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THE COLLABORATIVE PRODUCT DEVELOPMENT IN THE COMPUTER INTEGRATED FACTORY

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Abstract

Nowadays, all manufacturing factories are computerized. The product information becomes digital and can be shared among various participants of the extended enterprise: customers, suppliers and business partners. The Product LifeCycle Management Information System (PLM-IS) becomes collaborative and integrates people, processes and technologies in a context of Customer Satisfaction and Total Quality. Customers opinions and suggestions on products represent a potential of knowledge so high that can be considered a true strategic asset for the acquisition of enterprise competitive advantages. In this paper, a new model of Collaborative Computer Integrated Factory (CCIF), where PLM is integrated with Manufacturing Execution System (MES), Enterprise Resource Planning (ERP) and Computer Aided technologies (CAx), is proposed. The MES receive from ERP/PLM system information on collaborative product design and convert them into machine commands for PLC, CNC and mechanical devices.

Key words: *web 2.0, product lifecycle management, enterprise resource planning, cad,cam, plm, erp*

1. INTRODUCTION

In recent years continuous changes have occurred in enterprise organizational systems, from single enterprise to company networks until customer oriented extended enterprise. All this has been done with the support of evolving Information Technology. Information Systems as Enterprise Resource Planning (ERP) has become Extendend ERP (EERP) (Weston and Ted, 2003) including Customer Relationship Management (CRM), Human Resource Management (HRM) (Li and Chen, 2002) and Supply Chain Management (SCM).

With continuous market changing and globalization, the enterprise specializes in a core business and restructures towards distributed organizations with an increase in the value creation. The production and distribution is performed by more specialized partners that collaborate among themselves. It is necessary to control the business processes that are distributed along the supply chain and integrate the software that support the product lifecycle in the various stages.

In the manufacturing factories also the industrial software has evolved from the first version of Computer Aided Design (CAD) to new versions of Product Lifecycle Management (PLM) (Danesi et al., 2006) where many people can together conceive, plan and develop advanced solutions of products.

Nowadays, enterprise invests more in customers, business partners, trust relationship, mutual cooperation, sharing and exchange of information.

The product and its information become digital and can easily be sharing with other partners. Sharing the digital content of the product is possible thanks to collaborative software and Web 2.0

technologies (blogs, wikis, forums, social networking). Thus a bi-directional channel is established between customer, suppliers and producer and a process of co-creation and co-production is activated. Enterprise itself will stimulate the birth of these virtual communities to communicate and collaborate with customers and suppliers.

In this paper we present a new model of Collaborative Computer Integrated Factory (CCIF) open to customers . This paper is organized as follows: in the next section we give a description of literature and software evolution in the factory while in the third section a factory processes-based is presented. In the fourth section CCIF model is discussed with particular attention to a new enterprise philosophy of Collaborative PLM. The fifth section is devoted to present Production Methodoloy for Customer Satisfaction while in the sixth section the percentage of enterprise PLM solutions is showed. Finally some conclusions are drawn.

2. LITERATURE AND EVOLUTION OF THE SOFTWARE IN THE DIGITAL FACTORY

The automation of physical processes in the factory started almost simultaneously with the office automation and enterprise computerized management. The first applications of computers in mechanical design had introduced by General Motor Corporation around 60's. The drastic reduction of costs in the microelectronics has allowed the rapid spread of this technology and the evolution towards three-dimensional Computer Aided Design (CAD).

The proliferation of more powerful and reliable microprocessors (around middle 70's) has facilitated the development of digital machines to CNC machines, Programmable Logic Controller (PLC) and Robot Control. All this has encouraged the development of technology Computer Aided Engineering (CAE) (MacKrell and Herzog, 2002) to support the engineering design in the automatic generation of programs for numerical machines with Computer Aided Process Planning (CAPP) and Computer Aided Manufacturing (CAM)(Bettig and Bapat, 2006). In the 2000s all these electronic system have integrated in a new collaborative software solution Product Lifecycle Management (PLM) that manages all enterprise processes in the building of product.

