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DIVISIÓN DE INGENIERÍA Y ARQUITECTURA

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THE INTEGRATION AND COMMUNICATION OF ERP SYSTEM AND PLM PROCESS AND THEIR IMPACT OVER KNOWLEDGE MANAGEMENT

TESIS

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POR:

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Los miembros del Comité de Tesis recomendamos que la presente Tesis presentada por el Ing. Héctor Oziel Almaguer Vela sea aceptada como requisito parcial para obtener el grado académico de Maestro en Ciencias con especialidad en:

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Este trabajo esta dedicado…

…a **DIOS** por haberme dado la fuerza necesaria en momentos de flaqueza, por haber alumbrado mi camino, y por haber estado a mi lado siempre que necesite de Él.

A mi **madre Angélica,** que le debo la vida, que por su amor, sencillez, y humildad. Por que me enseñó el camino del estudio y la honradez; por estar conmigo siempre y enseñarme que “la familia es primero.”

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"quedo en deuda con TODOS ustedes."

Nowadays, a lot of companies, no matter the size, require good management for their product development processes to enable create quickly and right-to-market products. These companies need also to plan their resources ensuring that quality products are produced according to customer requirements.

It could be possible to integrate ERP and PLM system technologies that can operate in the company concurrently, related indirectly or directly against one another, where integration and communication could benefit to the company in: 1) ensuring consistent use of product and plant-related information, 2) Reducing the time to bring new and enhanced products to market at a lower cost while improving quality, 3) Creating and using common product-related terminology and processes throughout the business, and 4) Enabling the management of knowledge by its transformation and improving customer requirements.

The need to count with a methodology that supports the integration of the systems' technologies, whether, in the implementation phase of a development process or if is already implemented can become a great application tool. Some authors propose tools and technologies such as Workflow Management Systems that could support the implementation or integration of this system in a company.

A reference model that integrates the system's element must be first developed. However, this reference model does not have a methodology to implement systematically the changes that could overcome in the company. For this reason, Action Research and Six Sigma were used to guide the development of a methodology for the integration and communication systems. A framework and methodology is presented in order to understand how to achieve this integration and communication between ERP systems and PLM process enabling KM. This is will become clear when the methodology were applied for two experiments in Caterpillar Mexico.

Finally, and after the implementation of the methodology in the two experiments the results and benefits obtained are reviewed based on the objectives proposed by the author. The conclusions and recommendation for a further research are also presented.

CHAPTER 3 Framework, Model, and Methodology for ERP, PLM and KM Integration and Communication. *Page*

CHAPTER 4 Case Study *Page*

CHAPTER 5 Results, Conclusions and Further Research *Page*

CHAPTER 1

1. INTRODUCTION

1.1. Context

Throughout history, the human being has tried to communicate, by emitting sounds and making signs. According to the Escalona publication [Escalona, *et al*, 2004], it infers that communication is currently one of the most important elements of any organization, since it directly determines its operations. Some businesses have underestimated the role that communication fulfills in the formation of its corporate culture, and the totality of influence that it has in the efficient accomplishment of the objectives and designed goals for the organizations.

In the same article, Andrade [Andrade, 2003] defines organizational communication as: "The messages that are exchanged between the members of an organization. These messages can be clearly referred from labor to personnel matter and they can be directed to the lower, upper or equal levels of the employee"; that is why the need of a robust system that integrates people, processes and information to support this communication is important for any organization in the development and/or implementation of new products in order to achieve an adequate organizational communication by having the right information at the right moment.

Nowadays with a large quantity of information through all organizational levels, the good communication, processing and utilization of information and knowledge, and adequate structure or sequence in the processes play an important role in the success of projects/process implementations for companies.

Three concepts: communication, processing of information and knowledge, and structure or sequence in the processes, all interact together and integrate under a sound administration and planning of resources followed by a well structured strategy execution as well as a good leadership could be good characteristics that can be translated into the success of the business objectives such as: delivering, product quality, process time, etc. during the development of new product or project. Integration of these characteristics is presented in figure 1.1.

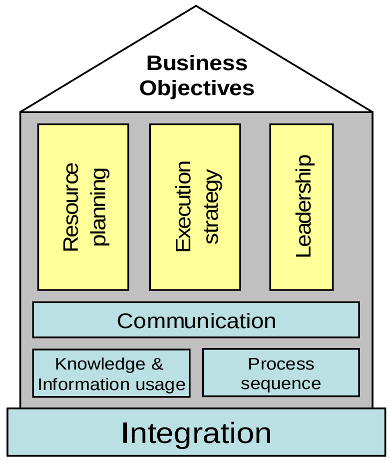


Figure 1.1. Integration of characteristics to improve business goals

In this era of global competition and accelerated product life-cycles, the need of getting new products to the market faster is more compelling than ever before [Reinertsen, D., & Smith, P., 1997]; consequently, the research and usage of new technologies and methodologies such as Enterprise Resource Planning (ERP), Concurrent Engineering, Product Life Cycle Management (PLM), Total Quality Management (TQM), Project Management (PM), Production System (PS), etc., are adapted from large to small companies worldwide as part of their business strategies.

Dean Palmer in the paper "Talking the Same Language" [Palmer, D., 2002] mentions that most of major consultant firms agree about the ingredients for a successful IT project implementation, and, for the third ingredient, he mentions "you'll need an effective communication process, achieved through teams", this IT approach of integration could be also applied to any type of project or manufacturing system such as PLM or ERP.

New technologies and methodologies need a high-quality communication system that enables integration among them and with the user; thus, identifying and fulfilling an organization's objectives. However, these kinds of technologies also require certain expertise like engineering, manufacturing, planning and procurement, administration, etc. This kind of expertise is based on people's experiences and their knowledge of the process, which could be a good improvement if it is integrated into this new technology.

1.2. Research justification

Nowadays, a lot of companies, no matter the size, require good management of development processes for their products. Ed Miller, [UGS, 2006] president of CIMdata, mentions: "PLM manages the innovation process, enabling companies to quickly create right-to-market products and to leverage part re-use," but these kind of companies need to also plan their resources, and for that, Miller mentions that ERP could be used to "ensures that quality products are produced according to customer demand in a timely and cost controlled manner".

According to these requirements, it could be possible to integrate these two system technologies that can operate in the company concurrently, related indirectly or directly against one another, where integration and communication could benefit [Miller, K., 2005] the company in the following ways:

- Ensuring consistent use of product and plant-related information by personnel in organizations throughout the enterprise;
- Reducing the time to bring new and enhanced products to market at a lower cost while improving quality;
- Creating and using common product-related terminology and processes throughout the business.

The justification for this research is based on the need to define a methodology that enable the communication and integration between PLM stages and ERP modules, helping to enter, process, and manage data and information required in the proper time, and by doing so, enabling the usage of Knowledge Management in the organization. If this relationship, Process for PLM, Data and Information for ERP and People for Knowledge Management could be integrated and communicated no matter the size of the organization, could mean in the achievement of one or more of the three benefits proposed by Miller [Miller, K., 2005], plus indirectly establishing the bases of knowledge management of the company.

Figure 1.2 shows the integration and communication that could exist between ERP, PLM and KM, against Information, Process and People, respectively.

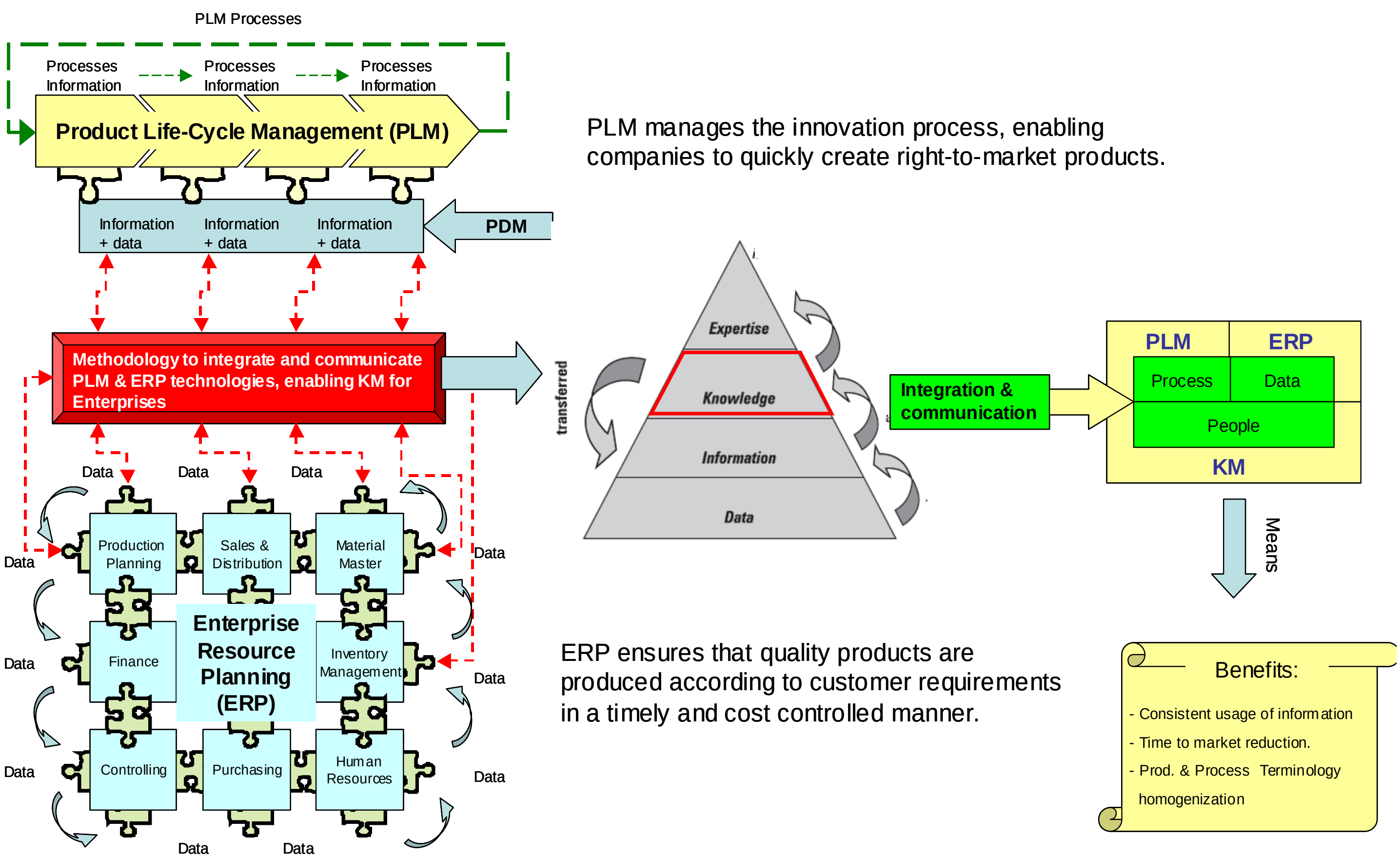


Figure 1.2 interrelations between PLM, ERP and KM, against Process, Information & Data and People, respectively

1.3. Problem statement.

The integration exist as part of PLM process or ERP systems structure, both tools handle common data and terminology that could be used as the “link” to connect each other. Knowledge is reflected as the information needed for each stage of the PLM and as part of the data and information entered to the ERP.

Some specialized vendors offer solutions to enable “full” integration, or third party supplier can reach a “medium” but acceptable integration with the development of tools such as “Workflow Management Systems” or WFMS. But the creation and implementation of a tool is just a small part of the process that must be followed.

A Methodology or Model that supports the proper integration and communication of process, data and information, and people against PLM, ERP, and KM respectively is not defined, and when there is not a well defined process to follow up, it could means in “rework or delay” for the company, “people frustration” or even worst, the failure of the project due to the weak integration and communication of Process, Data and Information, and People in the company. That is why is important to define the steps that must be follow up in an integration project of this nature.

1.4. Aims and Objectives

Partial integration could exist among the different modules of an ERP, being limited only to the reach of their own individual ERP development. In some occasions, ERP suppliers and developers offer interfaces or developments that could be adapted to enable the extension with some applications such as, Product Life Cycle (PLM), Customer Relationship Management (CRM), and Supply Chain Management (SCM).

Veruzka Medina, [Medina, V., 2001] in her thesis, wrote about the importance of the “integration in business,” and explained the perspective of integration between several development and manufacturing processes, and how the integration has consequences on the exchange of technical and production data (information flow), project management (control flow), as well as distribution logistics (material flow).

The aim of this research is to define a methodology that enables integration and communication between PLM processes, ERP systems, and people's Knowledge Management.

In achieving this aim, the major objectives of the research can be stated as follow:

a. To explore and understand the integration and communication that could exist between: PLM processes and ERP systems and their impact to support knowledge, abilities, and expertise of the people involved; in order to define an Integration and Communication Model for theses three elements: PLM, ERP and KM.
b. To develop a methodology that could be applied in any kind of industries that count with an ERP system in place (PLM and KM could be handled in informal way), based on the integration and communication model.
c. To apply the methodology proposed and show how is improved the "integration" and "communication" between ERP systems, PLM process and people KM.
d. To reach at least one of the three benefits proposed by Miller [Miller, K., 2005]: (a) consistent use of product and plant-related information by personnel in organizations throughout the enterprise; (b) reduce the time to bring new and enhanced products to market at a lower cost while improving quality; and (c) create and use common product-related terminology and processes throughout the business.

1.5. Research scope

The scope of this thesis will cover only the integration of some stages of the PLM ignoring the "definition of the need" and the "product disposal" stages due to the fact that the first stage does not need the functionality of an ERP in order to be defined (actually, this stage needs to be completed before any data is entered into the ERP system); and the second stage, which means to manage the negotiation of inventory and tooling disposal from the company. The scope covers all possible modules of ERP technology and PLM process by the usage of Product Data Management or PDM (Concurrent Engineering is out of scope) and their impact over Knowledge Management. The CRM system is also out of the scope, because the methodology will be defined solely in terms of the internal integration between the different areas of the company, not within the context of customers.

1.6. Research environment

In figure 1.3 is shown the environment in which this research was carried on. From one side there is the customer needs were key elements (cost, delivery time and quality) affects customer decision in gets products or services. The customers can now look for a product or service in any part of the world with the use of communication tools such as the Internet which it make increase the possibilities to pick the best option. From the other side there is the organization or company who try to be the best option in satisfying customer's requirements and at the same time making profit, supported in the integration and communication of their people, process and systems available (among other factors).

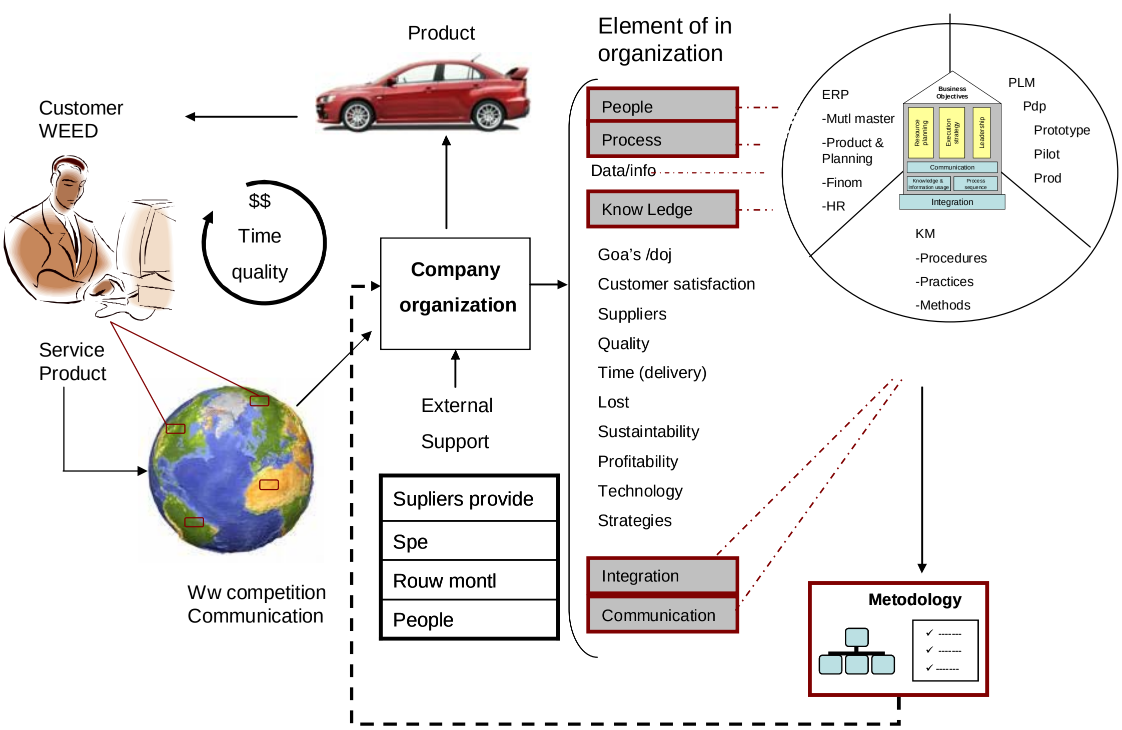


Figure 1.3 Research environment frameworks

1.7. Thesis Organization

This thesis is organized into five chapters described below:

Chapter one provides to the reader the context and the justification on which this research is carried out, along with the statement of the problem, aims and objectives, the research scope; and finally the "environment" that mentions the main topics of this thesis.

Chapter two presents the state of the art concepts related to this research, such as Product Life-Cycle Management (PLM), Enterprise Resource Planning (ERP), Knowledge Management (KM), and their relationship or “integration,” in order to better understand each system and process, supporting the solution applied by the methodology that help to solve the problem stated in Chapter one.

Chapter three explains framework and methodology proposed to get the integration and communication required between ERP and PLM related to information and/or knowledge processed-generated and supported with the literature reviewed.

In chapter four, is presented the application of the methodology that will be introduced in chapter three and applied to the two cases of studies from Caterpillar Mexico, where the integration of PLM and ERP systems supported with KM, were strongly needed for the administration of this company.

Finally in chapter five, the results, discussions, conclusions and further research are presented.

CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CAE	Computer-Aided Engineering
CPPD	Concurrent Product and Process Design
CRM	Customer Relationship Management
DMAIC	Define, Measure, Analyze, Improve, Control
DoD	Department of Defense (USA)
ERP	Enterprise Resource Planning
ICF	Integration and Communication Framework
ICM	Integration and Communication Methodology
ICMdl	Integration and Communication Model
ICS	Integration and Communication System
ILF	Integration Level Factor
ILI	Integration Level Index
IPPD	Integrated Process and Product Development
IT	Information Technology
JIT	Just-in-Time
KM	Knowledge Management
MRP	Material Requirements Planning
PDM	Product Data Management
PLM	Product Life-Cycle Management
PM	Project Management
PPD	Product and Process Development
PS	Production System
QFD	Quality Function Deployment
SCM	Supply Chain Management
SECI	Socialization-Externalization-Combination-Internalization
SIT	System Integration Test
TQM	Total Quality Management
TRIZ	Teoriya Resheniya Izobretatelskikh Zadatch (teoría de resolución de problemas y de invención)
UAT	User Acceptance Test
WFMS	Workflow Management System

CHAPTER 2

2. LITERATURE REVIEW

2.1. Introduction

To better understand the problem and try to define a model and methodology for the problem stated in the chapter one, this section presents the research conducted over the main topics currently used as related to the thesis: Product Life-Cycle Management, Enterprise Resource Planning, Knowledge Management and their integration. Figure 2.1a depicts the organization of this chapter

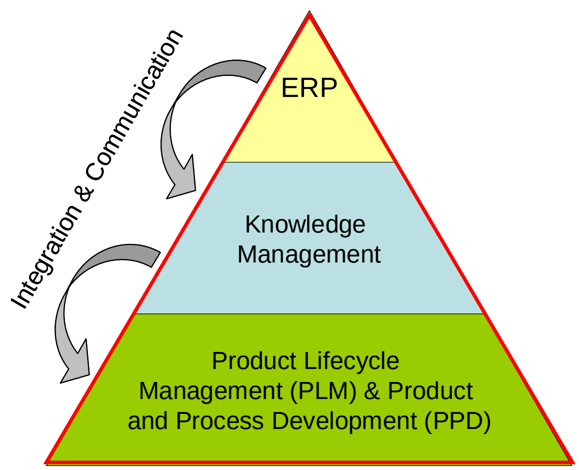


Figure 2.1 Chapter organization

This chapter is divided into five sections; the first chapter provides an overview of Product and Process Development (PPD) with a short look about its fundaments. In the second section, the Product Life-Cycle Management (PLM) model is analyzed, over its different stages. The third section explains the terms of the Enterprise Resource Planning better known as ERP. The fourth section discusses this knowledge and its classification including Knowledge Management (KM). Finally, the fifth section will explain how the previous topics, PPD, PLM, ERP and KM, could be integrated, thereby establishing a hypothesis solution that will be used in the methodology for the problem stated.

