer and its behaviours. A case study from the golf club industry is used to illustrate the domain modelling.

3.1 Mass customization

Mass customization is a key answer to take into account the dynamics of customers' requirements. Mass customization consists of making products in large volume and adapting to individual customer needs, in accordance with mass production principles.

To cope with the volatility of customers needs, characterized by a dynamic evolution of the products, SC have to adapt their structure and their coordination processes. The organizational structure of the companies has to be adapted in order to deliver personalized products in shorter delays than those necessary for their manufacturing. In this context, the period between the order receipt and the delivery date corresponds to time necessary for the product customization and delivery.

Such objectives are conditioned by the conception of adapted processes and products. The use of standardized methods and modular products contributes to the reduction of delivery periods and to the acceleration of personalization. SC directed by the production and distribution of personalized products adapt their organizational structure as well as their relations among companies, altering material, informative and monetary flows. To give an efficient answer in shorter delays, the personalized product transformation activities become strictly to order.

3.2 Domain Modelling

The level of abstraction used in domain modelling has to correspond with the objective of formalizing the domain knowledge so as to describe the structure and the behaviour of the considered SC. At this level we use models and specific formalisms in the domain of industrial networks. The domain modelling is based on approaches proposed in [19, 20]. The representation of the SC structure is based on the concept of responsibility network that we have extended to the customer actor.

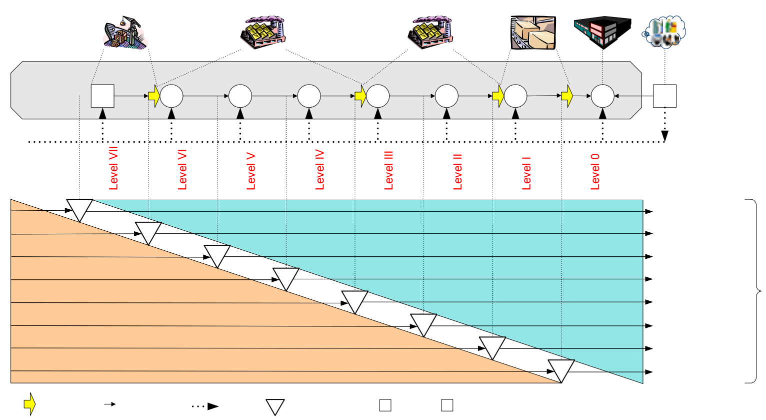


Figure 1 Reference model for the actors' coordination of SC

We proposed in [21] a classification of the activities of actors in a SC according to eight levels of personalization illustrated in Figure 1. Each actor is characterized by its role and its responsibilities. The set of these characteristics defines an activity network. Each actor of the network has to coordinate its activities with the other actors to meet the demand. This demand enters the chain through orders. The entry point of an order in the SC is termed the order penetration point [22]. This point corresponds to a node in the activity network of the SC and depends on the level of personalization required by the client. Locating the order penetration point consists of determining the point of order entry on the physical flow of products.

Identifying the personalization level allows positioning the de-coupling point [23] on the actors' network. This identification defines the management policies and the relations among actors upstream and downstream of this point. The nature of orders defines the typology of the SC by products' personalization level. This implies specific informational and material flows. The customer relationship and the location of the order penetration point define the structure and the behaviour of the SC actors. The adopted domain modelling is based on two complementary models which are the Structural Model and Dynamic Model.

3.2.1 The Structural Model

The structural model describes the elements and the links which form the SC. The representation of the SC is based on the concept of "responsibility network". The SC is composed of a set of autonomous actors who have roles and additional responsibilities in line with their competencies and the activities which they are able to perform for the product transformation. A responsibility network is represented in each decision-making level according to an “inter” and “intra” organizational decomposition (inter-enterprise, inter-department ...). This refinement offers a recursive representation of the organization (SC, Enterprises, Departments, Cells and Resources).

A responsibility network can be defined at the decision-making and/or operational levels. It formalizes the roles of each element of the SC. Roles are defined according to the elements in interaction (supplier/client links) and to the activities assigned to each actor (assumed as responsibility). The responsibility network according to the Inter-Enterprise level is decomposed into a new responsibility network at the Enterprise level. This decomposition implies redefinition of objectives by level, highlighting the coordination of actors according to their activities. It specifies a network for each decision-making level.