In terms of logistics and production processes we have been an evolution from Material Requirements Planning (MRP) to MRP II, Customer Relationship Management (CRM), Supply Chain Management (SCM), Enterprise Resource Planning (ERP) that support all enterprise activities (accounting, financing, production, human resources, sales,…) and ERP II or Extended ERP that include also CRM and SCM. In the supply chain it is important to consider the ITS (Intelligent Transportation System) and Radio Frequency IDentification (RFID) based on mobile and wireless technologies for tracking the product location.

Nowadays, the enterprise reach business goals develops communication channels between various actors (Jagdev et al., 2008): enterprise-suppliers (B2B), enterprise-customers (B2C), enterprise-employees (B2E), computer – mobility devices (M2M).

In the context of integrated production environment, different automatic platforms have been used: Computer Integrated Manufacturing and Engineering (CIM/CIME), MIRS (Modular Integrated Robotized System).

The Computer Integrated Manufacturing (CIM) (Nagalingam and Lin, 2008) implements the full automation and the integration of all enterprise activities as business planning, design, production, factory store and sale. The information flow is automated from order arrival to product conception and shipment of finished product.

The automatic factory Modular Integrated Robotized System (MIRS) (Kopacek et al., 1999) has

revolutionized technology and traditional methods of production. The new robotic process is based on the concept of a small factory that with very high flexibility is strategically placed in the territory according to market needs. In a robotic space of hundreds of square meters, the work of the robot covers the production cycle without interruption, without moving semi-finished or intermediate stages of factory store. The first automatic factory that has implemented the MIRS technique was Pirelli S.p.A company. With this technology the company has reduced the average time of transit of materials, from a few days of the traditional process to a few hours and has produced a pneumatic tire every three minutes.

These automatic techniques make an on-line integrated management of the whole business lifecycle, from purchasing to marketing, from research to design, from production to logistics. The program of CIM/MIRS manages all phases of production: engineering, initial design, instruction generation of the production cycle, robot movements, materials automatic supply, quality control, handling of finished products. In the production plant we passed from Numerical Control Machines to the Flexible Manufacturing Systems (FMS) (Shafiei and Sundaran, 2004).

With the enterprise restructuring in processes and relative increasing importance of 90s, software companies have developed many tools for Business Process Automation (BPA) systems and WFM (Workflow Management). The business processes have increase their speed with the use of communication software. A WFM system (Cardoso et al., 2004) is primarily a system of sharing information and documents (Document Management) based on a common data repository, which manage accesses, authorizations and permissions.

In recent years, every business process is seen and considered as a service and the new paradigm web-based Service Open Architecture (SOA) is borned (Dan et al., 2008).

SOA organize, use, manage the IT resources and associate specific services to user needs. SOA exploit web services for meeting customer demands in order to provide a specific service. Different services can be modified or combined (mash up) to create a new service. SOA support, very well, automatic integration of supply chain processes and in particular SCM, CRM, HRM, ERP, PLM.

3. FACTORY PROCESSES-BASED

The enterprise is a set of subsequent activities in the same direction and with the same objective: the creation of value. With the market globalization and changing customer demand (quality and timeliness), companies have been encouraged to increase innovation and reduce product time-to-market and hidden inefficiencies in the organization. In the research of the value, companies have gradually abandoned the competencies not-core by outsourcing, making a network of more cooperating entities (de-verticalization). In this way the value generated by the core business of the company is increased.

In the value chain the core element is the business process. The business process consists in a set of coordinated and inter-functional activities (also with other companies) to achieve a business target that contributing to the creation of value. The restructuring of enterprise in processes is, very well, supported by Internet-based technologies, that already pervade many enterprise activities.

With the web technologies it is possible reduce errors and defects in the product life cycle and enhancing the quality product. In the Internet-era the technical office goes beyond its limits and boundaries and reach the global and extended company.

In the large-scale manufacturing companies the Supply Chain Management (SCM) is web-based and manage in a timely manner all the stage of the supply chain: document preparation, shipment, trading, material delivery. We can insert orders via web and make the tracking of them.

