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MAKING PRODUCTS ACTIVE WITH INTELLIGENT AGENTS FOR SUPPORTING PRODUCT LIFECYCLE MANAGEMENT

Martin G. Marchetta

PhD in Engineering
CEAL, Logistics Studies and Applications Centre, School of Engineering, National University of Cuyo, Centro Universitario, CC405 (M5500AAT) Mendoza, Argentina
mmarchetta@fing.uncu.edu.ar

Frédérique Mayer

PhD in Automatic Control
ERPI – Equipe de Recherche sur les Processus Innovatifs, ENSGSI, Institut National Polytechnique de Lorraine, 8 rue Bastien Lepage, BP 90647 (54010) Nancy Cedex, France
frederique.mayer@ensgsi.inpl-nancy.fr

Raymundo Forradellas

PhD in Artificial Intelligence
CEAL, Logistics Studies and Applications Centre, School of Engineering, National University of Cuyo, Centro Universitario, CC405 (M5500AAT) Mendoza, Argentina
kike@uncu.edu.ar

ABSTRACT: Modern organization paradigms within manufacturing enterprises have arose in last years, like Agile Manufacturing and collaboration, in order for enterprises to increase their productivity and be more competitive in front of shorter due dates and increasing product qualities required by customers. Most previous works on PLM and currently available systems are usually focused on the use of additional information to support business processes, and integrate limited information of lower-level applications (CAD, CAPP, etc). However, little emphasis has been put on making products more intelligent during their complete lifecycle, in order to exploit PLM information for improving their development and management. In this paper, a framework based on intelligent agents is proposed, for giving products active behaviors, in order to assist people involved in PLM to reduce lead times and costs, and improving product quality. Application of the proposed framework to a product definition example is presented as a case study.
Keywords: PLM, Active Product, Intelligent Agent, Virtual Enterprise, Concurrent Engineering.

1 INTRODUCTION

Current international context has forced enterprises to optimize their operations and to collaborate, in order to be competitive. This has yielded the need of reducing lead times and costs, and increasing final product quality. In order to achieve these objectives, collaboration (NOF, 2007) among peer enterprises has been more and more accepted, creating the so called virtual enterprises (MING et al., 2008; CROXTON, 2001).

Product Lifecycle Management (PLM) is considered a key concept in order to maintain consistency, efficiency and quality as products are created, from conception to disposal (SAAKSVUORI; IMMONEN, 2005). PLM involves the management of product information and the integration of business processes from birth to obsolescence of a product (SHARMA, 2005), and it is crucial for effective management of corporate intellectual capital (AMANN, 2002).

Until some years ago, integration and collaboration was implemented mostly along the supply chain. However, currently this integration has been extended including not only supplier and customers as partners, but also peer enterprises, as shown in Figure 1. These partner enterprises share much information concurrently, so PLM now turns to be a fundamental support to maintain consistency and to capitalize concurrent engineering and collaboration benefits in these scenarios.

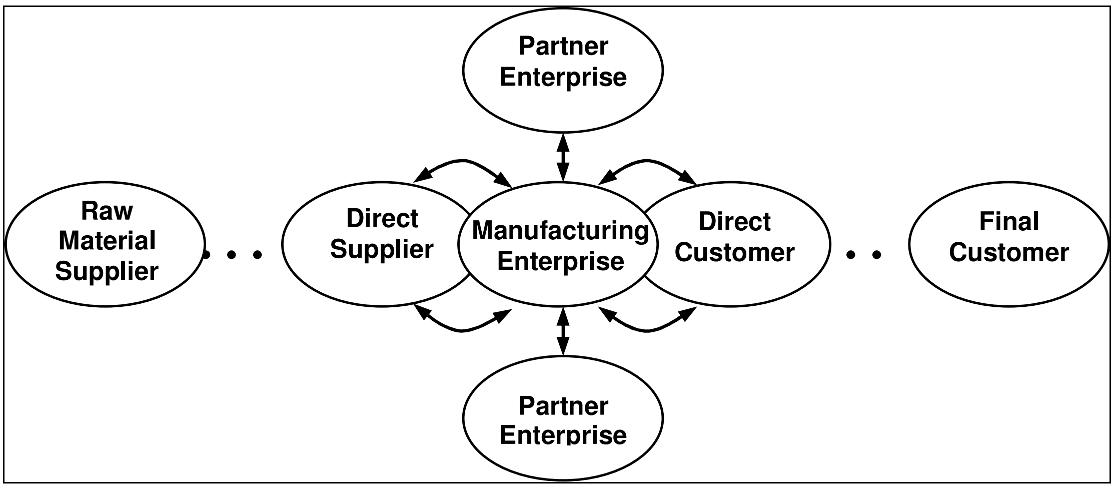

Figure 1 – Virtual enterprise and supply chain integration of current manufacturing enterprises
Source: Authors

Current mixed partner-partner (BHANDARKAR; NAGI, 2000) and customer-supplier relationships (CROXTON *et al.,* 2001) create special issues not present before. Because business processes now cross enterprises' physical barriers, products information must be shared across heterogeneous systems (with different data formats and semantics), and coordination of activities needs to consider people, information with different ownership, policies and cultures.

Previous works have focused on several aspects of PLM. However, only recently the need of putting more intelligence on products, for making them “active” (MOREL, 2007) during their own development and management process has been recognized, and some efforts have started to be done. Currently, the evolution of information technologies allows giving active behaviors to (both materialized and under development) products, which can help companies to handle complexity, reducing inconsistencies and optimizing product’s definition and manufacturing activities.

In this paper, a framework for making products actively involved in their own development and management within PLM is proposed, which puts emphasis on an applications architecture based on intelligent agents. The framework is aimed at defining the relevant entities, interaction types and information sources for proactive support to PLM, and explores suitable techniques and technologies to implement it.

2 PREVIOUS WORKS ON INFORMATION EXPLOITATION WITHIN PLM

PLM has evolved in recent years along different research directions, focused on the creation, storage and use of product information. Among these aspects, the most relevant one from the point of view of this work is the product information exploitation along its lifecycle. This aspect raises some issues, such as interoperability due to different information formats and semantics, and the difficult to guarantee completeness and consistency (SAAKSVUORI; IMMONEN, 2005).

