Implementation of Product Lifecycle Management Tools using Enterprise Integration Engineering and Action-Research

Article *in* International Journal of Computer Integrated Manufacturing · October 2010

DOI: 10.1080/0951192X.2010.495136 · Source: DBLP

4 authors:

Nicolas Penaranda
Formel D Mexico

Ricardo Mejia-Gutierrez
Universidad EAFIT

David Romero
Tecnológico de Monterrey

Arturo Molina
Tecnológico de Monterrey

Implementation of Product Lifecycle Management Tools using Enterprise Integration Engineering and Action-Research

Nicolas Peñaranda[1], Ricardo Mejía[2], David Romero[1], Arturo Molina[1*],

[1]Tecnológico de Monterrey, México, [2]Universidad EAFIT, Colombia

Abstract. This paper describes how Enterprise Integration Engineering (EIE) and Action-Research (A-R) can be used to support the implementation of Product Lifecycle Management (PLM) tools. The EIE concept is used to align the corporate strategies with the use of PLM technologies in order to impact the Key Performance Indicators (KPIs) in the enterprise. An EIE reference framework is proposed to define strategies, evaluate performance measures, design/re-design processes and establish the enabling tools and technologies to support the enterprise strategies, while A-R is proposed to guide the PLM tools implementation at various stages of the product development process. An industrial application is described to demonstrate the benefits of applying EIE, A-R and PLM in an enterprise.

Keywords: Enterprise Integration, Enterprise Modeling, Product Lifecycle, Action-Research, Industrial Application.

1 Introduction

Business managers are looking for new ways of improving their company's performance. For this reason, concepts like Enterprise Integration (EI) and Product Lifecycle Management (PLM) have emerged to help companies to be successful facing these challenges.

EI is a domain of research developed since 90's as an extension of Computer Integrated Manufacturing (CIM). EI research is mainly carried out within two distinct research disciplines: Enterprise Modeling and Information Technology. The first discipline refers to EI as a set of concepts and approaches that allow the definition of a global architecture for a system, the consistency of a system-wide decision making, the notion of a process which activity flow model goes beyond the borders of functions and the dynamic allocation of resources as well as the consistency of data (Vernadat, 2002). In the second discipline, Information Technology, EI is carried out through the integration of several enterprise systems, like: Enterprise Resource Planning (ERP), Supply Chain Management (SCM), Customer Relationship Management (CRM), Business Process Management Systems (BPMS) and also by authoring functional applications such as: Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), Office automation, etc. (Panetto and Molina, 2008). All these systems and applications support the implementation of processes that sustain the enterprise operations.

Enterprise Integration Engineering (EIE) is the collection of modeling principles, methodologies and tools that support the integration of different enterprise lifecycle entities (e.g. enterprise, project, product, processes). The EIE foundation relies on the creation of an enterprise model of the different entities in an enterprise, aiming at building a complete representation of an enterprise that consists on the definition of their mission, strategies, Key Performance Indicators (KPIs), processes and competencies and their relationships (Nof et al., 2006). EIE allows a detailed description of all the key elements of an entity (e.g. activities, information/knowledge, organizational aspects, human and technological resources) and several languages may be used (Cuenca et al., 2006). In an enterprise model, this description provides the means to connect and communicate all the functional areas of an organization to improve synergy within the enterprise, and to achieve its mission and vision in an effective and efficient manner (Molina et al., 2005). Furthermore, EIE enables an enterprise to share key information/knowledge in order to achieve business process coordination and cooperative decision-making, and therefore achieving Enterprise Integration.

PLM is a strategic business approach that is used to achieve "Enterprise Integration" for product development. It has the intention to reduce inefficiencies across the whole product lifecycle (Grieves, 2006). The PLM concept is focused on integration of lifecycle information and knowledge supported by computer aided engineering technologies such as: CAD, CAM, CAE, and Knowledge-based Engineering Systems (KBES).

[*]Corresponding Author: Tecnológico de Monterrey, Campus Ciudad de México, Del Puente 222, Col. Ejidos de Huipulco, Tlalpan, 14380, México, D.F. E-mail: armolina@itesm.mx Phone +52 55-54831604 Fax +52 55-54831606

PLM aims to support the management of the product development process through the stages of its lifecycle, from its conception to its recycling or disposal. PLM is recognized by World's leading universities, institutes, and solution vendors as the next big wave in enterprise software applications in the market and as a key technology to support the new competitive strategy, value chain strategy and production/service strategy in an enterprise (Ming et al, 2005). The emerging software market is a suite of tools used to plan, manage and execute lifecycle activities, which include identifying business opportunities, prioritizing R&D efforts, developing new products, and supporting their production and introduction to the market (Rozwell and Halpern, 2004) or even closing the lifecycle loop as Jun et al. (2007) proposed by integrating new technologies to gather real-time feedback.

However, PLM systems might be considered also an important concept for a complete Enterprise Integration in an enterprise that aims to carry out lifecycle engineering activities. The work presented by Jianjun et al. (2008) describes an example of product lifecycle engineering design based on a Design for eXcellence (DFX) approach and treating information exchange issues in order to lead the engineering design to an effective and efficient adoption of a sustainable product development paradigm. Gao et al., (2003) at Cranfield University has integrated Product Data Management (PDM) and PLM technologies, to demonstrate that PLM can improve enterprise's ability to effectively manage their supply chains and collaboration around concurrent product developments between separate offices and also with sub-contractors, enabling Enterprise Integration.

PLM integration and coordination in an enterprise remain challenging because of its knowledge intensive nature. The study carried out by Siddiqui et al. (2004) investigates the problems and issues faced by companies when implementing PDM systems, which is one of several components needed for a complete PLM implementation. A set of key factors, such as a lack of management support, implementation issues, user acceptance and costs, should be considered. Furthermore, according to Bygstad et al. (2008), the turbulence of the business environment and the technical environment complexity are the main challenges to face. Schilli and Dai (2006) emphasize the necessity of a deeper understanding of a current business, the design of appropriate processes and the implementation of a supporting IT architecture. Garetti et al. (2005) propose a set of experimental learning techniques and a change management approach in order to reach a better PLM implementation, recognizing the central role of virtual simulation, business process analysis techniques and process mapping, and remarking on the importance of adopting solutions that are flexible and adaptable due to the constant changes in enterprises processes. Another important component of PLM systems is workflow management, which is an issue as illustrated by Rouibah et al. (2007). The enhancement of process design through the creation of building blocks as well as the enhancement of organizational structure through the usage of roles as a resource for process activities is a major achievement for PLM definitions.

For these reasons there is a strong need for a systematic, methodological and technology supported approach to develop and sustain a successful PLM implementation in an enterprise, which is aligned to achieve a complete Enterprise Integration. Action-Research (A-R) is proposed in this paper as a methodology to support the implementation of PLM technologies in an enterprise.

This paper describes how Enterprise Integration Engineering (EIE) - a framework and a methodology for Enterprise Integration - have been used to align the strategic objectives of an enterprise to improve its engineering processes using information technologies, in particular in the implementation of PLM tools. The underlying methodology used to support the PLM implementation process is A-R in order to take a systematic approach of planning, implementing, observing and evaluating the process. By using A-R it is possible to improve Key Performance Indicators (KPIs) in the enterprise and justify the implementation of PLM technologies. A case study in a real enterprise is presented to demonstrate the usage of this methodology.

The paper has been organized as follows: Section 2 describes how the EIE reference framework can be used to guide the PLM realization project. Section 3 describes how A-R can be used to guide in three cycles a PLM implementation. Finally a case study is described in Section 4 to demonstrate the applicability of EIE and A-R in PLM implementation projects.

2 Enterprise Integration Engineering Reference Framework

The EIE reference framework components are depicted in Table 1. The EIE reference framework has its foundations on CIMOSA, ARIS, PERA, ZACHMAN, and GERAM reference models and frameworks. EIE uses reference models and frameworks to support strategies development by applying three key concepts: (1) lifecycle principles, (2) enterprise models, and (3) instantiation in different domains (Chen and Vernadat, 2004) (see Figure 1). Each of the different components provides guidelines, methodologies and tools to engineer business process changes (Molina et al, 2005). The components are: (1) Strategy

and Performance Evaluation Systems, (2) Reference Models for Enterprise Modeling, (3) Decision-making and Simulation Models and (4) Knowledge/Information Technology.

Table 1 – EIE Reference Framework Components for PLM implementation

EIE Components	Activities	Tools
Strategy and Performance Evaluation Systems	• Define strategies: competitive strategy, value chain strategy and production/service strategy. • Define KPIs: quality, volume, time, costs, flexibility and environment.	• SWOT. • Porters 5s. • Scenario planning. • Balanced scorecards.
Reference Models for Enterprise Modeling	• Define enterprise model and core processes. • Describe Enterprise Model AS-IS and TO-BE: functions, information, resources and organization. • Determine KPIs of core-process.	• Enterprise modelling languages (IDEF0, UML). • Business Process Model Notation (BPMN). • Event-driven Process Chains (EPC).
Decision-making and Simulations Models	• Define logic models of best business practices and IT and its impact on KPIs. • Design AS-IS and TO-BE simulation models to evaluate decision-making. • Evaluate KPIs based on the use of best business practices and IT implementation.	• Program logical models. • System dynamics models. • Discrete event simulation. • Business process analysis.
Knowledge/Information Technology	• Define data, information and knowledge models. • Decide type of IT application: functional, coordination, collaboration or knowledge management. • Design IT architecture. • Determine IT infrastructure.	• Product Lifecycle Management (PLM). • Business Process Management Systems (BPMS). • Business Process Intelligent (BPI). • Enterprise Systems (ERP, CRM, SCM, etc.). • Enterprise Content Management (ECM).