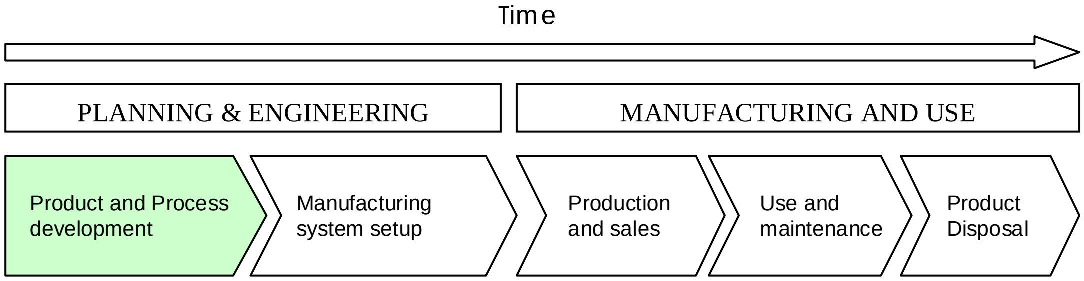


Figure 2.2 Product Life-Cycle Stage Diagram

In figure 2.2, the Product Life-Cycle diagram, adapted from the original defined by Joaquin Aca [Aca, J., 2003], puts together product development and process development into a single phase called: "Product and Process Development" or PPD, (this adaptation will be explained in detail at the PPD and PLM section over this thesis).

2.1.1. Communication process

As stated in chapter one, communication plays an important role in organizations, in all levels between humans and systems; therefore, before entering into the explanation of the main topics of this thesis, the concept of communication will be presented in detail.

According to Britannic Encyclopedia [Communication, 2007], the subject of communication has intrigued people since the time of ancient Greece. Up to modern times, the topic was usually included in other disciplines and taken for granted as a natural process inherent to each discipline. In 1928, the English literary critic and author I.A. Richards offered one of the first (and in some ways still the best) definitions of communication as a discrete aspect of human enterprise:

> Communication takes place when one mind so acts upon its environment that another mind is influenced, and in that other mind an experience occurs which is like the experience in the first mind, and is caused in part by that experience.

It is implied that communication in is influence by technology beginning in about 1920, where the technology has attracted the attention of many specialists who have attempted to isolate communication as a specific facet of their particular interest [Communication, 2007].

2.1.2. Product and Process Development (PPD)

For PLM the diagram adaptation (fig. 2.2), the second stage is the "*product and process development (PPD).*" that According to Kevin Otto & Kristin Wood in their book, product development "is the entire set of activities required to bring a new concept to a state of market readiness. These activities include everything from the initial inspiring of new product vision, to business case analysis activities, marketing efforts, technical engineering design activities, development of manufacturing plans, and the validation of the product design to conform to these plans" [Otto & Wood, 2001]. Product development is a process whereby the task of creating, understanding, communicating, testing, and persuading, are related to knowledge and expertise of the personnel who participate in the process.

Conversely, Joaquin Aca, [Aca, J., 2003] define Process Development as "the selection of material and manufacturing processes for all individual components of the product in development."

To integrate these two concepts, Product Development and Process Development, into "Product and Process Development" or PPD, could be taken the 2nd principle for Integrated Process and Product Development (IPPD) described in the DoD IPPD Handbook by Joaquin Aca [Aca, J., 2003]:

> Concurrent Development of Products and Processes: Processes should be developed concurrently with the products they support to ensure that the product design does not drive an unnecessarily costly, complicated, or unworkable process when the product is produced and fielded.

Every company has different procedures for the development of products and processes out of necessity, there is no single "best" development process. This is due to the sophistication of the product, the competitive environment, the rate of technology change and the change of the system or process within which the product is used; this and many other factors shape the PPD change for every company.

This change leads to different levels of speed, analysis, and sophistication required for the success of the PPD. M. Rezayat [M. Rezayat, 2000] defines some of the keys activities that could be adapted for the success of a PPD development (see Appendix 1).

When you examine companies that succeed in product and process development such as: 3M, Sony, Black & Decker, Polaroid, Caterpillar, they have one thing in common: the development is divided into a number of well-sequenced stages [SQW and Gregson, G., 2006].

One idealized example of this set of sequenced stages that can be applied, no matter the industry context or size of the project is shown in figure 2.3, adapted from Michael Edwards' article [Edwards, M. 1989]. It includes the explanation for each stage in (see Appendix 1).

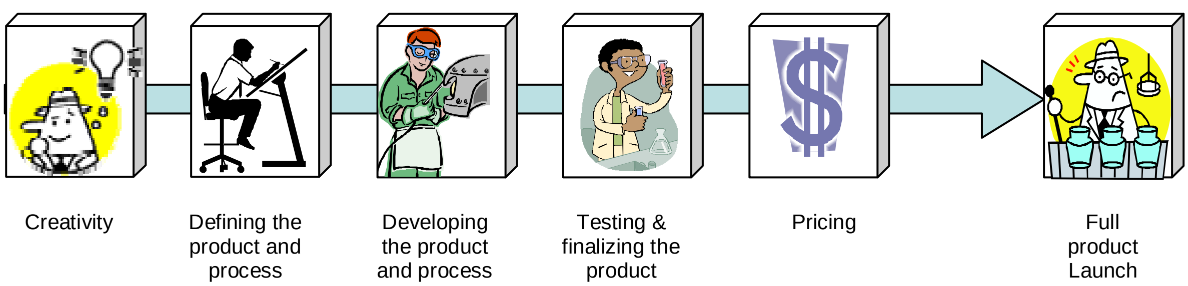


Figure 2.3 Idealized set of stages in a Product and Process Development (PPD)
Adapted from [Edwards, M. 1989; SQW and Gregson, G., 2006]

To reduce the time that the process takes, some companies are completing several steps at the same time using the concept of "concurrent engineering," as it was explained in the usage of IPPD cited by Aca [Aca, J., 2003]. These steps could be eliminated or integrated as needed. For this research, were made a modification to the original model was made by including the PPD instead of just having product design or process development.

PPD failures are often the result of incorrect decisions made in the early stages of the develop process. Failures are also common in companies that concentrate on new product development that fits its own needs rather than market demand. Marketers see new product development as the first stage in product life cycle management, and engineers see it as part of Product Life-Cycle Management [Edwards, M. 1989].

Successful PPD, on the other hand, begin with clear business strategy, supported by a realistic understanding of internal capabilities as well as the consumers and the competition. Companies that develop successful products find they can use the same proven approach to idea generation and development year after year [Edwards, M. 1989] This can be understood as a knowledge recycling.

2.2. Product Life-Cycle Management

Product Life-cycle Management or PLM is a term used for the process of managing the entire life cycle of a product from its conception through design and manufacture to service and disposal [Stark, 2006]. The PLM can be considered with six phases, according to figure 2.2, where the first three phases are related to the planning and engineering activities, and the last three stages are oriented to the supply chain by a manufacturing and usage point of view.

One of the major advantages of PLM is that it enables a better information flow across the entire organization. An additional advantage of PLM is that surpasses a simple cost reduction perspective through a revenue perspective to improve efficiency and productivity. PLM has the opportunity to increase innovation, functionality and quality by means of better organization and use of the intellectual capital of an organization [Grieves, M. 2006].

An adaptation from the original PLM model proposed by Aca [Aca, 2003], consist in put together in the first phase the product and process development, where product development represents the collection of market requirements and product design, and the process development represents the selection of material and manufacturing process for the manufacture of products [Sanchez, J.M. 1998].

The second stage of figure 2.2 is the “Manufacturing Systems Setup,” which includes the selection of a supplier’s standard, components, process planning and facility design. This step is also the so-called “pilot stage”, which was in the past stage, a prototype to fulfill and succeed customer requirements. Now it is the product made more profitable for the company, by looking for the best supplier, lean processes, and balanced production according to procurements (forecast and/or demand).

Finally the last three stages from the PLM diagram are related to activities in the supply chain such as “**production and sales**” stage (includes packaging), where work orders, sales orders and purchased orders must be set on the right time according to product lead times in order to get sufficient delivery performance. The "**uses and maintenance**" stage of process and products, is where a maintenance plan is created for the correct operation of the production line (this stage could take into count the quality of the product and production line as well). The end of the cycle is the "**disposal**" stage, meaning that a product is no longer satisfactory due to its obsolescence because of a product improvement resulting in an engineering change, or because of a product market phase out; therefore, all material and tools used on this product must be disposed of in the best possible way as to avoid minimize possible loss of the company's capital.

The PLM defines the requirements and capabilities that allow manufacturers to manage information and facilitate communication with partners and customers across the entire product life-cycle from product concept and planning to the final retirement of the product. Since PLM software captures the richer product content, enterprises should look at the integration needs between PLM software and sourcing applications, such as Enterprise Resource Planning (ERP).

This integration will help management to instantly know what changes have been made and if their subsequent impact is important. It also allows people from other divisions or areas to take action regarding procurement and compliance issues earlier in the product and process development, for example.

All companies need to manage communications and information with their customers, suppliers, and internal resources using a Customer Relationship Management (CRM) system, a Supply Chain Management (SCM) system, and an Enterprise resource planning respectively.

In addition, manufacturing engineering companies must also develop, describe, manage and communicate information about their products (PLM). This could be done by using Workflow Management Systems (WFMS) according to Mejía [Mejía, R., 2003].

The core of PLM (figure 2.4) is in the central management of all product data and knowledge and the technology used to access this information. Although PLM emerged as a discipline from tools such as CAD/CAM and Product Data Management (PDM), the integration of these tools must be viewed with methods, people and the processes through all stages of a product's life.

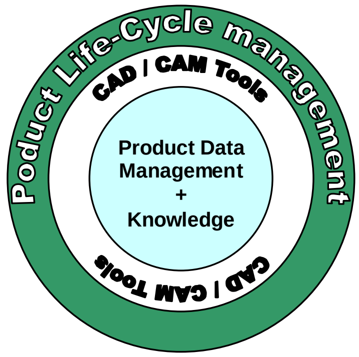


Figure 2.4 the core of PLM, product data management

2.2.1. Phases of Product Lifecycle and corresponding technologies

Many software solutions have been developed to organize and integrate the different phases of the PLM that should not be seen as a single software product; PLM is a collection of software tools and working methods integrated to address either single stages of the life-cycle connect different tasks or manage the whole process.

Some software providers cover the total PLM range while others only include single applications. Some applications can cover many fields of PLM with different modules within the same data model.

An example of some software that could be used for PLM integration is presented the figure 2.5, where the different software could be seen in Appendix 1.

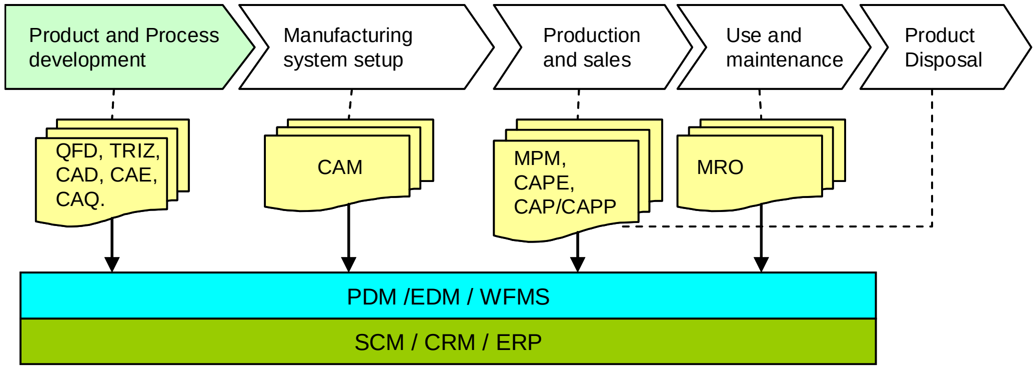


Figure 2.5 PLM and corresponding technologies

It should be noted, however, that the simple software classification does not always fit exactly; many areas overlap and many software products cover more than one area and do not fit easily into one category. It is also important to remember that one of the main goals of PLM is to collect knowledge that can be reused for other projects to coordinate simultaneous development of many products.

None of the above phases can be seen in isolation. In fact a project does not run without sequence or in different way of the other product and process development projects. Information should flow between different people and systems.

The main part of a PLM is the coordination and management of the product. This includes managing engineering changes and release status of components; configuration product variations, document management, planning project resources, and timescale and risk assessment. These tasks' graphical, text and metadata such as product BOM's (Bill of Materials), production orders setup, and manufacturing routing creation needs to be managed too.

Some of the benefits and characteristics that a company could gain with the implementation of a PLM system technology are presented in the appendix 1 of this thesis.

2.3. Enterprise Resource Planning (ERP)

Talking about changes in his article, John F. Rockart indicates that, the change in the business world began in the 90's with the rise of a globalization resulting in a more competitive environment [Rockart, 1996]. This tendency to the globalization carries to implement new organizational strategies that transform and affects the coordination, the control systems, the administrative practice and the organizational structure for global business.

According to Allan Hald, [Hald, 1993] these changes represent significant opportunities that supported the technological innovations that will permit transformation of the processes of business and administration. The demand for innovation makes the demand of integral services grow allowing the business to compete globally. Thomas Malone and John Rockart call to this "technology coordination", this is a simple definition of the new services as they currently are: the integration of the computers and the telecommunications [Hessler, 1993].

The business should be led by a global strategy that permits a plan to carry out all its activities in the context of a single worldwide system. According to Hessler [Hessler, 1993], this definition converges in three points of view:

a) The business globalization is a concept that involves a global strategy, which permits to a company to have a plan in the world environment for its products, marketing, manufacturing, logistics, and research and development.
b) A global company should have a system of delivery that could be highly sensitive to the needs of the local clients, with the capacity to provide support, with the same degree of excellence.
c) A global company learns to balance aspects of it self that must be viewed and planned as a global system with aspects that should be highly sensitive to local requests.

Many companies believe that developing its own technology is better than buying existing technology in the market. Nevertheless, there are systems such as Enterprise Resource Planning or ERP that permit it to acquire large competitive advantages, reducing costs and time in the process [Abetti, 1989].

According to Brenda Olvera [Olvera, 2005], an ERP is an information system, capable of facilitating the flow of information among various processes of business in an organization, because it covers various modules, from the role of strategic planning of the business to the functional and operating roles, giving integrated and cross information across all the processes of the business. This union is given through a system that is strongly integrated that shares data and has instantly available information at any moment. [Olvera, 2005]

An ERP system is also known as packages of solutions for the business. Nowadays, it has been converted into tools that permit the maximization of work to coordinate all the functions of a business under the “same” application, generating integrated information that helps in the making of strategic decisions [Figueroa, 1998] by the business.

ERP systems can include software for manufacturing, order entry, accounts receivable, accounts payable, general ledger, purchasing, warehousing, transportation and human resources. Evolving out of the manufacturing industry, ERP implies the use of packaged software rather than proprietary software written by or for a single customer [Davenport, 1993].

ERP modules may be able to interface with an organization's own software with varying degrees of effort, and, depending on the software, ERP modules may be alterable via the vendor's proprietary tools as well as proprietary or standard programming languages [Sane, Vamseedhar, 2005].

A new class of packaged application software has emerged over the past decade; the ERP software solution that try to seek the integration of the complete range of a business’s processes and functions in order to present a complete view of the business from simple information and IT architecture [Klaus, Rosemann and Gable, 2000].

2.3.1. ERP architecture

Scott Hamilton explain in his book the basic architecture for an ERP system, that consist of 12 business functions utilizing a common manufacturing database [Hamilton, S., 2003], as shown in figure 2.6.

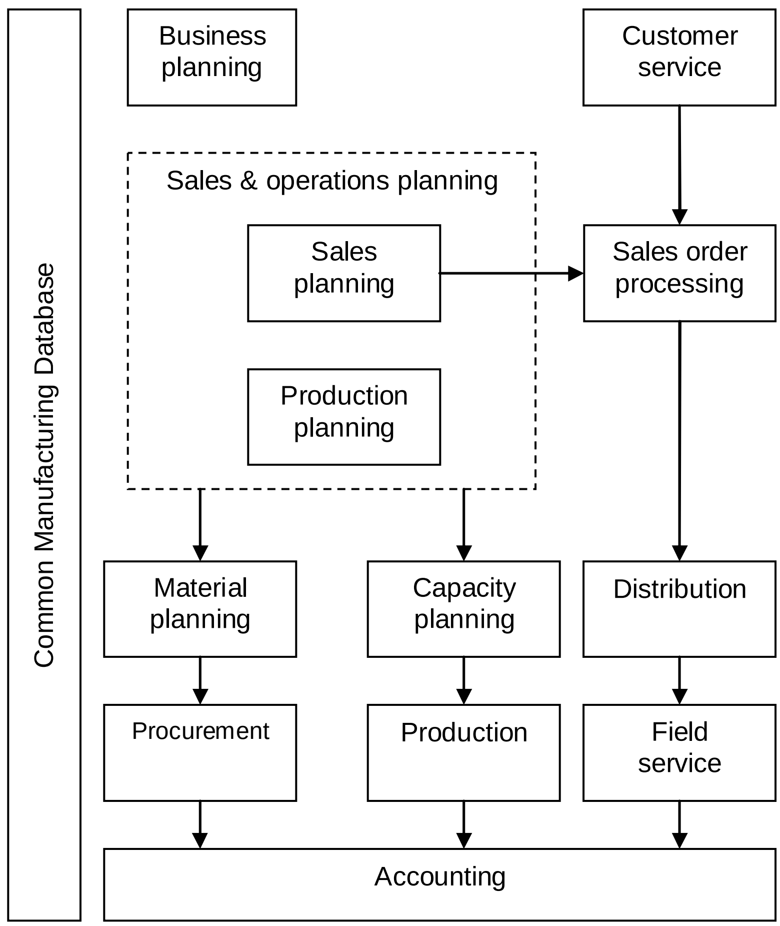


Figure 2.6 Common manufacturing Database
[Adapted from Hamilton, S., 2003]

This top-down model shows how aggregate plans (the business, sales, and production plans) drive the detailed plans for the coordination of supply chain activities. The accounting function tracks the financial applications of supply chain activities.

2.3.2. Critical success factors on an ERP implementation.

Since this thesis will take the study case based on an ERP implementation, it is prudent to understand what factors could take effect in an ERP implementation project.

In the implementation of an ERP system inside of an organization, the complexity makes the integration of the business resources (people, process and the system itself) takes a lot of time, and requires important changes in the actual processes, procedures, politics, metrics, etc. during the implementation. This could be a problem for the business.