3.2.2 The Dynamic Model

The dynamic model defines the behaviour of each element of the structural model and identifies the interaction modes used within the SC. The design step of the Dynamic Model is based on the NETMAN (NETworked MANufacturing) methodological framework [20], developed in our laboratories. This framework concerns the conception and the implementation of the organizational structure of hierarchical or heterarchical industrial networks. It allows economic planning, control and management of the activities of the actors of the network in a dynamic environment. Each independent business unit of the actor's network is represented as a center. These centers collaborate and coordinate with the other centers by interactions of flows (informative and physical). The external actors in the considered organization are customers and suppliers. The informative flows used to associate with the dynamics of the system are:

- **The needs** are represented as orders and forecasts characterized by the personalization levels.
- **The offers** are expressed by personalization levels and delays per market zone [24].
- **The coordination data** are expressed from the performance analysis defined from a local and global point of view (actor and actors' network) [21]. The performance analysis provides information concerning actions carried out by actors.
- **The coordination models** are developed according to two approaches: the network models and the center models. The network models represent the activity coordination within the SC. The center models describe the coordination of the actors within the center. These models are shared according to two modes of transmission, upstream and downstream. We specify the contents of information exchanged between actors to obtain an efficient coordination.

3.3 *The industrial case*

The illustrative SC is inspired by major manufacturers from the golf club industry [24]. Depicted in Figure 2, this chain is characterized by specific combinations of product personalization levels being offered to specific markets. The demand is the market response to these offers, translated into customers in each market each deciding or not to purchase a specific set of golf clubs at a specific time. Actors who compose the SC are considered autonomous and collectively responsible to supply final products on all market zones. Upstream in the chain, a set of suppliers is responsible to deliver components and raw materials to the Golf Club Manufacturer.

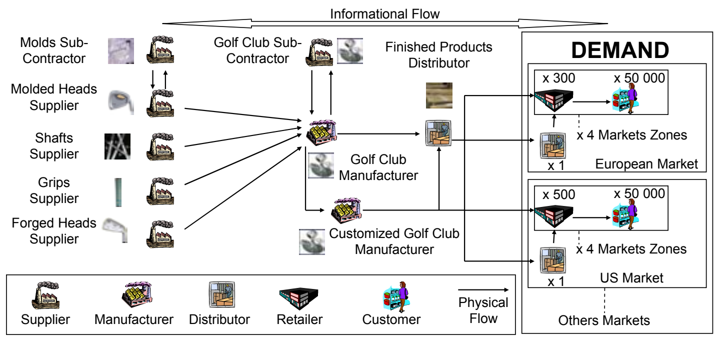


Figure 2 An industrial case from the golf club industry

3.3.1 *The Structural Model*

The structural model is built around a set of actor types comprising producers, assemblers, processors, fulfillers, distributors, retailers and customers. Producers have the responsibility to deliver raw materials and/or components to the Assembler. Processors are responsible for performing specified operations on parts. The Assembler and the Fulfiller both have responsibilities to transform raw materials and/or components into final products, the difference lying mostly in the fact that fulfillers make personalized products, strictly to order, while assemblers can assemble standard products and modules, and produce them either to stock or to order.

Final products are delivered to the Distributors and Retailers. Distributors deliver final products to Retailers. Retailers sell final products to the Customers. Retailers form a physical and organizational interface between Customers and the manufacturing network. At the level of Retailers, final products are stored and then delivered to customers. The number of Retailers is specified by market zone. Each customer is located in a specific market zone. Figure 3 represents the structural model of the industrial case at the Inter-Enterprise level through a responsibility network.