It is possible improve and optimize the forecasting, production and delivery times, align planning and production and continually update the production plan and deviations from the schedule plan.
The company processes-based is an adaptive enterprise that respond with agility to frequently changing conditions.
For the agile management of business processes the enterprise use Business Process Management (BPM) (Harmon, 2008) solutions. This technology model and design processes and deals them as strategic assets. With BPM it is possible to align external factors with enterprise business strategies.
The web-based platform allows the management of business processes, models, content and document management, collaboration and data integration.

4. THE COLLABORATIVE COMPUTER INTEGRATED FACTORY

4.1 The CCIF model

In this section we present a Collaborative Computer Integrated Factory (CCIF) model opening to customers and operating in a cooperative environment. Different forms of collaboration, supported by web technologies, as co-marketing, co-design, co-engineering, co-manufacturing are now facilitated from software tools and network architecture. All components of CCIF (Figure 1) are full linked among themselves. With Collaborative Computer Integrated Factoring we can increase the productivity (more products in less time), visibility and competitiveness in the global market and we can have different advantages: integration of various devices into a single coordinated system, exchange of information in real time, continuous monitoring of the industrial plant, system scalability and efficient management of costs.

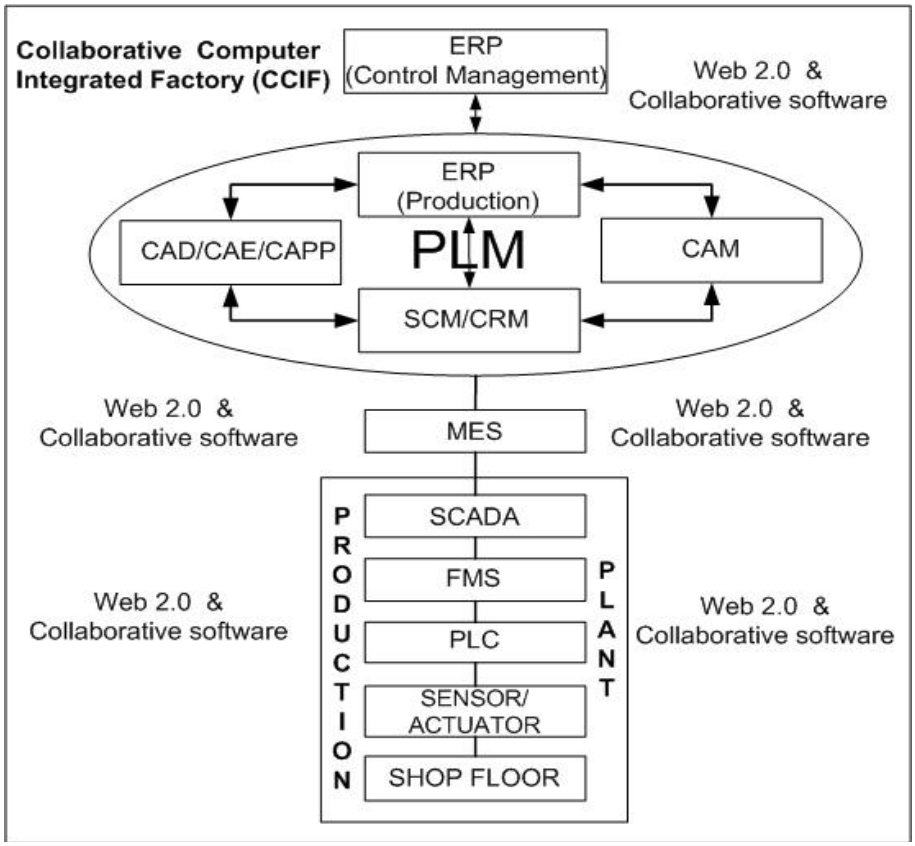


Figure 1. Computer Integrated Factory (CIF) model.