Jing Ranzhe and Qiu Xun, [Jing R. & Xun Q, 2007] define two main phases for an ERP implementations; they said that ERP is one of the important systems on the market to help companies to achieve their business objectives and to be strong enough to enter the competitive market. However, some difficulties and problems affect the implementation of ERP systems. Theses phases are (figure 2.7):

- The “pre-implementation” or the prior analysis to define the objectives of the project, functional reach, total price, necessary resources, concrete needs of the organization, calendars, etc. to manage and evaluate the profit value that suppose the ERP implementation is projected to have.

- The implementation project itself including developments, system tests, go-live.

- Implementation and post go-live support.

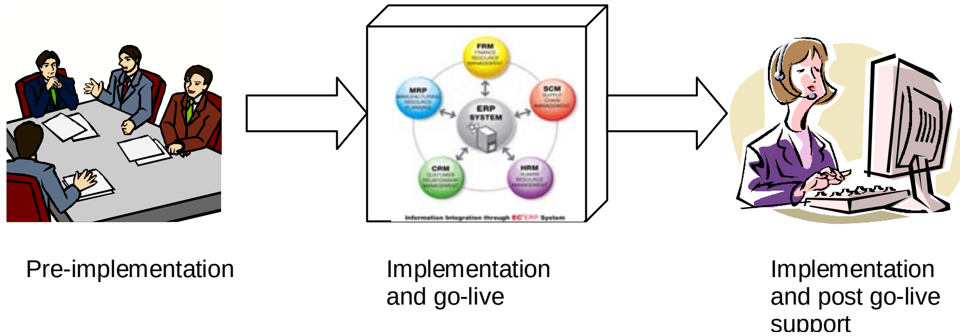


Figure 2.7 phases of an ERP implementation

Referencing the implementation of an SAP ERP system at Procter & Gamble Company, Derek Prior and Nigel Rayner from Gartner consultant define a number of factors that could affect the success of ERP implementation [Prior, D. & Rayner, N, 2002].

Figure 2.8 represents the critical success factors adapted from Jing Ranzhe and Qiu Xun, [Jing R. & Xun Q, 2007] for ERP implementation through the analysis made over previous successful cases. These factors are explained in detail:

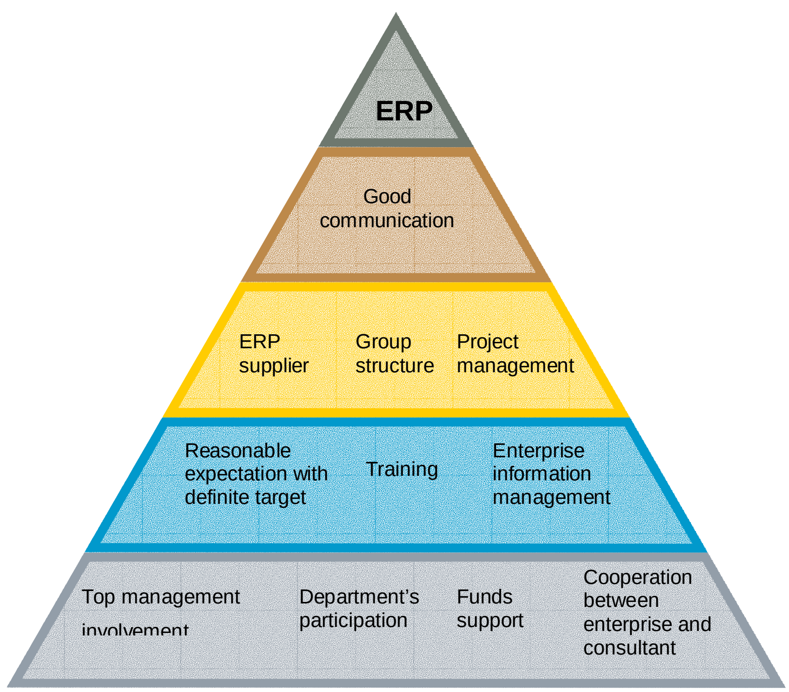


Figure 2.8 Critical success factors on an ERP implementation

a. Top management involvement.

The support of top management has been widely recognized as imperative. If there is no support of top management, there will be no investment decision and no resources to use for the project. Without commitment of resources from upper management, the ERP system is not going to succeed.

b. Department's participation.

The principal benefits that can arise from ERP system are linked to expected gains in the efficiency and effectiveness of business processes that come about with the availability of more accurate and timely information. ERP can offer integration of the business functions and the reduction of data collection and processing duplication efforts [Molla, A. & Bhalla A., 2006].

c. ***Funds support.*** The abundant budget funds can keep the progress of project on going.

d. Cooperation between enterprise and software supplier (consultant).

The enterprise has its own processes, but the ERP software also has predefined processes; therefore, how to synthesize this difference is critical if the implementation is to succeed. As expected, there usually is user resistance to change in the work culture as reported during an ERP implementation [Al-Mashari, M, A Al-Mudimigh and M Zairi, 2003].

Often a project manager who has reengineering experience, hands-on IT knowledge, (particularly system implementation experience) business analysis skills and a good political stature should be employed [Zuckerman, A.1999, Abdinnour-Helm, S, ML Lengnick-Hall and CA Lengnick-Hall, 2003].

e. Reasonable expectation with definite target.

The implementation of ERP is accompanied by significant process changes, as the organization develops new ways to use the ERP system. The ability to define the before and after picture of key business processes is important [Pollock, N, R Williams and R Procter, 2003], in other words, expectation must be managed with attainable objectives.

f. Good communication.

Open and honest communications are very important to satisfy the information needs of the users and to prevent the circulation of unfounded rumors. Messages must be consistent and effective bi-directional communication [Joseph Sarkis, R.P. Sundarraj, 2003]. The management must reform the need for internal and external communication to reach a unanimous opinion so, the project can progress realistically.

g. Training.

It is important to realize that the integrated, cross-functional scope of an ERP system requires a large proportion of the workforce to be trained in various ERP system skills. Many employees lack prior computer skills. Moreover, training programs are generally more effective if closely tailored to the requirements of each user group.

The comprehension and acceptance of the employee affects the project's progress; it could directly cause large data or operation mistakes without the proper user training [Haag, S, P Baltzan and A Phillips, 2006].

h. Group structure.

The proportion of the technical personnel and manager must be reasonable, because the ERP implementation needs not only technical expertise, but also needs solid management and leadership [Mabert, VA, A Soni and MA Venkataramanan, 2003].

i. Project management.

Successful implementation is highly dependent on an effective ERP project management team. Project management involves the use of skills and knowledge in coordinating the scheduling and monitoring of defined activities to ensure that the stated objectives of the implementation projects are achieved.

It includes adequate strategic alignment, effective planning and project management techniques, identification of performance measures, appropriate use of methodology and effective process redesign [Major, E and M Cordey-Hayes, 2003] and [Mandal, P and A Gunasekaran, 2003].

j. Enterprise information management.

The level of enterprise information management is the foundation to the adaptation of an ERP system. It can help the employee becomes suited for the new role more quickly.

k. The ERP supplier-consultant services.

The success of an ERP system also depends on the selection of the correct system. Companies intending to acquire of-the-shelve ERP systems should take a close look at the ERP providers [Parr, A. and Shanks, G., 2000]. Some of the factors that should be taken into account when choosing a supplier are presented in appendix 1.

2.3.3. ERP business process structure

The requirements of an ERP system are relatively few: unique item identification, demand, in dependent materials, and supply. These four items (figure 2.9) are the four basic elements of an ERP just as oxygen, fuel, and source of ignition are the basic elements of fire. If one is missing, then ERP is not possible [Ptak, C. & Schragenheim, E., 2003].

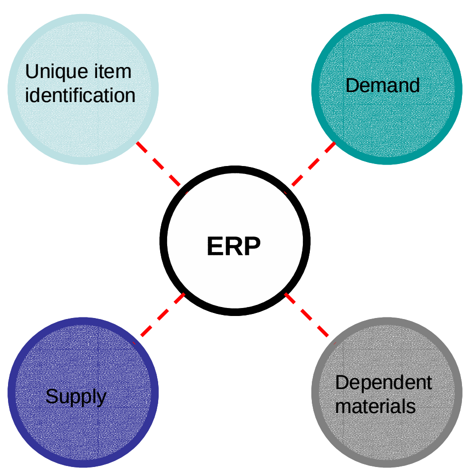


Figure 2.9 the four basic elements of ERP

To have an effective integrated system that yields a positive return on investment, each of these items must be very accurate. Without this accuracy, the users of the system will second guess the output of the system and develop manual processes instead of using the desired integrated planning and control processes.

This becomes even more challenging when individual ERP systems are connected to an integrated supply of chain. If there are any inaccuracies in the input or output and no human intervention is possible the entire supply chain is adversely affected.

The ERP systems are conformed by modules or sections where each module controls a part of the business. An example of these modules integrated into an ERP system that will be used in the second case study (SAP R/3) it's shown in figure 2.10, and in the table 2.1 were S.R. Siriginidi [Siriginidi, 2000] groups them into main sections for a better understanding:

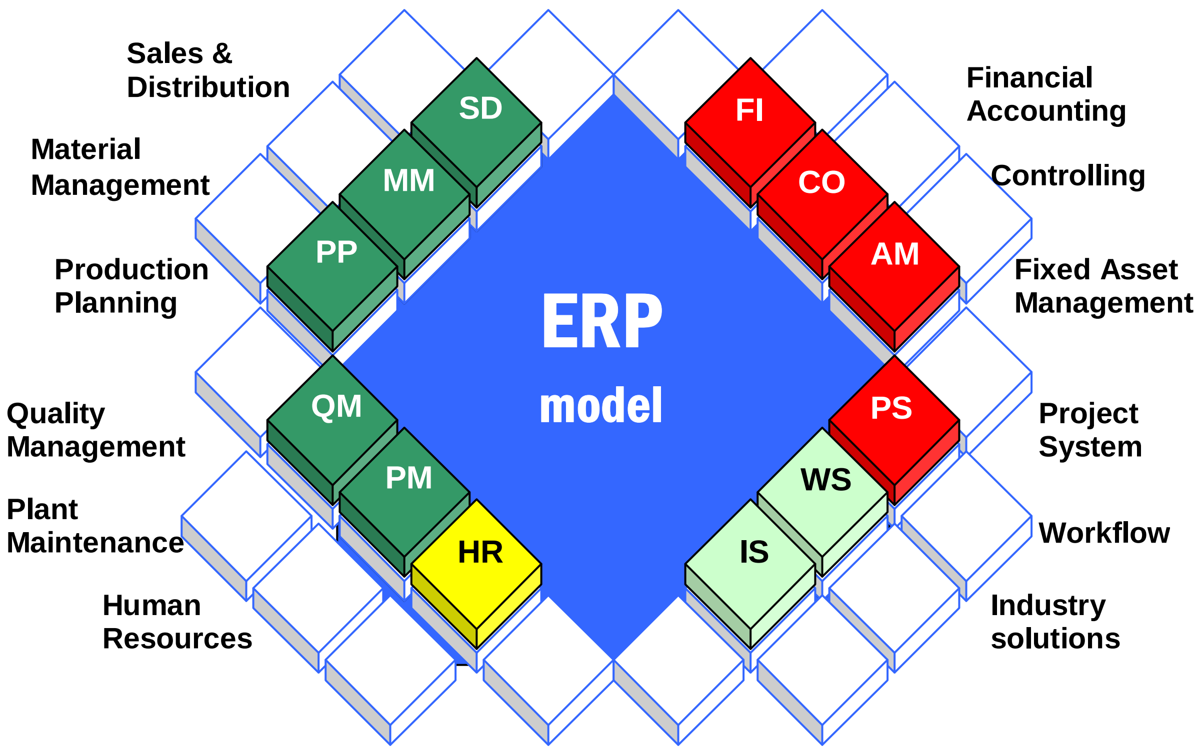


Figure 2.10 ERP modules example

(Adapted from SAP R/3 and Caterpillar Mexico)

Main sections	Process controlled
Production Planning	Engineering data control (material master, bill of materials, process plan and work center data).
	Works documentation (work orders, shop orders release, material issue release and route cards for parts and assemblies).
	Shop floor control and management, others like costing, maintenance management, logistics management.
	Workflow (integrates the entire enterprise with flexible assignment of tasks and responsibilities to locations, positions, jobs, groups or individuals).
Sales & Distribution	Resource flow management (production scheduling, finance and human resources management).
	Sales, purchase and inventory (sales and distribution, inventory and purchase).
	Material requirement planning (MRP).
	Logistics, production planning, materials management, plant maintenance, quality management, project systems, sales and distribution.
Finance & Controlling	Financial, accounting, treasury management, enterprise control and asset management.
Human Resources	Personnel management, training and development and skills inventory.

Table 2.1 ERP main sections grouping [Siriginidi, 2000]

Some of the benefits that a company could gain with the implementation of a good ERP system technology are presented in the appendix 1 of this thesis. The main vendors are listed too.

2.4. Knowledge

A fundamental question that has raised deep debate since the beginning of human history, inspiring the greatest philosophers such as Confucian, Plato, Aristotle, Russell, who have dedicated their lives to answer the question: ***what is knowledge?*** [Zheng, J., Zhou, M., Mo, J. and Tharumarajah, A., 2000]

According to Thomas H. Davenport and Laurence Prusak their book defines it such that "knowledge is a fluid mix of framed experiences, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of the knower. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices, and norms" [Davenport and Prusak, 2000]

As Lester C. Thurow said in his article, "it is only people's knowledge that cannot be quickly replicated and copied, as knowledge and expertise have to be created and developed individually." Knowledge can only be employed through people [Thurow, 1997]. Figure 2.11 shows what Thurow and Allee explain about knowledge.

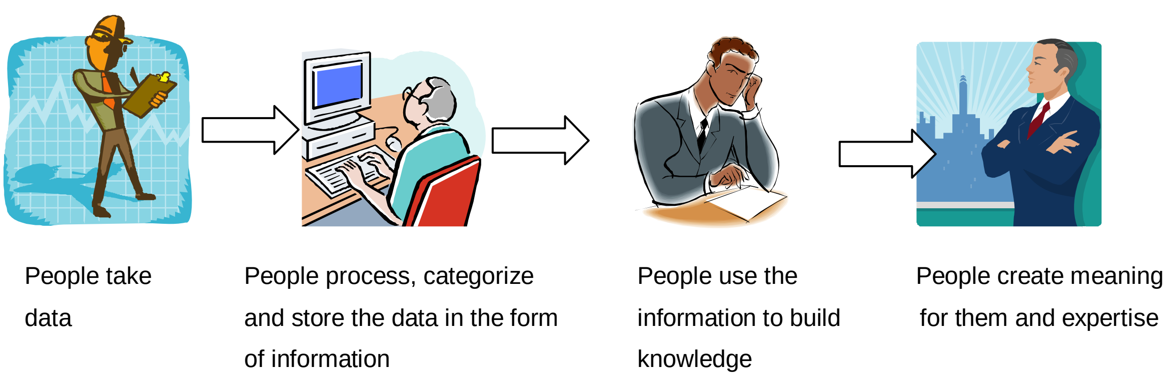


Figure 2.11 knowledge usage and creation by the people
(Adapted from Thurow, 1997)

Verna Allee [Allee, V., 1997], agrees with Lester and state that "irrespective of the type and availability of technology, it is people that take in data, process it, sort it, categorize it, and store it in the form of information and use it to build knowledge and create meaning for themselves and expertise for the organization"

2.4.1. Knowledge hierarchy and classification

To be able to better understand what is the knowledge, the Hierarchy of the Knowledge is presented as proposed by Silke Bender and Alan Fish in their article [Bender & Fish, 2000], which is shown in the Figure 2.12.

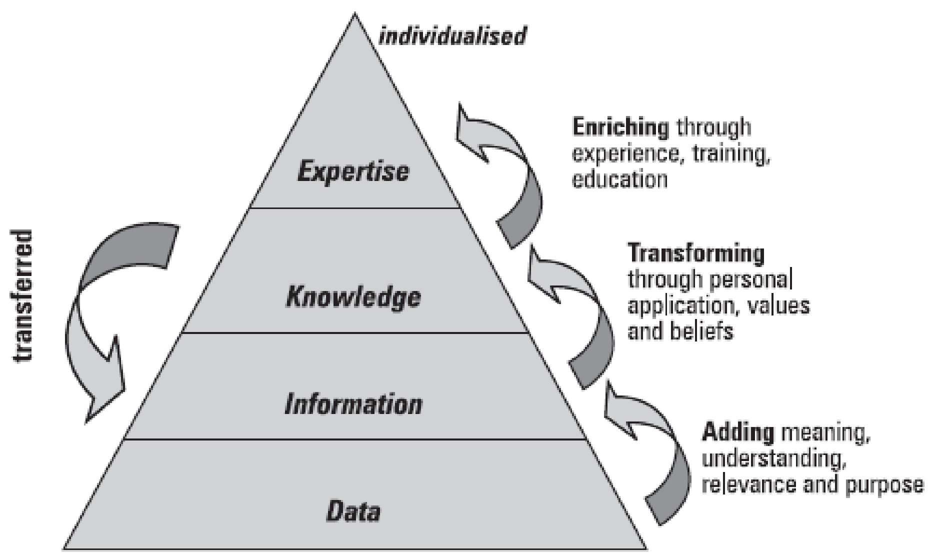


Figure 2.12 Knowledge Hierarchy
[Bender & Fish, 2000]

Similar to figure 2.11, the most basic element in the Hierarchy of the knowledge is the data, of which the information arises and from this arises to knowledge resulting in dexterity or "expertise" in the tip of the hierarchy.

The ***data*** is an event out of context, since it has no inherent context; it is unmeaning relation in to anything else. The ***information*** answers the question "what" and "who". It is not just a collection of data. ***Knowledge*** provides answer to the questions “when”, “where” and “how.” And ***expertise*** answers the question “why.”

For an in depth understanding about all these four elements from the knowledge hierarchy, each element is defined in appendix 1.

Two of the most prominent authors in KM, Ikujiro Nonaka and Hirotaka Takeuchi [Nonaka, I. and Takeuchi, H., 1995] suggest in their book that, the corner-stone of the Theory of Organizational Knowledge Creation is the substantiate distinction between tacit and explicit knowledge classification.

Knowledge could be classified into explicit, implicit, tacit, declarative, procedural and strategic, this classification and diagrams to differentiate the classifications will be explained as follow:

a. Explicit, Implicit and Tacit Knowledge

Explicit knowledge, as the first word implies, is knowledge that has been articulated and, more often than not captured in form of text, tables, diagrams, product specification, and so on.

Implicit knowledge is knowledge that can be articulated but it has not. This is the kind of knowledge that can often be teased out of a competent performer by a task analyst, knowledge engineer or other person skilled in identifying the kind of knowledge that can be articulated but has not. [Nickols, F., 2003]

Tacit knowledge is the knowledge that cannot be articulated. It comes from the personal experiences of someone, and is seen affected by personal beliefs, values, and perspectives. It is not visible nor is it documented, and it requires a direct and more personal communication [Giannetto and Wheeler, 2001]. This dimension alludes so much to what we know, but has yet to been externalized in a formal way, as if were not consciously aware of the knowledge.

In the figure 2.13, can be seen a useful diagram to better understand the distinctions between explicit, implicit and tacit knowledge.

