

A multi-agent approach to support simultaneous design of a product and its supply chain

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Abstract: *in recent decades, the simultaneous design of a product and its supply chain has become a trend in the manufacturing industry. This approach, requiring massive data sharing, allows different designers to collaborate in order to choose the best product design along with its corresponding supply chain, taking into account cost, quality, and time.*

To get a successful collaboration between designers, we need to model communication flow between product and supply chain designers during all product lifecycle. This model must be simple and easy to adopt by any company structure.

In this paper, we present a multi-agent approach that aims to support communication between product and supply chain designers in a simultaneous design.

Unified modeling language (UML) is used to model this approach.

Keywords—simultaneous design; product design; supply chain design ; multi-agent system ;

I. INTRODUCTION

Several research focuses on the product and supply chain design. Indeed, most previous works have treated supply chain design only after the product design is finalized. Recently, research studies showed that 85% of logistics costs are driven by design choices [1] and over 70% of product cost is determined by decisions during this phase of development [2]. Also, most benefits of collaboration among supply chain partners lie in the design phase of the product lifecycle since the cost of design changes increases as the design phase of the product lifecycle ends and the manufacturing phase starts [3]. Therefore, it is important to integrate product architecture decisions and supply chain decisions during the early stages of the product development. [4].

Thus, a lot of value is given to cooperation and coordination between supply chain partners and product designers. Following these findings, many studies, approaches, tools and methods were conducted.

The majority of works dealing with the simultaneous design are based on analytical modeling approaches

(analytical deterministic models, stochastic analytical models ...) [5]. However, these studies have several limitations: they do not model the interactions between the different actors. Models proposed do not explicit the behavior of actors, particularly their reactive, independent and proactive nature [11]. Indeed, simultaneous design needs multidisciplinary workgroups to communicate and cooperate [12] in order to choose the best product design and supply chain configuration in terms of cost, quality and time. This leads to the emergence of a new kind of need: the creation of systems involving all actors of the designing activity (product designers and supply chain partners) and facilitating communication among product lifecycle.

Multi agent-systems (MAS) have been considered as very promising enablers for providing a computer supported cooperative environment in areas that require coordination, negotiation, and communication among various organization units [13]. That is why the agent approach is an interesting technology to model the complexity of product-supply chain design.

Actually, in all works dealing with concurrent design of product and its supply chain, we could not distinguish a study that adopts the multi-agent approach. In addition to that, the agent approach was either used in the product design only [12] or in the management of the supply chain [16] [17]. From this came the idea of modeling a system based on autonomous and intelligent agents that aim to understand and study the behavior of designing actors promoting collaboration.

In this work, we study the case of product re-design. The modified product needs a reconfiguration of the old supply chain (for example: new supplier, new production site or technologies, contract termination with a former supplier...). We propose a framework of product-supply chain design processes and a multi agent system for communication and negotiation between partners.

This paper is organized as follow: the next section presents a literature review of works that of simultaneous

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design and multi-agent systems. In the section III, we propose a framework of simultaneous design of product and its supply chain. Then, the agent approach adopted to support the collaboration between designers of a product and its supply chain is discussed in a detailed way. Finally, a meta-model is presented with UML explaining the MAS approach that was adopted in our research.

II. LITERATURE REVIEW

Researches that are considering the simultaneous design of the product and its supply chain are very recent. Before that, the priority was given to the product design. Appelqvist et al. (2004) [14] justify this by the fact that the cost of products is usually much higher than the cost of production and logistics. However, logistics costs have undergone significant changes in recent years.