Some works propose limited support and coordination mechanisms both within a single activity and between activities and partner enterprises. Assistance on specific activities [e.g. CAPP (TONG; LI; YUAN, 2008)] within a single company has been proposed. Support for collaboration between customers, suppliers and partner enterprises focused on specific activities has also been proposed (MING et al., 2008).

Another application for information exploitation is related to change propagation. Consistency maintenance of both product information (MA; CHEN; THIMM, 2008) when changes are made through product development) and design documents (SHIAU; WEE, 2008) have been addressed.

Researches related to intelligent products have also been developed, on which the idea is connecting the physical products with their counterparts within information systems, based on intelligent agents, holons, RFID and other technologies (MEYER; FRÄMLING;

HOLMSTRÖM, 2009; VALCKENAERS , 2009; YANG; MOORE; CHONG, 2009). The use of different kinds of agent technologies (holonic approaches, multi-agent systems, etc) (MARIK; LAZANSKY, 2007), composition of services through semantic interoperability (CONTRERAS; SHEREMETOV, 2008) and multi-agent systems for planning and coordination (FORGETA; D'AMOURSA; FRAYRET, 2008) are examples of recent efforts for putting more automated support to PLM.

The kind of applications taking advantage of PLM information is restricted to a few activities and to specific problems. Putting intelligence on products is starting to be explored, but there is no general framework defining the overall structure of interactions, involved entities and information sources for exploiting information within PLM without specifying a specific aspect or activity to be supported.

3 BUSINESS PROCESS MODEL FOR PLM AND SCM

In previous works, the product role within PLM has been to be an information hub, concentrating all data required by different activities along the PLM. This limited view allows people from companies to get answers to questions regarding product information, but only people take the initiative for exploiting this information. PLM business processes have also been studied, but there has been a separation between these two dimensions (PLM business processes and information to support them), what reduces the benefits obtained from the implementation of PLM.

Current technologies allow putting active behaviors inside information systems, what turns them into an active actor during PLM activities. This gives the possibility of having additional benefits as product information is generated and stored, like identifying optimization opportunities or detecting potential risks, rather than only passively answer questions when people need it.

Several processes must be carried out by an industrial enterprise having relationships both along the supply chain (with suppliers and customers), and with partners during product development and/or production. Considering this scenario, Figure 2 depicts a logistics and production oriented business process model.

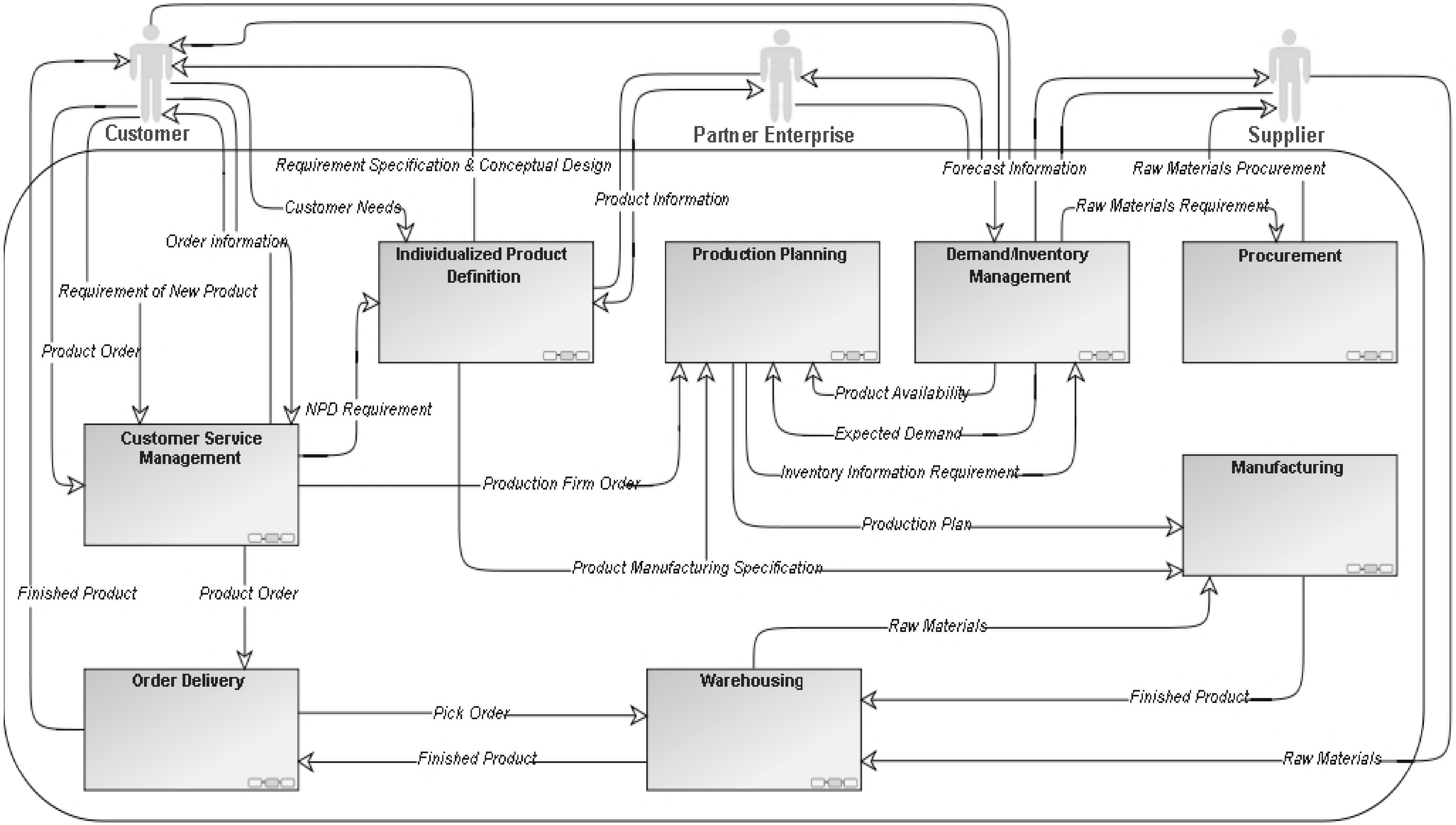

Figure 1 – Overview of Business Process Model for joint PLM and SCM
Source: Authors

The model is based on two different (and somehow complementary) views of business processes in logistics (CROXTON et al., 2001; FRAZELLE, 2002). Processes of a product development and manufacturing company are shown inside the rectangle. The supplier, the customer and the partner enterprises are external actors. Partners are enterprises which design other product's components, or that manufacture products designed by the company.