In Figure 1 we can observe the following sub-system:

- ERP (Enterprise Resource Planning) for global management of the company.
- ERP for production data management (production system)
- CAx technology: CAD/CAE for product design and engineering, CAPP for processes planning and CAM for planning and production control
- CRM/SCM, CRM manages customers relationship while SCM manage supply chain
- PLM for product lifecycle management
- MES (Manufacturing Execution System) for control and production planning
- SCADA (Supervisor Control and Data Acquisition) for enterprise area supervision
- Production plant: FMS, PLC, Sensor/Actuator, shop floor (mechanical devices)

ERP, software application, manages and controls the enterprise. An ERP includes different modules that supporting a variety of business functions such as finance, amministration, logistics, manufacturing, marketing, human resources, supply chain management, customer care. In the CCFI we consider the ERP production system that manages product information on materials (bill of material, suppliers orders, material receiving, inventory management), production (working orders, scheduling and production control) and distribution (product delivery, transportation and shipping).

In the automatic context, we consider CAD solutions for product design, CAE for product engineering and CAM for manufacturing. Integrating these sub-systems we obtain useful information to following sub-systems and to production plant: Flexible Manufacturing System (FMS) and Shop Floor (SF).

The main element of CCIF model is PLM system that we will explain, in details, in the next section.

The PLM systems is interfaced with production plant by a Manufacturing Execution System (MES) (Kletti, 2007). MES is an environment of high-level configuration that allows to describe operational procedures for manufacturing. MES is the digital “nervous system” capable to coordinate and synchronize production processes, the flow from ERP/PLM to production plant (FMS & SF) and distribute the tasks other sub-level systems. It receive from ERP/PLM information on working cycle and convert them in machine commands for production and processing sequences. This production system align more effectively the areas of maintenance and production with business goals in order to optimize the asset performance management. The MES integrate the production in the supply-chain and give visibility on what happens in the factory.

In the Collaborative Computer Integrated Factory it is important the control and monitoring of devices at different levels of production plant. This control and monitoring is supported by specific software (Table 1):

Table 1 – Software Control for plant elements

Manufacturing Plant Elements	Software Control
Area	Supervisor Control and Data Acquisition (SCADA)
Cell	Flexible Manufacturing System (FMS)
Machine	Programmable Logic Control (PLC/CNC)
Sensor/Actuator	Sensor/Actuator Control (S/AC)
Mechanical Devices	Shop Floor Control (SFC)

The first level of monitoring system is Supervisor Control and Data Acquisition (SCADA) (Kilpatrick et al., 2008) that supervise the working productive area. The system SCADA manages and controls operating processes in the following stages: data processing, production and processes setting, alarm situations management, alarm response, results analysis, screen visualization.

The supervision is supported by web technologies. immediately accessible from user through web browser or mobile phone (java and web service) in a bi-directional, multiuser and security channel. In the SCADA level the real time requirements are reduced. These requirements are higher at lower level (mechanical devices control).

Each device of production plant (FMS, PLC/CNC, sensor/actuator, mechanical devices) is equipped with an ethernet card and present an integrated web server as single point of access for diagnostic, check and testing. The use of intelligent field devices involve a closer interaction between process and automation. In each mechanical devices (shop floor) many solutions of Multimedia Human Machine Interface (M-HMI) are used to ensure an enterprise strategy of common visualization closer to cinema and theater systems. M-HMI is an interface for users, to interact with specific types of machines or tools in modality Graphical User Interface (GUI) and Web User Interface (WUI), that allows to exchange web page by a browser.

4.2. A New Enterprise Philosophy: Collaborative Product Lifecycle Management

Product Lifecycle Management (PLM) is: "A strategic business approach that applies a consistent set of business solutions, to support the implementation of collaborative activities: creation, management, dissemination and use of information that define a product through the extended enterprise, from concept stage to the end of the life of a product, integrating people, processes, information and enterprise systems" (Brown, 2003).

Generally the term "lifecycle" represents a set of steps that are recognized as individual stage of a product: conception, design, planning, realization, development, distribution, disposal and recovery.