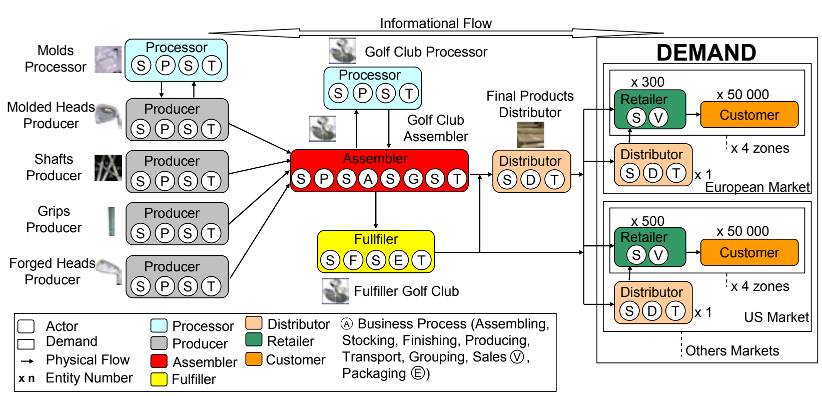


Figure 3 A Structural Model at the Inter-Enterprise level

3.3.2 *The Dynamic Model*

The dynamic model depicted in Figure 4 at the inter-enterprise level is based on a part of the responsibility network described in the structural model (Shaft Producer, Golf Club Assembler, Golf Club Fulfiller, Distributors, Retailers and Customers). Customers express their needs by sending orders to the Retailers. These needs rise up along the responsibility network to the appropriate de-coupling point. The Customer relationship described in Figure 4 is an Assemble-To-Order relationship. The de-coupling point is situated at the Golf Club Assembler.

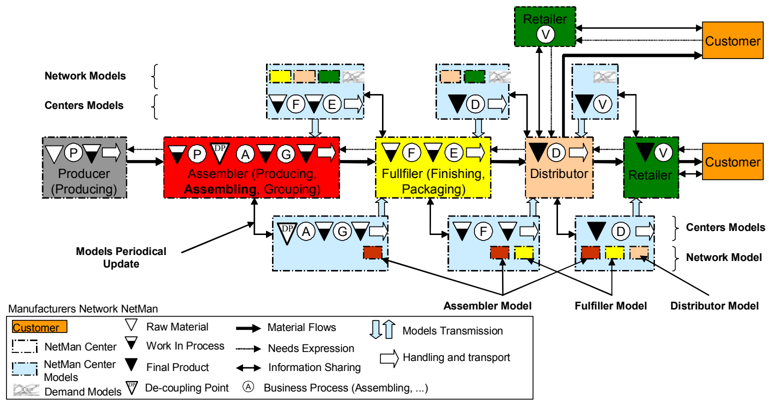


Figure 4 A Dynamic Model at the Inter-Enterprise level

Transformation activities are then made in a pulled flow from the de-coupling point to the Customer. Figure 4 illustrates how network models and center models are shared between SC's actors to detail their coordination. This representation shows SC actor's behaviours in term of Customers needs translating the dynamics of the demand. Customers can purchase popular products stored at the Retailer or place an order for an out-of-stock popular product or for a personalized product fitted to his specifications. The retailer can transfer customer orders to others Retailers, to Distributors, or to the Golf Club Assembler depending on the established business rules.

4 Agent-Based Modelling and Simulation of a Customer-Centric Supply Chain

This section presents an agent-based modelling for the simulation of customer-centric SC. The proposed approach feeds from the domain modelling and permits an agent based simulation of the SC on a specific agent simulation platform. First we define the agent based modelling process according to two different abstraction levels: the conceptual and operational levels. At each level a specific agent model is defined. Then for each of these models, we define the modelling objectives and process, and we illustrate it through the case study introduced in the previous section. Finally, we present the adopted multi-agent platform for our prototype implementation and give some details on the simulation of the customer actor of the SC.

4.1 *Agent-Based Modelling process*

We propose to model and simulate customer-centric SC based on the agent paradigm. The proposed agent-based modelling represents the SC as a network of agents which adapt their behaviours to the evolution of the environment. Environmental dynamics are mainly characterized by the specification of the customer's behaviours. In section three, at the domain level, we have described the structure and the dynamic of the considered SC. The structure is represented by various decision-making levels in a unified framework describing behaviours and interactions of the actors according to these levels.

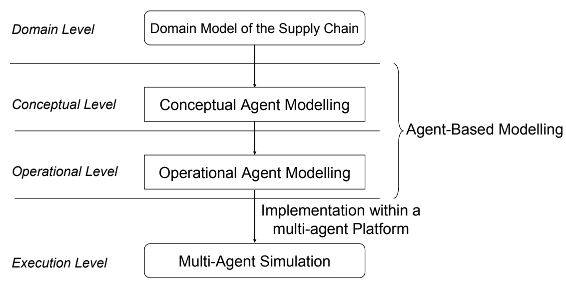
The agent-based process proposed for customer-centric SC representation is based on a specific domain modelling presented in section 3 (input of the process) and is composed of two agent models associated to two abstraction levels:

- The *conceptual level* translates the domain modelling in an agent-based modelling disregarding technical considerations associated with the execution of any simulation. The conceptual modelling obtained is defined by several models allowing to specify the architecture of the MAS. This approach also specifies for each agent its behaviours as well as its interactions.