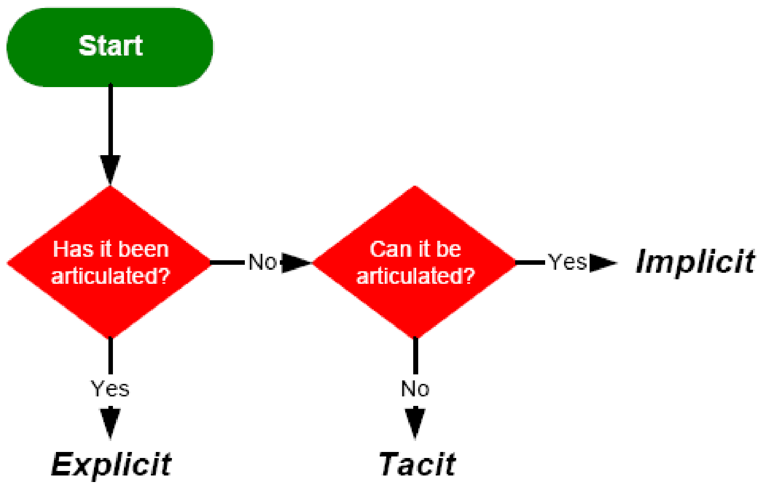


Figure 2.13 Explicit, Implicit and Tacit Knowledge
[Nickols, F., 2003]

b. Declarative, Procedural and Strategic Knowledge

Declarative knowledge consists of descriptions of facts, things or methods and procedures. For practical purposes declarative knowledge has much in common with explicit knowledge; in fact, both kinds of knowledge may be treated as synonyms. This is because all declarative knowledge is explicit knowledge; that is, knowledge that can be and has been articulated.

Procedural knowledge, it is knowledge that manifests itself in the doing of something, as such it is reflected in motor or manual skills and in cognitive or mental skills. This knowing *is in the doing*. Another view of procedural knowledge is knowledge about how to do a task or procedure.

Figure 2.14 is a useful diagram to better understand the distinctions between declarative and procedural knowledge.

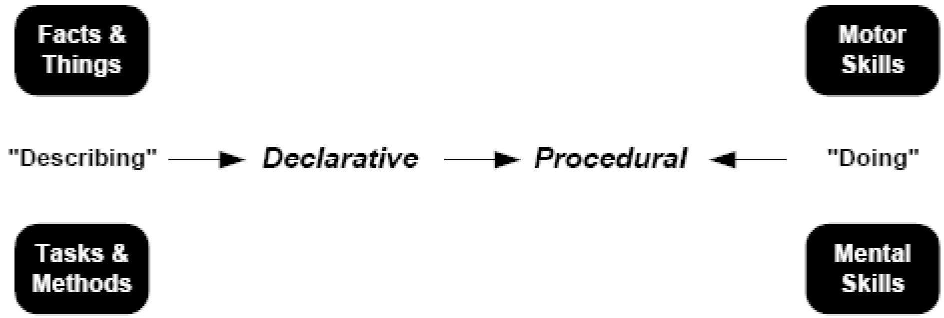


Figure 2.14 Declarative and Procedural Knowledge
[Nickols, F., 2003]

Strategic knowledge, is a term used by some to refer to what might be termed know-when and know-why. We can separate strategic knowledge only in the describing; not the doing. Consequently, strategic knowledge is best thought of as a subset of declarative knowledge instead of its own category.

In general, we seem to imply three things by our use of the word “knowledge.” First, we use “knowledge” referring to a “state of knowing”, by which we also mean to be acquainted or familiar with, to be aware of, to recognize or apprehend facts, methods, principles, techniques, etc. This common usage corresponds to what is often referred to as ***“know about.”***

Second, we use the word “knowledge” referring to “the capacity for action,” an understanding or grasping of facts, methods, principles and techniques sufficient to apply them in the course of making things happen. This corresponds to ***“know how”***.

Third, we use the term “knowledge” referring to “codified, captured and accumulated facts, methods, principles, techniques, and so on”. When we use the term this way, we are referring to a body of **knowledge that has been articulated and captured** in the form of books, papers, formulae, procedure manuals, computer code and so on. [Nickols, Fred, 2003]

2.4.2. Knowledge conversion (SECI model)

Knowledge conversion can be achieved when tacit and explicit knowledge interacts through the processes of: socialization, externalization, combination and internalization according to Nonaka and Takeuchi, [Nonaka, I. and Takeuchi, H., 1995]. In figure 2.15 the four ways to transfer knowledge are it's presented.

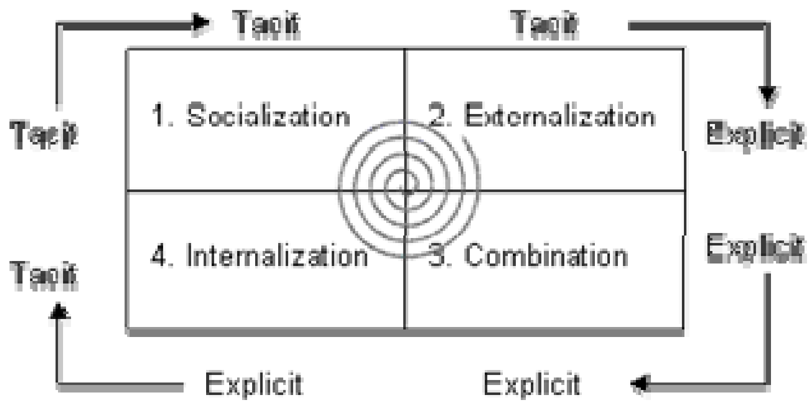


Figure 2.15 Nonaka SECI model
[Adapted from Nonaka, I. and Takeuchi, H., 1995]

a) Socialization: from tacit to tacit knowledge. It is a process to share experiences and in this way create tacit knowledge that can share mental models and technical abilities. An individual can acquire the tacit knowledge of another without the use of the language; it can be by observation, imitation or practical acquisition; in itself the experience of a person is the knowledge that can be transmitted. The emotions and the context are of utmost importance in the experiences that are shared and assimilated.

b) Externalization: from tacit to explicit knowledge. It is a process to articulate the tacit knowledge in explicit concepts taking form of metaphors, analogies, concepts, hypothesis or models. This way of conversion is seen typically in the concepts creation process and is prompted for the dialogue or the collective reflection. A frequent method to create a concept is the use of the deductive and the inductive reasoning. Once the explicit concepts are created, they can be shaped.

c) Combination: from explicit knowledge to explicit. Processes to systematize concepts in a system of knowledge. This way of conversion involves the combination of different bodies of explicit knowledge. The individuals exchange and they combine knowledge through media such as documents, meetings, telephone conversations or computer networks. In the business, this occurs when the administrators put into operation the visions of the company, the concepts of business and the concepts of products.

d) Internalization: from of explicit knowledge to tacit. This it is the process to express the explicit knowledge in tacit "to learn, doing it". When the experiences through the socialization, externalization and combination, are adopted in bases of the tacit knowledge of the individuals, the shared mental models are shaped by know-how or technical skill. These return valuable assets to the organization. Because of the manner the knowledge is being transmitted, the learning in the organization is being generated and being returned as part of the culture of the business. The documentation of this experience helps the individuals enrich the company’s tacit knowledge, also helps the creation of manuals, and to recount histories.

To better understand the knowledge conversion, in Appendix 1 is an example using the SECI model.

2.4.3. Knowledge Management (KM)

Companies are beginning to become aware about that knowledge resources are essential to the development of their organizations [Carneiro, A., 2000]. Nowadays, the knowledge and Information Technology (IT) are critical success factors for strategic formulation.

In Knowledge Management (KM), is a bottom-up ongoing process finding valuable data and uses for raw information, which is then shared across organizational boundaries [Bonner, D., 2000]. This holistic, organic process guides the organization's development and exploitation of tangible assets and intangible knowledge resources [McCune, J.C., 1999].

> "Knowledge Management is a formal, directed process of determining what information a company has that could benefit others in the company and then devising ways to making it easily available" [Liss, K., 1999].

Steps in this process include how knowledge is captured, evaluated, cleansed, stored, provided and used [Chait, L., 1998].

In the article by Nada Kakabadse, *et al.* [Kakabadse et al. 2003] said that for some, KM is a "conscious strategy of getting the right knowledge to the right people at the right time, helping people to share and put information into action in ways that strive to improve organizational performance" [O'Dell, C. and Jackson, C., 1998]. For other authors, it is "formalization of and access to experience, knowledge, and expertise, that create new capabilities, enable superior performance, encourage innovation and enhance customer value" [Beckman, T., 1997].

According to an European survey the 73% of companies chose the business definition of KM as the ''collection of processes that govern the creation, dissemination and utilization of knowledge to fulfill organizational objectives" [Murray, P. and Myers, A., 1997].

The purpose of knowledge management is to integrate internal and external knowledge at all times in order to confront the environmental changes, both within and outside of the organization, to solve existing problems as well as to innovate for business expansion. However, to fulfill these functions, the organization has to provide a learning environment to maximize its human resources. [Chattel, A., 1998]

The collected knowledge can be organized by indexing the knowledge elements, filtering it based on contents, and establishing linkages and relationships among the elements. This knowledge is then integrated into a knowledge base and distributed to the decision support applications [Shaw, M. J., et al., 2001].

Jon-Chao Hong and Chia-Ling Kuo [Hong, J.C., and Kuo, C.L., 1999] in their article said that, basically, sharing of learning comes in two forms: knowledge sharing and wisdom sharing. The former can be further divided into information sharing, implicit knowledge sharing, and explicit knowledge sharing; while the latter can be divided into sharing of belief, value, and thinking. All these different types of sharing and their relations are illustrated as follows in the table 2.2 and figure 2.16.

Knowledge sharing	1. Information sharing: knowing where information is and sharing the situation.
	2. Implicit knowledge sharing: sharing how but not why, for instance, knowing how to make a cake without the chemistry involved.
	3. Explicit knowledge sharing: sharing both how and why. For instance, knowing the chemistry of a cake making and further trying the change to components cake.
Wisdom sharing	1. Belief sharing: understanding what it is expecting what is going to happen, and the sharing of both.
	2. Value sharing: decision making and thinking sharing of what is important, what we should do, and what we can do.
	3. Thinking sharing: the cutting point of thinking and thinking approach sharing as how and why we think.

Table 2.2 elements of knowledge management adapted from
[Hong, J.C., and Kuo, C.L., 1999]

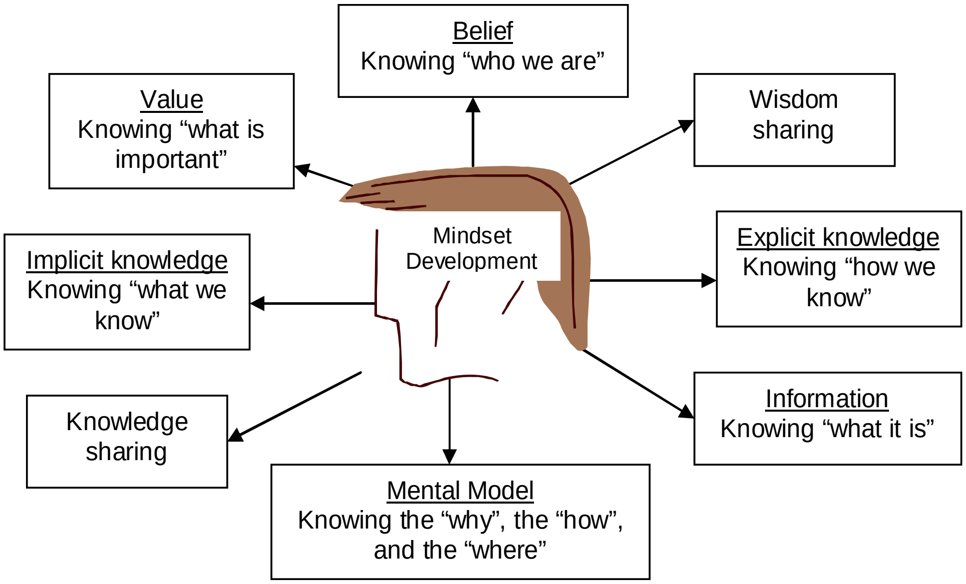


Figure 2.16 a mindset development for KM

[Hong, Jon-Chao Hong and Kuo, Chia-Ling, 1999]

One of the important issues in knowledge management is the organization, distribution and refinement of knowledge. Data mining tools that can be acquired from third parties suppliers can generate knowledge.

2.5. Main topics integration.

In this section, the main topics (PPD, PLM, ERP and Knowledge) referred by several authors, are being put together and discussed in order to find a hypothesis solution for the problem stated in chapter one about integration and communication between ERP, PLM, and KM technologies and process.

2.5.1. Types of Integration

Integration consists of putting components together to form a synergistic whole. System integration can range from no integration at all to loose integration or to full integration. Vernadat considers that there are different types of integration [Vernadat, 1996]:

a. ***Loose integration***: two systems are loosely integrated if they can merely exchange information between them with no guarantee that they will interpret this information in the same way. In other words, they are just connected and coexist in a larger system.

For instance, two systems linked by a dedicated interface is an example of loosely integrated systems. They can exchange data and information but there is no guarantee that they "understand" each other.

b. ***Full integration***: two systems are fully integrated if:

1) The specificities of any one of these systems are only known to the system itself and not by the other one.
2) The two systems both contribute to a common task.
3) The two systems share the same definition of each concept they exchange. For instance, two systems connected by a standard protocol, using the same ontological definition of shared concepts, and coordinating their tasks are fully integrated, although they may be built on totally different technologies and use different internal languages and procedures.

c. ***Horizontal and vertical integration***: concerns physical and logical integration of business processes from product demand to product shipment, regardless of the organizational boundaries.

Horizontal integration mainly includes the technological flow, like the flow of material and flow of technical documents. Typical examples are: concurrent engineering in design and engineering offices for Product and Process Design and Development, Just-in-time (JIT) management for production planning and control by means of integrated logistic chains.

Vertical integration, concerns integration between the various management levels of the enterprise, such as decision-making integration, where a management level defines the set of constraints for its lower management levels, which in turn send feedback information to their upper management level (like status reports) and so on.

Vertical integration mainly concerns the decision flow, for example: orders or objectives sent from one management level to the lower level one, and feedback information or status reports from one management level to the upper level.

d. ***Intra/Inter-enterprise integration***: Intra-integration is related to the integration of the internal business processes from a given enterprise. Indeed, it is sufficient to limit the definition to integration of business processes because it covers the flow of information, the flow of material, and the flow of control. Inter-integration (or enterprise inter-networking) is about the integration of business processes of a given enterprise with the business processes of other enterprises, or even sharing some parts of business processes by different cooperative enterprises.

2.5.2. Enterprise integration.

Inter-enterprise integration is the basis for the extended enterprise concept. In practice, full integration is the aim for intra-enterprise integration while inter-enterprise integration relies in many cases on loose integration.

Enterprise Integration is a process in which an enterprise is transformed into an adaptable business system, capable of acting purposefully and coherently as a whole in the interest of its current and strategic business goals in an optimized manner. [Bernus, *et al.*, 1996].

2.5.3. Integration in manufacturing systems.

According to the investigation developed by the Next Generation Manufacturing Project (NGM), four operational strategies are basic for a successful company in the future manufacturing environment. Three relate to building important components of the company such as: people, knowledge, and equipment for product realization. Underlying these is a strategy for integration [Jordan, *et al.,* 2000]. Figure 2.17, represents these four operation strategies.

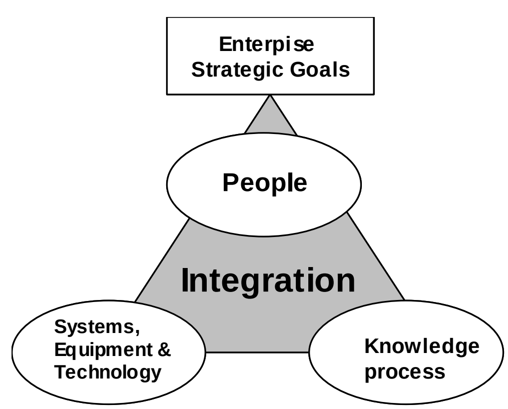


Figure 2.17 Linking corporate goals and operational strategies

[Jordan, *et al.*, 2000]

Veruzcka Medina [Medina, V., 2001] explains some concepts that must be taken into account for manufacturing systems integration: these concepts are presented in the following statement as well as the definition of integration:

> "Integration is what will allow the fruits of the other strategies to be spread over geographic zones, working together efficiently and effectively. While companies currently may need to emphasize one or more of the strategies, all companies will need to pursue all of them over time".

- People (Human resources). Manufacturing enterprise cannot function without people. People are the essential knowledge assets of the company in a knowledge-competitive world.
- Knowledge (methods, practices, techniques). Competitive companies are going to compete by having more knowledge and using it better, such as knowledge about business processes and alternatives, material, design, manufacturing, etc.
- Process, equipment and technology. It is necessary to design, build or acquire multiuse equipment and processes, meaning reconfigurable manufacturing cells, short time setups, and programmable control systems.
- Integration. From a holistic point of view, these three components should be integrated in order to achieve a successful enterprise strategy. Therefore, Integration is the fourth operational strategy.

Enterprise Integration is the link of these operational strategies, a very complex but essential subject for the success of a future enterprise. There are different types of integration; moreover it encompasses different issues and components for a successful implementation [Medina, V., 2001].

2.5.4. Main concepts integration

a. PPD integration in PLM.

PPD could be seen as a proactive process, where the right resources are located in the right place to identify market changes and seize new product opportunities before they occur (in contrast to a reactive strategy in which nothing is done until problems occur); PPD sees new product development as an ongoing process in which a new product development team generally looking for opportunities using communication tools such as customers survey, collaborative product process development (CPPD) by internet/intranet portals, engineering specifications, QFD, etc [Otto & Wood, 2001].

When PDP and PLM are put in the same context, both systems seem to be interrelated in such a way that one cannot exist without the support of the other. Based on figures 2.1 and 2.2 it is clear that the PPD stage has some relationship with the PLM stages. The table 2.3 shows the interrelation between the systems.

System	**STAGES**					
PPD	Idea generation	Design the concept	Developing the concept (prototype)	Test the prototype	Pricing the final product	Full product launch
PLM	Customer need	PPD	Manufacturing system setup	Production & sales	Use & maintenance	Disposal

Table 2.3 PPD and PLM interrelation

The first phase of the PPD is shown the generation of an idea, which is just the result of the interpretation by a person that saw the opportunity in the market, and subsequently translating the need of the client (which is also the first phase inside the PLM) into a product once it passes all the other phases.

The second stage of the PLM is the so called “Product and Process Development” stage, ad here is where in the PLM the process becomes stronger, because the conceptual design of the product is defined in this stage.

Following the “workflow” by the rest of the PLM stages, up to the stage of “Pricing the final product”, at the end there is a prototype of the product that tries to cover the original need of the customer or market for which was designed.

If the prototype fulfills its objectives, it can continue to the “Manufacturing system setup” stage from the PLM, where with the support of fabrication, and with the adequate tools, a procurement system for data, and for the production line, can be established by looking for optimal efficiency and being ready for the “Full Product Launch”. In a certain amount of time, the product will cover a life cycle, according to figure 2.2, of the stages of “usage and maintenance” and then “the disposal” or phase-out of the product.

In too many occasions, the product life cycle tends to recycle and start again, due to product innovation or to the introduction of a new product in the market.

b. ERP and PLM integration.

As a partner in business from Accenture firm, Michael Wetzer, said on his article [Wetzer, M., 2003]: “a fresh look at PLM shows how it can now provide what for many companies has been the missing product development link: the capability to truly integrate existing ERP and CRM capabilities with integrated and real-time product information”, PLM means that the core capabilities of multiple functions and organizations are leveraged across the extended enterprise in the right moment at the right time with good communication.