Two types of customer orders may be received by the enterprise: new product development orders and orders for existing products. In addition to this, at any moment the customer may ask for information about its order's state and/or the state of the development process of the new product. All these information flows are handled by the Customer Service Management process.

The Order Delivery process takes care of coordinating all activities to put products in the location accorded with the customer. The Warehousing process includes all warehouse management activities, such as picking, put away, storage, etc.

Individualized Product Definition process groups all new product development (NPD) activities, including turning customer needs into requirement specifications, designing the product, creating manufacturing specifications, etc. This process is at the core of our model, since it handles consistency and coordination both inside the company (with other business processes) and with the environment (partners, suppliers and customers).

In this work, the system for supporting coordination and consistency maintenance within this process is modeled as an active one since it uses all the available information to proactively help managing the complete product's lifecycle.

The Production Planning process aims at accommodating demand to manufacturing resources considering firm orders, forecasts and manufacturing process plans indicating routings, bills of materials, time and other resources. Demand/Inventory Management forecasts demand in order to support procurement and production planning. Procurement is concerned with handling of buying orders. Finally, the Manufacturing process is in charge of products creation using manufacturing resources. It mainly uses product specifications from Individualized Product Definition and the amount of units to be produced, when they should be produced and with which resources from Production Planning.

Integration with partner enterprises is mostly carried out by means of the Individualized Product Definition process, yielding a great number of interactions of all types, including interactions along the supply chain, interactions with partner enterprises, and also within several activities inside the process itself.

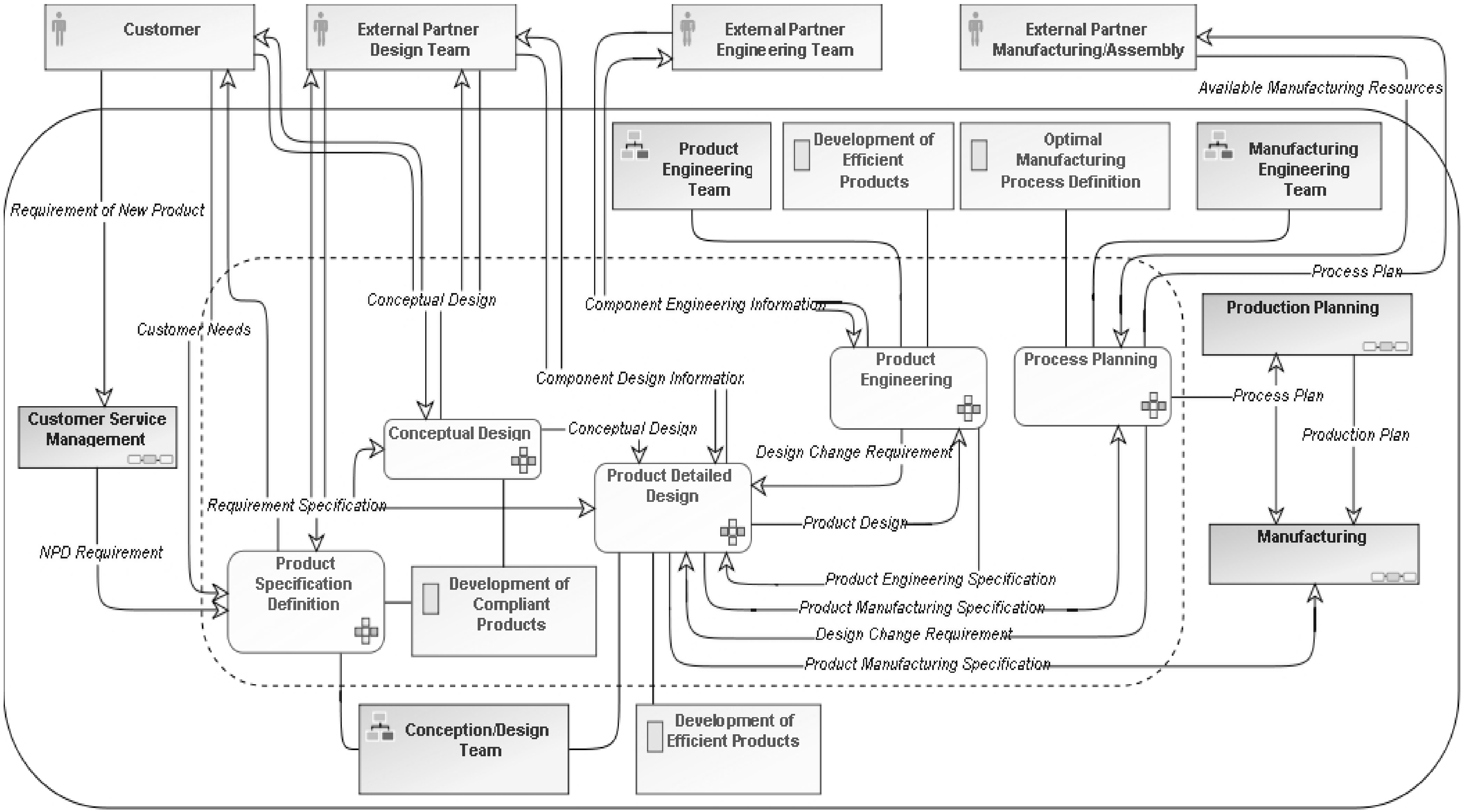

Figure 2 – Individualized Product Definition's functional diagram
Source: Authors

Figure 3 presents the Individualized Product Definition functional diagram. The process is composed of 5 main activities: Product Specification Definition, Conceptual Design, Product Detailed Design, Product Engineering and Process Planning. In a concurrent engineering environment, these activities are carried out in an overlapped way, rather than sequentially. Thus, there is a complex (and usually asynchronous) information exchange among them.