The PLM can help enterprise to transform more ideas into successful products (from concept to post-sales services supply) with a strong emphasis on the design phase that consume 80% of the total cost and therefore this phase is crucial in the planning stages.

PLM solutions include all participants (geographically distributed companies, business partners, suppliers, OEM manufacturers and customers) in the collaborative product manufacturing.

The PLM is an interchange software between data design and production management; it isn't only software application but also a thinking way, a new strategy. People inside the company must be persuaded to adapt this system that involves a change in the work modality and in the review of enterprise processes and organizations. The PLM is an "engine of innovation" and an enabling factor for a review process that allows the positioning within the value chain.

With PLM we can manage evolving modification that allow us to know, at any time, the configuration of a specific product delivering to a specific customer. PLM brings benefits in terms of timing, cost, quality as the opening skills and business knowledge (intellectual warehouse).

With the Bill Of Materials (BOM), the PLM can realize different product views of the product (three-dimensional handling; model animations, drawings, zoom and movements) and describe the structure for trading or manufacturing objectives. PLM exchange data also with EERP: data on customer ordering, suppliers buying and daily production planning. It centralizes and improves product data management: requirements, specifications, electrical diagrams and maintenance manuals. The PLM enhances the level of visualization and interoperability between different CAD formats and support the exchange of information on product configuration.

The Product Lifecycle Management is a source of opportunities for manufacturers and a new approach to product development. The PLM manages and tracks the entire "product system" and all activities linked to it, in its different stages of life with integrated and collaborative tools.

PLM is implemented in a virtual workspace that use collaborative web 2.0 tools (Consoli, 2008) (videoconference, document sharing, electronic witeboards, messaging/routing, forum, weblog, chat, e-mobility) and different platforms of Enterprise Information Collaborative Portals (EICP).

The PLM is a collaborative platform (Figure 2) that link ERP to other Extended Enterprise Applications, with management of information product-centric, as PDM, CAx technologies, SCM, CRM.

PLM increase communication, coordination and collaboration with partners of a extended enterprise. It is a collaborative space interconnected among person involved in the product lifecycle (designers, marketing people, sales, manufacturers, OEM manufacturers, suppliers and customers) that can access and collaborate in real time.

It supports the implementation of Collaborative Product Development (CPD) in the conception, design and development of the product (co-design, co-engineering, co-manufacturing, co-marketing, co-selling).

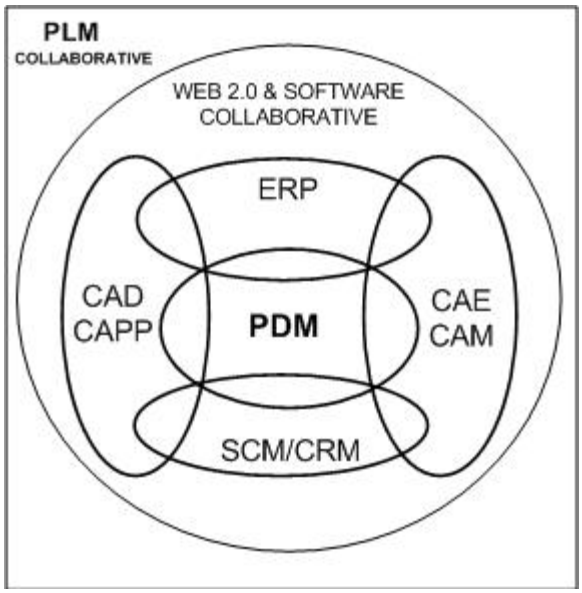


Figure 2. Collaborative PLM.

We can summarize following architecture of Collaborative PLM (Figure 3) that include all subjects/objects involved in the product lifecycle strategy.