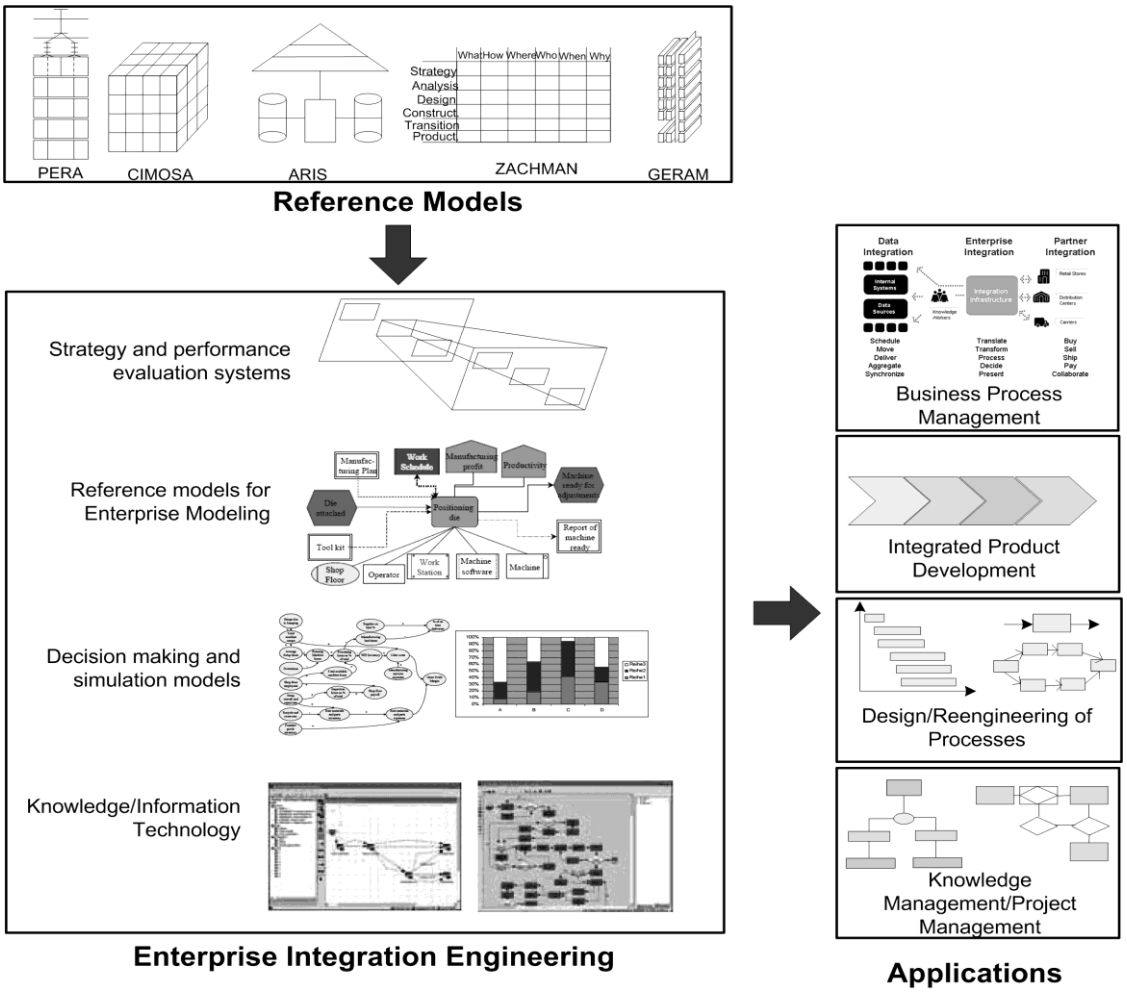

Figure 1. EIE Reference Framework, Foundations and Applications

Strategy and Performance Evaluation Systems: They support the definition of three types of strategies in the enterprise (Molina, 2003), namely:

(1) *Competitive strategy*: It should be translated into a set of decisions of how an organization can deliver value to the customer.
(2) *Value chain strategy*: It is about making decisions of how an enterprise will establish an organizational model (external and internal) that will exploit the different possibilities to build an effective and efficient value chain
(3) *Production/service strategy*: It defines how the enterprise will produce or deliver its products and/or services.

All these strategies are associated with performance measures to evaluate the impact of the strategy pursued in an organization.

Reference Models for Enterprise Modeling: It supports the visualization of enterprise knowledge, processes and associated performance measures in order to identify areas of opportunity for improvements. It comprises five groups of the main business processes to describe a generic structure of an ideal intra- and inter- integrated extended enterprise:

(1) Strategic planning.
(2) Product, process and manufacturing system development.
(3) Sales and service.
(4) Order fulfillment and supply chain management.
(5) Support services.

In Figure 2, the process groups and their interactions are depicted.

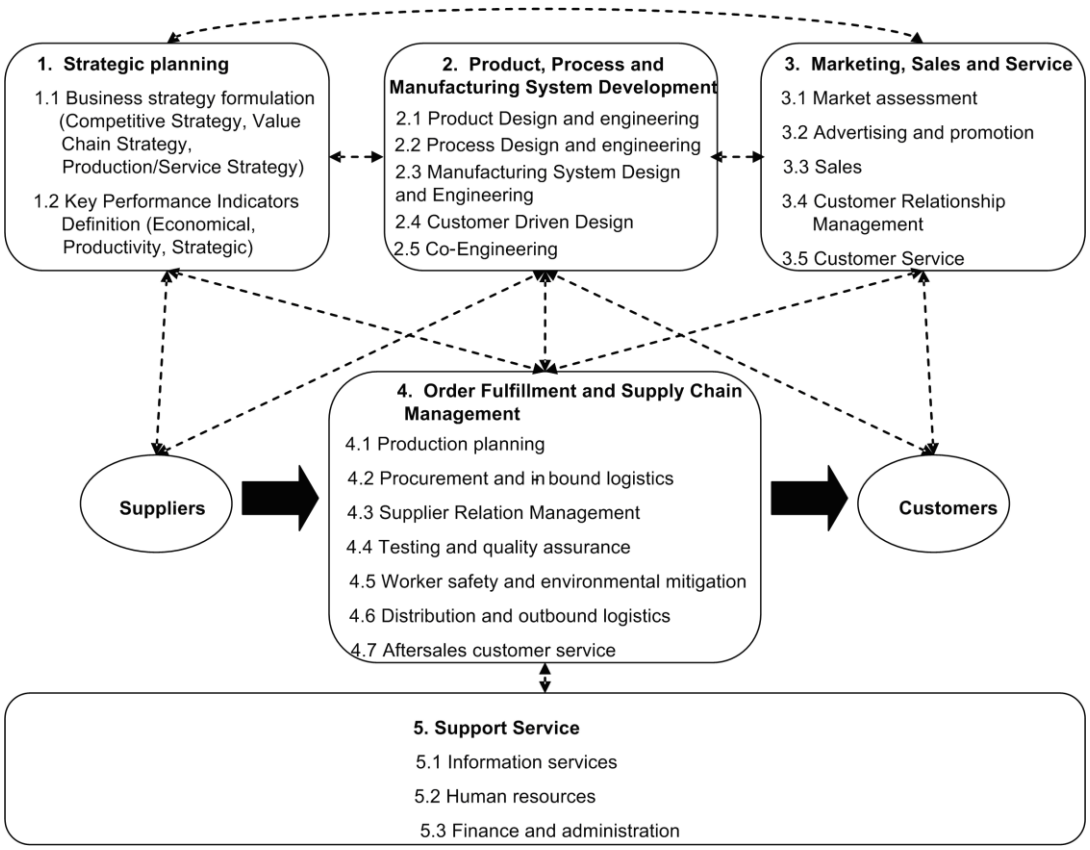

Figure 2. Enterprise Model and Integrated Business Processes

Decision Making and Simulation Models: They support the evaluation of different strategies and the implementation of the best manufacturing practices and information technologies using different simulation tools such as: dynamic systems and discrete event simulation. Best practices are defined in terms of logic program models to describe their impacts on business performance. System dynamics simulation: The applied theory of system dynamics and dynamic systems modeling method come primarily from the work of Forrester (1980). The models are built based on feedback loops of key performance measures, cause-and-effect models, feedback influences and impacts or effects. Therefore enterprise models of behavior have been developed to demonstrate the effects and impacts of best

practices implementation on performance measures (Molina and Medina, 2003). Discrete event simulation: Simulation is the most common method used to evaluate (predict) performance. The reason for this is that a quite complex (and realistic) simulation model can be constructed using actors, attributes, events and statistics accumulation. Business processes simulation can be performed, for example, in order to evaluate resource usage and to predict performance measures among others (e.g. delivery time, costs, capacity usage, etc.) (Molina et al., 2005).

Knowledge/Information Technology: PLM systems allow product data management and use of corporate intellectual capital (knowledge). PLM, BPMS and Business Process Intelligence (BPI) tools support the execution and analysis of process using business and IT perspectives. BPMS allow process design, execution and tracking based on process engine technology. BPI analysis supports decision making for predicting and optimizing processes. Enterprise systems include applications such as: ERP, CRM and SCM. Enterprise Content Management (ECM) integrates the management of structured, semi-structured, and unstructured information, such as software code embedded in content presentations, and metadata together in solutions for content production, storage, publication, and utilization in organizations (Päivärinta and Munkvold, 2005). Therefore, the utilization of PLM, BPMS and ECM systems together with BPI analysis capabilities permit to track the document lifecycle and capture experiences in the process design executed. Also, allow companies to support business change using a technology driven approach, and permit the project visibility, knowing who, what and when has to deliver each activity as well as the information and knowledge sharing along all the product lifecycle. The final goal is to integrate all the applications in order to achieve Enterprise Integration.

The EIE reference framework can be applied to different fields such as: business process management (Li et al., 2005), integrated product development (Chin et. al., 2005), processes redesign/reengineering, knowledge management and project management. The application presented in this paper, offers to scientific and industrial communities a different consideration of the Design Process as the integration of Key Business Processes and therefore, be treated with EIE formalisms. This consideration improves implementations as, nowadays, companies have a certain level of maturity around enterprise systems such as ERP, SCM or CRM, but PLM is a novel strategy that should be considered in the same way. A novel methodology is then proposed, and validated through a case study, based on A-R in order to follow a methodic approach to implement PLM tools, enabling KPI definitions and Process Modeling in order to identify key Activities, People, Information and Resources, needed to a successful implementation.