3.1 Hierarchy of product-automated support along product lifecycle

Integrated PLM within a concurrent engineering/virtual enterprise paradigm involves interactions among several types of entities and at different abstraction levels, such as inter-activity interactions within a single company (MA et al, 2008) and inter-company vs. intra-company scenarios (SHIAU; WEE, 2008). Since each interaction type entails different issues (e.g. information ownership, concurrency, etc), and also presents different potential opportunities for realizing active-product's benefits, a structured categorization of these interactions is needed.

Both the "business processes" and the "virtual enterprise" dimensions are considered here for the proposed classification. Another aspect to be considered is that the product development process, as defined in this article, includes several internal activities, and also has relations with other business processes within a single organization. Additionally, individual activities themselves present opportunities for improving the development process by means of an active product approach. As a result, a 4-level interactions hierarchy, depicted in Figure 4, is proposed here as follows:

1. Inter-process/multiple company interactions: it is represented in the figure by thick continuous arrows. It involves information exchanges between processes in different companies within the virtual enterprise. Information ownership must be taken into account, since interactions cross a single enterprise barriers.
2. Inter-process/single company interactions: this case is depicted by gray arrows in the figure. It is related to interactions among business processes within a single company.
3. Inter-activity interactions: inside a single business process, there exists the need of coordinating activities which contribute to its value chain. This is especially true when activities whose results impact on the other ones are executed concurrently. This interaction type is shown in the figure with dotted arrows, and activities are represented by ellipses.

4. Intra-activity interactions: Within a single activity the number of people involved may be very small, and so the information exchanged, so the most important thing an active product may contribute with is exploitation of information in order to optimize results of that activity.

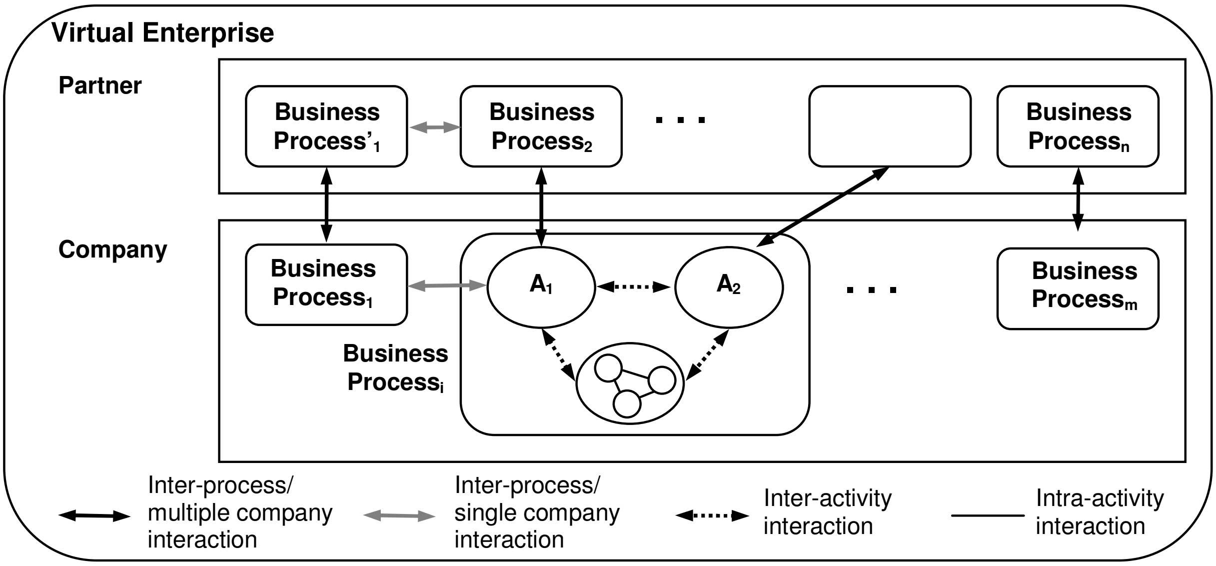

Figure 4 – Hierarchy of active-product's interventions along its lifecycle
Source: Authors

These interactions are points for potential contribution of automated support by an active product. An active product is similar to an expert advisor who actively integrates all the information across the product's lifecycle, resulting in a PLM system of PLM inter and intra systems, from business to manufacturing and across all the partners, as a whole (MAIER, 1998). For inter-process situations (types 1 and 2), most important benefits include change impact analysis, propagation/notification of changes to (and only to) relevant people, global optimization, risk assessment, feedback on project evolution, etc.

Considering inter-activity interactions (type 3), similar benefits can be obtained, but restricted to activities within a single business process. Finally, inside a single activity (type 4), local multi-objective optimization can be supported by the product, as well as other aids such as know-how acquisition through machine learning (MARCHETTA; FORRADELLAS, 2006a, MARCHETTA; FORRADELLAS, 2006b), plan recognition for identifying user's intentions, retrieval of patterns used in the past in a mixed-initiative approach (ALLEN; GUINN; HORVTZ, 1999), automated task completion (MARCHETTA; FORRADELLAS, 2007), etc.

3.2 Applications architecture

Software applications that support product development have emerged independently from the need for automated support of individual activities (CAD, CAM, scheduling, CRM, etc), which has generated issues related to interoperability, data formats, lack of coordination and collaboration support, etc. Figure 5 shows a typical applications architecture used within product development companies within virtual enterprises.