Many researches dealt with simultaneous design of product and its supply chain, use analytic models. Salvador et al. (2004) [6] qualitatively analyze how the supply chain including manufacturing and distribution networks should be configured when different degrees of customization, i.e. high-level or moderate level, are adopted. Huang et al. (2005) [7] explore the integrated optimization of platform products, manufacturing processes and supply chains using Generic Bill of-Material (GBOM) for representing product families and the genetic algorithm for solving the optimization problem, respectively. Also, in recent works [8] Huang et al. apply Nash game theory to optimize platform product family and supplier selection decisions. For El Maraghy and Mahmoudi (2009) [9], they proposed a multi-period model that optimizes simultaneously BOM and supply chain choices. The model proposed for every product several BOM alternatives and one of them is selected in the optimal solution. In addition to that, Baud-Lavigne et al. (2012) [15] proposed an analytical approach using mixed linear programming to optimize the supply chain with product standardization. In this work, Baud Lavigne et al. showed the impact of product standardization on supply chain configuration. Kumar and Chatterjee (2013) [10] also developed a mixed integer linear programming (MILP) models to simultaneously optimize product line decisions and supply chain configuration. Finally, Dong Yang, et al (2015) [5] formulates joint configuration of a product family and its supply chain as a leader-follower Stackelberg game that is enacted through a bi-level hierarchical optimization mechanism to model the coordination between two self-interested decision makers for product family configuration and supply chain configuration, .Dong Yang, et.al formulates A nonlinear, mixed integer programming model for the bi-level joint decision in the leader-follower game.

In the other side, recent years have known an important scientific production focusing on the principles of collaboration via multi-agent systems. These works generally deal with the product design or the supply chain management. For example, Nfaoui (2007) [16] present a generic model allowing a flexible modelling of the supply chain by multi-agent properties. He tested a set of negotiation protocols that were modeled with the AUML (Agent unified modeling language). The used tests show that it is possible, by connecting the agents to the information systems of supply chain actors (APS or ERP, etc.), to bring an important help to the collaborative decision-making. Gamoura and Chehbi (2013) [17] propose an approach based on agents for modeling and simulating a collaborative supply chain, Gamoura proposes a framework of modeling and simulating called "MACSC" that is based on BDI (Belief-desire-intention) agents operating in an AGR organization.

Concerning product design using MAS, Yeh-Chun Juan (2009) [12] propose a process-oriented multi-agent system development approach to support the cooperation-activities of concurrent new product development among workgroups that are working on product design.

These researches have proven the effectiveness of MAS in a collaborative environment.

In the next section, we will present a framework modeling simultaneous design of product and its supply chain. This model will be a basis of our studies.

III. A FRAMEWORK TO MODEL SIMULTANEOUS DESIGN OF PRODUCT AND ITS SUPPLY CHAIN:

The proposed framework for simultaneous design of product and its optimized supply chain is shown in figure 1. This framework uses two conceptual viewpoints: product design and supply chain configuration.

Several design scenarios or alternatives of bill-of-material are generated in the re-design step of product. In fact, the new product design (re-design) can affect either product components or the configuration of the supply chain or both at once. That means we can have problems of allocation or/and location of different partners. We assume that marketing studies about the future demand of product are done (it's not the object of this paper).

Fig.1 describes the structural links between product design and supply chain configuration. These links presents the information flow.