3 Methodology for implementation of PLM based on EIE and A-R

The methodology proposed in the EIE reference framework is based on Action-Research (A-R) (Barskervillea and Wood-Harper, 1996). A-R is defined as a spiral process that allows action (change and improvement) and research (understanding and knowledge) to be achieved at the same time (Barskervillea and Pries-Hejeb, 1999). A-R, which emphasizes collaboration between researchers and practitioners, has much potential for the Information Systems field, because it represents a potentially useful qualitative research method, and it supports the practical problem solving, as well as the theoretical knowledge generation (Avison et al., 2001; Chiasson et al., 2008). In this methodology, an A-R cycle is constituted by four phases:

(1) Plan
(2) Act
(3) Observe
(4) Reflect

For the PLM implementation in an integrated way, three A-R cycles are proposed, which increase the knowledge in the business model and suggest improvements in the AS-IS process (see Figure 3).

By the accomplishment of the third A-R cycle, it can be said that the PLM system is implemented. However, as EI is the integration of several enterprise systems, the A-R cycles may continue, but oriented to achieve a complete EI implementation by considering other enterprise systems (e.g. ERP, SCM, CRM) if they are not implemented yet. An improvement of the PLM system may be carried out, if needed. The different cycles of this methodology are described in the following sections.

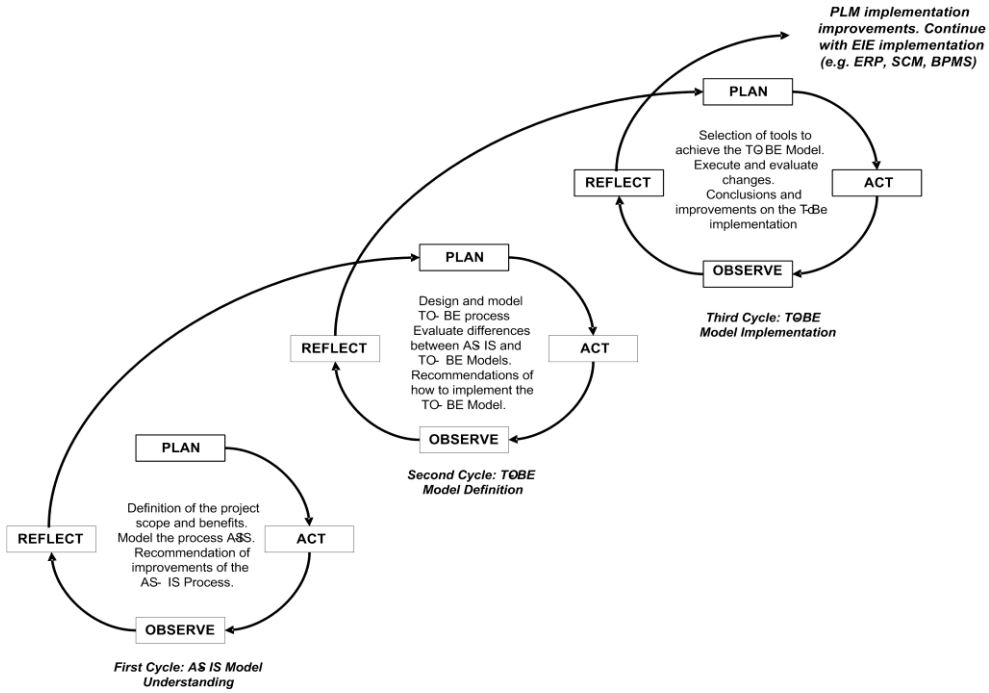

Figure 3. Methodology for a PLM implementation based on EIE and A-R

This methodology provides a progressive way to evaluate the existing processes; define KPIs; as well as design, develop, and implement an improved PLM process. It provides practical benefits as it is suited to projects of high industrial potential (consulting oriented) to implement novel and complex technologies. For this kind of approaches A-R has shown to be a valuable method to implement PLM systems with evolutionary knowledge and experiences through reflective cycles. It provides consistency across projects enabling a better planning, based on conclusions issued from reflections phases without avoiding flexibility to match project complexity.

3.1 First A-R Cycle - Enterprise Strategy and AS-IS modeling

In the first cycle the enterprise strategy has to be understood and clarified. The objectives of this first cycle are: (1) to describe enterprise strategy and its KPIs, (2) to model the process AS-IS and, (3) to suggest new improvements on the AS-IS model. These objectives are achieved using interviews with strategists and process owners, which know the current strategy of the enterprise and understand the product development process in the enterprise. The different stages of this first cycle are described next.

3.1.1 Plan

Define work team, responsibilities, activities and resources. A project plan is made, according to the scope, resources and work team defined. The integration of a multidisciplinary team is suggested, which could include strategic planners, process owners and information technology analysts to incorporate a diversity of perspectives during the AS-IS and TO-BE models definition.

Analyze the vision, mission and strategic objectives in the enterprise. This activity is a fundamental step to align the product development process improvements with the enterprise strategy. External consultants may improve process definition, because they act as impartial actors and can perform an analysis without influence of personal interests. The strategic objectives in the enterprise can be presented as KPI related to quality, volume, time, costs, flexibility and environment. These indicators will lead to the following benefits:

- Economical: Profit, Sales, ROI.
- Productivity: Value added per employee, Value added per invested capital.
- Strategic benefits: According to the competitive strategies selected by the enterprise. They can be: operational excellence (e.g. cycle time, process cost, yield), customer focus (e.g. customer loyalty, customer satisfaction), and product/process innovation (e.g. sales of new products, time for developing new products, time for recovering investment).

Define project scope, impacts and benefits for the enterprise. The PLM implementation impacts and benefits must be defined, and it must have a clear influence on KPIs (e.g. costs reduction, time to market, or improved capacity to develop products). The EIE concept can guide the efforts of implementing the PLM system pursuing Enterprise Integration.

Analyze the business strategic elements and Key Performances Indicators (KPIs). To set the context for the PLM system implementation, there is a need to clarify the enterprise strategy (competitive strategy, value chain strategy or production/service strategy). After the enterprise strategy has been clarified, KPIs are selected to monitor the impact on it. The *competitive strategy* aims to achieve competitive advantage by following at least one of these three possible strategies: (a) operational excellence, (b) product leadership, or (c) customer focus. Such generic strategies are related to Porter's (1990; 1996) proposal: Cost leadership (operational excellence strategy), differentiation (product leadership strategy) and focus (customer focus). Once the enterprise competitive strategy is understood, it is possible to translate it into a set of decisions about how the organization can deliver its value proposition to the customer. *Value chain strategy* is about making decisions on how an enterprise will establish an organizational model that will best exploit its potentials and opportunities to build an effective and efficient value chain. Different directions can be considered and adopted as a value chain strategy: (a) vertical integration, (b) strategic business units, (c) horizontal integration and (d) collaboration (vertical or horizontal network). Finally, a *production/service strategy* is based on the following elements:

- Product description: Defines criteria required for an enterprise to qualify or to win an order in a specific market.
- Customers and suppliers characterization: Defines customers' expectations and requirements imposed on suppliers.
- Process definition: Specifies performance measures required in the execution of the activities in the process.

All these factors are defined by order-qualification and order-winning criteria (Hill, 1989). The criteria are: price, volume, quality, lead-time, delivery speed and reliability, flexibility, product innovation and design, and lifecycle status. Based on all these performance measures the following production/service strategy can be defined (Rehg and Kraebber, 2005): Make-to-Stock (MTS), Make-to-Order (MTO), Assemble-to-Order (ATO) and Engineer-to-Order (ETO). New production/service strategies have been defined by Molina et al. (2007), which include Configure-to-Order (CTO) and Build-to-Order (BTO). The product/service strategy defines the criteria that must be satisfied by the enterprise in order to be able to compete in the selected markets and industries.

Table 2 – Guidelines for Strategy Definition Activity

Business Strategies	KPIs		Examples		
Competitive Strategy			**Competitive Strategy**		
• Product Leadership • Operational Excellence • Customer Focus	• New sales • New products • Operational costs • Time to deliver • Customer satisfaction • Customer loyalty	→	Product Leadership KPIs: # of new products introduced to the market, % of sales related to new products	Operational Excellence KPIs: Operational costs, Time to market	Customer Focus KPIs: Customer satisfaction
Value Chain Strategy			**Value Chain Strategy**		

• Vertical integration
• Strategic business units
• Horizontal integration
• Collaboration
  ○ vertical network
  ○ horizontal network
	• Quality
	• Volume
	• Time
	• Cost
	• Flexibility
	• Environment
		→	Horizontal integration to share resources among strategic business units
			
			Horizontal collaboration to incorporate industry partners in product innovation
			
			KPIs: Flexibility, Cost, Time
				Vertical collaboration to create a network of suppliers to reduce costs and assures time to market
				
				KPIs: Logistic costs, Time to deliver
					Strategic business units to understand better the customer requirements
					
					KPIs: Customer requirements meet, Customer claims

Production/Service Strategy	
• Make-to-Stock (MTS) • Make-to-Order (MTO) • Assembly-to-Order (ATO) • Configure-to-Order (CTO) • Build-to-Order (BTO) • Engineer-to-Order (ETO)	• Quality • Volume • Time • Cost • Flexibility • Environment

→

Production/Service Strategy		
Engineer-to-Order (ETO) to innovate and create new products KPIs: Flexibility, Cost, Time	Configure-to-Order (CTO) to reduce manufacturing cost and time to market KPIs: Manufacturing costs, Time to deliver	Build-to-Order (BTO) to create customized products KPIs: Customer rejections, mass customized products delivered

Identify the key business process with highest impact and drivers of change. PLM could support different business processes. Some of them of particular interest for authors are: co-design, co-engineering and product development. Some KPIs in PLM implementations may be: time to market, cost reductions, increase collaboration between stakeholders, improved organization efficiency, and reduction of project execution time. Other indicators defined by IT analysts are: how long it takes to a process to be executed, what resources were used to execute that process, among others (Peñaranda et al., 2007). It is important to define which process is going to be analyzed, including specific stages of the whole business process in the enterprise. The stages selected must have high benefits and impacts in selected KPIs.