- The *operational level* renders the previously obtained simulation of the conceptual agent model operational. At the conceptual level, the set of agents is defined and a general decision-making behaviour is described for each agent. At the operational level, specific actions are determined corresponding to the prescribed behaviour of each agent. At this level, the internal software architecture of each agent is also defined as a composition of interacting elementary software agents. At this level we consider specificities and constraints related to the implementation environment.

Figure 5 illustrates the proposed modelling approach highlighting various abstract levels. In the following sub-sections we develop each of the agent-based modelling levels by clarifying their objectives.

Figure 5 Proposed multi-agent modelling process



4.2 Conceptual Agent Modelling

Conceptual Agent Modelling transposes the domain model into the agent paradigm. In order to introduce the Conceptual Agent Modelling we present the objectives of the process and an illustration.

4.2.1 Modelling objectives and process

The actors and their behaviours, captured in the Structural and Dynamic Models, are translated as a set of agents. Each agent is defined according to his beliefs, behaviours, and interactions links, hence specifying the overall architecture of the MAS.

We represent actors of the real world associated to the SC by agents. Thus Conceptual Agent Modelling identifies agents associated to the actors of the SC, including the customers. Actions or operating behaviours of these agents are specified for simulation through the Operational Agent Modelling.

4.2.2 Illustration of Conceptual Agent Modelling

To illustrate the Conceptual Agent Modelling, we focus here on the Shaft Producer. The interaction with Customers is represented by elementary activities such as order sending. The specification phase allows us to formalize the Domain Model using the agent paradigm. As one illustrative possible modelling alternative, we propose to model the Shaft Producer through a team of five SC agents. As shown in Figure 6, four agents are respectively responsible for each of the main activities actually touching the products: raw shaft supply, shaft transformation, shaft supply and shaft distribution. The fifth SC agent is the Shaft Producer agent, responsible for managing demand and planning production. Each SC agent is characterized by its role, its responsibilities and by the activities it is able to realize.

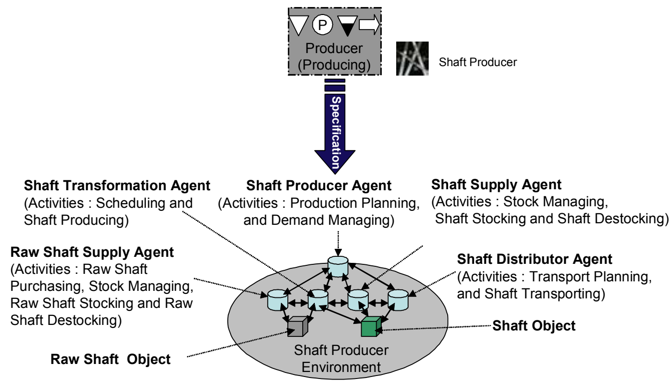


Figure 6 Conceptual Agent Model of the Shaft Producer

As an example, the Raw Shaft Supply Agent has a Distributor role. It is responsible for purchasing, receiving, delivering and controlling the inventory of raw shaft. Its activities are to: (i) receive and stock raw shaft section, (ii) manage raw shaft purchases (reorder method), (iii) control raw shaft inventory, and, (iv) distribute raw shaft to the Transformation Agent. We identify the interaction links (physical and informative) existing between agents. The physical links allow objects (raw shaft and shaft) to circulate along the physical flows.

4.3 Operational Agent Modelling

The objective of Operational Agent Modelling is to create an executable model from the Conceptual Agent Model (CAM). Designing the Operational Agent Model involves the integration of individual agent characteristics defined at the Conceptual level: social properties, organizational structure, interactions protocols and environmental constraints. Each characteristic implies a top-down description. The actions of each agent associated to the decision-making behaviour are specified. Specificities and constraints related to the adopted implementation environment are also taken into account at this level.