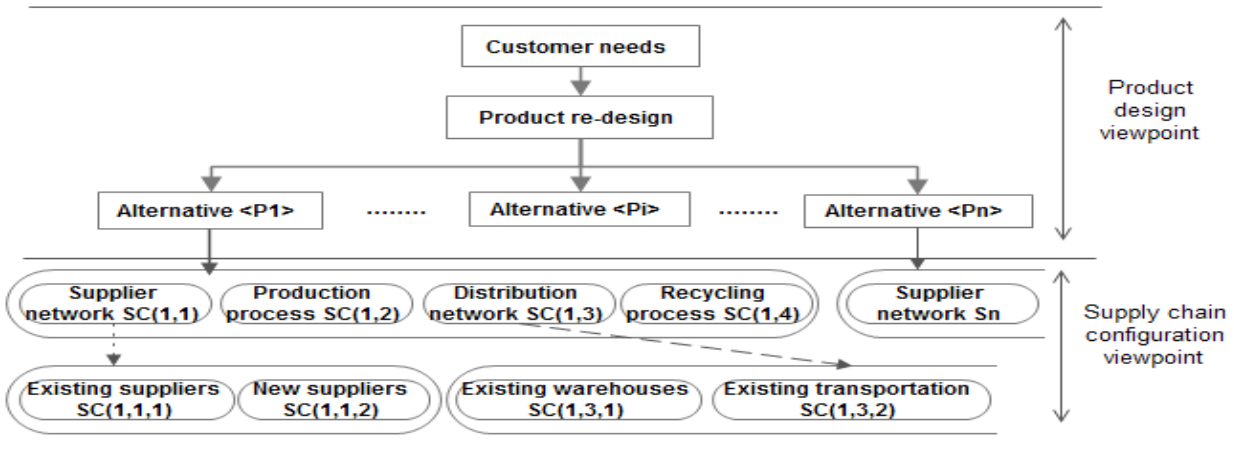


Figure 1: simultaneous design (product-supply chain) framework

The supply chain is designed as a set of levels [18] following the levels of bill of materials of the product, starting from supplier level. The supply chain design consists on choosing each level in relationship with a predecessor level (customer) and a successor level (supplier).

Figure 2 shows an illustrative example of the initial product P and the two redesign alternatives suggested. We suppose that the initial product is composed of components C1, C2, and C3 and raw materials Rm1, Rm2 and Rm3. Components C4, C5, and C6 are new ones.

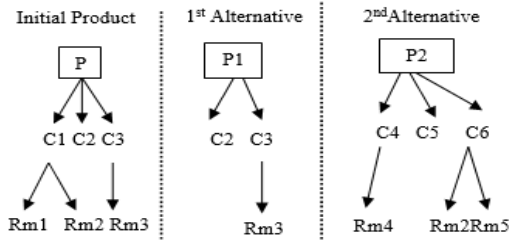


Figure 2: Illustrative example of redesign alternatives bill-of-material

To each product design alternative corresponds a supply chain that ensures the achievement of all operations related to the life cycle of a product. We evaluate the cost of each supply chain alternative (fig.3) so as the best product alternative is chosen according to supply chain costs.

To facilitate the communication between product designers and supply chain partners following this framework, we suggested an agent approach based on levels. The architecture of the proposed model will be detailed in the next section.

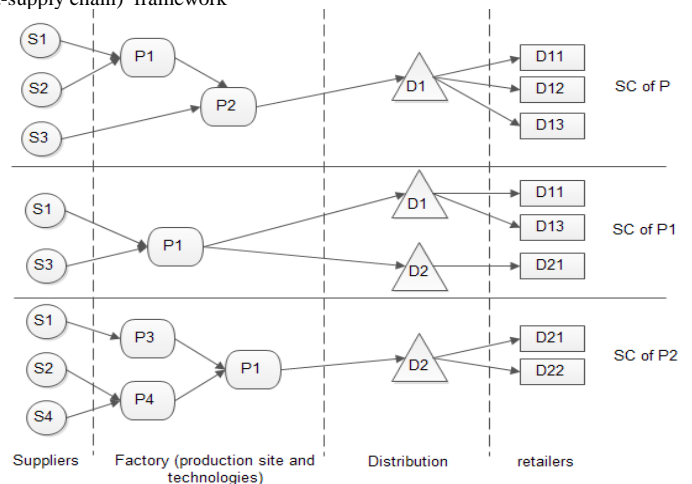


Figure 3: Examples of Supply chain configuration corresponding to different bill-of-material

IV. MODEL BASED ON AGENTS FOR SIMULTANEOUS DESIGN PRODUCT-SUPPLY CHAIN:

As each design project, we need a collaborative system for information exchanging and negotiating to make the best decision.

Based on the framework presented in the previous section, the multi-agent system proposed is divided into two levels: product design level and supply chain configuration level.

A. Conceptual model : a multi-agent system for simultaneous design of product and its supply chain :

According to Ouzizi [18], an architecture based on levels enables the control of consistency at each level. It ensures horizontal coordination (between agents of the same level) and vertical coordination (between agents of different levels).

The system contains two different multi agent systems that communicate and negotiate design choices (fig.4).