3.1.2 Act

Model process AS-IS. The AS-IS model represents how the product lifecycle process (e.g. product, process or manufacturing system) is currently executed. In order to perform an efficient AS-IS analysis, the use of graphical representations is suggested, which help to identify duplicated information, parallel activities, and information and material flows. There are some standard notations and languages recommended to model business process. The first recommended by authors and possibly the most used Business Modeling Language is ARIS (Scheer, 2000). ARIS is the union of methodologies (Kalnins, 2004), where modeling with its eEPC (extended Event-Process-Chain) diagram and other related diagrams is only a part, as it takes into account different views of the business process. There are some other tools that will depend on the level of confidence and expressibility needed, such as: IDEF0 (Integrated definition methods), UML (Unified Modeling Language) and BPMN (Business Process Management Notation). Some authors give a set of parameters to select the most suitable language as, for example, those from Bertoni and Cugini (2008): Formality extent of the modeling language, Easiness of understanding, Level of detail, Goals description and Process simulation.

As mentioned languages meet authors' requirements, four domains must be represented to build the AS-IS model for the identification of the current enterprise state: process, information/knowledge, organization and resources (Mejia et al., 2004), (Molina and Medina, 2003).

- *Process domain:*
  It describes the activities of an integrated product development identifying the information flow through the product lifecycle, resources, controls, inputs and outputs incorporated in each activity. The objective is to identify the core-processes and activities of an enterprise.
- *Information/knowledge domain:*
  This domain allows the detailed description of data, information and knowledge required in an integrated product development. Their structure must be considered, in order to define the starting specifications for a Product Data Model (PDM). This facilitates the understanding of how product and manufacturing information is structured.
- *Organization domain:*
  The human resources identification and the way they are organized are defined within the organizational domain. It must establish the relations among functional areas and departments, as well as partners involved in a simultaneous engineering environment (e.g. (concurrent engineering). The organization structure is important, in order to identify the key players in engineering activities, not only for execution, but also for reviewing, supervising and monitoring.
- *Resource domain:*
  It identifies the different technologies and applications used for organizations' processes operation and management. Table 3 describes some technologies that can be classified in functional, coordination, collaboration and information management (Mejia et al, 2007).

Table 3 – Computer Applications Classification

	Functional	**Information/ Knowledge Management**	**Collaboration**	**Coordination**
Aim	To carry out and support specific functions	To share and manage Information and knowledge	To interact and communicate	To manage and control tasks
Definition	Function oriented systems that support engineers in specific tasks	Product information and knowledge management systems to enable the exchange of product and manufacturing information and knowledge	Collaboration systems to foster cooperation among engineers	Coordination systems to support sequencing of activities and flows
Examples	• CAD/CAM/CAE • ICAD (Intelligent CAD) • Knowledge-based Engineering Systems (KBES) • Simulation and Prototyping Systems	• Net meeting • Chat • Multicasting • e-mail • Computer Supported Cooperative Work (CSCW)	• Project management • Workflow systems • Groupware • e-management • e-project	• Product model • Manufacturing model • Product Data Management (PMD) • Knowledge-based management systems (KMS) • Product Lifecycle Management (PLM) system

3.1.3 Observe

Evaluate AS-IS model. Build and use discrete event or dynamic system simulations to identify improvement areas in the AS-IS model. Using these simulations is possible to identify which specific activities in the AS-IS process could be reformulated and also, which tools could improve this process. The indicators defined are measured to obtain the initial state of the model (AS-IS) before the TO-BE model implementation.

3.1.4 Reflect

Analyze and propose improvements in AS-IS model. Decide what recommendations and improvements can be made to the AS-IS model and propose KPIs for the new model (TO-BE). Evaluate the implications of changing the process in the process, information, resources and organization domains.

3.2 Second A-R Cycle - TO-BE Model Definition

In the second A-R cycle, the TO-BE model definition is proposed and analyzed. The core-process identified is improved within the enterprise strategies. These improvements are achieved using tools as dynamic system simulations and logical models. The different stages of this second A-R cycle are described in following subsections:

3.2.1 Plan

Elaborate a modeling plan based on logic models. Logic models are tools to design, plan and evaluate programs to achieve organizational benefits. Logical models are defined in terms of benefits, impacts, effects, results and activities of a specific project (Molina et al., 2000), (Alter and Egan, 1997). The pursuit of the logical model allows the identification of the performance indicators that best fit to the enterprise strategy. Therefore it is possible to define KPIs for the TO-BE model. Different logic models of best manufacturing practices have been defined in order to describe the potential impact in an enterprise of a specific project (Molina et al., 2000).

In Table 4, different components of the logical model have been mentioned of what must be defined in a logic model.

Subsequent table (Table 5) describes all the activities, results, effects, impacts and benefits of implementing a PLM using an Action-Research methodology.

Table 4 – Logical Model to define Best Practices

Activities	Results	Changes/Effects	Impacts	Benefits
Activities to be performed by the improvement project using different methodologies, human resources and technologies	Products produced by project activities, immediate results of the project	*Enterprise:* • Strategies • Policies • Processes *Business Process:* • Strategic planning • Product, Process and Manufacturing System Development • Marketing, Sales and Service • Order Fulfilment and Supply Chain Management • Support services *Organization:* • Structure • Practices/ Procedures • Techniques/ Methods *Human Resources:* • Ability (leadership) • Experience (best practice) • Knowledge (technique) *Technological Resources:* • Information Systems: - Design - Implement - Operate • Machinery and Equipment: - Optimize - Adapt - Replace	*Performance Indicators:* • Quality • Volume • Time • Costs • Flexibility • Environmental	*Economical:* • Profit • Sales • ROI *Productivity:* • Value added per employee • Value added per invested capital *Strategic:* • Operational Excellence - Cycle time - Process cost - Yield • Customer Focus: - Customer loyalty - Customer satisfaction • Product Leadership: - Sales of new Products - Time for developing new products - Time for recovering investment

Table 5 – Definition of the PLM implementation using a Logical Model

Activities	Results	Changes/Effects	Impacts	Benefits
FIRST CYCLE: AS-IS Model Understanding *PLAN* • Define work team, responsibilities, activities and resources • Analyze the enterprise vision, mission and strategic objectives. • Define the project scope, impacts and benefits for the enterprise • Analyze the business strategic elements and KPIs • Identify the key business process with highest impact	*FIRST CYCLE: AS-IS Model Understanding* • Project benefits, impacts, strategies and work team defined • Objectives and priorities of the enterprise identified • Key business process identified • KPIs identified • AS-IS model developed • Improvements proposed in the AS-IS model	*Enterprise:* • Organize nodes to disseminate best practices in design, manufacturing and management practices • Evolve to process oriented engineering projects *Business Process:* • Improvement in Product , Process and Manufacturing System Development process *Organization* • Change team structure and sequence of	*Performance Indicators:* • Value added for invested capital • Profitability • Productivity • Customer satisfaction with final product • Customer satisfaction with service provided • Time to deliver- Product Development time (on a like-to-like project basis) • Time to deliver- Product Development time predictability (variation from	*Economical:* • Bring products to market faster, reducing costs • Decrease process cycle time and cost *Productivity:* • Efficiently find and reuse successful designs • Identify duplicated activities, increasing value added by employee *Strategic:* • Operational Excellence: - Leverage the experience gained in related design

and drivers of change ACT • Model the process AS-IS OBSERVE • Evaluate the AS-IS model REFLECT • Analyze and propose improvements in the AS-IS model		activities • Allocate resources in the way with greatest return on investment in a product portfolio *Human Resources:* • Cultural changes in support of innovation • Improve knowledge in TO-BE model defined • Project members trained in PLM systems *Technological Resources:* • Product Lifecycle Management (PLM) tools • Product Data Management (PDM) • Content management application and project management • Design to retire applications (CAD, CAM, CAE) • Collaboration enablers • Visualization	design to delivery) • Cost-Initial cost predictability (variation from design to delivery) • Cost- Initial cost (on a like-to-like project basis) • Quality -Incidence of product defects • Quality -Incidence of design correction • Flexibility • Value added by employee (Profit / # employee) • Environment - Safety	and development projects conducted in other business units and/or at other enterprise locations - Adopt new business models that provide a more competitive position than business models of the past - Improve the product development process oriented to product development time reduction - Gather and transfer knowledge related to product design • Product Leadership: - Design better performing products - Design for maximum manufacturability - Decrease time for developing new products • Customer Focus - Improve the product development process oriented to customer loyalty
SECOND CYCLE: TO-BE Model Definition *PLAN* • Elaborate a modelling plan based on logic models *ACT* • Design and model TO-BE process *OBSERVE* • Evaluate the TO-BE model *REFLECT* • Analyze the differences between AS-IS vs. TO-BE • Define the scope of TO-BE implementation	*SECOND CYCLE: TO-BE Model Definition* • TO-BE model designed • Proposal about improvements in organization, resources and process • Assessment of potential improvements • The differences between AS-IS and TO-BE model analyzed			
THIRD CYCLE. TO-BE model implementation *PLAN* • Elaborate an implementation plan based on logical models and the TO-BE model *ACT* • Execute changes in workflow process, organization, human and technological resources *OBSERVE* • Perform accountability of changes, impacts and benefits *REFLECT* • Conclusions and improvements in workflow process, organizations, human and technological resources	*THIRD CYCLE. TO-BE model implementation* • PLM implemented (knowledge/ information management tools, collaboration and coordination tools) • Changes in workflow process, organization, human and technological resources • Changes, impacts, and benefits measured • Team with experiences in PLM systems (cultural change)			

3.2.2 Act

Design and model the TO-BE process. Modifications in the TO-BE model are included for improving process efficiency. The TO-BE model reflects the team's improved process to be implemented in the PLM system. Also, this TO-BE model will be the base to define the product development workflow in the following stages. As well, as in the AS-IS model definition, process modeling notations as ARIS, IDEF0, UML and BPMN are recommended to describe the TO-BE model. Barros and Hofstede (2008) propose five principles that have to be considered when modeling the conceptual business workflows: (1) organizational embedding, (2) scenario validation, (3) service information hiding, (4), cognitive sufficiency, and (5) execution resilience. According to Armistead and Machin (1997), there are tendencies about the role of processes in structuring organizations and, in particular, the development of horizontal organizations structured purely around processes. In general, the organizations appeared to be taking a less radical view. Instead they had developed matrix-based organizations between functions and processes, and tended to adjust their functional structure to align with their identified processes.