According to the CIMdata report the integration of Product Lifecycle Management (PLM) and Enterprise Resource Planning (ERP) significantly improves the productivity and effectiveness of users and organizations working with product and plant-related information. These two enterprise domains encompass many of the critical functions required to develop, test, manufacture, deliver, use, and support a product throughout its life, and integration of PLM and ERP can deliver significant benefits for companies of all sizes [CIMdata, 2005].

The comparison between PLM and ERP is natural. There are inevitable questions that compare and contrast PLM and ERP systems, for example: if we have an ERP, do we need PLM system? Are PLM and ERP competitive approaches? How do PLM and ERP could work together? Michael Grieves [Grieves, M. 2006], in his book, provides an analysis and comparison between both systems that is explained as follows:

Modem organizations are divided into functional areas; these common areas are design and development, engineering, production, sales and service, and disposal and recycling. Organizations also possess domains of knowledge. Domains of knowledge are areas of distinct knowledge about certain things that have a common theme. The most common domains of knowledge in an organization are knowledge about products, customers, employees, and suppliers.

Product Lifecycle Management by definition encompasses the product domain of knowledge, and crosses all the functional areas, as shown by the vertical bar in figure 2.18. PLM consists of all the information that deals with the product in the design and development phase, the engineering phase, the production phase, the sales and service phase, and the disposal and recycling phase. PLM clearly is intended to match with the domain of knowledge about the product and to encompass all the functional areas of an organization.

ERP, on the other hand, does the opposite. As shown by the horizontal bar in the figure 2.18, ERP crosses the various domains of knowledge (product, customer, employee, and supplier) but only focuses on the functional areas of production and sales and service. ERP is also primarily transaction-based. It is concerned with taking the information about a transaction, with respect to the product, the customer, the employee, and the supplier and tracking that information in order to produce its unit of interest: a completed order.

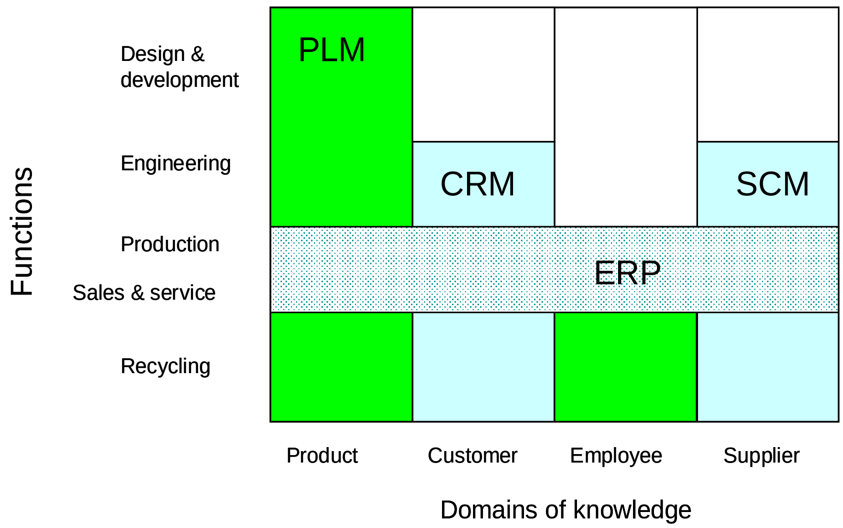


Figure 2.18 Comparing Systems
adapted from [Grieves, M. 2006]

As it can be seen, however, ERP and PLM have an area of overlap in the areas of production, sales and services with respect to the information that they are concerned with.

Before of review the figure 2.18, it is known that PLM and ERP are complementary systems and that, by definition, PLM is more concerned with the domain of product knowledge and less concerned with the transaction than is ERP.

This is not to say that ERP systems cannot incorporate PLM-like informational bases within them. In some cases, vendors of ERP systems would like to do that in order to be able to branch out their ERP systems. However, what this does say is that on a conceptual basis, PLM and ERP systems are defined as complementary although their implementations might attempt to encroach on each other’s functions.

Some of the Business Practice and Technology Factors for ERP and PLM integration, Approaches to Development and Examples of integration development between ERP and PLM could be seen in detail in the Appendix 1.

c. Knowledge in PPD.

Talking with several major manufacturers, M. Rezayat identified a number of requirements for next-generation product development. These include integrating the supply chain into the total process, capturing and re-using best practices, and specifying key characteristics early in the design process. Because 60–80% of all components in products from these Original Equipment Manufacturers (OEMs) are fabricated by outside suppliers, the manufacturing knowledge no longer lives within the walls of these corporations [M. Rezayat, 2000].

Rezayat also mentions that, as a result, when a new design is being conceptualized, this manufacturing knowledge cannot be reused easily to address issues such as manufacturability and cost. Consequently, a generic ability is needed to electronically express, capture, exchange, and reuse knowledge in a meaningful way.

The goals in such an environment are a reduction in cycle time, improvements in product quality and variety, and reuse of best practices in the design of new products. A metric in practicing this so-called "Knowledge Based Product Development" or KBPD, is the ability to provide the right information to the right person at the right time and in the right format. To do this, the following two key elements as the foundation for implementing a KBPD system are proposed:

1. Capturing the information in the form of knowledge by putting the data into a specific context with attached rules, processes, and instructions.
2. Creating the means to update, manage, and reuse this knowledge throughout the extended enterprise.

Product and Process Development PPD has emerged as the lifeline for many businesses and industries. This process can be complex to organize and manage. The management of PPD units and processes require both maintaining a balance between order and disorder and careful attention to knowledge management.

The core of the PPD process is based on knowledge, its creation, utilization and the management. Organizational knowledge is a unique asset and scarce commodity of an organization. Yet, creating, replicating and transferring knowledge within PPD teams, between PPD teams, and between organizational units is difficult to carry out.

Davenport and Prussak [Davenport and Prusak, 2000] suggests that innovation and speed to market are essential for business success and will become increasingly critical in the future. According to Quinn the intangibles that add the most value to these activities are knowledge-centric. Most product development is moving towards team-based structures, because teams are believed to increase individual commitment and performance.

d. Knowledge in ERP.

A good approach to Knowledge in knowledge management against ERP, is seen in the paper by Shuojia Guo, *et al.* [Guo, S., et al., 2006], where they said that while ERP and KM systems emphasize different characteristics, the primary goal of the both systems is to improve the competitiveness of enterprises in global markets. From a practical point of view, KM systems are not preferred to be implemented in isolation, but concurrently with numerous subsystems such as PDM, CAD, SCM, and even ERP.

A few authors have suggested that it is possible to implement ERP and KM concurrently with ambidextrous results [Tushman and O'Reilly, 1997]. As implementation of two different IT concepts, the key characteristics of ERP and KM are quite different in their orientation:

With ERP systems focusing primarily on managing physical assets and KM systems on innovation and utilization of knowledge assets [Chan, R., 1999], in general, ERP defines business processes as standard routines to maximize organizational efficiency.

In comparison with the orientation of ERP systems, KM emphasizes continuous learning at the individual and organizational-level as a complementary approach to improving productivity and efficiency.

Enterprise information systems such as ERP can provide the information platform for knowledge capturing, storing, sharing, and innovating since KM must depend upon integrating data and information though ERP. KM integrated with ERP can improve the business processes managed by ERP to increase firms' competitive advantages. The interaction between ERP and KM systems are synergistic and of significant importance.

In a given enterprise in which ERP and KM systems are implemented concurrently, the interaction between ERP and KM systems can be discussed from two perspectives: the effects of ERP on KM, and the benefits from KM for ERP implementation. ERP systems can provide transaction-processing capabilities that help integrate all of a firm's transaction activities. Using such transaction processing information, a firm can plan its activities, such as production, in which KM can be useful for a series of activities including transaction-processing support [Bendoly, E., 2003; Kennerley & Neely, 2001]. For example, SAP provides solutions for knowledge management and transfer, which is integrated into an interface to share with various other components of the system.

ERP and KM can be integrated on the basis of existing ERP and KM systems, or a newly developed KM system can be integrated into an existing ERP system. In the first approach, the relationship between ERP and KM is incorporation. In the second approach, a KM system is integrated into an ERP system in terms of modules. The first approach is generally considered as a common approach.

e. Knowledge in PLM

PLM is a strategic business approach for the effective management and use of the sum of retained knowledge that an organization accumulates in the course of delivering its objectives [Peñaranda, N., 2007].

The development and manufacture of products requires a wide range of information to support the decision making processes involved in the different stages of their life-cycle. [Costa, C., and Young, R.I.M., 2000]

2.6. Summary

A detailed review was made about each one of the concepts related to communication and integration, Product Life Cycle (PLM), Product and Process Development (also related to Product Development or Process Development), Enterprise Resource Planning (ERP) and Knowledge Management (KM) technologies, through papers, magazines, books, thesis and web pages from authors who talked about it, and the possible integration that could exist, in order to have a better understanding and the basis required to talk about them. It was also made a revision about some of the solution proposed by different authors to similar problems or at least related to one of the concepts mention before.

It can be referred that really exist a relationship among each one of the concepts, and in some occasions this relationship becomes strong according to the perspective that were analyzed (PPD vs. PLM, ERP vs. PLM, KM vs. ERP & PLM), but now it is clear that it is possible achieve a kind of level of interrelation among them.

Some authors propose methods, tools and technologies that could support the implementation or integration process; however the integration level is restricted more to the use of functional tools and vendor software than a systematic approach that established a methodology to be followed in order to integrate PLM, ERP systems and KM practices.

In many of the integration cases revised, this integration was achieved due to the support of commercial applications that could result in a high cost of investment for development and integration according to the kind of systems owned by the business. In other case third party vendors provide a tool that could be used as a Workflow Management System (WFMS) to loosely integrate ERP, PLM and KM systems in the organization.

Just as was mentioned in the beginning of this chapter, the communication (related to the communication between technologies systems and its interaction with the people) is one of the most important points, along with the data and information that will be later transformed into knowledge. However in the meantime, this data is just transferred by means of information that flows through the systems and process defined by WFMS, which could be a good tool to utilize in order to achieve the integration among the different systems for the new proposed methodology.

The need to count with a methodology that supports the integration of systems' technologies, whether in the implementation phase of a development process or if is already implemented, can become a great application tool. Accordingly to the businesses were realizing the competitive advantages that can be obtained by getting their systems interconnected, such as introduction and process time improvement, diminishing the duplicity of information among systems and utilizing the knowledge developed for future applications or projects.

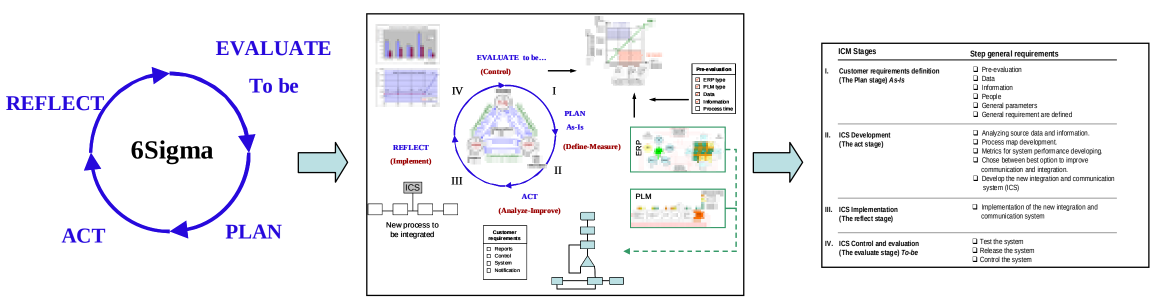
CHAPTER 3

3. FRAMEWORK, MODEL, AND METHODOLOGY FOR ERP, PLM AND KM INTEGRATION AND COMMUNICATION.

3.1. Introduction.

This chapter will be explain the research methodologies used by the author in the current research work, the integration framework that was defined with the help of the research methodologies and the methodology developed based on the framework defined in order to solve the stated problem and improve the integration and communication levels between PLM, ERP and KM to achieve the goals defined in chapter one.

Figure 3.1 represents how this chapter is divided into three main sections, where the first part is related to the research methodologies used by the author: “Learning Evolution Cycles” by Action Research and “DMAIC” by Six Sigma.



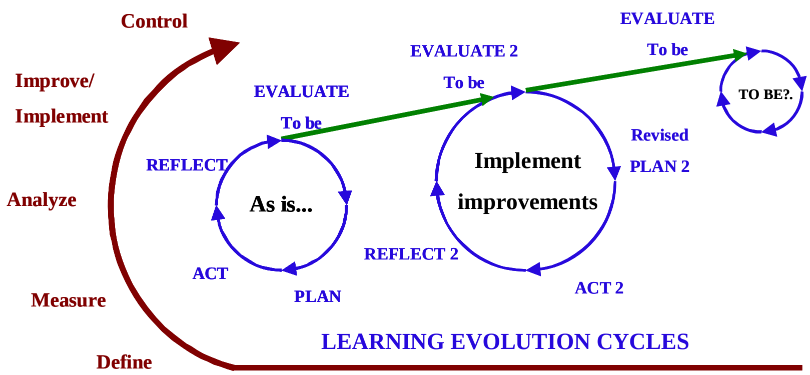
Research methodology | Model and Framework | Methodology

Figure 3.1 Chapter Story Telling

The middle section of the figure represents the framework that shows the structure and model followed for the integration and communication methodology. In the last part of the figure, the detailed activity plan is presented for the methodology execution, as well as the considerations to take before applying this methodology to any business.

3.2. Research methodologies: Action Research & Six Sigma

As can be seen in figure 3.2, this thesis research was carried out based on two defined methodologies: “Learning evolution cycles” from “Action Research”, and “DMAIC” by Six Sigma.



Research methodology relationship	
Action Research	6 Sigma
Plan	Define Measure
ACT	Analyze Improve
Reflect	Implement
Evaluate	Control

Six Sigma –DMAIC–

Figure 3.2 Learning Evolution Cycles and Six Sigma Phases Interaction

In the first instance, for Learning Evolution Cycles, previous experiences and lessons learned from the “*As is*” state are used to change the current state of the process by the application of improvements in order to achieve the “*To be*” desired state.

Action research aims to contribute to the practical concerns of people in an immediate problematic situation and to further the goals of social science simultaneously. The objective of action research is to study a system and to concurrently collaborate with members of the system while changing what is together regarded as a desirable direction. Accomplishing this requires the active collaboration of the researcher and client, and thus stresses the importance of co-learning as a primary aspect of the research process. [O'Brien, R., 2001].

Action research method is used in real situations of experimental studies, since its primary focus is on solving real problems. However, it can be used by social scientists for preliminary or pilot research, especially when the situation is too ambiguous to frame a precise research question [O'Brien, R., 2001].

On the other hand, Six Sigma is a system of the better practices, developed by Motorola in 1987, with the objective to reduce process variation and eliminate defects. It is a result-oriented methodology with a focus on quality projects [Jay, 2001]. It is a way to measure and obtain results in favor of the elimination of defects in the products, and is directly connected to the customer's requirements [Hernandez, N., 2002].

According to Brey [Brey, 2001], Six Sigma emphasizes an intelligent blending of the wisdom for the organizations with proven statistical tools to improve both the efficiency and effectiveness of the way an organization meets customer needs. Its application requires the use of tools and statistical methodologies (mostly) to eliminate the variability of the processes and to produce the expected results, with the minimum possible number of defects, lowest costs and maximum customer satisfaction.

The author of this thesis propose the usage of this two methodologies to integrate a robust research method were Six Sigma will provide more specific tools for supporting the decision-making based on facts for each step of action research. With action research as the base for improvement, a constant cycle of process improvement could be adapted in continuous evolutionary and improvement cycles based on previous experience and improvements. Steps, stages and tools can be seen in table 3.1

Methodology	**Stages-steps**			
Action Research	Plan	Act	Reflect	Evaluate
Six Sigma	Define-Measure	Analyze-Improve	Implement	Control
Method. tools	Surveys, voice of customer, suppliers input-process output	Map of process, varianza analysis, design/redesign	Management of the process	Integral control panel

Table 3.1 Action Research and Six Sigma Correspondences

Under these two approaches, the framework and methodology will be supported for the Action Research and Six Sigma tool application in the integration of PLM, ERP and KM. This will be further explained in the subsequent two sections of this chapter.

In order to better understand how Action Research and Six Sigma works, a more complete explanation is located in appendix 2.

3.3. The Integration Framework.

The author of this thesis proposes a Framework and Methodology to achieve the Integration and Communication for ERP data and information, PLM for processes, and KM for people's Knowledge, supported by the methodologies of Action Research and their steps, and Six Sigma tools in all stages. These two methodologies working together as means to ensure the success of the Integration and Communication Methodology (ICM) as applied in industry or organizations.

The framework in the figure 3.3 represents the sequence of application for the ICM in industry, and the model as the relationship (at the center) with the three elements to integrate, people, process, data and information in terms of knowledge, PLM and ERP, respectively. These will be explained in more detail later.

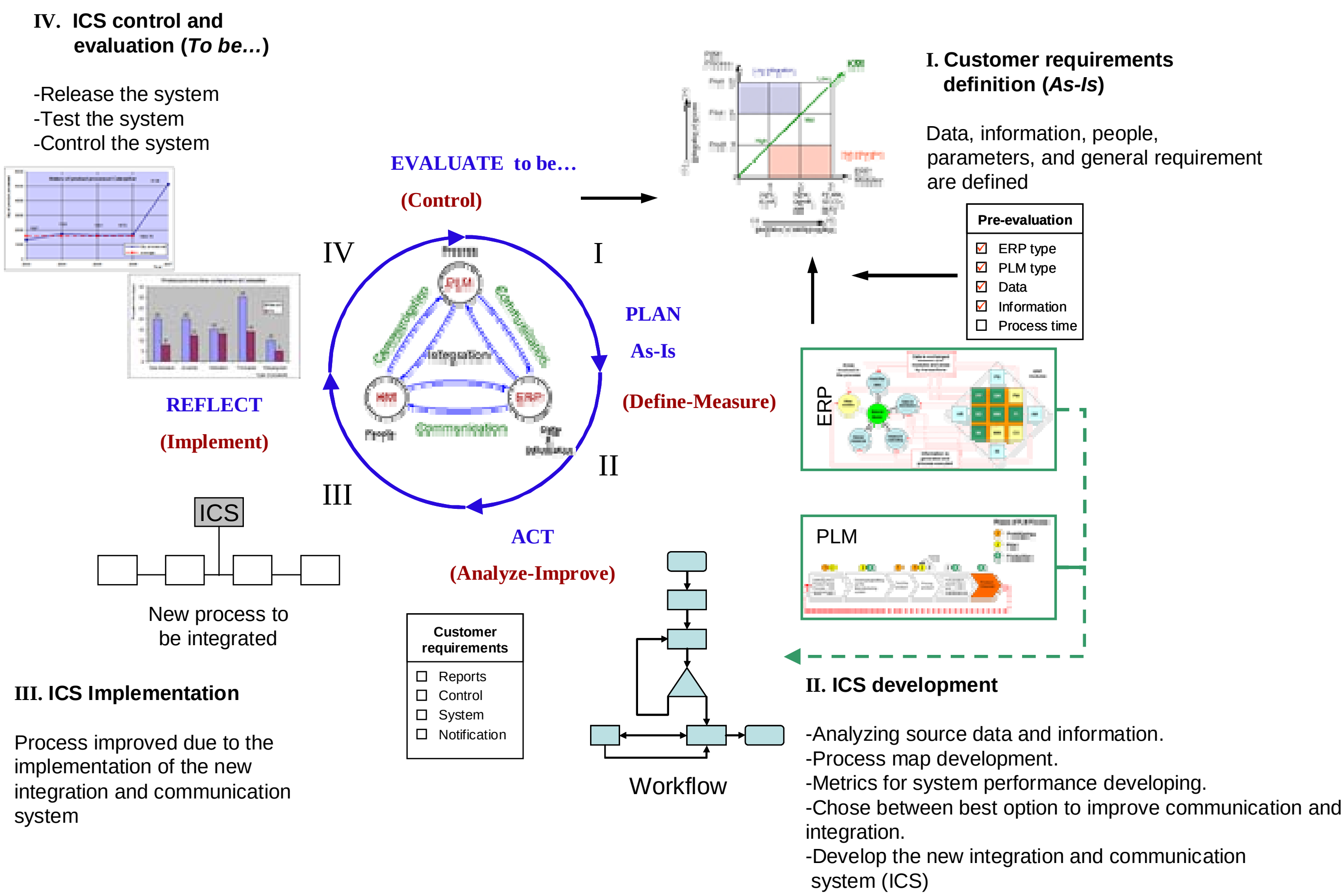


Figure 3.3 Integration and Communication Framework (ICF)

The ICF, was designed by taking the frameworks created by Medina [Medina, V., 2001] and Mejía [Mejía, R., 2003] as reference. They applied their research to the Deaming's circles for continuous improvement and leaning evolution cycles from action research respectively. Both authors refer to their investigations with the aim of integration for their respective systems. They also define a methodology based on their frameworks. The contribution from the author to this research thesis is in addition to the usage and support of Six Sigma methodology as a research methodology and pre-evaluation step at the first stage, in order to make a judgment about the company situation, and see if the methodology could be applied in any other analysis or development.