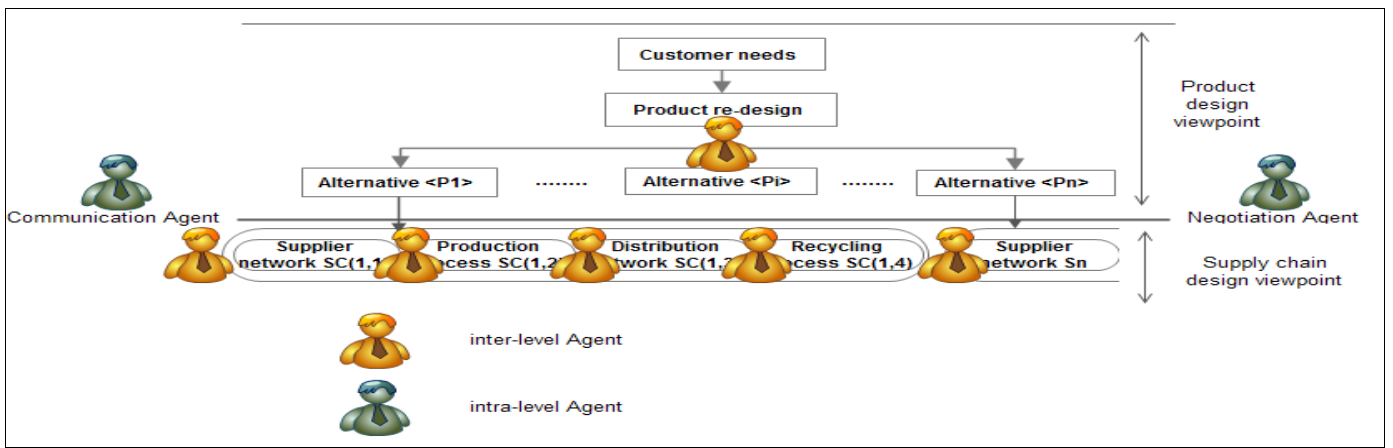


Figure 4: Multi agent system for simultaneous design

Communication between levels is done as follows:

- Communication in a horizontal structure: between agents that are at the same level. There is no supervisor, or client server. This is the case of collaborative work in which each agent performs a task to complete one job.

- Communication in a vertical structure: the agents are structured by levels, and locally, a horizontal communication can be found at the same level.

In the proposed framework, communication is done by two main agents: “Communication agent” and “Negotiation agent”.

In addition to communication agents, the framework contains Design agents with decision making tools that are supporting designers in design activities.

In the next section, we will present and model multi-agent systems according to each level (product design and supply chain configuration)

B. Modeling the multi-agent system for product design:

Many alternatives of the initial product P are proposed P (i). The product design agent is a software agent that assist human designers in product design activities. It integrates CAD (Computer Aided Design) systems. This agent is used by the designer to perform key design tasks through cooperation with other software agents.

The product agent design ensures Constraints satisfaction. These constraints are:

- Product design constraints: among product elements (i.e. features, parts, or sub-assemblies) in different forms, such as equation, rule...etc., corresponding to the design requirements.

- Supply chain constraints: in fact, in a simultaneous design both product design and supply chain constraints must be involved, so supply chain constraints must be respected by product designers.

All these constraints are defined before starting product design.

The role of this agent is presented using UML class diagram. It illustrates the links between different parts of design activity and the product design agent.

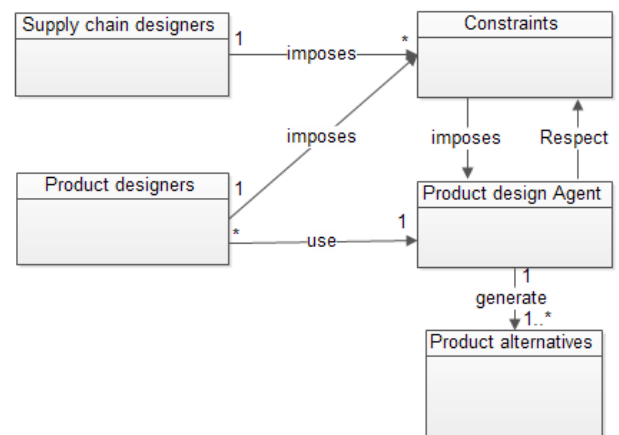


Figure 5: class diagram of product design process

C. Modeling the multi agent system of supply chain configuration:

Supply chain configuration contains several levels, these levels are hierarchically configured according to the bill of materials of product alternatives. When receiving a product alternative, the supply chain configuration starts from suppliers’ selection, then comes the production process design, distribution configuration, and finally recycling process and centers are selected.