4.3.1 Modelling objectives and process

The Operational Agent Model (OAM) is derived from the CAM. Each “conceptual” agent of the CAM associated to a SC actor generates an “operational” agent of the OAM. This “operational” agent is defined as a composition of interacting elementary agents according the "Agent Actor" model defined in [39]. These elementary agents are cognitive or reactive, and an operational agent is composed of one cognitive agent and/or none or several reactive agents:

- A *cognitive agent* deals with the *decisional activity* of a conceptual agent. Such cognitive agent is a deliberative agent, it can play one or several role, and its decision-making behaviour are specified by Behavioural Plans (BP). BP allow the agent to act so as to reach its aims. Decisions can require communication for the information request or for the carrying out actions.
- A *reactive agent* is responsible for an operative activity associated to the represented conceptual agent. The behaviour of a reactive agent is defined as state charts, and is linked to the decision-making behaviour of the responsible cognitive agent. The states specify actions carried out after the reception of messages from the cognitive agent or of signals resulting from the environment.

Two different “operational” agents of an OAM can interact at two levels: between their cognitive agents by exchanges of messages in the context of BP associated to specific roles, and directly between their reactive agents by exchanges of signals. The first interaction mode concerns the information flows and the second interaction mode concerns the physical flows and their coordination (physical links).

In the context of SC modelling, for a given operational agent, the decisional activity of its cognitive agent is associated to the decision making of the SC actor represented, and the operative activity of its reactive agents are associated to the physical activities of this actor.

Thus the OAM is composed of a set of agents, which represent the actors of the SC. To these agents, we allocate behaviour similar to those of the actors that they are modelling. Our objectives are to study the interlaced behaviours of a physical system in which complex logistical and production processes are running, and a decision-making system in which complex decisions processes are running. On one hand we have to define behaviours and reactions of the physical system based on decisions of its decision-making system. On the other hand we have to define how these decisions also depend on the state of the physical system.

Figure 7 From SC Actor to SC Agent

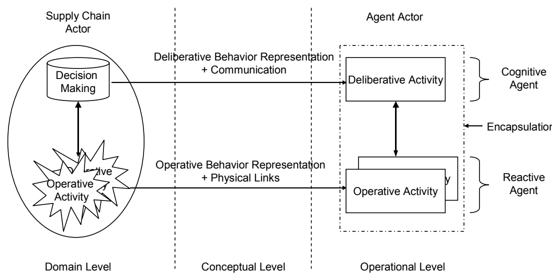


Figure 7 presents the mapping of SC actors to SC agents based on the process modelling, [25]. The encapsulation principle defines the following relation: the reactive agents perform operational activities from decisions taken by the cognitive agent. The OAM is composed of two agents' societies, one of cognitive agents and the second of reactive agents. This decomposition allows differentiating behaviours, roles and competences adopted by the actors within the organization of the system. The aim of the implementation phase is to carry out the OAM on a dedicated Multi-Agent platform.

4.3.2 Illustration of the Operational Agent Modelling

The OAM is composed of two agents' societies, one cognitive and one reactive. This decomposition allows differentiating the behaviour, the roles and the competences adopted by agents. The OAM is formed by all the agents composing the CAM. Figure 8 shows the OAM of the Shaft Producer actor previously described.

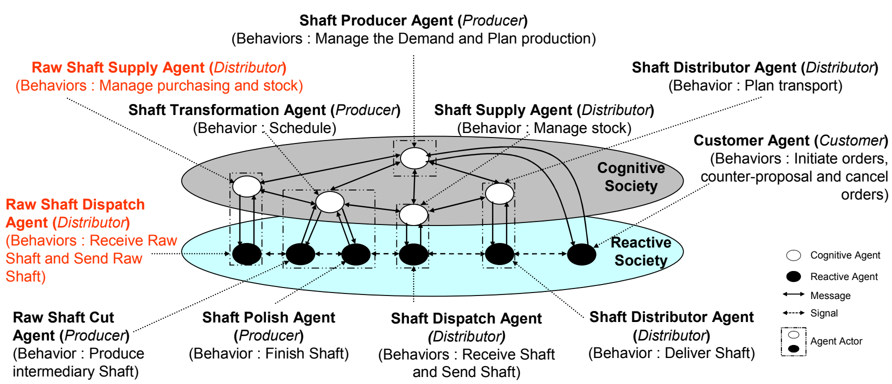
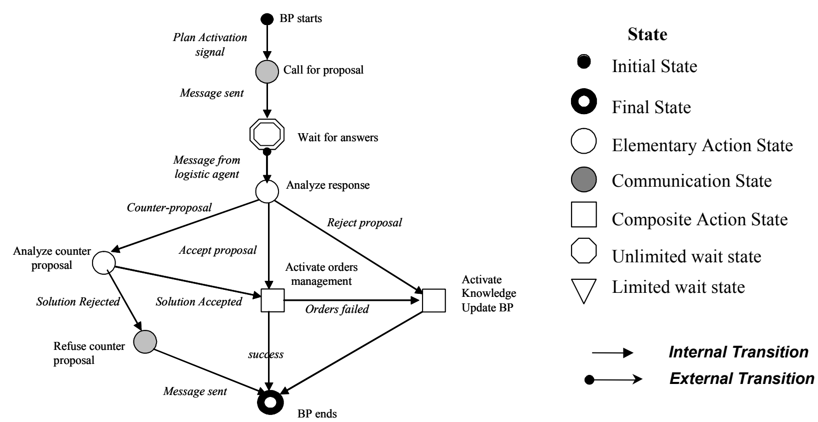