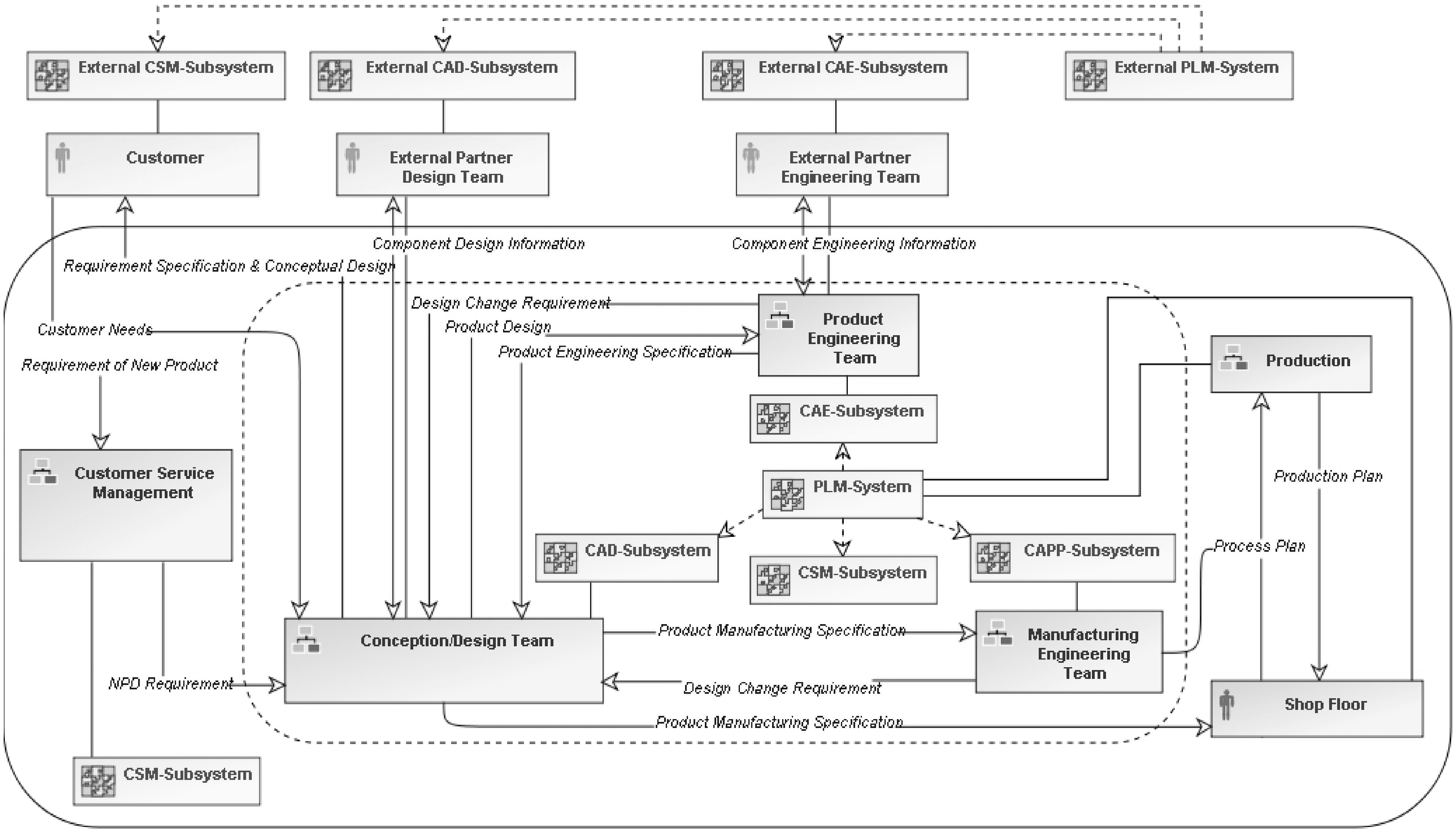

Figure 3 – IT applications architecture typically used within virtual enterprises for product development
Source: Research

Because of the great diversity in the nature of activities covered along the PLM, it is difficult to create a single software application for supporting all of them. Besides, many companies have made great investments in solutions to individual problems. Moreover, within virtual enterprises it is likely that different software solutions be used to solve the same problems (e.g. different CAD/CAPP/CAM systems). Because of these reasons, interoperability between existing applications has turned to be a recurrent issue.

Usually PLM systems provide interoperability by being an information backbone (DENKENA et al., 2007). Standards are very important for achieving interoperability (RACHURI et al., 2008), and those related to information exchange (e.g. ISO 10303), have supported this trend.

The problem with this approach is that much information must be converted to other formats in order to pass it from one system to another, which usually produces some semantic information loss. Besides, these information exchanges are usually made by means of manual coordination mechanisms, and through external support applications such as e-mail. Product information should be handled within the systems as much as possible, avoiding conversions and re-conversions, and non-structured communication mechanisms.

Especially because of the common current "pull strategy" of product information exploitation, many optimization opportunities as well as early detection of global problems can be missed. These improvement opportunities may be related to any of the interaction levels mentioned in section 3.1. For example, by enriching product information with the rationale for its design, its manufacturing plan, etc. automated reasoning and optimization techniques may be used in order to improve its quality and profitability. Techniques like artificial intelligence planning and constraint satisfaction may be used to produce alternative solutions to design, manufacturing planning or production scheduling problems, and other techniques like simulated annealing, may be used for optimizing solutions. Patterns across different product development activities may be captured through machine learning (e.g. through learning of decision trees, association rules, etc) and be later used.

Figure 6 depicts the proposed global IT architecture. For simplicity, only entities relevant to the individualized product definition process are included in the figure. The architecture aims at providing a structured integration infrastructure to: (1) Support development of applications with proactive behaviors; (2) Support enhanced interoperability among heterogeneous systems (different applications, from different vendors, owned by different organizations, etc); (3) Reduce information exchanged in non-structured formats.

Reduce information re-work, by including rationale and semantics behind product development decisions within the PLM system.