In the middle of the framework-methodology there is the "integration and communication model" (ICMdl) proposed by the author of this thesis, where the main objective is to represent the inherent relationship between the three main elements (ERP, PLM and KM) in order to obtain integration and communication in organizations.

The framework begins with the first stage, where a pre-evaluation of the company must be performed to see if the methodology can be applied to the company; this will enable an overview of the current situation before spending time on other tasks. During this stage, data, information, people, parameters and general requirement need to be defined.

In the second stage the sources of data and information are analyzed in order to create the process map or "workflow." Subsequently, metrics are defined to measure the system's performance and chose between the best options to improve communication and integration and develop the new integration and communication system (ICS).

This third stage is about the implementation of the ICS, and, finally, stage four is about the test and release of the ICS with the proper control tools. Table 3.2 shows the main stages and their requirements as defined by the ICM:

ICM Stages	General requirements
I. Customer requirements definition The Plan (*As-Is*) stage	☐ Pre-evaluation ☐ Obtaining data ☐ Obtaining information ☐ People is chosen to form the work team ☐ General parameters are defined ☐ General requirement are defined
II. ICS development The Act stage	☐ Analyzing source data and information. ☐ Process map development. ☐ Metrics for system performance developing. ☐ Chose between best option to improve communication and integration. ☐ Develop the new integration and communication system (ICS)
III. ICS Implementation The Reflect Stage	☐ Implementation of the new integration and communication system
IV. ICS control and evaluation The Evaluate (*To be…*) stage	☐ Release the system ☐ Test the system ☐ Control the system

Table 3.2 ICM Main Stages and Requirements

3.3.1. The Integration Model

There are several technical challenges in the integration of ERP, PLM and KM technology systems. First challenge concerns defining how the three systems can be integrated in a single model. To make this possible, and more easily to understand, the author will refer to the consequences that could be obtained, such as “process” for PLM, “data and information” for ERP and “people” for KM.

At the center of the framework (figure 3.3) there is the “integration model” that will be used to represent inherent integration and communication relationship between the three main elements proposed by the author, defined as the result of the six sigma and action research application.

Figure 3.4 depicts the model that will be used in the framework and methodology with the intention to better understand the possible interaction between the three main concepts, and by doing so show the integration and communication.

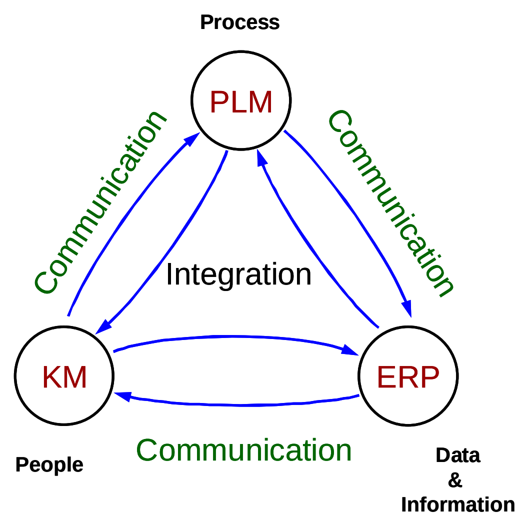


Figure 3.4 Integration and Communication Model (ICMdl)

To understand how the three elements "People, Process and Data/Information", are related and how they interact with each other, it is important for the purpose of this research to define it:

The People element (KM)

The People element of the model is finally explained. For the model in figure 3.2, the process (PLM) can be applied just as virtual process that contains some stages that need to be performed in order to deliver products to customers; Data/Information (ERP) on the other hand, must be implemented in order to apply the methodology proposed by the author. Nevertheless is not enough to only have a virtual or real PLM process or a Data/Information system (ERP), if is nobody uses is; in fact, this is the main reason for the interaction with the people element in the model.

People will interact and communicate with the other two elements by entering data and information into the ERP system after they have a need to produce a product for the PLM process. These people will use their available data and information and their previous knowledge (acquired by personal experience, training, etc.) in order to create more knowledge or expertise (figure 2.11) that could be used later in another process.

The Process element (PLM)

This process refers to the PLM technology and the processes that are managed under this application. PLM can manage product and process development, implementation and setup (figure 2.1). However, based on the phase of the process applied to the product, one or more stages of the PLM can be dismissed.

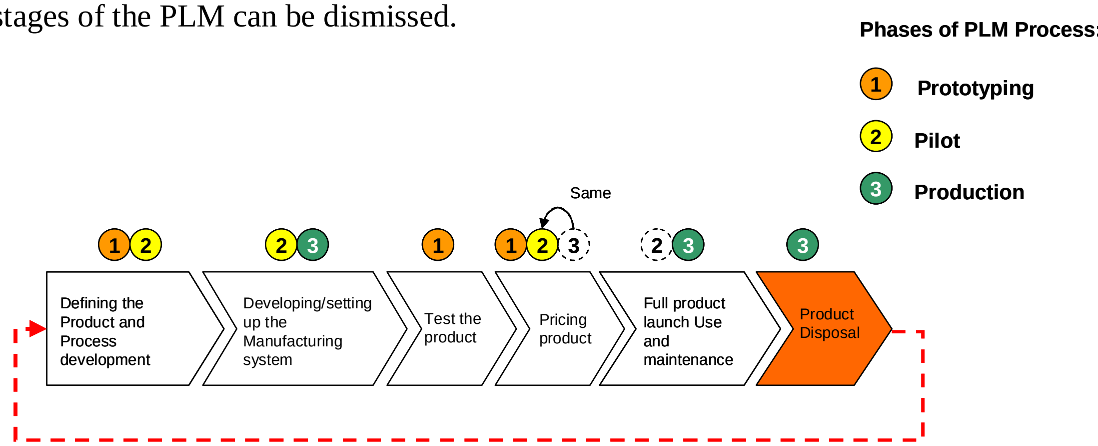


Figure 3.5 Prototype, Pilot and Production PLM Process

Figure 3.5 shows the three different processes adopted for the author on this thesis: Prototype, Pilot and Production process.

The processes needed for a product fabrication are managed by the people (specialized work team) that by using process such as Project management, follows all the sequence steps of the PLM by setting up the data (according to the process) needed for the ERP system in order to procure the raw material, purchase finished material as need, and schedule the production orders against the delivery dates established by the customer for each process starting with the prototype process, followed by the pilot process and the full production (and ramp up) process.

The data, information and knowledge generated over the early process (prototype and pilot) of the PLM could be subsequently used to quickly establish normal production process set up. This is how the “process” interacts with people and data/information over the model.

The Data-Information element (ERP)

As it was explained in chapter 2, ERP systems can be conformed by five main areas according to their structure: Material Master, Production and Planning, Sales and Distribution, Finances and Controlling, and Human Resource. Each one is formed by modules were data is stored, recorded and retrieved as needed by the personnel (figure 3.6).

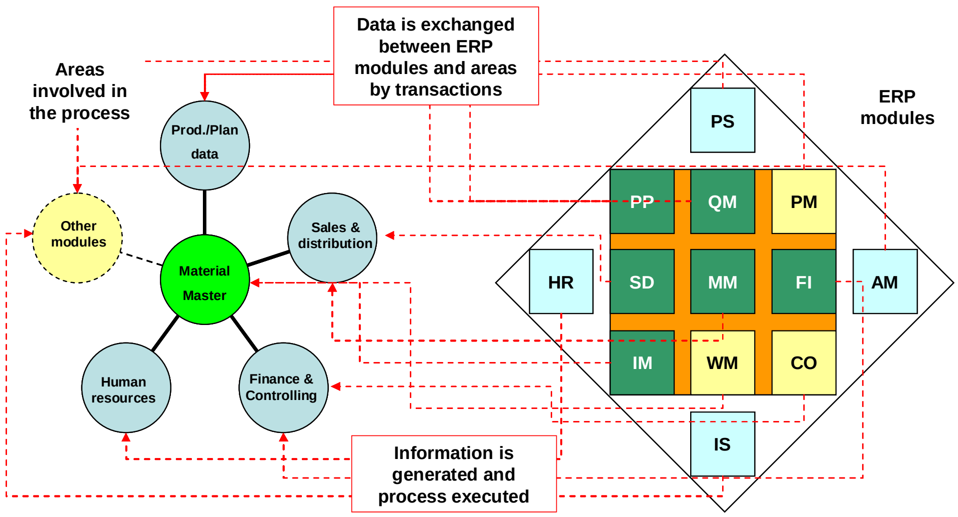


Figure 3.6 left: five main areas integration, Right: the ERP modules each area

These modules are interconnected to each other in order to exchange and execute data by transactions and retrieve relevant product information that will be used to execute process such as production, material procurement, and sales. An example of this data could be seen in table AP. 3.1 from appendix 3.

Data is generated according to the PLM process and is entered into the ERP system by the person with the appropriated pertinent knowledge and experiences. Since ERP is only a system, that will not work without people and process interaction.

In some occasions, the ERP vendors support the workflow development, which could be a good albeit expensive option for integration. For the purpose of this thesis, the ERP SAP model was used as reference according to its importance in main vendors charts (Appendix 1). A depth explanation about PLM and ERP elements could be consulted in Appendix 3.

3.4. Integration and Communication Methodology (ICM)

In this section, the created framework is used to define a sequence of steps based on the four stages of table 3.2 in order to state the methodology that must be followed in order to achieve the level of integration and communication desired according to the company requirements and the three elements (figure 3.4) from the ICMdl of this thesis

ICM Stage	ICM Steps
I. Customer requirements definition (*As-Is*) "The Plan"	a. Pre-evaluation of the company b. Integration level desired is established. c. Define the areas and process involved. d. Define the area's requirements. e. Define data or information to integrate.
II. ICS development	a. Process mapped against PLM b. Deployment Map (Mapping the process to integrate). c. Metrics gathering/definition d. Information formats definition e. Integration and Communication System (ICS) decision made and development.
III. ICS Implementation	a. Implementation for System Tests. b. Compare the New System wit the as-is.
IV. ICS control and evaluation (*To be…*)	a. System Integration Test (SIT – Only for team members) b. End user training. c. User Acceptance Test (UAT – For end users). d. Launch and Release the ICM System (On-Line). e. Integration system Control.

Table 3.3 ICM Stages and Steps

The structure for this methodology was created by taking the methodology proposed by Villa as reference [Villa, P., 2004], where it was proposed a series of steps in order to translate the current process and implement a flow system. In some aspects, that is what happened during the application of this methodology, with possible development and application of a Workflow Management System (WFMS) by increasing the capabilities of the current systems.

Some of the steps from the ICM are mandatory, but others can be omitted if they do not make sense or cannot be applied due to organization's structure. Before reviewing the methodology, each element of the ICM's application will be explained in further detail.

3.4.1. Customer requirements definition (*As-Is*) - "The Plan"

This section of the methodology is formed by pre-evaluating of the company, establishing the desired integration level, defining the areas and process involved, the definition of the area's requirements, data or information to integrate it is shown as part of the main framework in figure 3.7.

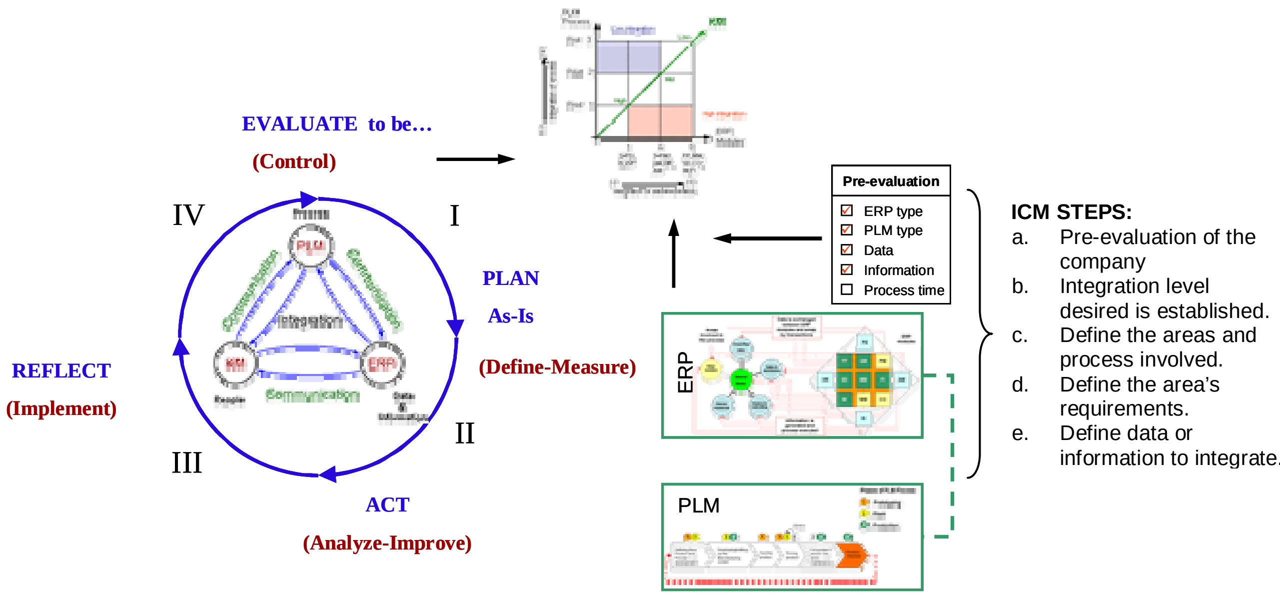


Figure 3.7 Framework-Customer requirements definition – "The Plan"

a. Pre-evaluation of the company

One of the most important parts of the ICM is "pre-evaluation" of the company. This consists of a questionnaire [1] that will help from the beginning to define if the ICM is applicable according to the actual company's environment systems, processes and requirements.

This questionnaire will provide a quick overview of the company's current situation. The questionnaire is shown in appendix 6. The correct person to complete this evaluation is the

[1] For ERP and PLM system which could be in process or planned for the company to implement will be considered as already implemented, and most of the times this integration methodology could be align to the implementation development schedule in order to be considered further improvements and dates.

one with the more experience about the company's systems, technologies, and processes. If the company does not fulfill the questionnaire, the methodology cannot be applied and the process is finished.

Some considerations and restrictions must be taken into account: 1) If in the company where the methodology is applied does not have a PLM process established, the lowest rank of integration will be obtained but the methodology can continue by referring to PLM as a "virtual" PLM process; 2) If in the company where the methodology is applied does not have an ERP, the methodology cannot continue because there is not an ERP process to control, nor data to manage. 3) If the company where the methodology is applied does not have a formal or informal KM process in place, the methodology can be applied and KM will be improved and formalized.

The first stage of the ICF is called "The Plan." Once the company passes the pre-evaluation test, is time to start with the definition of the "parameters" or "requirements" that will help the project leader to know how the actual organization can adapt the framework and model. The current situation of the company is **defined** supported from the pre-evaluation step. Next integration levels are defined, the core team is selected, the requirements of the organization are defined, the processes to integrate are defined, and the data and the information are also defined.

The use of a survey is a good tool to obtain the requirements of the company based on the customer requirements, as well as the development of a Suppliers-Input-Process-Output or (SIPOC) to define the process to integrate these input/output variables.

b. Integration level desired is established.

Trying to compare the different concepts can be hard; when technologies and process are compared, the relationship is harder to define because of the intricate context of every element. However defining where a company stands with their actual relationship among systems and process is more compelling than ever. This is why the author of this thesis, defines the following equation with the objective of simulating the relationship between ERP, PLM and KM in terms of integration (equation 3.1).

$$ILI = \frac{(PLM_{ip} + ERP_{idi}) \bullet (KM_{PLM} + KM_{ERP})}{ILF}$$

$$were : ILF = 0.72$$

Were: ILI = Integration Level Index.

PLM_{ip} = PLM integration process

ERP_{idi} = ERP integration of data/information

KM_{PLM} = Knowledge management in terms of PLM

KM_{ERP} = Knowledge management in terms of ERP

Equation 3.1 Integration Level Index (ILI)

Equation 3.1 states that the Integration Level Index (ILI) is directly proportional to the product of the sum of PLM and ERP and Knowledge Management in terms of PLM and ERP, and indirectly proportional to the "Integration Level Factor" defined with the value of 0.72 for this research. This equation could be represented in the figure 3.8 and 3.9 as follow:

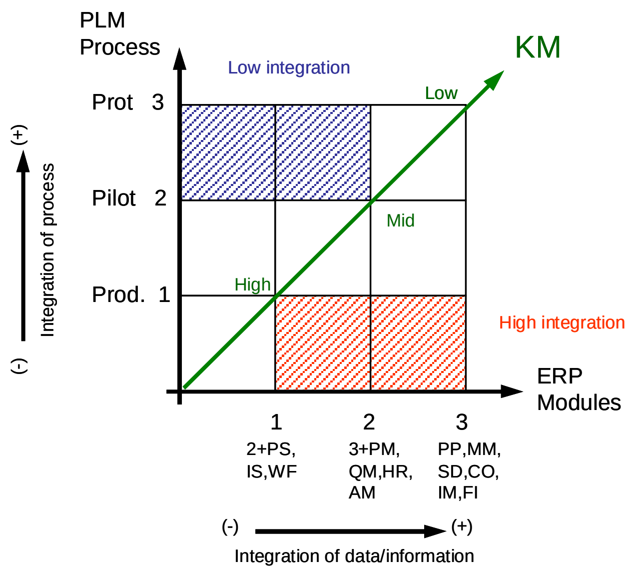


Figure 3.8 Integration Level Index Relationship (PLM + ERP)

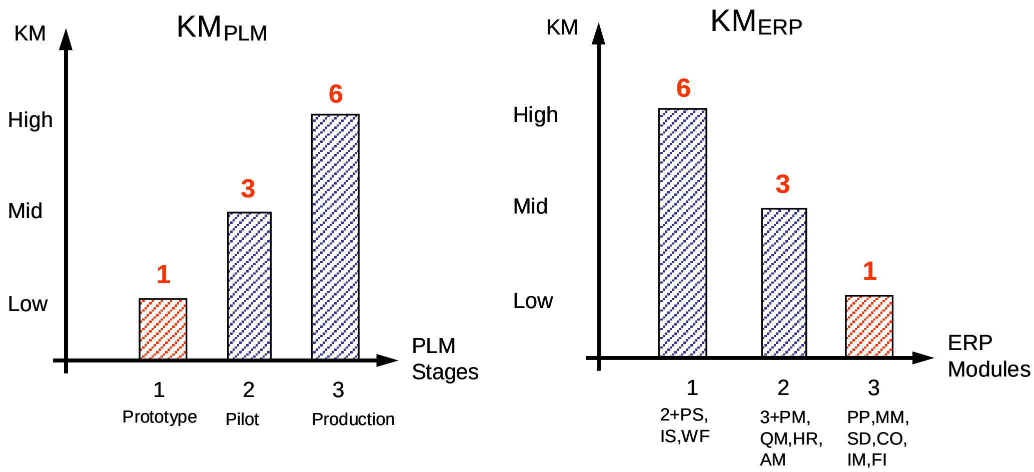


Figure 3.9 Integration Level Index Relationship (KM_{PLM} + KM_{ERP})

The objective is to define the Integration Level Index, by using the general information gathered from the pre-evaluation stage. Taking the PLM and ERP data and entering it into figure 3.8 will obtain the process and data values (1 to 6 points). In the same way, now compare KM against the ERP and PLM values of every column (1, 3, 6) to obtain from 0 to 12 points. Finally use equation 3.1 or table 3.4 to easily obtain the value of the Integration Level Index, where values equal to 0 has not integration, values from 1 to 40 have low integration, values from 41 to 70 have medium integration and values from 71 to 100 have a high or good integration level.