Figure 8 Operational Agent Model of the Producer Shaft Agent

The previously introduced Raw Shaft Supply Agent is composed of two agents, a cognitive agent and a reactive agent. The cognitive part of this SC Agent is represented by the Raw Shaft Supply Agent. This agent is responsible for the realization of the decision-making activities, involving complex behaviours. The reactive part of this SC Agent is represented by the Raw Shaft Dispatch Agent. This agent is responsible for the realization of the operational activities, involving physical activities.

Agents are represented with a Belief Desire Intention architecture [26] based on plans. These plans are specified by state charts according to the Agent Behavior Representation (ABR) formalism [27]. Figure 9 illustrates the behavioural plan for the "Raw Shaft Purchasing" Agent.

Figure 9 Behavioural Plan "Raw Shaft Purchasing" for the Raw Shaft Supply Agent



The Raw Shaft Supply Agent has a second Behavioural Plan allowing it to establish and to manage communication links with an agent responsible for the raw shaft transport (Logistic Agent). These communication links are particularly achieved by sending order propositions, orders confirmation or refusal according to the received counterproposals.

Reactive agent architecture is based on reflex states. The agents' behaviours are implemented with state chart diagrams UML/AUML [28]. Figure 10 illustrates the behaviour of the Raw Shaft Cut Agent.

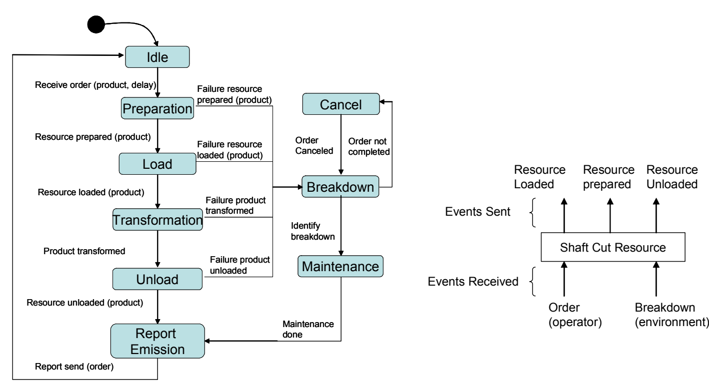


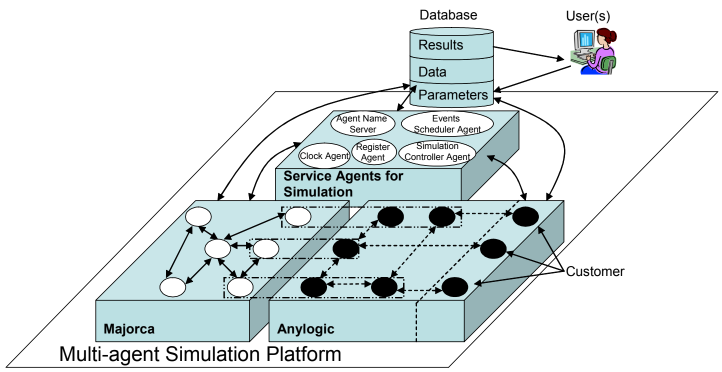
Figure 10 Behavioural Representation of the Raw Shaft Cut Agent

Received events trigger the activation of the state chart and the Sent events result from actions of the agent. The agent which is responsible for the transformation of raw shaft into intermediary shaft, the Shaft Transformation Agent sends orders to the Raw Shaft Cut Agent. In answer to this event and according to states and transitions activated in the state chart, the Raw Shaft Cut Agent will send out one of three specified events.