To each supply chain level, we associate an agent that is fitted out of a decision support tool according to each design activity, selected designs must have the lowest cost and respond to product constraint.

The different agents that constitutes the multi agent system of supply chain configuration are:

- Supplying agent: this agent is responsible of supplier’s selection. The supplier network may contain a set of

existing suppliers S (1,1,1) or a set of new suppliers S (1,1,2). Actually, after receiving the product alternative P(i) from product design, supplying agent select from the set S(1,1,1) the appropriate suppliers that can provide the raw materials necessary for P(i) assembly and that are respecting both product design constraints and supply chain design constraints. In case there is a lack of raw materials (no existing suppliers or suppliers cannot provide the required quantity), supplying agent sends a tender to new suppliers S(1,1,2). New suppliers propose different offers, and then the supplying agent select the best offer that respond to design constraints.

Fig.6 present a class diagram model of supplying agent activities and its relation with other design elements.

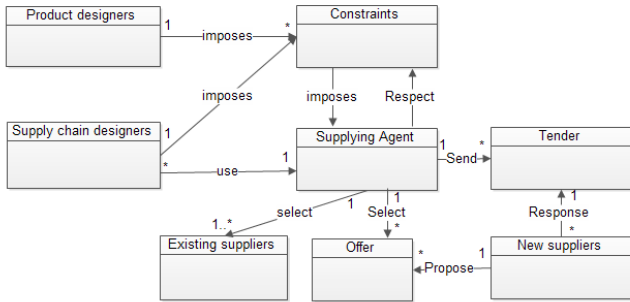


Figure 6: class diagram of supplier's selection process

-Production agent: After suppliers' selection, production configuration must be done according to product bill-of-material and assembly modules. At this stage, different choices must be made, different constraints are imposed: product demand, delay constraints, existing centers' capacities, type of existing technologies, technologies' capacity, labors' capacities...etc. According to this constraints, production agent select existing production centers or existing technologies that has the capacity to deal with product demand or delay constraints. In case product demand is high and/or delay is short, production agent can select the implementation of new technologies, and/or new centers or asking for subcontractors.

Figure.7 is a class diagram modeling production agent activities.

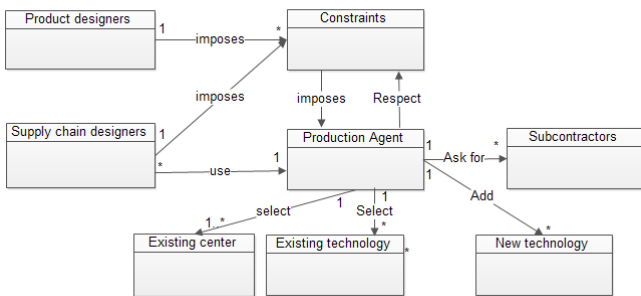


Figure 7: class diagram of production choices

-Distribution agent: After selecting production elements, many constraints are added to design constraints. The distribution agent is responsible of selecting warehouses and

transport according to product characteristics like product package model. Actually, constraints changes and design tasks that are made by the previous agents can affect the distribution network or transport. On the one hand, if capacity of existing warehouse is low, new warehouses must be implemented, and more transport must be added. On the other hand, product package constraints can affect transports' choice.

Fig.8 is a class diagram that present different links that distribution agent is making:

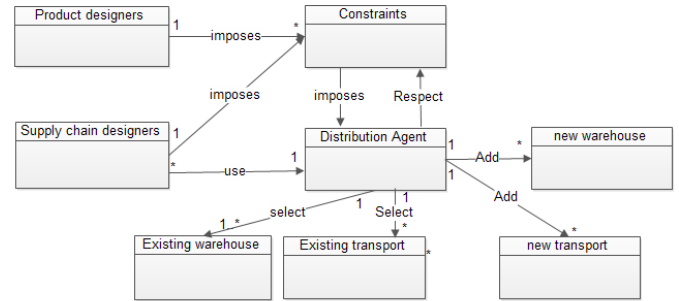


Figure 8: class diagram of distribution choices

-Recycling agent: Constraints added by the other agents can affect the recycling means, or centers' network. In fact, the type of raw materials and assembly means are important constraints that should be taken by recycling agent. Fig.9 present class diagram that model different tasks made by recycling agent.