Integration level index	
0	No integration
1-40	Low integration
41-70	Mid integration
71-100	High integration

	Figure 3.8						
Figure 3.9	PLM_{ip} + ERP_{idi}						
KM_{ERP}+KM_{PLM}	0	1	2	3	4	5	6
0	0.00	1.00	1.00	1.00	1.00	1.00	1.00
2	0.00	2.78	5.56	8.33	11.11	13.89	16.67
4	0.00	5.56	11.11	16.67	22.22	27.78	33.33
7	0.00	9.72	19.44	29.17	38.89	48.61	58.33
4	0.00	5.56	11.11	16.67	22.22	27.78	33.33
6	0.00	8.33	16.67	25.00	33.33	41.67	50.00
9	0.00	12.50	25.00	37.50	50.00	62.50	75.00
7	0.00	9.72	19.44	29.17	38.89	48.61	58.33
9	0.00	12.50	25.00	37.50	50.00	62.50	75.00
12	0.00	16.67	33.33	50.00	66.67	83.33	100.00

Table 3.4 Integration Level Index (ILI)

The ILI for this methodology will be the main metric to review of further process stages. The explanation on how the values from table 3.4 were calculated is found in appendix 6.

The actual structure has to be compared with the structures defined for PLM and ERP (Appendix 6) in order to see if the current structure can be expressed in form of diagrams (see if it fits), and sees the scope of the integration based on the modules of the ERP or the PLM stages that will cover.

c. Define the areas and process involved.

In this section all areas such as purchasing, sales, finances, controlling, engineering, manufacturing, and inventories, must be mapped according to PLM process and the data and information of ERP system diagrams in order to obtain all possible relationship and variants between these areas adjacent to the PLM processes.

Personnel that support the integration methodology will be selected according to their knowledge, skills, and availability. They will perform system testing and will participate in processes mapping. These people will be called “key business users" and will be part of the project’s core team.

d. Define the area’s requirements.

In this step, personal interviews, meetings with the involved areas, and surveys will be used in order to obtain the specific system requirements defined by the areas. Some of these requirements could be the system’s sequence, reports, specific metrics and/or indicators.

e. Define data or information to integrate.

In this step as in previous, personnel interviews, surveys and meeting with the areas involved will be used in order to obtain the specific system requirements according to the users, with the aim of taking care not to duplicate the entrances between the systems except where truly required.

This data can be unique item identification, dependent materials, and demand and supply information, according to the section 2.3.3 ERP Business Process Structure and table AP.3.1 at the appendix 3 that contains ERP areas and their generic main data.

3.4.2. ICS Development – "The Act"

According to the action research methodology, the second stage of the framework is called "Act;" this is the more extensive stage of the ICM. This stage can be represented based on the main framework in the figure 3.10.

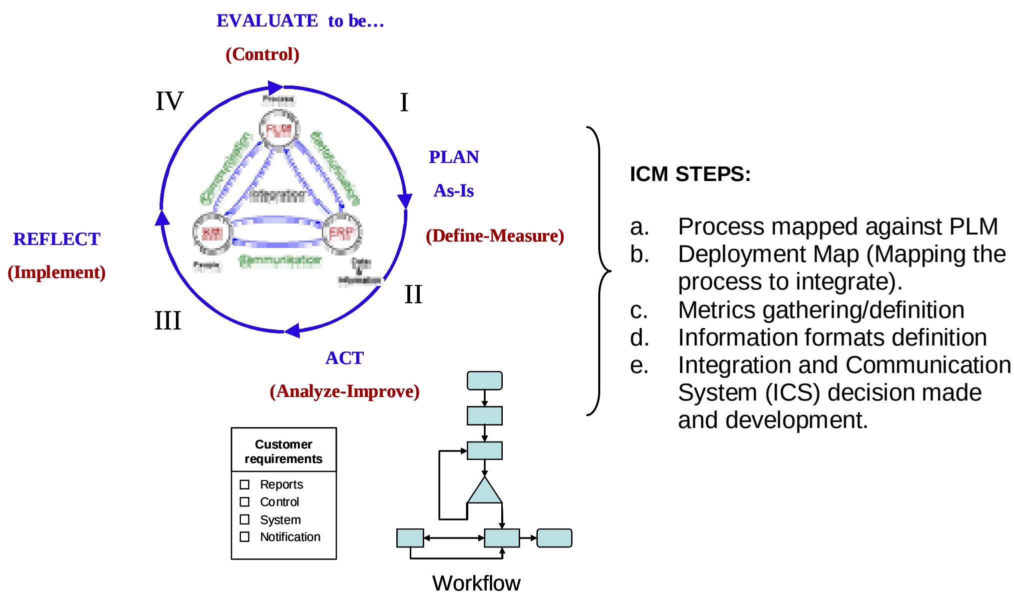


Figure 3.10 Framework-ICS Development – "The Act"

All the information and data gathered from the previous stage is **analyzed.** The different processes are mapped against the PLM activities performed by the areas in order to obtain a deployment map or "workflow" that will help in understanding how the interaction could be established among the three elements of the model.

Some metrics could be obtained or defined, such as process lead times or process performance versus the amount of information generated, that will help to **measure** or establish objectives, or improve the system in the future. Some formats (se Appendix 6) will be defined to enable the usage of KM.

The company will make a decision about to adapt a customized current ERP or PLM system that the supplier or vendor creates. Alternatively, the company could find a third party supplier that in base of the deployment process map, could offer an integration solution with a “Workflow Management Systems (WFMS)” (for a better understanding about WFMS capabilities see Appendix 3).

This decision depends on some factors such as the ERP system or PLM process, the size of the company and the desired level of integration needed. More detailed information that could help in making the decision is presented in the table 3.2 that will be reviewed during the methodology explanation in this chapter. Once the decision is made, the integration system is developed, based on the deployment map process, the business requirements, the defined process and the data and information selected.

a. Process mapped against PLM

All the processes of the company related to the PLM stages are compared against the diagram in Appendix 6 in order to define the possible variation in the process by defining the stages for the development and introduction of new products over their different phases: prototype, pilot and production. Variations such as engineering changes, source of supply change, and phase-outs, must be also considered.

b. Deployment Map (Mapping the process to integrate).

Process Maps or “workflows” are among the most essential tools of Six Sigma, in which improving, designing, measuring, and managing process are the primary focus [Pande, et al., 2000]. The basics of a process map are simple: a series of tasks (rectangles) and decisions/reviews (diamonds), connected by arrows to show the flow of work. That supports the analysis of some specific problems such as: disconnects activities, bottlenecks, redundancies, rework loops and decisions/inspections. In the figure 3.11 there is shown an example of a workflow:

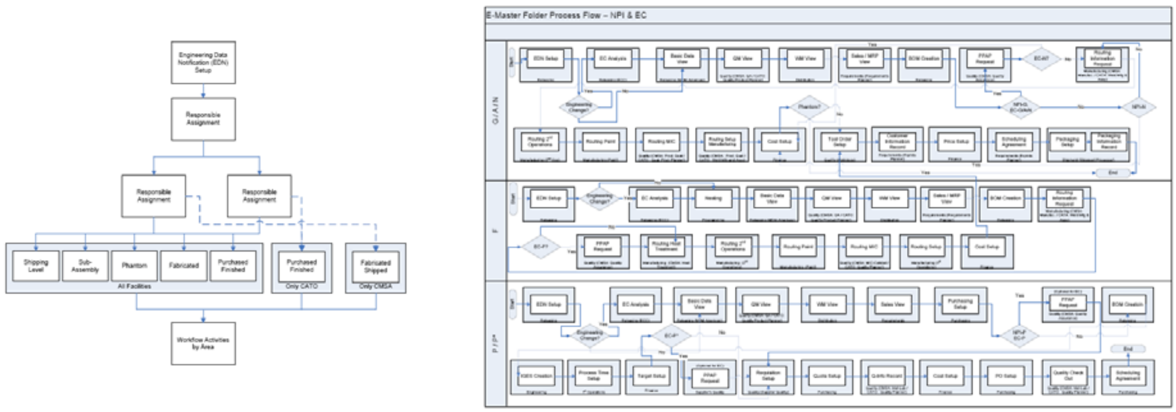


Figure 3.11 a workflow example

Commercial software that offers the capability to support the development of "workflow management systems or WFMS" could be a good option for the integration and communication between different kinds of systems and processes.

This software must be validated and compared with other systems even if it is from the same company that developed the ERP or PLM.

Since the define measure and analysis stages were already completed, it is now time to put all the information together and perform the application development that will support the integration and communication enhancement between the systems.

c. Metrics gathering/definition

In this part of the methodology, current metrics can be used or redefined according to new parameters that can make possible the improvement of the process.

Metrics such as: process times, information tracking, and bottleneck visualization, are just a few of the metrics that could be obtained as an improvement with the implementation of this methodology.

d. Information formats definition

These formats are designed to present a summary of the data concerned with a respective area, through research or general inquire. The integration of KM, ERP and PLM is shown by this format, because, it is gather data from the ERP system, this data that was entered due to one or few of the PLM stages, will enable the possibility to serve as a further information or knowledge for the people who retrieve and uses the information contained in these format. An example of the format could be seen in Appendix 6

e. Integration and Communication System (ICS) decision made and development.

This is the phase that can take the most time during the development of the process; here is where the requirements of the organization are integrated with the parameters needed in order for the PLM, ERP and KM to become integrated and communicate with the system (ICM).

During this phase, the team analyzes the flow process charts by trying to understand how the information will flow. The variables from the ERP that need to be implemented and that would present any interaction with each one of the PLM phases are defined.

The first option (Figure 3.12) represents a medium integration (horizontal and vertical) where the sequence and lead times from the stages of the PLM are already defined and are connected to the current ERP. This connection could be impossible with the implementation of a homemade WFMS system developed internally by the company systems experts or by a third party consultant that provides the technical support for the development of this tool.

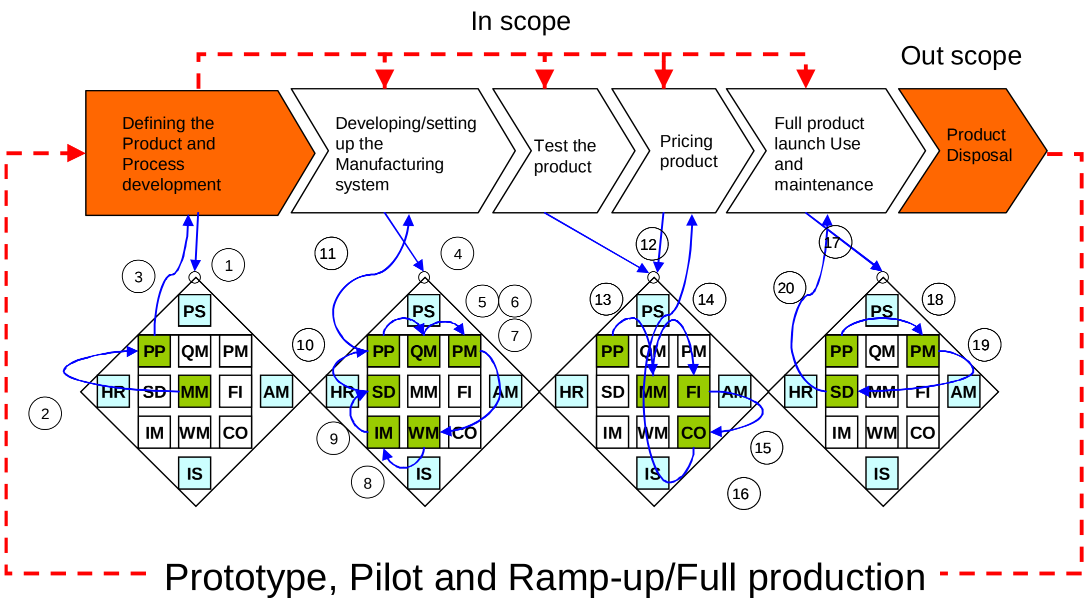


Figure 3.12 Medium Integration Representation

With this WFMS, it could also be possible to integrate activities that enable the conversion of tacit knowledge to explicit knowledge with simple tools, such as query formats or text data field, that are completed by the user before advancing or releasing the workflow to the next area of the process.

This kind of integration is recommended more for small and medium companies that do not want to spend large amounts of money for workflow consultants or a dedicated team that implements the integration and communication methodology. A list of software and vendors is presented in Appendix 3.

The second option, (figure 3.13) represents high integration (Full Integration) and communication level. This option is completely dependant on the ERP or PLM system already implemented or that will be implemented in the company. ERP and PLM works at the same time in the same platform what makes easy to share common data and information.

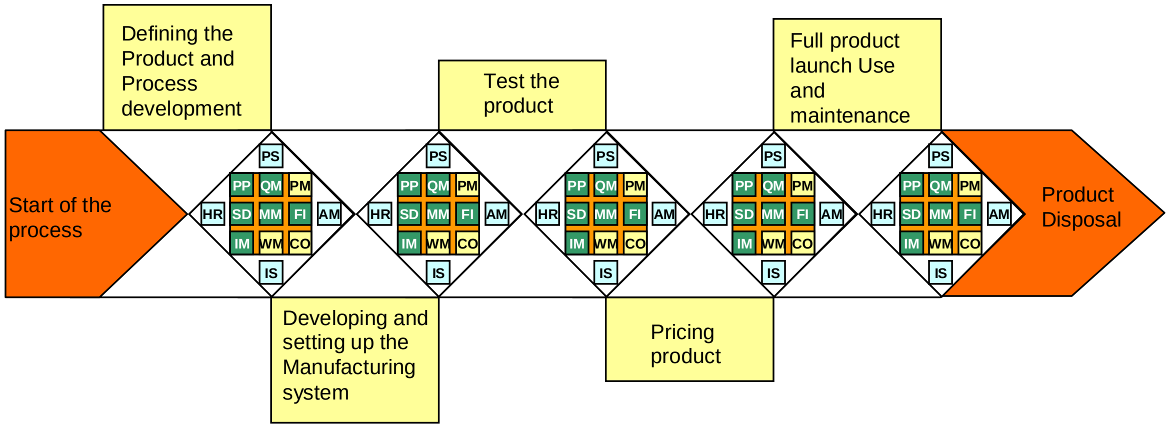


Figure 3.13 Full Integration Representation

Some vendors that distribute and implement these kinds of systems could offer the platform, module or interface to connect some functionalities of both systems. Some times the system already owned comes with the PLM and ERP functionality.

For this option, the integration could be adapted to the exact needs of the company according to their PLM stages, the flow tasks and the information and data processed through the ERP by means of the ERP or PLM systems supplier-vendor.

However, there is the big possibility that depending on the ERP or PLM systems already implemented in the company, the suppliers will not offer the kind of integration required or it could be a big investment in time or money if it is available; consequently, the option of the “workflow” development becomes a good alternative even for the big enterprises.

Nevertheless, the company’s decision of the presented options depends in the expectations of the company concerning the desired level of integration and communication and how much money there is available and they are willing to spend.

This development can be made in some occasions with the support of expert consultants on the programming language for ERP and PLM systems and can generate very good and complete integration and make communication possible. Conversely, this communication and integration can be achieved by enabling some application or modules, that most of the times are not included in a standard implementation.

In other occasions, with the support of a third party consultant who provides technical support, an independent "workflow" system development, that does not related to the programming in which ERP and PLM were developed. With this workflow, a very good integration between ERP and PLM can be achieved to improve communication and knowledge management.

The decision depends on some factors that should be considered such as the size of the business, the cost and time improved in the development, the configuration flexibility (this means the ease difficulty in adapting the system to the needs of a company), the level of integration among ERP-PLM, the integration with KM and the availability in the market.

Table 3.5 contains a comparison of the characteristics and recommendations made by the author for the type of development involving a system made in the same language of the ERP or PLM with support of the systems consultant (option A), and system made by a third party supplier that could create a WFMS (option B) for the company.

			Score	
Characteristics	Option A	Option B	Option A	Option B
Development cost	High	low-medium	1	5
Development time	Medium	Medium	3	3
Configuration flexibility	Medium	High	3	5
ERP-PLM integration	High	Medium*	5	3
ERP-PLM communication	High	Medium*	5	3
KM integration	Medium	High	3	5
Availability in the market	Low	Medium	1	3
Application recommended for:				
Big enterprises	Recommended	Medium	5	3
Small & Medium enterprises	Not recommended	High recommended	1	5
			27	35 Total

1. Worst
3. Same
5. Best

Table 3.5 Comparison between two options for the development of the integration system

The decision about which development system choose depends completely on what the company is seeking and how much the company wants to invest; however, it could be said "that the more expensive way is not always the best option, but what really adapts to the company's needs and gives the desired results is the best decision". Nevertheless, at the end of this stage the ICS must be finished and ready in order to begin the testing.

The author of this thesis agrees with Mejía [Mejía, R., 2003] about choosing the development of a WFMS as the best option, because there this is an easy and cheap way to perform an approach to the integration improvement desired for the company, as it was shown on Mejia's research. The addition of some improvements could make this WFMS smarter for the common and/or repetitive activities on a company.

3.4.3. **ICS Implementation** – ***"Reflect"***

The third and fourth stages are related to the **<u>improvement</u>** gained with the development and implementation of the integration system, when compared to the "*as is*" stage. Figure 3.14 represents the third stage of the main framework, the "reflect stage:"

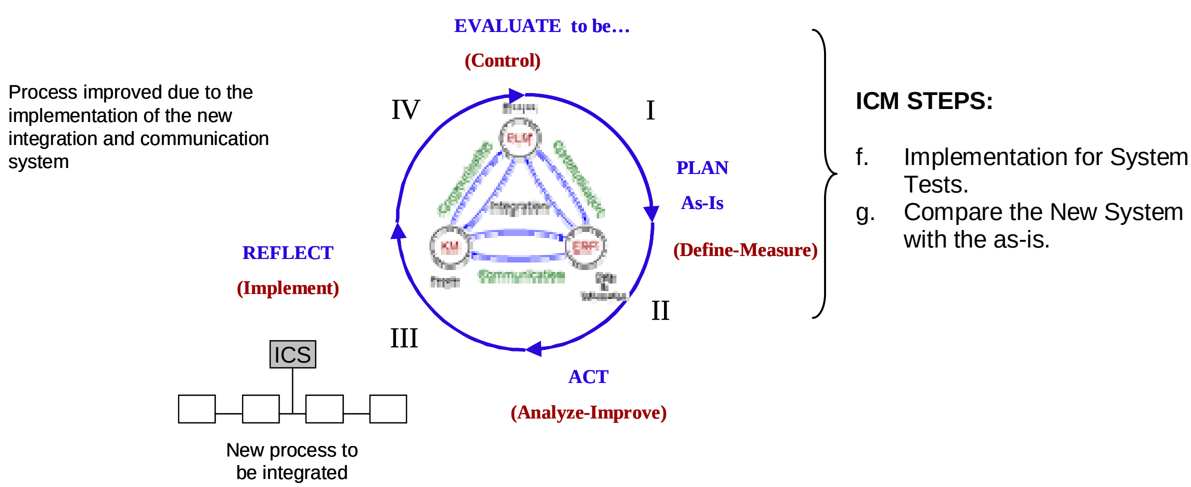


Figure 3.14 Framework-ICS Implementation – "Reflect"

a. Implementation for System Tests.