4.4 The Multi-Agent Simulation Platform

In this section we detail the characteristics of a simulation platform. The simulation makes possible the comprehension and prediction of phenomena based on the experimentations through the execution of different scenarios. The simulation tool has to support the understanding by the user of the simulated SC behaviours. A Multi-Agent Simulation Platform is typically composed of the following modules: (i) the *model parameters* expressing the needs of the study, (ii) the *user interface*, (iii) the *service agents for simulation* composed of generic elements such as the Simulation Clock and the Events Administrator, and (iv) the *Operational Agent Model*.

Figure 11 The multi-agent simulation Platform



In our current implementation, the service agents include: (i) the *Agent Name Server*, (ii) the *Register Agent*, (iii) the *Clock Agent* for time synchronization, (iv) the *Events Scheduler Agent* for events synchronization, and, (v) the *Simulation Controller Agent* responsible for the management of simulation parameters. Figure 11 presents the general architecture of our Multi-Agent Simulation Platform prototype, depicting the modules and the inter-module links. The main modules are the Database, Majorca for the cognitive agent society, Anylogic for the reactive agent society, and the Service Agents.

The Database provides the interface between the user and the platform for the definition of simulation parameters, the recording of simulation data and the display of results. Cognitive agents are based on MAJORCA agents' models (Jess Engine Agents [29] Oriented ABR) [27]. MAJORCA is a platform which proposes a Multi-Agent development environment based on Behavioral Plans specified with the ABR formalism. Reactive agents are implemented within the Anylogic environment (development and simulation of discrete, continuous and hybrid systems). Figure 12 presents a development interface showing the conception of the reactive agent society. Every agent is built according to its role (one or several behaviours implemented with state charts).

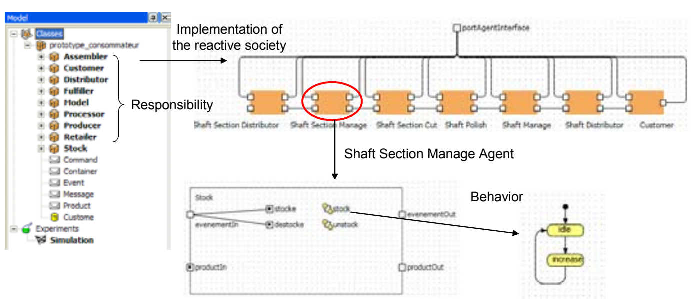


Figure 12 Reactive Society Implementation

This model is obtained by positioning the agents composing the reactive agent society (defined by their roles) from the accessible roles in the responsibility network. Once positioned in the network, the agents are interconnected according to supplier/client links.

4.5 Simulation of the Demand

Demand for a given personalization level is considered one of the essential elements forming the dynamic environment of the SC. The personalization level is described according to the relation between Customers and the SC. As mentioned earlier, Customers can either acquire products from Retailers who generate orders in case of unavailability or the need for a personalized product, or place orders via a Business-To-Consumer (B2C) e-commerce web interface. Personalization offers include the archetypical options presented in [38]: popularizing, varietizing, accessorizing, parametering and tailoring.

In our works we put particular emphasis on the simulation of the Customers, taking into account personalization levels and market zones. Table 2 presents the characteristics associated to products per personalization level for a specific market, here the Canadian Market. For every personalization level, an appropriate mix of products is proposed. Table 2 computes the number of product combinations offered in the Canadian market for each personalization option, through the combinatorial multiplication of their intrinsic product components.