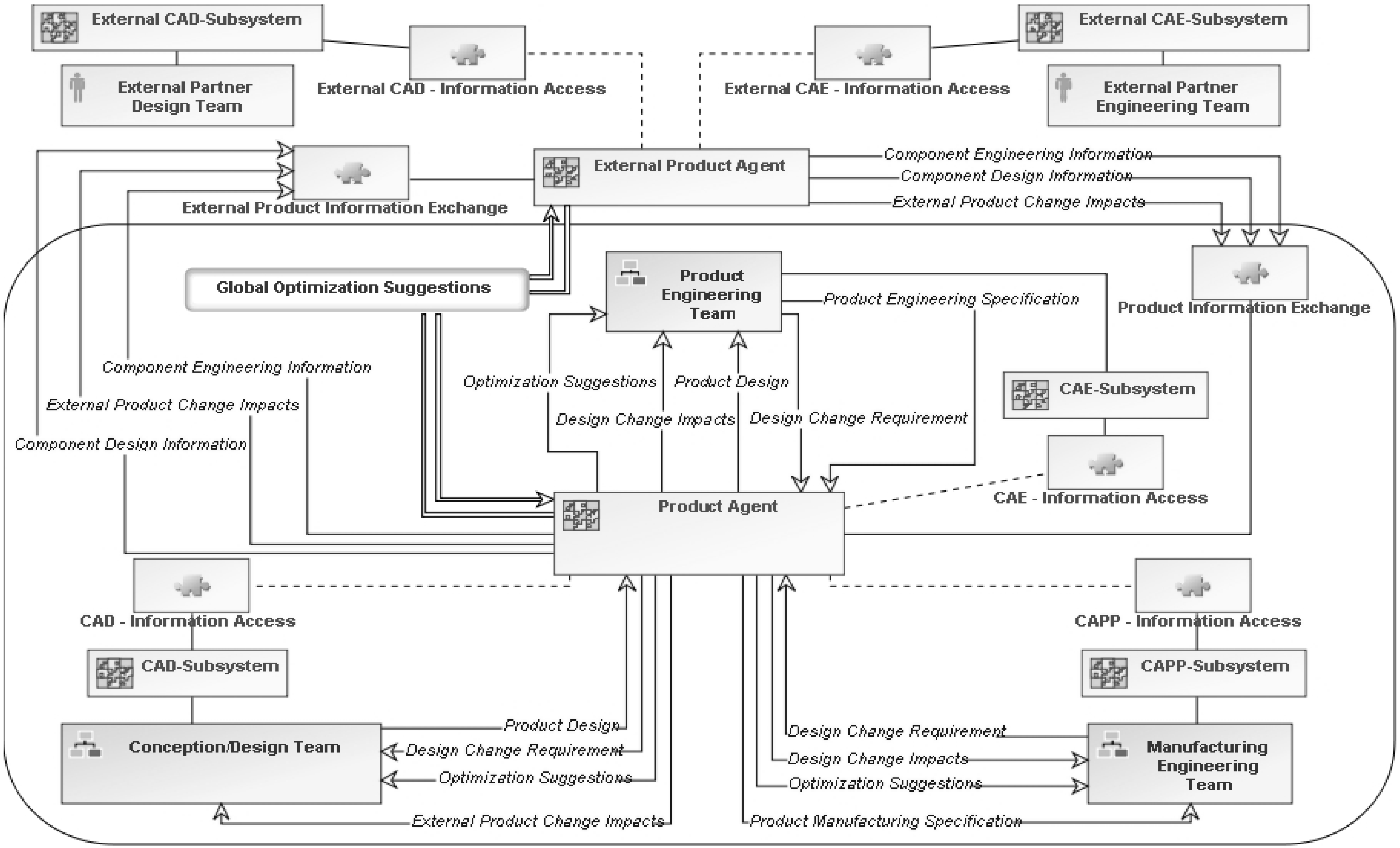

Figure 4 – Proposed IT applications architecture for supporting active-products
Source: Research

This architecture can be accommodated to be independent of the particular software solution or application vendor. In order to realize the proposed objectives, as much semantic information as possible must be put into the system. This will allow not only pointing to product design and manufacturing specification files, but also to automatically reason on them, make improvement suggestions, identify impact of distributed changes made along different activities, and support other kinds of improvements such as global optimization.

It is common nowadays to have interfaces to access information stored within systems through web services and Service Oriented Architectures (SOA) standards. This allows reusing knowledge already available in current applications, such as CAD, CAPP, CAM, ERP, etc, and gives the architecture the capability of taking advantage of information distributed across different locations. As depicted in Figure 6, coordination, collaboration and information exchanges are possible between organizations through interfaces exposed as services.

Since there is no system able to support all relevant product information, global optimization can be achieved by means of collaborative optimization techniques. In the proposed framework, the main idea is to consider the product at the core of its lifecycle management, not only as a reactive entity, but also as a proactive one capable of identifying opportunities to be exploited and to suggest how to do that.

In figure 6, an entity called Product Agent is at the center of the architecture, and plays the role of an active product. Product Agent is an Intelligent Agent (RUSSEL; NORVIG, 2002; Wooldridge; Jennings, 2002), whose environment is composed of both reactive (e.g. other applications) and proactive entities (e.g. human users, teams or other artificial agents) involved in PLM activities and processes. The Product Agent acts as an automated expert connected to all the applications supporting PLM activities, which is capable of identifying events that take place on the environment and to act as a consequence. It has also the ability to communicate with other agents when not enough information is available to make (or suggest) decisions, such as when information from different partners must be put together. This also allows managing information property issues, since there is no single agent having all the information but a set of agents, each one having access to a part of it, which communicate with each other to exchange data.

Thus, the system moves from isolated automation islands towards a PLM integrated system whose organization can be compared to the notion of system of systems (MAIER, 1998). This concept is related to adaptable distributed systems which interact with each other, resulting in productivity and functionality that are greater than that provided by the sum of individual systems. In the proposed framework, the notion of system of systems is considered as a potential artifact (MAYER; AUZELLE, 2007) in order to design a PLM system having active behaviors, supported by the underlying systems, data bases, information models and processes.

Several issues must be solved in order to achieve the enhanced capabilities mentioned above. First, this new system must be able to automatically exploit information created and processed by people scattered across the virtual enterprise. Second, the system must be capable of communicating with other similar systems, which may represent other's interests and intentions. Third, it must also be able to access information from both autonomous and non-autonomous systems, such as CAD and CAPP systems. And finally, it should do all of this autonomously and dynamically, which means that it must detect special situations and act accordingly without having continuous and direct human intervention. Combined to our proposed modeling framework, intelligent agents are a suitable technology for supporting this.

3.3 Proactivity and intelligent agents

The implementation of a PLM framework, like the one described in previous sections, requires technology having some properties that give it the ability to provide enhanced PLM information exploitation. The active-product exchanges information both in response to user demands (regular queries like current development stage, estimated release dates, optimization recommendations etc.), and proactively without human intervention (e.g. proposing optimizations, etc).

In order to proactively assist teams and organizations in PLM, a product needs to have the ability to detect relevant events and to make decisions automatically. Wooldridge and Jennings (WOOLDRIDGE, 1995) discussed several definitions of intelligent agents including a "weak" one in term of 4 properties an intelligent agent should have: autonomy, social ability, reactivity and proactivity.