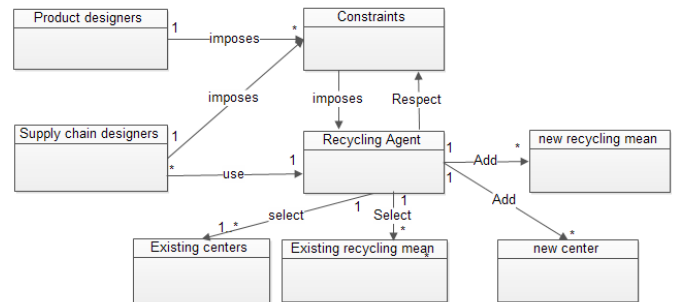


Figure 9: class diagram of recycling choices

In the end of supply chain configuration, alternative and supply chain cost are send to the product designer who decide to validate the proposed configuration or making another product alternative.

In the next part, we present how this two levels can communicate and manage their negotiations.

D. Modeling communication between product and supply chain designers:

To make a link between product and supply chain designers, we need to model agents that facilitate communication, and data transfer. These agent can make horizontal communication (between agents of the same level) or vertical communication (between product designers and supply chain designers). These agents are: communication agent and negotiation agent.

- *Communication agent:*

This agent is responsible of communicating information, documents, costs and alternatives related to the design. It works primarily with a communication protocol (fig.10). This protocol can achieve two mainly main-method:

- *SendProposal()*: to send proposals of designers.
- *AcceptPropose()*: to confirm acceptance of the proposal.

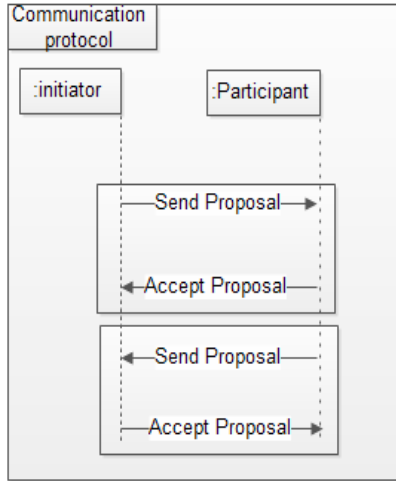


Figure 10: Communication protocol

- *Negotiation agent:*

The negotiation is the mechanism by which the agents can establish a common agreement. In case of intelligent agents and MAS (multi-agent system), the negotiation is considered as a basic component of interaction because the agents are autonomous [19]. Negotiation agent is defined as follow:

In designing steps, many constraints are generated from different design agents. If a constraint is not respected by a design agent, negotiation agent intermediate and then the design agent responsible of constraint violation has two choices:

- Modify his design as to respect constraints imposed by other designers

- Negotiate with design agent that imposed the violated constraint to change it. In fact, when there is a constraint violation associated to the parts designed by different designers, the constraint violation message should be delivered to the designers who might be affected by the proposed changes.

This agent can achieve these main methods:

- SendProposal()* : design agent send the proposed design to the design agent that imposed the violated constraint.

- Accept_proposal()*: permits to end the conversation between the two members if they agree on changes. If a member is still not satisfied with the changes he can:

- RefuseProposal()*: we choose a maximum number of iterations n (number of modifications). If the number of iterations is exceeded, the Product design agent will be involved as a mediator and decide about changes that must be done (Fig 11).