Canadian market	Number of options per parameter				
Parameters for iron sets offer	Popularizing	Varietizing	Accessorizing	Parametering	Tailoring
Club head models	2	4	4	4	4
Metal alloy	1	1	1	2	4
Availability both sides per model	2	2	2	2	2
Lofts per model	1	1	1	3	7
Lie angles per model	1	1	5	9	13
Sole grinds per model	1	2	2	3	6
Shaft type/flex per model	3	12	20	40	60
Length per shaft	1	1	5	15	30
Adjusted weight per shaft	1	1	5	5	19
Grip types per shaft	1	3	10	20	35
Grip size per grip	1	1	2	6	6
Number of iron set combinations	12	576	800 000	466 560 000	125 483 904 000
Service Offer (average figures)					
Delivery delay (days)	1	3	5	10	30
Delivery reliability (fulfill rate)	95%	95%	90%	90%	75%
Penalty for late delivery (per day late)	$20	$10	$10	$10	$25
Price	$850	$900	$1 000	$1 200	$2 000

Table 2 Offers versus personalization level, source [24]

A Customer Agent represents a human customer in a market zone. This agent generates an order if an offer made to him by a retailer or an e-store satisfies his needs and meets his expectations. The offers made to him vary depending on the market zone and the expression of his needs. The demand is the number of demanded products, specified per time period, per personalization level and per market, prior to negotiation with the retailer due availability issues. Demand is thus clearly potentially different from sales.

For simulation purposes, it has to be estimated through some appropriate probability distribution. Figure 13 illustrates such time-phased demand estimation for each personalization level. It exhibits a strong seasonal pattern as is the norm in the golf club industry. These estimates become the core based on which the demand instances are generated, translating in customers dynamically entering retailers or logging in an e-commerce site. These demand curves are recorded in the Database which allows the user to obtain an aggregated vision of the demand. However the SC Agents in the simulation do not have access to the generated demand distributions.

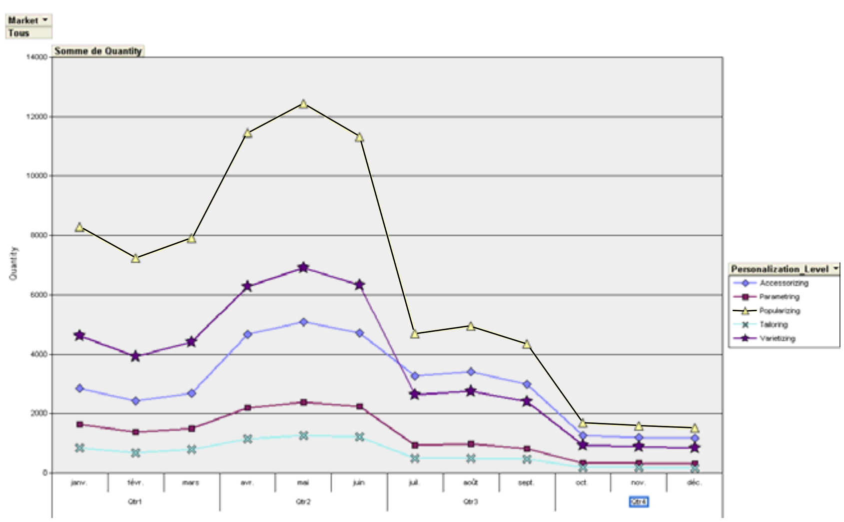


Figure 13 Estimated demand per market per personalization level

5 Conclusion

The new economy is characterized by stiff competition and high market and technological turbulence, with an emphasis on ever delighting customers. For an enterprise to maintain a competitive position, it is fundamental for it to be demand driven and customer centric, exploiting the dynamic and stochastic nature of the demand, stemming from fast evolving customer expectations. It is essential to develop and exploit agility and intelligence in its SC so has to better profitably delight its customers.

In this paper we have proposed an agent-based modelling approach for simulation of customer-centric SC. This approach allows a satisfactory representation of the structure and behaviour of the SC, specifically taking into account the operating policies induced by the expected shape of the demand. Agents have the ability to adapt their behaviours to the environment modifications. Hence, they are able to play different roles depending on the various management policies. The choice of the adapted role is guided by the decoupling point position. It allows the agents to determine the better policy to ensure the customer relationship according to the personalization level.

The approach is based on three modelling levels: Domain Modelling, Conceptual Agent Modelling and Operational Agent Modelling. Each actor of the SC is represented by one cognitive agent and/or none or several reactive agents. Interactions between cognitive agents correspond to actors' information exchange whereas interactions between reactive agents concern physical flows. The agent-based operational model of the SC implemented on the simulation platform, leads to the simulation of two societies of reactive and cognitive agents in interactions.

The perspective consists in the experiment of the developed prototype for observation and analysis of the impact of alternative manufacturing network configurations, management strategies and policies. The results will focus on the behaviour and performance of the SC as a whole and of each actor involved in it, especially in a customer-centric context.

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