3.2.3 Observe

Evaluate the TO-BE model. The use of dynamic systems and/or discrete simulation is considered at this stage in order to determine impacts and benefits in the TO-BE model. This evaluation is based on the objectives defined in the logic model.

3.2.4 Reflect

Analyze the differences between AS-IS and TO-BE models and define specific projects. This activity intends to identify the differences between the AS-IS and the TO-BE model. It decides benefits and impacts in the current product development process. Impact on the organization and project members are difficult to measure and analyze, but it is recommended to get them involved in the entire implementation project to achieve a greater acceptation.

Define the scope of the TO-BE model implementation. It is necessary to define which will be the first stages in the proposed process that are going to be implemented in the third A-R cycle. Therefore the implementation is done by phases, which optimize resources (human and technological) in the implementation cycle (the third A-R cycle).

3.3 Third A-R Cycle - TO-BE model implementation

In this third A-R cycle a set of tools are selected to implement the TO-BE model proposed. An essential consideration for the TO-BE model implementation is the interoperability between selected technologies. Important efforts are being done by research communities on maturity models for interoperable environments according with the stakeholders' requirements. Therefore, it is essential to consider standards for the feasibility to introduce innovative technologies for interoperability, tending to achieve PLM objectives (Subrahmanian et al., 2005).

The stages of this third A-R cycle are described as follows:

3.3.1 Plan

Elaborate an implementation plan based on logical models and the TO-BE model. In this activity benefits, impacts, effects, results and activities are defined in the implementation project. Also, tools/applications are selected to complement the TO-BE model. This activity is used to set-up the entire technological infrastructure (applications and tools) and personal training. The infrastructure must be aligned with the TO-BE model, and this infrastructure must not be selected before developing the TO-BE model. This last issue is essential to be successful in the PLM implementation.

3.3.2 Act

Execute changes in workflow process, organization, human and technological resources. Based on the TO-BE model, changes in mentioned resources are executed. These changes are carried out in the technological infrastructure that was implemented in the previous stage. Garetti et al., 2005 propose three ways to implement these changes in the enterprise: (1) The niche project and follow-up approach - this is

the selection of a niche area inside the enterprise to implement and verify the results and benefits of the implementation experiment in a comparatively short time; (2) the overall and step-by-step approach - which needs more time to careful planning of the project within the full enterprise scale; and (3) mixed strategy - where many project segments are organized, adopting the niche mode.

3.3.3 Observe

Perform accountability of changes, impacts and benefits. Measurable parameters and monitoring techniques that allow business managers to coordinate, track and control the product development process are identified. The workflow model has to be considered, in order to have a guideline for associating all measurable data. This data includes, for example, the enterprise and suppliers resources involved in each activity (human and technological), which are important for cost estimations (important measurable parameter) and also for workload analysis. Furthermore, assigned dates and time for each partner are also included, in order to control delays or precedence problems based on unfinished activities. Similarly, activities' input and outputs should be controlled, for managing information flow and availability of further activities (Peñaranda et al., 2006).

3.3.4 Reflect

Conclusions and improvements in workflow process, organizations, human and technological resources. After the environment is technologically integrated and implemented, it has to be managed and the loop for continuous process management is closed by the use of monitoring techniques. It provides external visibility while product development is being executed. The process management tracks events and data from the workflow execution and provides both real-time and historical tracking of what occurs in the workflow engine. Finally, an improvement process is performed, in order to analyze a possible new TO-BE model (the current process in execution is now converted in the AS-IS) and maybe new design ameliorations can be proposed to improve the business process (Peñaranda et al., 2006). After this cycle, Enterprise Integration implementation could be continued with the integration of different business processes in the enterprise or the improvement of the PLM system implemented.

4 Case Study

The following case study was developed in a Mexican SME (Small and Medium Enterprise) named IECOS (Integration Engineering and Construction Systems). A key advantage of having access to this company was the company size as, for SMEs, access to information and close contact with managerial levels facilitates the task of understanding the AS-IS model. The opposite case can be experienced with OEMs (Original Equipment Manufacturers) as the way to capture the AS-IS model is usually more difficult.

4.1 First A-R Cycle - AS-IS Model Understanding

4.1.1 Plan

Define work team, responsibilities, activities and resources. The multidisciplinary team in charge of developing this project was composed by: (1) PLM implementation team and (2) product development process actors (Based on A-R principles). The "PLM implementation team" was constituted by an IT analyst and a product development process specialist, their main activity was to lead and advise the achievement of the project. Three main "product development process actors" were identified: IECOS it-self, manufacturing supplier and the customer.

Analyze the vision, mission and strategic objectives in the enterprise. The commitment of the enterprise was confirmed, as IECOS had interest in strengthen the product development process. For this reason a technological area was created to generate and innovate in new products. The current interest in the enterprise is to produce "medical devices", as it offers a great business opportunity.

Define the project scope, impacts and benefits for the enterprise. The project objective is to optimize performance in "Engineering-to-Order (ETO)" business processes (production/service strategy) which is based on an architecture that naturally integrates customers and suppliers. The project scope is focused on product design and manufacturing. IECOS has been working in collaborative environments to integrate suppliers and customer, and to achieve a complete EIE it is necessary to implement a system that impacts

on the following issues of the product development: (a) time to market reduction, (b) project management improvement, (c) project team integration improvement, and (d) increasing product quality. These benefits can be reached with a structured and effective PLM implementation.

Analyze the business strategic elements and KPIs. The business strategic elements and the key performance indicators impacted are clarified in table 6:

Table 6 – IECOS's Selected Strategies

Strategies	IECOS' Strategies	KPIs
Competitive Strategy	• Product Leadership (leading strategy) • Operational Excellence (supporting strategy)	• Product development time • Product development cost
Value Chain Strategy	• Horizontal integration to incorporate all project members in the product lifecycle • Horizontal collaboration between IECOS with customers and suppliers	• Product development time • Number of design iterations • Incidence of product defects
Production/Service Strategy	• Engineer-to-Order (ETO) to innovate and create constantly new products†	• Product development time • Number of design iterations • Incidence of product defects

Identify the key business process with highest impact and drivers of change. The core-process defined was the product development process, which starts from customer's requirement to product manufacturing. This process implies a high collaboration between project members. For this reason, collaborative, coordination and information management tools would be evaluated and selected to support collaborative business processes.

4.1.2 Act

Model the process AS-IS. Interviews were carried out by the PLM implementation team to the product development process owners and actors who described their roles in the product development process. Activities from each partner (IECOS, Customer and Supplier) are shown in Figure 4:

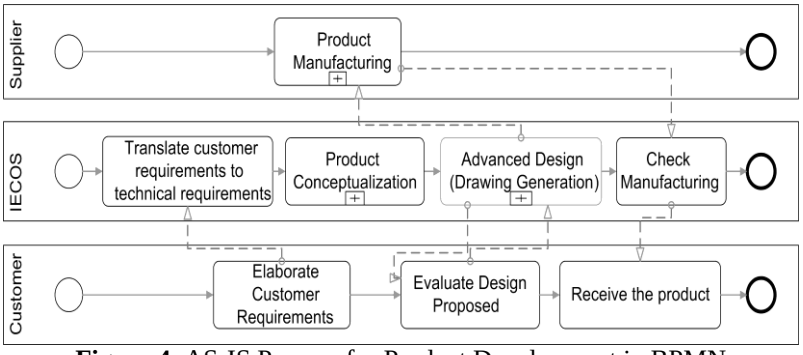

Figure 4. AS-IS Process for Product Development in BPMN

4.1.3 Observe

Evaluate the AS-IS model. After analyzing the product development process by the BPMN model, some conclusions were obtained. The AS-IS model has been used by IECOS in several projects, but many problems were discovered in the collaboration and document management between project members. Information is distributed by e-mail or fax; design and manufacture tasks are discussed in face-to-face meetings and sometimes via phone calls. Due to the lack of integration, the design is evaluated by the customer in the last stages of the design process. This issue causes several iterations in the process (conceptualization and advanced design sub-process). This causes that process owners have to re-make many activities resulting on a lack of time for product improvements.

† ETO strategy is related to products that are manufactured to meet specific customer's needs, requiring unique engineering design or significant customization. Main characteristics in this model are: high customization, long delivery time, no inventory level, high product complexity, and the source of competition is based on differentiation and no repetitiveness (Amaro and Hendry, 1999).

4.1.4 Reflect

Analyze and propose improvements in the AS-IS model. In the AS-IS model, some problems were identified, as information sharing and all actors involvement in each project's decision. Information can be stored and captured; however, there are difficulties to retrieve stored information. Changes in the product development process, organization, human and technological resources are necessary to improve the current model. Improvement of the customer requirements capture, using QFD tools, can decrease the customer interaction in the design process, although the use of collaboration tool is necessary to improve the interaction between IECOS and the manufacturing supplier (Revelle et al., 1998).

4.2 Second A-R Cycle - TO-BE Model Definition

4.2.1 Plan

Elaborate a modeling plan based on logic models. Table 7 summarizes the logical model developed. It describes the benefits, impacts, effects, results, activities and problems/necessities in the TO-BE definition. The final objective of this TO-BE model is to improve collaboration, document management and coordination within the project team along the entire product lifecycle.