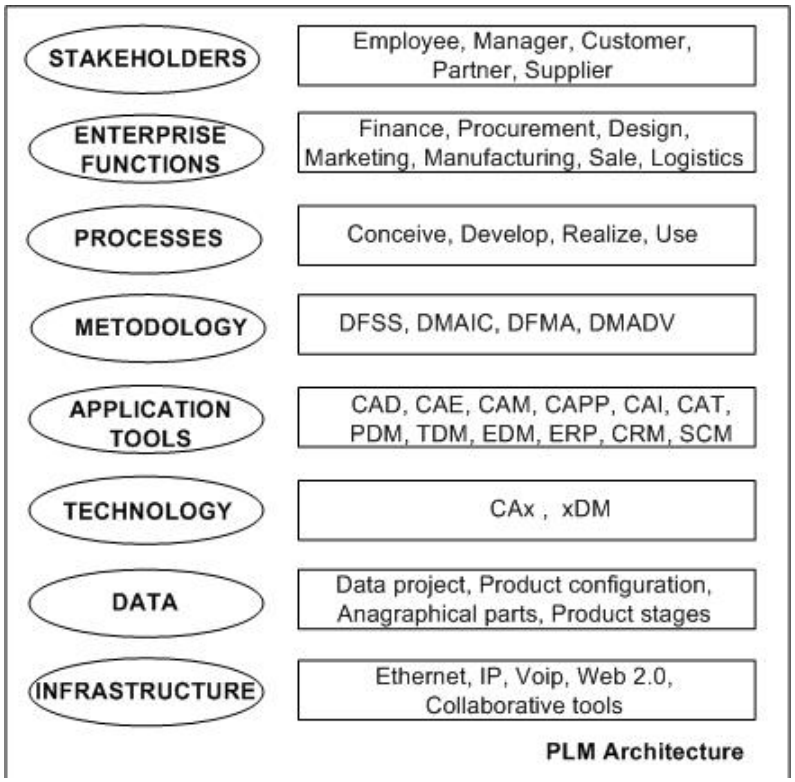


Figure 3. Architecture of Collaborative PLM

PLM include a module of virtualization environment (Digital Mock-up) that allow the realization of Simulation Driven Product Development (SDPD) methodology. This methodology is useful for simulating an entire development process, from raw materials to final product and conclusive test in a context of common and unified environment.

The Digital Mock Up allows a realistic simulation of a product from different points of view (style, design, production and maintenance) by providing a significant support to various decisions for product development.

DMU make a virtual simulation of a product and its components. The digital or virtual models eliminate the need of a physical prototype and allow to manufacturer to design the product with interactive components. The virtual model contains all data associated with the product and brings more advantages than a physical prototype. With DMU we can make any kind of simulation and calculation. We can really see inside the structure of the product and identify problems as the risk of breakage caused by excessive stress. On virtual prototypes we can make mechanical tests and see the results and therefore we can select the best project before going in the production.

4.3 . Product Information Management

There is a common element to all stakeholder and enterprise functions: the product. Around it, process innovation, development, suppliers, customers, partner, employees (Extended Enterprise) revolve. The product can be seen from two perspectives: object (engineering - CAE/CAM) and artefact (management - ERP); two different views, but highly complementary. In this context, product and manufacturing processes are developed simultaneously (Concurrent Engineering) for reducing time of launch of new products in the market. Each process generates useful information (enterprise asset) to manage.

The data generated through the design and productive process are integrated in Enterprise Application Integration (EAI) as ERP, SCM and CRM but also with Administrative Systems and Cost Management.

The product information interest all lifecycle stages: conception, design, development (that include prototype completion, different test, industrialization, preparation of technical documentation). This information, available in digital form and supported by web technologies, is able to share among many people and in different geographical area.

The product information presents different attributes:

- product definition (technical specifications, reference standards, marketing design specifications)
- product configuration (Bill of Material -BoM- , configuration and product sales)
- product parts (components, catalog, views)
- document management (archives, modifications, versions/revisions, access and security),

Product information describes how the product is designed, its physical features, schemes, modules, bill of materials (BOM), work cycles and processes with technical documentation associated.

The product information is managed from Product Data Management (PDM) that is basically an Information System for storing, archiving and managing product engineering data and related workflows. PDM include Technical Data Management (TDM), Engineering Data Management (EDM), Product Management (PM), Product Information Management (PIM).