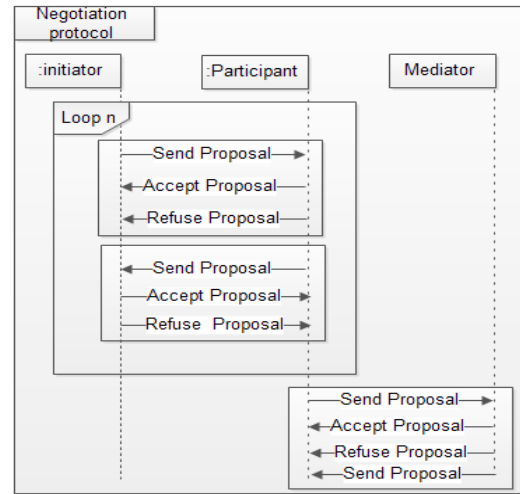


Figure 11: Negotiation protocol

E. *Class diagram of the general multi-agent system model:*

In the following class diagram we regroup all agents presented in previous parts, this model show the links between all agents.

In this model, Product designers and supply chain designers makes different design alternatives using “Design agents”, and generate supply chain “costs”. At the end of every design step, “constraints” are added by “designers” and must be respected by design agents. Design agents can communicate with each other and send different proposals via communication agent. If a constraint conflict is triggered, negotiation agent intermediate to make negotiation between the design agent and other agents concerned by constraint violation. (fig.12)

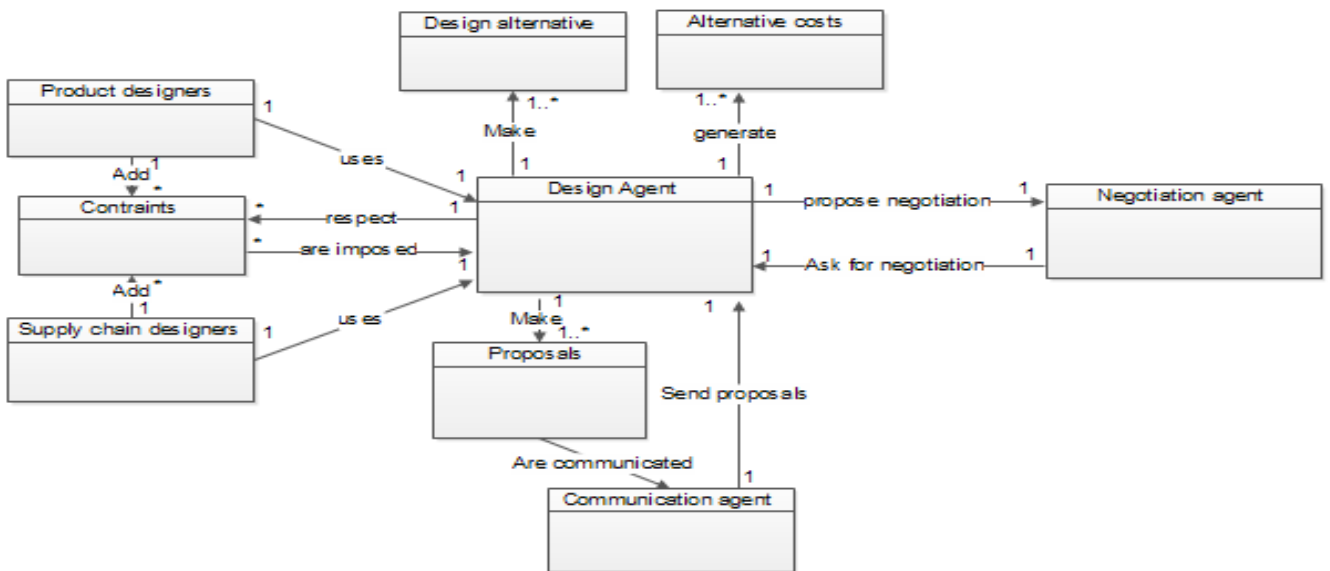


Figure 12: general class diagram of multi-agent system for simultaneous design of product and its supply chain

V. CONCLUSION:

In this paper, we present a model of multi agent system that ensure the simultaneous design of product and its supply chain. This model present a general view of proposed system and interactions between different designers.

The presented model will be a basis for our next works that will deal with decision making tools in order to give to the design agents the capacity to make decisions and choose the best product alternative according to its supply chain costs.

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