Table 7 – Logical Model Summary: Second A-R Cycle Plan

Logic Model	
Benefits	• Strategic: Improve the product development process oriented to product development time reduction. • Productivity: Identify duplicated activities, increasing value added by employee, improve project team integration.
Impacts	• Increase value added by employee. • Decrease incidence of design correction.
Effects/ Changes	• Enterprise: Evolve to a process oriented engineering projects. • Human Resources: Improve knowledge in the TO-BE model defined. • Organization: Change in the team structure by involving customer and suppliers in the product development decisions.
Results	• TO-BE model designed (organization, resources and process improvements). • Proposal about improvements in organization, resources and process. • Assessment of potential improvements. • The differences between AS-IS and TO-BE model analyzed. • Experiences in the TO-BE model definition.
Activities	• Implementation methodology (A-R).
Problem	• Lack of time of the process owners.

4.2.2 Act

Design and model the TO-BE process. The product development process has been re-configured to allow customer monitoring along the entire process (see Figure 5). Also, supplier can interact and participate in the design process developed by IECOS, achieving a design that minimizes potential problems in the manufacturing and assembly stages. A unique product data management is used to store, capture and retrieve all product information generated by the project team. Using this proposed model, a workflow can be developed to automate the process, and the team coordination can be improved.

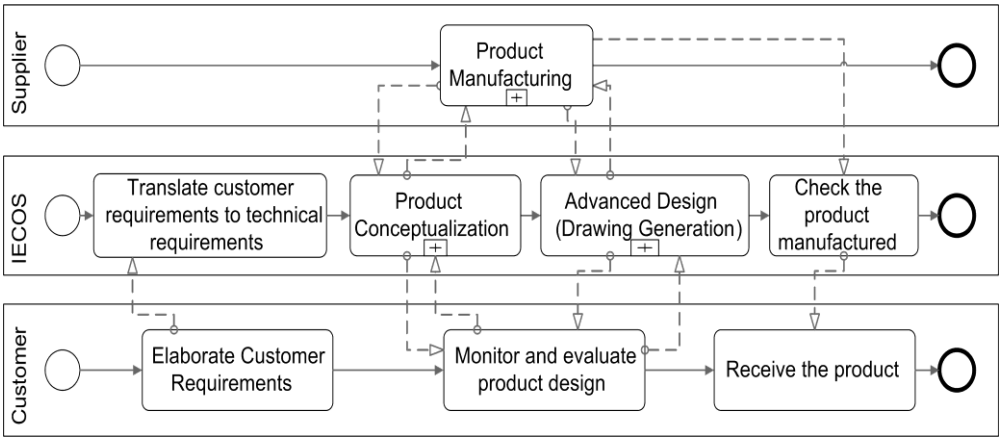

Figure 5. TO-BE Process for Product Development in BPMN

Some changes in the organization, process, information and resources are necessary to achieve this business opportunity:

- **Organization Domain.** A new organizational structure has to be developed, including the product development area. Customer and suppliers have to actively participate in design decisions, improving customer satisfaction and manufacturing quality and cost.
- **Functional Domain.** Product development process has to be extended to manufacturing development. Some activities were added to involve suppliers and customer in the design phases.
- **Information Domain.** IECOS presents a product information model. This model is structured in components, which are associated with product functions. Link the Manufacturing model with the product model, using bill of materials and manufacturing specifications were developed.

4.2.3 Observe

Evaluate the TO-BE model. The improvements in the TO-BE model are focused on the implementation of the coordination, collaboration and information/knowledge management tools, which reduce the product's time to market and improve the quality.

4.2.4 Reflect

Analyze the differences between AS-IS and TO-BE models and define specific projects. The main difference between AS-IS and TO-BE models is the possibility to integrate all project members in each design decision. The information is stored and can be retrieved for future projects (achieving Knowledge Management). Under this approach, project evolution can be consulted by using workflows, capturing the knowledge generated in each project phase.

Define the scope of the TO-BE implementation. This implementation is going to be focused on product development process in IECOS, from product conceptualization to product manufacturing. For this reason, it is required to involve the customer and manufacturing supplier in this implementation.

4.3 Third A-R Cycle - TO-BE Model Implementation

4.3.1 Plan

Elaborate an implementation plan based on logical models and the TO-BE model proposed. Improvements in the TO-BE model are focused on the implementation of coordination, collaboration and information/knowledge management tools. They contribute to reduce the time to market and improve the product quality. An integration of functional tools is proposed to achieve coordination between different actors, which have different tools to develop their activities. This integration is reached by using document imaging and CAD viewers to integrate the content of these functional tools. The logical model developed in this A-R cycle identifies benefits, impacts, effects, results, activities and problems/necessities (see Table 8).

4.3.2 Act

Execute changes in workflow process, organization, human and technological resources. In this stage, proposed TO-BE model is implemented and changes in the workflow process, organization, human and technological resources are described as follows:

Workflow Process: The product development process was built in the workflow execution system of SmarTeam (Dassault Systèmes) platform (see Figure 6), based on the proposed TO-BE model. This workflow allows information traceability and an overall view of the design process. Each activity contains a set of tasks, and it is linked to a specific user, who becomes responsible of tasks accomplishment. Documents, such as QFD results, can be attached to any activity of the workflow, enhancing decision making according to product specifications throughout the entire product design process.

Table 8 – Logical Model Summary: Third A-R Cycle Time

Logic Model	

Benefits	• Economical: Bring product to market faster, reducing costs.
	• Productivity: Increase in aggregate value per employee and per invested capital.
	• Strategic:
	  o Product Leadership: Increase time for developing new products.
	  o Operational Excellence: Decrease process cycle time and cost, Gather and transfer knowledge related to product design.

Impacts	• Decrease product development time (project time). • Decrease number of design corrections (hence less iterations). • Increase product quality (less incidence of product defects).

Effects/ Changes	• Technological Resources:
	  o Use of PLM system for project development, based on TO-BE model definition.
	  o Functional tools integration (data and application integration).
	• Organization:
	  o Change team structure and sequence of activities.
	• Human Resources:
	  o Project members trained in PLM systems.
	  o Multidisciplinary team in place.

Results	• PLM implemented (knowledge/information management tools, collaboration and coordination tools). • Changes in workflow process, organization, human and technological resources. • Team with experiences in PLM systems (cultural change).
Activities	• Implementation Methodology (A.R).
Problem/ Necessity	• Cultural changes (resistance to use a new technology and concept). • Investment in new technologies.

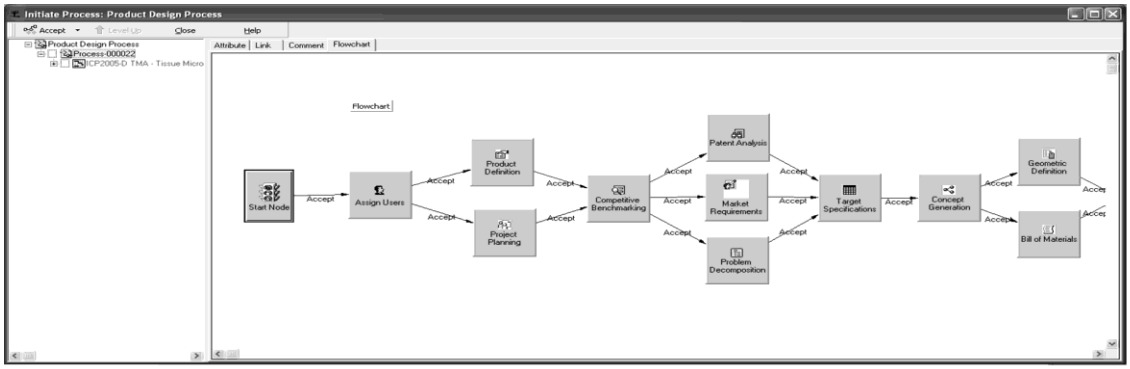

Figure 6. Product Conceptualization Sub-process: Workflow Process developed on SmarTeam

Organization Resources: IECOS organization has been modified to support a horizontal integration in the product development process, and a set of specific activities were identified for each project member. Marketing, manufacturing (supplier) and design department were integrated in one product development process, and each one has specific responsibilities over the final product, not only in their particular areas.

Human Resources: The main activity was the training and support in the PLM system. The training was given to suppliers, customer and product design team. Convincing them that using PLM tools can improve the collaboration and the information management process is an important task for the success of this implementation.

Technological Resources: In this case study, SmarTeam and QuickPlace/SameTime were implemented as PLM technological platform. SmarTeam offers an information/data management (see Figure 7), which is supported by logical links between product data, metadata creation and tree structure data. Also, SmarTeam offers a web module, which allows the information integration inter/intra enterprise and a viewer module that allows information sharing between the project team, without special applications to visualize some documents (e.g. CAD files).

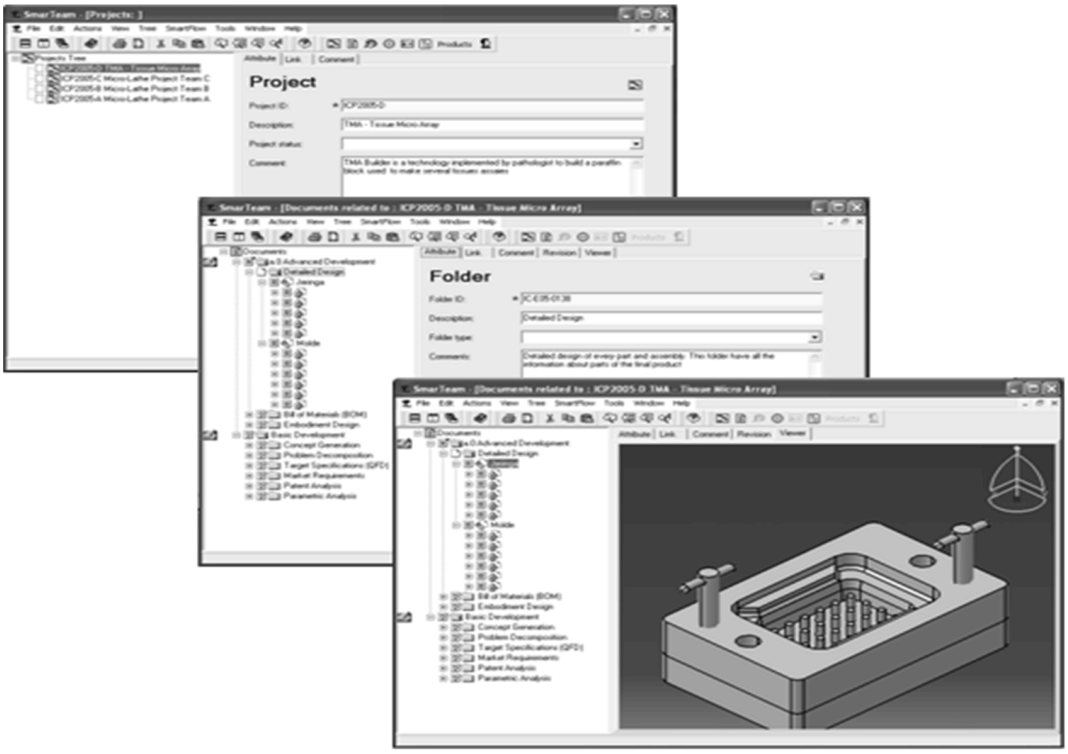

Figure 7. Product Data Management loaded into SmartTeam

QuickPlace (IBM application) is used as the collaboration platform. It is a workspace on the Web for team collaboration among customers, suppliers and Business Partners. QuickPlace provides access to information and documents at any time whether team members are co-located or geographically dispersed. In this platform, additional documents related to project management (e.g. project members, due dates, instructions or tutorials) or documents related to document management (as version control) may not be needed (Figure 8). Also, QuickPlace can interact with SameTime, which provides chat, videoconferences, whiteboard and applications sharing in order to enhance collaboration.