The PDM is able to provide an efficient data management and a functionality to support specific needs of different organizations: marketing, design, manufacturing, production, logistics, sales, technical

assistance. A PDM provide right information at the right time, in the right format and to right people supporting the entire organization in the product manufacturing with lower cost, better quality and timeliness. PDM contains the list of project participants, authorization, reviews, versions and the phases of product lifecycle in its business process.

The software PDM (Su and Liu, 2008), with a single centralized database stores and manages all product information. PDM system is composed by different modules:

- information warehouse or vault, where product data is stored in a structured modality
- information management, responsible of system administration, data accessibility, security and integrity, concurrence, archiving and recovery
- workflow management for defining workflows and registering their histories
- user interface, for supporting user activities (queries, reporting, etc.)
- system interfaces for ERP, CAD, CRM

5. MANUFACTURING METHODOLOGY FOR CUSTOMER SATISFACTION

New product development is the lifeblood of organizations. Enterprise must frequently make changes in product and process design to meet customer requirements. For an efficient product design that minimizes product's defects engineers spend many time and money on the production planning.

There are different methodologies of design-engineering-production for Customer Satisfaction and Quality Function Deployment (QFD) (Hsu, 2007). In this context it is important consider CTQs (Critical to Quality), characteristic measurable keys of a product/process whose performance must meet customer needs. It is important align product design and improvement with customer requirements.

Those methodologies provides a set of operating rules to improve manufacturing processes from product design. In the cycle of product development it is important the consistency between functionality and manufacturability. The product must meet the functional specifications and be, in the same time, easy and economical to manufacture, assemble and maintain. The rational decisions, during the product design, influence costs more than successive improvements.

There are different production methodologies (Creveling, 2002) to select optimum designs and processes for manufacturing (parts of) product.

- DFSS (Design for Six Sigma)

Implement a solution/product that meets customer requirements. The name Six Sigma is a program to monitor variance for bringing the quality of a product/service at one level (3, 4 defective parts per million).

- DMAIC (Define, Measure, Analyse, Improve, Control)

Define the project goals and customer requirements. Measure the process to determine current performance. Analyse and determine causes of the defects. Improve the processes by eliminating defect causes. Control future process performance. This methodology aims to continuous manufacturing improvements.

- DFMA (Design For Manufacturing and Assembly)

Design in a conceptual and simply way for Manufacturing with calculate of cost drives. Assembly

component in a conceptual design.

- DMADV (Define, Measure, Analyse, Design, Verify)

Define the project goals. Measure and determine customer needs and specifications. Analyse the process options to meet customer needs. Design the process for customer requirements. Verify the design performance and ability.

Combining those methodologies it is possible to adapt system parameters of manufacturing methodology for increasing product/service effectiveness and meeting customer requirements.

6. IMPLEMENTATION OF EAI-PLM SOLUTIONS IN ENTERPRISE

Nowadays PLM solutions are used in sectors as Automotive, Mechanics, Electro-mechanics, Aeronautics. Commercially PLM is included in Enterprise Application Integration (EAI) systems like ERP, SCM, CRM.

Those software solutions, in the market, maintain good growth prospects. According to a recent AMR Research Survey, in the world, EAI systems increase from the current $ 50M to $ 60M in 2008 (above 5% of growth).

In particular, for specialist reviews (AMR Research, Cimdata, Daratech) the market PLM between 4-5 years will become comparable with ERP sales, which are projected to remain broadly stable ($ 20M).

A more careful analysis of data on the PLM can detect that this trend of growth is the result of two components of "Authoring Tools" (CAD, CAE, CAM,..) that provides a reduction in turnover of some points while the market for cPDm (instruments that in a PLM context manage product data and engineering collaboration systems) can have a growth with to digits (14-16%).

The following Figure 4 (source: NetConsulting 2007) shows, in the left side the strategic importance of EAI and therefore of PLM in Enterprise (the value is almost 4 on 5 as maximum) and in the right side the percentage of companies that already use or that will implement EAI solutions in the future; the value for PLM is egual to 40%.