Autonomy is related to the level to which the agent can act by itself without human intervention. Since one of the most complex tasks within concurrent engineering in large projects is to detect relevant events (such as collateral effects of changes or optimization opportunities) and to coordinate activities, an intelligent product agent should be as autonomous as possible.

Social ability allows an agent to communicate with other agents and also with humans. This is useful for improving interoperability since partner enterprises do not need to use the same applications or data formats, as long as the agents speak the same language (both semantically and syntactically).

Reactivity means that agents should receive requirements from human users, and respond to them. On the other hand, proactivity is related to goal-directed behaviors, which means that the product agent may take the initiative when it has detected events in the environment.

As an example of the role of these properties during PLM, consider the case of two partner enterprises that develop 2 components of the same product which are related through assembly interfaces. One of these components is being subject to product engineering, and a structural problem is found during this activity. Therefore, the engineering team suggests a design modification of the component. This design suggestion is a relevant event that must be detected by the product agent, since it requires change propagation and coordination of activities. Thus, when this design change is suggested, the product agent can search its knowledge base for finding alternative design patterns associated with the corresponding product requirement, and suggests them to the design team. When the design team makes a decision (which is another relevant event), changes made on the component are analyzed by the product agent and the required changes are propagated to the involved people, both inside the organization (engineering and manufacturing planning teams), and in partner organizations.

4 CASE STUDY

In order to illustrate how the product-agent acts within the proposed framework, some situations within a simple case study are commented here, on which potential techniques for implementing automated assistance are explored. Figure 7 shows a flowchart diagram of activities required for a product development project, starting with the detailed design (for simplicity previous activities are not shown in the diagram). In the figure, development teams within an organization interact with partner organizations and also with the product agent.

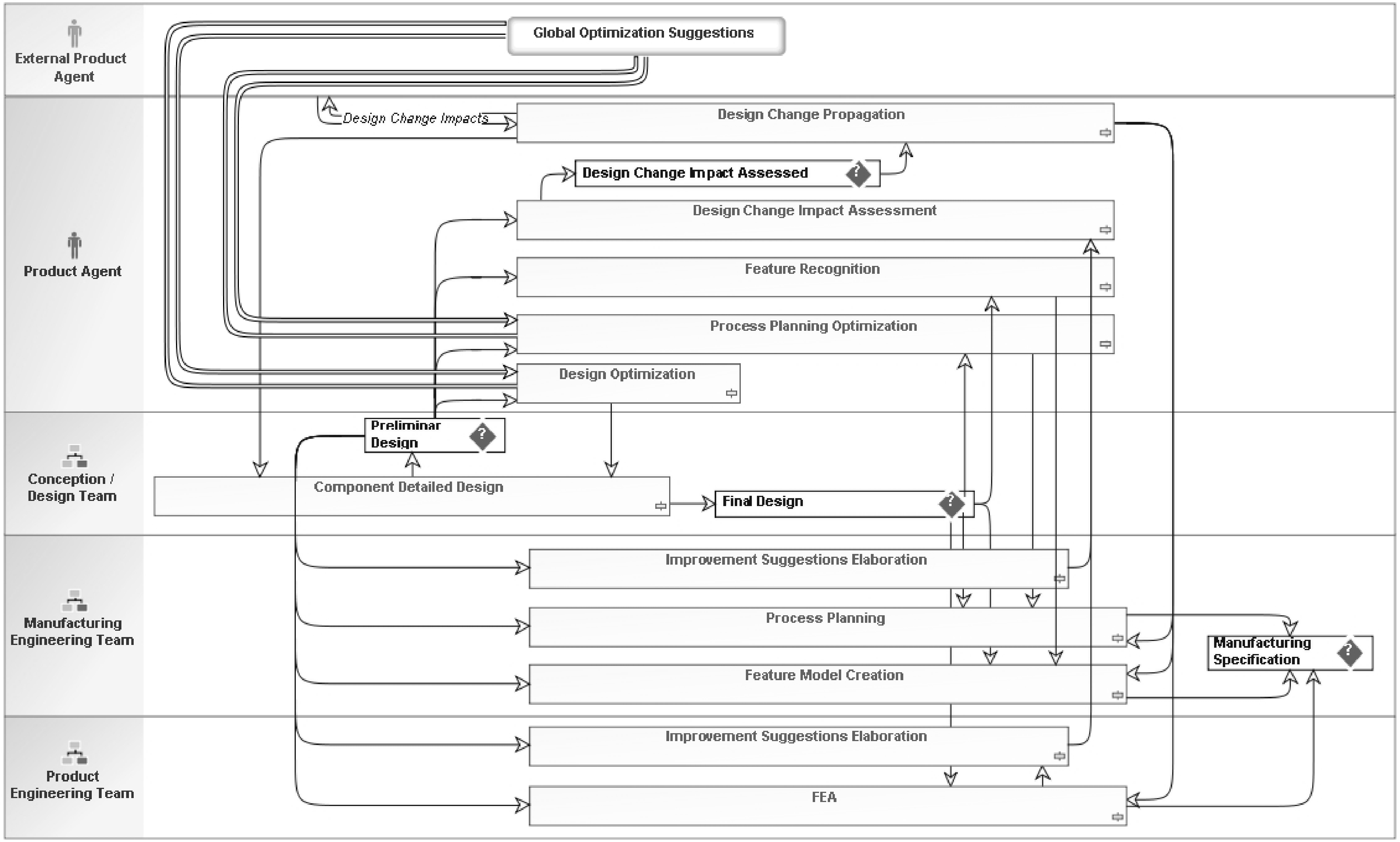

Figure 5 – Flowchart diagram for the Individualized Product Definition supported by Product Agent
Source: Research

After a product requirement specification is available, the first stage involves the creation of a preliminary design. As soon as a preliminary design is created, most of other activities can be started. Product engineering and manufacturing engineering team's activities can be performed in parallel. Changes in product's design or manufacturing specifications are relevant events that trigger the product's agent analysis mechanisms. From these analyses, assistances like automated change notification and propagation to the affected people are carried out. These changes may be directly introduced by users, or these users may accept improvement suggestions proposed by the product agent. Moreover, changes may be produced in processes within a single company, or in teams of a partner. A suitable Product Information Model (PIM) is necessary in order to determine which people and information elements are affected by some change. Product features (design features, manufacturing features, etc) are a useful tool to relate different product views (e.g. which design features respond to product's requirement, which manufacturing features are related to a design feature and which product's geometric elements are involved). This helps to determine the impact that decisions made in some activity have on other activities. Knowledge based techniques (e.g. expert systems, constraint satisfaction, etc.) may help to determine change impacts and support coordination.