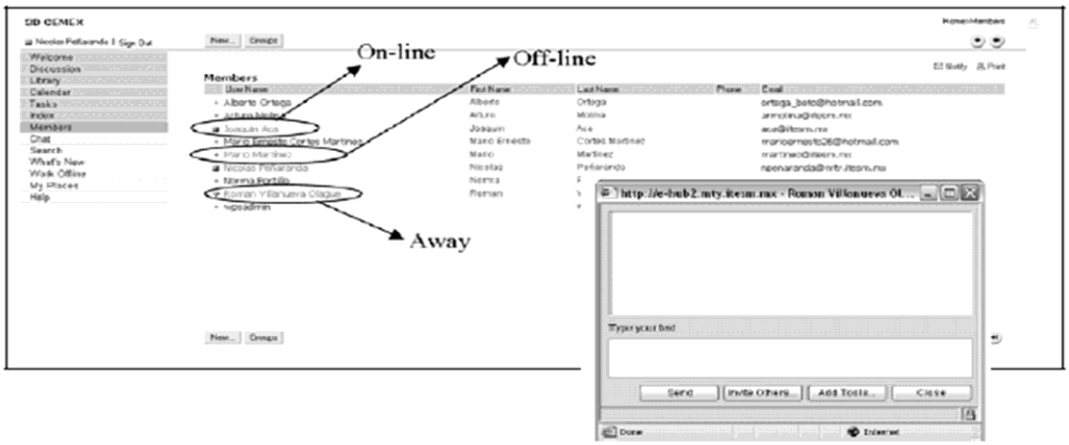

Figure 8. QuickPlace and SameTime Collaborative Tools

The complete component architecture is described in Figure 9, which requires the following IT infrastructure:

- E-HUB1 Server: Support the License Use Management and the QuickPlace.
- E-HUB2 Server: Support the SmarTeam Data Base and the SameTime.
- IBM-ST Server: Support the SmarTeam Foundation, Vault Server and SmarTeam Editor.
- CAX Server: Support SmarTeam WEB Editor and SmarTeam editor.
- PLMDC Server: Support the Domain Controller.

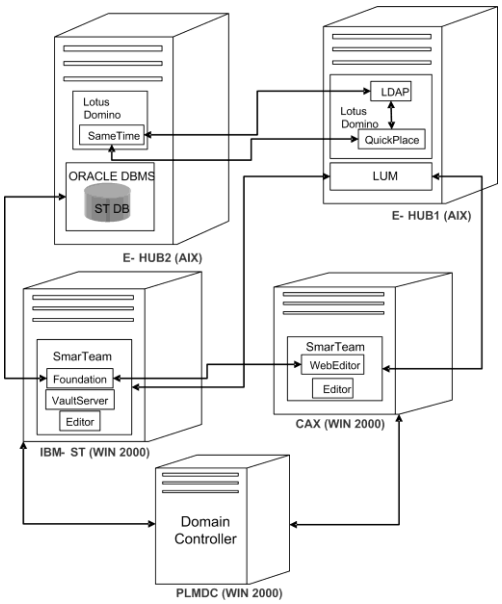

Figure 9. SmarTeam's Component Architecture

This architecture is the minimum infrastructure needed to obtain an optimal performance. Also, this architecture serves for ERP, SCM and/or CRM systems to achieve a complete EI. In the case study treated in this paper, the product development and supply management was included, achieving integration between the suppliers and customer by using Web applications (QuickPlace/SameTime and Web module of SmarTeam).

Finally the product manufacturing was achieved by being totally carried out through the implemented PLM system (see Figure 10). However the interaction between suppliers and designers was not supported this time by the collaboration tools implemented.

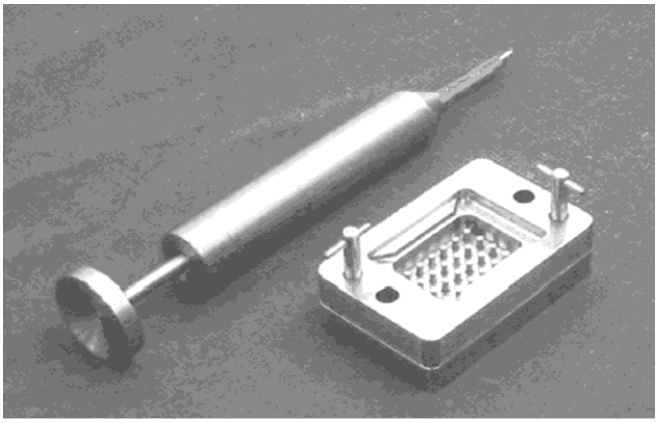

Figure 10. Final Product Manufactured using the Implemented PLM System

4.3.3 Observe

Perform accountability of changes, impacts and benefits. In this implementation the information/data management was improved, but it was difficult to completely integrate the suppliers and the customers. The workflow and the document management were only used by the design team (IECOS) to develop the product design. Using the PLM system, problems as version control, document search and retrieval, and project coordination were solved. Some indicators considered were:

- *Reduced time execution for the product development time (the entire project):* This reduction is because the improvement of the document management and also, the number of design iterations were reduced.
- *Improvement of the Integration level (suppliers, designers, and customer):* The integration was not fully accomplished, but the customer was able to check and comment the design of his

product while it was being developed. The supplier had some problems for the integration, and he only participated in the last stages of the process design.

4.3.4 Reflect

Conclusions and improvements in workflow process, organizations, human and technological resources. PLM implementation improved the information management, team organization and integration in the product design stages. The difficulty to completely integrate the customer and the supplier has revealed that the main problem is not the technological implementation, but the difficulty to carry out the cultural change within project members. Improvements in the time execution and project management were the key factors to achieve a successful implementation.

4.4 Reference Model and Methodology Results

In the case study presented throughout this paper, a successful PLM system implementation was carried out. However, other changes, such as process, human and organizational improvements, had great results on the enterprise. These results can be summarized in:

- *An improvement in the project management:* Changes in the process design and application of workflow systems showed a clear definition of each activity that has to be developed. In this case, each activity contains multiple tasks and was linked with standards formats to be filled by each responsible. The use of a workflow system (supported by Smart Team), enables process automation, enabling product development manager to know exactly the project status. With this system, the product development manager can be informed of responsibilities, problematic activities or deadlines.
- *Integration of suppliers and customers:* Key stakeholders were integrated during design process. Consequently, changes in the organization (roles definition) and process were carried out. These changes were supported with collaboration tools that enabled this integration.
- *Better document management.* Information search and retrieval is an important aspect to reduce Time-to-Market. Finding where the information is, produces a high spend of time as well as rework time spend. The use of product data management systems is an important solution, which centralizes all the information in a common database. This systems present metadata searchers and the possibility to link related data. These characteristics enable to search and retrieve information without asking other team members, improving efficiency and reducing product development time.

5 Conclusions

A PLM implementation methodology based on EIE and an A-R approach was described in this paper, as well as the results of its application in an industrial case study. The use of EIE reference model was an important aspect to propose a holistic reference model that can include key concepts such as enterprise modeling, enterprise strategy and technologies integration. Consequently, these concepts were included by authors to obtain a systematic methodology. Nevertheless, that was not enough. It was necessary to include the A-R concept as it is a practical and easy to use research method that gives to the methodology the possibility to be evaluated in each cycle and consequently to be improved. Moreover, A-R gives the possibility to reflect in each end of cycle and make decisions whether to follow to the next cycle or not.

PLM systems are a market differentiated and value-added customer solution that can be used to decrease project time and enhance product development process in a company. The proposed methodology is a systematic approach that offers a set of tools to achieve inter/intra-enterprise integration, enabling customer and suppliers to actively participate and monitor the product development process. During case study, some important factors for the implementation of these tools in the enterprise were identified such as:

- *The cultural change.* It is very difficult to change the way that some people are used to work. The main barriers to the success of PLM implementation may be: weak project management leadership, weak participation and commitment of team members (particularly the core team) and a lack of integration with geographically distributed partners.
- *PLM tools learning curve*. It is important to consider the time spent on training and learning how to use these tools. Generally, these tools are very specialized, and new vocabulary appear in the day to day work (e.g. check in, check out, release documents, etc.). For this reason the training process must to be a key activity in PLM implementation process. Suppliers and customer need training as well and continuous support in the first stages of the implementation.