The adoption of PLM solutions becomes very important for companies that working in the enterprise network in which the production activities (design, prototype implementation, industrialization, production on a large scale) are delocalized in different business partners .

In recent years, the last version of PLM software, more easy and flexible in the parameters setting, is commercialized also in the SME market.

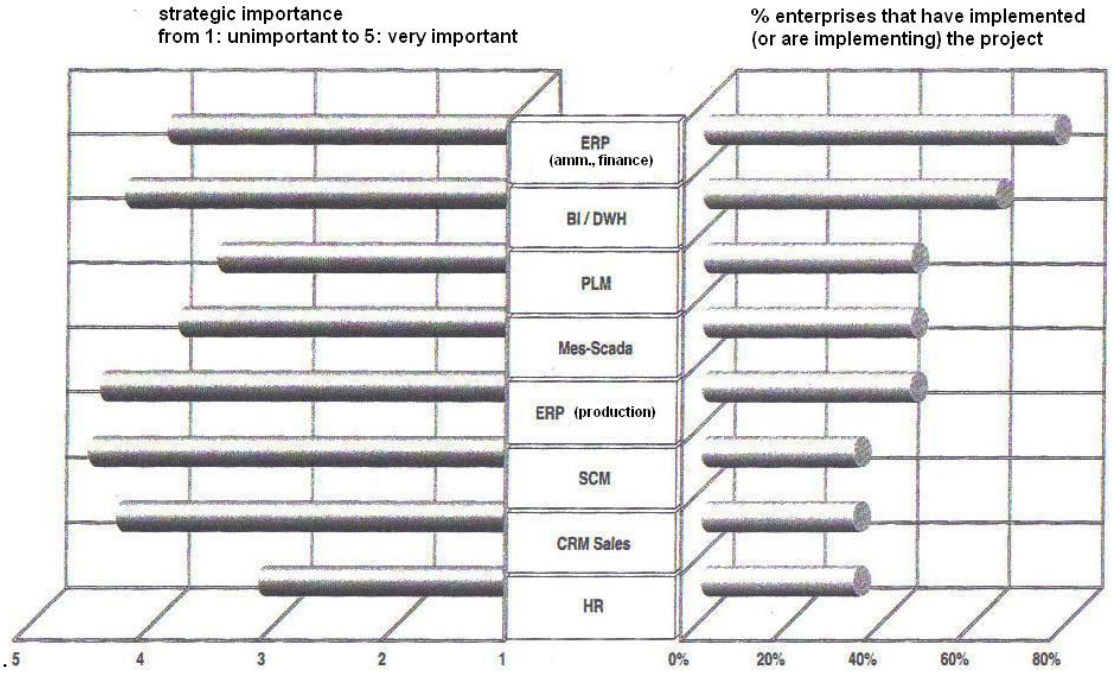


Figure 4. Percentage of enterprise that invest in EAI-PLM and strategic importance

7. CONCLUSIONS

In this work we propose a new model of Collaborative Computer Integrated Factory (CCIF), enterprise totally automatized, where all participants of supply chain (business partners, suppliers, customers) can collaborate in the product design and manufacturing.

All Enterprise Application Integration (EAI) like ERP, SCM, CRM are integrated in a Product Lifecycle Management (PLM) for optimizing the product design in the planning stage and reach so customers requirements. The PLM can help enterprise to transform more ideas into successful products (from concept to post-sales). The PLM is a new strategy, a new methodology and a new way of thinking, useful to manage the project and the production of a collaborative business company. This methodology combines very well with the philosophy of Extended Enterprise in the cooperating enterprise networks (de-verticalization) because involve the collaboration of all stakeholders and in particular of customers. Customers, with their opinions and suggestions, are a strategic asset for enterprise competitive advantages.

The expansion of web 2.0 tools and community social network, capitalize people experience in a context of global sharing collaboration. In the CCIF model before ongoing into production it is possible simulate design and production. The best simulated project will be used in the real product manufacturing.

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