Global optimization may involve improvements on several aspects of a product, such as design or manufacturing plan. Global product optimization involves collaborative optimization or information sharing, since it requires the consideration of product data from several processes and partners. The more information on resources, patterns and good practices is available, the better optimizations may be synthesized and suggested by the agent.

For example, if the design rationale has been formalized and stored in the PIM, automated reasoning (through ai-planning, expert systems, constraint satisfaction, etc) may be used to suggest alternative design patterns fulfilling the same product's requirements. These patterns may be hand-coded within the knowledge base, or may have been learned from past experiences. One way to formalize and store the design rationale is to associate design patterns (like design parametric features) with their functionality, and to associate also requirements with functionalities that may fulfill them, by representing this knowledge in some logic language, suitable for performing automated reasoning. Global optimization may allow the product agent to consider the design rationale of components beyond a single partner, by proposing improvements crossing enterprise's barriers.

Local assistances involve making easier some tasks such as feature identification and process planning, and suggesting alternatives for improving results (e.g. design and process planning optimizations). For example, an agent for the CAPP activity has been developed in previous works (MARCHETTA; FORRADELLAS, 2006a; MARCHETTA FORRADELLAS, 2006b; MARCHETTA; FORRADELLAS, 2007). This agent is capable of learning process planning patterns by observing decisions made by the manufacturing engineer. It also has the ability of synthesizing new process plans based on the available manufacturing resources and the product's design, as well as identifying manufacturing features from the product's geometry. While the manufacturing engineer is working on a new process plan, the agent tries to identify its intentions using plan recognition techniques and then the agent suggests different ways of completing the plan, including using the same known patterns (learned from past experiences) and creating new process plans fulfilling the same goals but optimizing some criterion (time, cost, etc). Figure 8 shows an overall schema of this agent.

After the final design has been obtained, final engineering analysis and process planning performed for completing the product specification. This information will later be used for production scheduling and manufacturing in order to create the physical product.

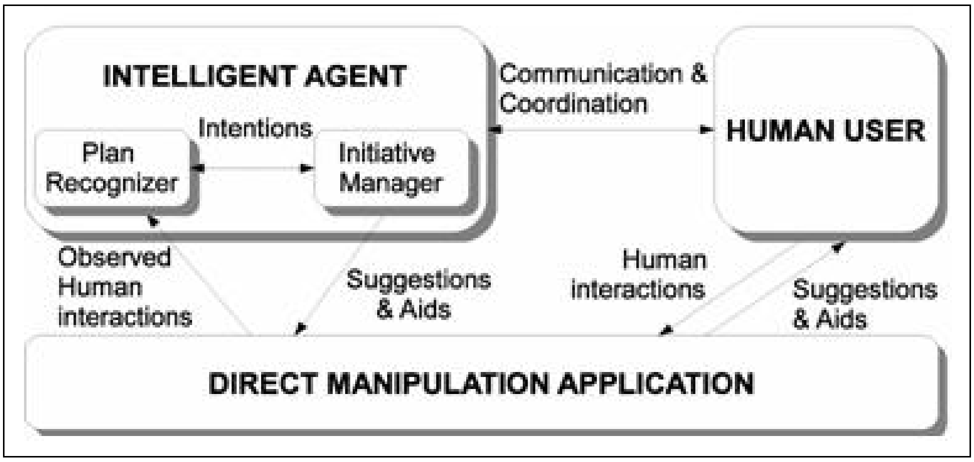

Figure 8 – Structure of a mixed-initiative system based on an intelligent agent for CAPP
Source: Research

5 CONCLUSIONS AND FUTURE WORK

In this paper a framework including a business process model, an architecture of applications and the use of modern technologies, particularly intelligent agents, was proposed to improve and enhance information exploitation along PLM. The presented framework aims at providing a suitable model to expand the participation of the product along its own lifecycle, in order to reduce time-to-market, improve final quality and reduce coordination and consistency issues in virtual enterprises embedded in the supply chain.

One contribution of this work is the integrated treatment of both the partnership within a virtual enterprise setting seen from the product development stages, and the Supply Chain Management integration, within the Business Process Model proposed.

Another contribution is the proposal of architecture of applications to support PLM by means of an intelligent product agent, having the properties of autonomy, social ability, reactivity and proactivity.

In addition to that, a hierarchy of interactions including the different kinds of assistance an active product agent may give to product development teams is also proposed, which is exemplified with some concrete coordination, local and global optimization opportunities. This allows generalizing the joint enterprise and application architecture to apply these and other automated assistances, instead of concentrating on a single one (such as change propagation).

Finally, this framework constitutes a starting point for implementing an integrated architecture for PLM, including suggestions on the use of modern technologies such as intelligent agents and other artificial intelligence and optimization techniques.

From the enterprise and application architecture point of view, future work will include a refinement on the business process model introduced here, as well as a product information model, which is required to support a product-agent within PLM. Additionally, application of the same active-product concept to previous and later stages, along manufacturing and logistics administration may be explored, to give the product the ability to coordinate its own production in the shop floor, storage, transportation, raw materials procurement, etc. In this approach a product would have an immaterial existence (the product agent, including its own information and knowledge), and a material one (the product that is physically constructed, stored, transported, etc). This enables new production management schemas to explore, such as distributed manufacturing and logistics coordination.

From the framework realization point of view, some research has already been done in the local optimization and assistance (the fourth level of the proposed interactions hierarchy), mostly in the CAPP activity (MARCHETTA; FORRADELLAS, 2006a; MARCHETTA; FORRADELLAS, 2006b; MARCHETTA; FORRADELLAS, 2007). Further work is needed in order to implement assistance along the complete proposed hierarchy. In the near future, the implementation of the CAPP local assistance agent will be finished, and research will continue for realizing agent support to other activities, especially on coordination, global optimization and change propagation, following the guidelines defined in this paper.

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