Further Research. As the PLM strategy is getting more and more acceptance in the industrial sector of developing countries, authors of this paper will continue to research around PLM implementations on Latin-American industries and all related methods and tools to facilitate their implementations and its approach to achieve full enterprise Integration. Future work includes the extension of the EIE Reference Framework toolkit for supporting the implementation of different engineering tools such as PLM systems as presented in this paper. After this experience, some limitations of the methodology may be stated as future work. For example, no "change management" strategies were tackled as, during implementation, the cultural change made difficult to achieve some tasks as they were planned. As it has been seen, usually PLM end-users are initially reluctant until they really see the day-to-day advantages on their own activities improvements. A stage to raise awareness, after third A-R cycle, may be of interest to research and industrial communities. This opportunity enables researchers and practitioners to think on strategies to implement PLM systems, but also to consider Post-implementation processes. There is also another opportunity on monitoring current projects developed under implemented PLM in order to collect some data and further experiences.

6 Acknowledgements

The research presented in this document is a contribution for the "Rapid Product Realization for Developing Markets Using Emerging Technologies" Research Chair, ITESM, Campus Monterrey (Mexico), the "Technological Innovation" and "Design of Mechatronics Products" Research Chairs, ITESM, Campus Ciudad de México (Mexico) and the "PLM tools implementation process for engineering projects" Research chair, EAFIT University (Colombia).

7 References

1. Alter, C. & Egan, M. (1997). Logic Modeling: A Tool for Teaching Critical Thinking Practice Evaluation. *Journal of Social Work Education*, **33** (1).
2. Amaro, G., Hendry, L.B. (1999). Competitive advantage, customization and a new taxonomy for non make to stock companies. *International Journal of Operations and Production Management.* **19**, 349-371.
3. Armistead, C. & Machin, S. (1997) Implications of business process management for operations management. *International Journal of Operations & Production Management*, **17,** 886-898.
4. Avison, D., Baskerville, R. & Myers, M. (2001). Controlling action research projects. *Information Technology & People*, **4**, 28-45.
5. Barros, A.P. & Hofstede, A.H.M, (2008) Towards the construction of workflow-suitable conceptual modeling techniques. *Information Systems Journal*, **8,** 313-337
6. Bertoni, M. and Cugini, U. (2008) Representing and sharing process knowledge in PLM systems design. *In proceedings of the 5th International Conference on Product Lifecycle Management*. Seoul, Korea.
7. Bygstad, B., Nielsen, P.A. & Munkvold, B.E. (2008) Four integration patterns: a socio-technical approach to integration in IS development projects. *Information Systems Journal*, Online Early Articles, DOI:10.1111/j.1365-2575.2007.00280.x
8. Chen, D., & Vernadat, F. (2004). Standards on enterprise integration and engineering – A state of the art. *International Journal of Computer Integrated Manufacturing*, **17**, 235-253.
9. Chiasson, M., Germonprez, M., & Mathiassen, L. (2008) Pluralist action research: a review of the information systems literature. *Information Systems Journal*, Online Early Articles, DOI: 10.1111/j.1365-2575.2008.00297.x
10. Chin, K.S., Lam, J., Chan, JSF., Poon, K. and Yang, J. (2005). A CIMOSA presentation of an integrated product design review framework. *International Journal of Computer Integrated Manufacturing*, 1362-3052, **18** (4), pp. 260–278
11. Cuenca, L., Ortiz, A. and Vernadat, F. (2006) From UML or DFD models to CIMOSA partial models and enterprise components. *International Journal of Computer Integrated Manufacturing*, **19** (3), pp. 248 – 263.
12. Forrester, J. (1980). *Principles of systems: text and workbook.* Cambridge, Mass. MIT.
13. Hill, T., (1989) *Manufacturing Strategy, Homewood,* Irwin, R.D. & Homewood, I.L. (eds.)
14. Gao, J.X., Aziz, H., Maropoulos P.G. & Cheung W.M. (2003). Application of Product data management technologies for enterprise integration. *International. Journal of Computer Integrated Manufacturing*, **16,** 491-500.

15. Garetti M., Terzi S., Bertacci N. & Brianza M. (2005). Organizational change and knowledge management in PLM implementation. *International Journal of Product Lifecycle Management.* 1, 43-51.
16. Grieves, M. (2006). *Product Lifecycle Management: Driving next generation of the lean thinking*. McGraw Hill. New York, USA.
17. Jianjun, Y., Baiyang, J., Yifeng, G., Jinxiang, D. and Chenggang, L. (2008). Research on evaluation methodologies of product life cycle engineering design (LCED) and development of its tools. *International Journal of Computer Integrated Manufacturing*, **21** (8), pp. 923-942
18. Jun, H.B., Shin, J.H., Kiritsis, D. and Xirouchakis, P. (2007). System architecture for closed-loop PLM. *International Journal of Computer Integrated Manufacturing*, **20** (7), pp. 684-698
19. Kalnins, A. (2004) "Business modelling. Languages and tools", *Mathematics in Industry*, **4**, pp.41-52.
20. Li, H., Fan, Y., Dunne, C. and Pedrazzoli, P. (2005). Integration of business processes in Web-based collaborative product development. *International Journal of Computer Integrated Manufacturing*, **18** (6), pp. 452 – 462
21. Mejía, R., Aca, J., Ahuett, H. & Molina, A. (2004). Collaborative e-Engineering Environments to Support Integrated Product Development. In: *Emerging Solutions for Future Manufacturing Systems.* Camarinha-Matos, L.M. (ed.), pp. 271 – 278. Springer, Austria, IFIP.
22. Mejia R., Lopez A. and Molina A. (2007). Experiences in developing collaborative engineering environments: An action research approach. *Computers in Industry*. **58** (4), pp. 329–346.
23. Ming X. G., Yan J. Q., Lu W. F., & Ma D. Z. (2005). Technology Solutions for Collaborative Product Lifecycle Management – Status Review and Future Trend. *Concurrent Engineering: Research and Applications* **13**, 311-318.
24. Molina A. (2003) "Developing the Enterprise Concept – The Business Plan". In: *Handbook on Enterprise Architecture*. Bernus, P., Nemes, L. & Schmidt, G. (Eds), pp. 333 – 369, Berlin: Springer.
25. Molina, A., Flores, M., & Caballero, D.M. (2000). Enquete sur les indicateurs de productivite et les meilleures methodes de l´industrie manufacturiere de Monterrey (Mexique) a travers une etude de Benchmarking. *Revue Francaise de Gestion Industrielle*, **19,** 63- 75, (in French).
26. Molina A., Garza J. & Jiménez G. (2005). Enterprise Integration Engineering as an enabler for Business Process Management. In: *Knowledge Sharing in the Integrated Enterprise*, Bernus, P., Fox, M. & Goossenaerts, J.B.M. (eds.), pp. 269 – 278. Springer / Kluwer.
27. Molina A. & Medina V. (2003). Application of Enterprise Models and Simulation Tools for the evaluation of the impact of best manufacturing practices implementation. *Annual Reviews in Control*, **27**, 221-228.
28. Molina, A., Velandia, M. & Galeano, N., (2007) Virtual Enterprise Brokerage: A Structure Driven Strategy to Achieve Build to Order Supply Chains. *International Journal of Production Research*, **45**, 3853–3880, DOI: 10.1080/00207540600818161.
29. Nof, S.Y., Morel, G., Monostori, L., Molina, A., & Filip, F. (2006) From plant and logistics control to multi-enterprise collaboration: Milestone report of the Manufacturing & Logistics Systems Coordinating Committee. *Annual Reviews of Control*, **30**, 55-68.
30. Panetto H. & Molina A., (2008) Enterprise Integration and Interoperability in Manufacturing Systems: trends and issues, *Computers in Industry*. **59** (7), pp. 641-646.
31. Päivärinta, T. & Munkvold, B.E, (2005). Enterprise Content Management: An Integrated Perspective on Information Management. *Proceedings of the 38th Annual Hawaii International Conference on Systems Sciences*, pp. 96- 96, DOI: 10.1109/HICSS.2005.244
32. Peñaranda, N, Aca, J. & Molina, A. (2005). Methodology for modular Industrial Plant Development using ALM tools: An Action Research Approach. In: *Research in Interactive Design*. Fischer, X. & Coutellier, D. (eds), pp. 117. CD Proceedings of Virtual Concept.
33. Peñaranda N., Galeano N., Romero D., Mejía R. & Molina A. (2006). Process improvement in a virtual organization focused on product development using collaborative environments. In: *12th IFAC Symposium on INCOM*, Llanes, S., Heinz-H. E. (eds). pp. 611-616. IFAC Proceedings.
34. Porter, M. (1990) *The Competitive Advantage of Nations*. The Free Press, New York.
35. Porter, M. (1996) *What is strategy?* Harvard Business Review, 74(6), 61-78.
36. Rehg, J.A & H.W. Kraebber (2005) *Computer-integrated manufacturing*. Pearson Prentice Hall, New Jersey.
Revelle, J.B., Moran, J.W. & Cox C.A. (1998). *The QFD Handbook.* New York: John Wiley & Sons.
37. Rouibah, K., Rouibah, S. and Van Der Aalst, W.M.P. (2007). Combining workflow and PDM based on the workflow management coalition and STEP standards: the case of axalant. *International Journal of Computer Integrated Manufacturing*, **20** (8), pp. 811 – 827.

38. Rozwell, C. & Halpern, M. (2004) Product Lifecycle Management for Life Science Firms. *Gartner Research Note*, TU-22-1634
39. Scheer, A.-W. (2000). *ARIS Business Process Modeling*. 3rd edn. Springer-Verlag, Berlin Heidelberg New York
40. Schilli B., & Dai F. (2006). Collaborative lifecycle management between suppliers and OEM. *Computer in Industry*. **57**, 725-731.
41. Siddiqui, QA., Burns, ND. and Backhouse, CJ (2004). Implementing product data management the first time. *International Journal of Computer Integrated Manufacturing*, **17** (6), pp. 520 – 533.
42. Subrahmanian, S., Rachuri, S., Fenves, S., Foufou, S. & Sriram R. (2005). Product lifecycle management support: a challenge in supporting product design and manufacturing in a networked economy. *International Journal of Product Lifecycle Management*, **1**, 4-25.
43. Vernadat, F.B. (2002). Enterprise Modeling and Integration (EMI): Current Status and Research Perspectives. *Annual Reviews in Control*, **26**, 15-25.