Once that the development of the system is completed, it is necessary to implement it in a controlled environment that permit to perform the necessary testing to adjust or correct any possible problems that were found in the new workflow system or modules added to the PLM or ERP according to the company decision.

It is recommended to leave this development or test environment for the improvements that could be presented after the release of the system.

b. Compare the New System with the as-is.

Now that the new Integration and Communication System (ICS) was developed for ERP, PLM and KM process and technologies, it is time to perform the validation of the integration level index, previously introduced in the first stage of this methodology, and compare the *"as-is"* to see if the *"to-be"* is correct.

If the *"to-be"* state was not obtained, return to previous stages and see if something was not considered correctly and make the necessary adjustments.

3.4.4. ICS control and evaluation the "*To be…stage*"

For the last stage, the integration development was already performed; it is now time to "evaluate" how the new system works. To make this evaluation the system should been implemented in a controlled environment in order to perform the necessary testing without affecting any current process before the new system is released. Figure 3.15 represents the "evaluate" stage and show how is related to the main framework (figure 3.3).

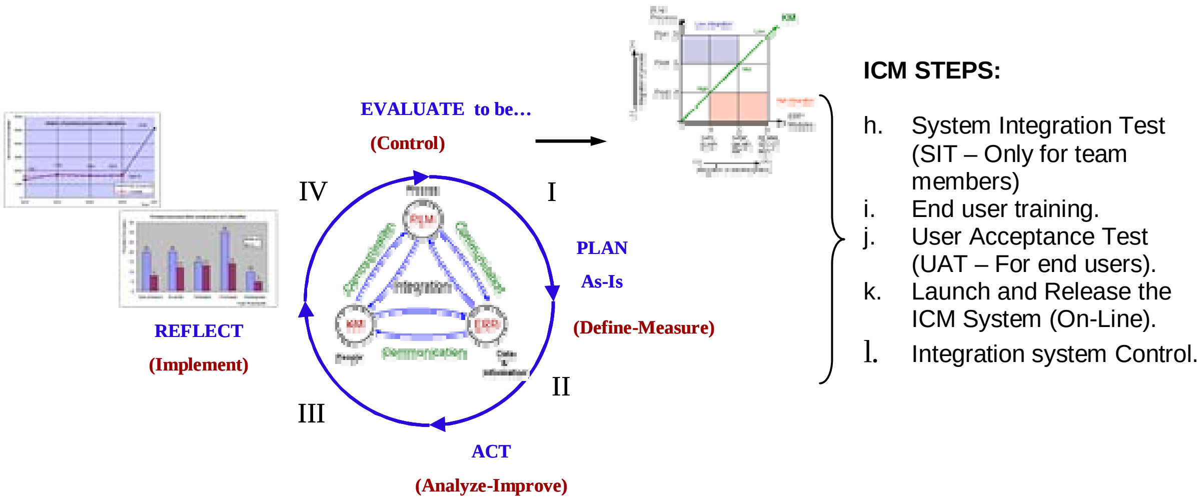


Figure 3.15 Framework-ICS Control and Evaluation the "*To be…stage*"

In this final stage, the "evaluation" of the implemented system, it is made by defining a "system integration test" or "*SIT*" that is tested simulating the different scenarios applied to the new system by the team members. Once the end users are properly trained in the usage of this new system, they should perform a "user acceptance test" or "*UAT,*" which is similar to SIT. Once the system pass the SIT and UAT, is ready to be released and set on-line, thereby enabling the integration of the knowledge generated by the creation and interchange of data and information that is entered into the ERP through and according to the PLM process stages managed by the people involved, who **<u>control</u>** their own system.

At this moment, the research methodology and framework have been explained and defined. Now it is time to integrate these two sections in order to obtain the "Integration and Communication Methodology (ICM) for PLM, ERP and KM".

The evaluation of the final integration is carried out by the members of the team who tested the different scenarios and settings with all the variables previously mapped by looking for possible failures. It is important to do "error provoked tests" where the objective of the test is to place erroneous data to see if the development system can detect these errors and can prevent any further decline of the integrity of the PLM and/or ERP systems. This kind of test is carried out until the desired level of integration and communication is obtained.

a. System Integration Test (SIT – Only for team members)

In this step the team members carry out integration tests on all the phases of the PLM, by testing the communication and integration against the ERP and showing how the knowledge is converted from tacit to explicit with aid of the system. The team also generates test script that will be used by end users in the step called "User Acceptance Test" (UAT).

b. End user training.

In this step the training of the end users is performed, where the team members are responsible for carrying out the training in their respective areas of expertise. It is recommended depending on the complexity of the process that the training is done in small groups for a better understanding.

c. User Acceptance Test (UAT – For end users).

This is the last of the tests where the end users after receiving the adequate training, testing their know-how about the new integrated system by means of executing the scripts generated in the phase of SIT by the team members, as a manner of practice, in order to obtain the acceptance of the end users.

d. Launch and Release the ICM System (On-Line).

Once the development, training, and integration and acceptance tests, are finish, it is time to release the system into production, which means that the system is officially turned on line by communicating and integrating the ERP, PLM and KM system technologies.

e. Integration system Control.

The system was developed seeking to fulfill the requirements defined by the business. The users were coached and trained and the necessary tests were carried out, but the methodology does not finish there.

As part of the improvements it is required to developed a module for the administration of the knowledge as a mechanism of continuous improvement, where its main objective is to enable the users to generate and record ideas of improvement about their own integrated system so that ideas could be later revised by the original team members that participated in the project to see if these ideas actually contribute to the improvement of the system or they are rejected because the lack of value added.

Technical backup should be established during a period of reasonable time for any problem that could be arise as a result of user feedback from the users, while measuring the growth of the system every month. Appendix 4, present the methodology format for all the activities that must be followed up in a timely basis, including the complete flow of all activities used for this methodology.

3.5. Summary

During this chapter, the integration of two research methodologies were performed to support the development of the Integration and Communication Framework and Methodology (ICF and ICM), the "Action Research" with the usage of Learning Evolution Cycles and "Six Sigma" with the Define-Measure-Analyze-Improve/Implement-Control (DMAIC) methodologies were established.

The second section was about the framework and model for integration and communication proposed by the author in order to achieve the integration of ERP and PLM systems technologies with KM. The four stages that form the framework: 1) Customer requirements definition (As-Is), 2) Integration and Communication System (ICS) development, 3) ICS

Implementation, and 4) ICS control and evaluation (To be…); and the three elements that integrate the model: People, Process and Data and Information. The "*As is*", the "*Model and Methodology*" were explained in detail.

In the third and final section explains the steps that conform the methodology (the ICM) based on the ICF framework presented before. It also explains how the methodology is implemented in any kind of enterprises, no matter the size, or kind of systems that the company has, as long as they have an ERP system in place. The two integration and communication option models were discussed according to the "*to be*", that based on some factors such as: the size and economy of the company, and the desired level of integration and communication, will support the decision of which ICS model should be implemented.

The author of this thesis recommends that for small and medium businesses, where the usage of and ERP system is just beginning or intends to bring updates to a more sophisticated system, the best option for the development of a system is the integration in a different language that of the ERP or PLM, because of the development cost and high flexibility. For large business, however, the option to use the supplier's actual technology (ERP o PLM) would be a good idea if they are willing to make big invest, although the system development option, one could fit very well too depending on the individual circumstances involved.

The ICF, ICMdl and ICM are independent of the industrial sector, and could be applied to any kind of organization from small to big companies since the company have implemented or in plans to implement an ERP system.

CHAPTER 4

4. CASE STUDY

4.1. Introduction

During this chapter the Integration and Communication Framework and Methodology (ICF and ICM) will be put to test in order to verify the effectiveness and efficiency as applied to two different experiments or case study, sponsored by Caterpillar Mexico (CMSA) [1], who try to reach the possible integration and communication that could exist between KM, PLM and ERP in terms of People, Process and Data and Information. These experiments are described below.

The first experiment it is about a 25 years old, custom-made ERP system, called "Maxcim" [2], which has not had any version update in recent years; basic integration and communication do not exist. The problem is exacerbated because no technical support exists today from original suppliers, making improvements or special developments impossible inside of this homemade ERP.

The second experiment refers to the SAP r/3 ERP system, where PLM capabilities were not included during the conception phase of the process and in the implementation phase, thereby becoming one of the main problems. Technical support exists for this system by a consulting firm (Accenture) who has experience in the implementations of this type. Investment and complexity for in-house technical support, is too high, even for Caterpillar.

For both experiments, KM is not considered as part of the normal process with in Caterpillar, since this concept has not been applied at the corporate level; consequently, when people leave the company, their expertise and knowledge goes with them. The objectives of the ICM application for both cases of studies are:

[1] Caterpillar México is formed by three main facilities one in Santa Catarina, N.L. called CMSA, other in Torreon, Coahuila called CATO and the last one in Reynosa, Tamps. Called ENTEC (see Appendix 5)

[2] The MAXCIM ERP System containing customer master record data, detailed booking, shipment, invoicing and returns history records, customer payment history and account balance status data.

a) Enabling/improving integration and communication levels between “virtual” PLM (for both cases) and ERP, thereby enabling the development of KM that could be used for the company’s new employees.
b) Develop and implement a WFMS to enable integration and communication in both case studies.
c) Achieve one of the three systems integration benefits listed by Miller [Miller, K., 2005]:
   i. Ensuring consistent use of product and plant-related information by personnel in organizations throughout the enterprise;
   ii. Reducing the time to bring new and enhanced products to market at a lower cost while improving quality, and;
   iii. Creating and using common product-related terminology and processes throughout the business.
d) Prove the effectiveness of the ICM when applied to a real case problem.

The structure of the experiment (figure 4.1) for both ICM case studies can be defined by the following structure of the ICF: first the “plan” stage for the definition, then the “act” stage for the analysis and development, followed by the “reflect” stage for the implementation, and finally the “evaluate” stage, where comparisons against the initial stage will be performed in order to obtain the integration and communication improvement

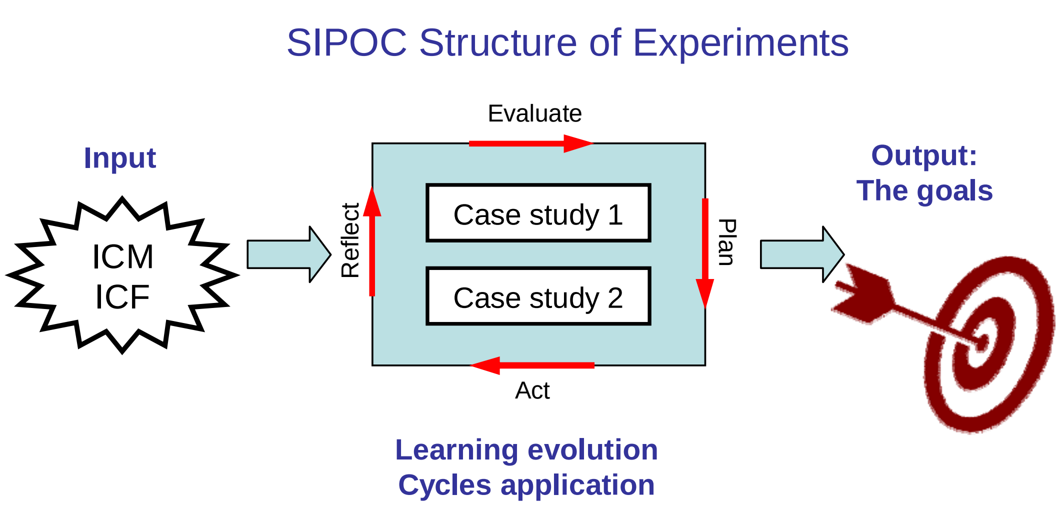


Figure 4.1 Experiment’s structure

4.2. Case Study One (CS1): CMSA-Maxcim

The first case study is about a more than 25-year old ERP system working in Caterpillar México: "Maxcim" (figure 4.2), that evolved from MRP to MRPII to later become, in some way, the ERP system that controls most of the processes established for the company.

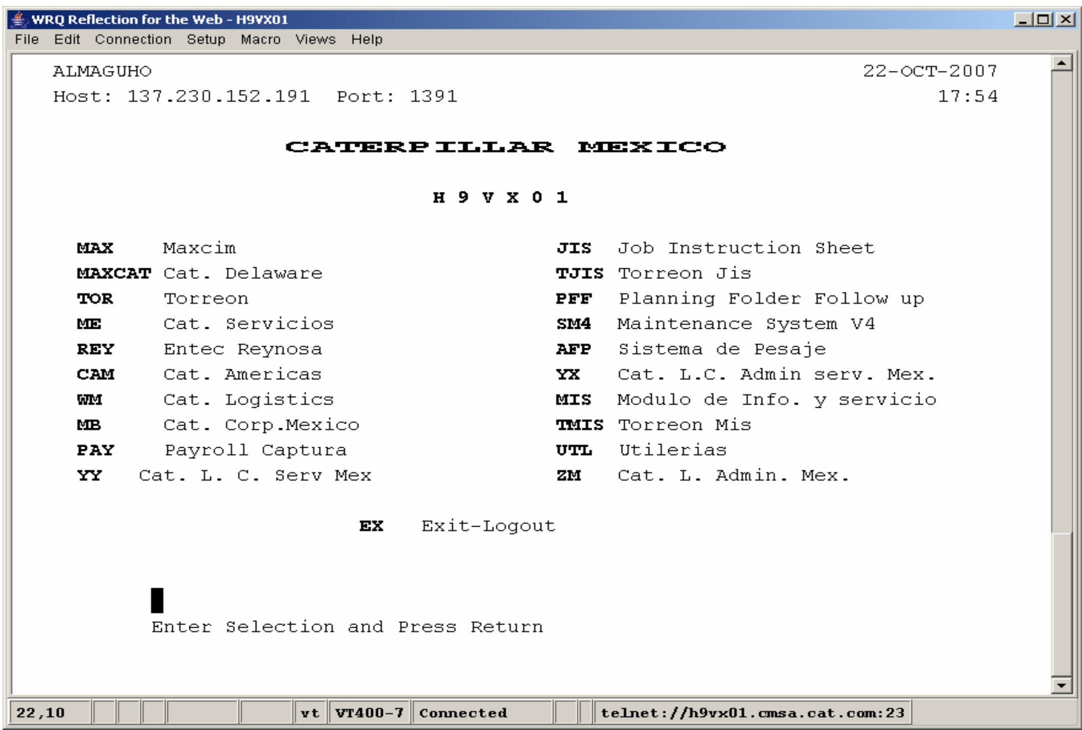


Figure 4.2 Maxcim main screen

The main problem of this system, including the clear lack of integration and communication both internal to the system and externally with the PLM and KM, is that the people, who should be involved in the process of data and information, does not receive notifications related about the products that should be processed by them at the right moment in the right time.

4.2.1. CS1: Methodology and Framework Application

I. Customer Requirements Definition (*As- Is*) "The Plan" Stage

a. Pre-evaluation of the company

The "Maxcim-CMSA" case study passed the pre-evaluation stage, which means that the methodology could be applied to improve the integration and communication between current ERP, PLM and KM. The pre-evaluation form that was completed for this case study could be found in Appendix 6.

b. Desired Integration Level is Established.

According to diagram 3.11, first in the ERP axis Maxcim obtains 2 points for all modules related to production, sales and distribution, and finance. In the PLM axis, due to the fact that there is not a system that controls the PLM process, 0 points will be given. This gives a total of 2 points for the Integration Level Index for PLM and ERP.

For diagram 3.12, the KM_{ERP} is 1 point because Maxcim does not have any enabled functions that are related to KM, but that is different from the KM_{PLM} point of view, Caterpillar Mexico does not have a proper system that controls the PLM stages or knowledge generated by the process. Informal information related to projects is archived by team leaders for all process (prototype, pilot, and production). This is why the KM_{PLM} obtain 6 points. This makes a total of 7 points.

Using the chart 3.1, entering first the value of 2 for PLM and ERP, and 7 for $KM_{PLM/ERP}$ results in the value of 19.44 points, which according to the index integration scale, the integration level is LOW because 19.44 is less than 40 points.

Desired integration level will be MEDIUM based on a virtual PLM process. Because the company does not have a KM system in place, the concept is not familiar to them.

c. Define the areas and process involved

The company manages three stages of the PLM process: the prototype, pilot, and production stages, for fabricated components, purchased finish components, sub-assemblies, phantom assemblies, and shipping levels.

Since the designs of the product is controlled form corporate business units, the stage of product development will be interpreted solely as support from Caterpillar Mexico.

According to these stages, the areas defined were, releasing, quality assurance, supplier's quality, purchasing, manufacturing, first and second operations, machining process, heat treatment, paint, and finance.

Main functions of the releasing area (also called Product Change Control) are related to the material master information set up and the bill of materials creation in Maxcim, the coordination of engineering changes to phase in/out products and the support in coordination together with the New Product Introduction (NPI) and manufacturing areas for the development of new products in the prototype, and pilot and production stages at CMSA. That is why the releasing area becomes a key area in the implementation for the ICM at CMSA.

d. Define the area's requirements.

According to a survey (Appendix 6) developed from the releasing areas where the objective was to get improvements their customer's areas point of view, the following requirements were found:

- Communication between the areas in the PLM stages.
- Accuracy of data processed in Maxcim system.
- Process time and customer feedback.
- Involvement in synchronization.

- Technical knowledge about the products and process.
- Obsolete and surplus material inventory avoidance control.
- Quality service to customers.
- Effective delivery date definition in conjunction with “work teams.”

It can be seen that communication, integration, knowledge, and data are elements presented as the requirements from areas involved in the process. More detailed explanation about each requirement can be found in Appendix 6

e. Define data or information to integrate.

The following data from table 4.1 was defined as the key data according to Maxcim and PLM stages:

Part number.	Product sales model	Manufacturing times
Part number description.	Standard cost	Purchasing lead times
Product code (fabrication line id).	Supplier name	Attachments of files such as notifications, nesting, product drawings
Task lists (routing) for processing the products	Process status (to identify the area)	
General data and comments	People responsible	Source code (procurement type, fabricated, assembly, purchased, shipping level, phantom).
Effective date.	Weights.	

Table 4.1 Key Data from Maxcim

II. ICS development: “The Act” stage

a. Process mapped against PLM.

According to figure 3.5 CMSA fits into almost all the distinct stages. Since this company does not perform the design and development of product, this stage of the same figure can be excluded and used data from their Product Data Management (PDM).

b. Deployment Map (Mapping the process to integrate).

A deployment map (figure 4.3) was created based on the different areas involved in the processing of information and data generation to Maxcim from the PLM stage of the project. Detailed workflows generated for all the variables and type of products are shown on Appendix 7.

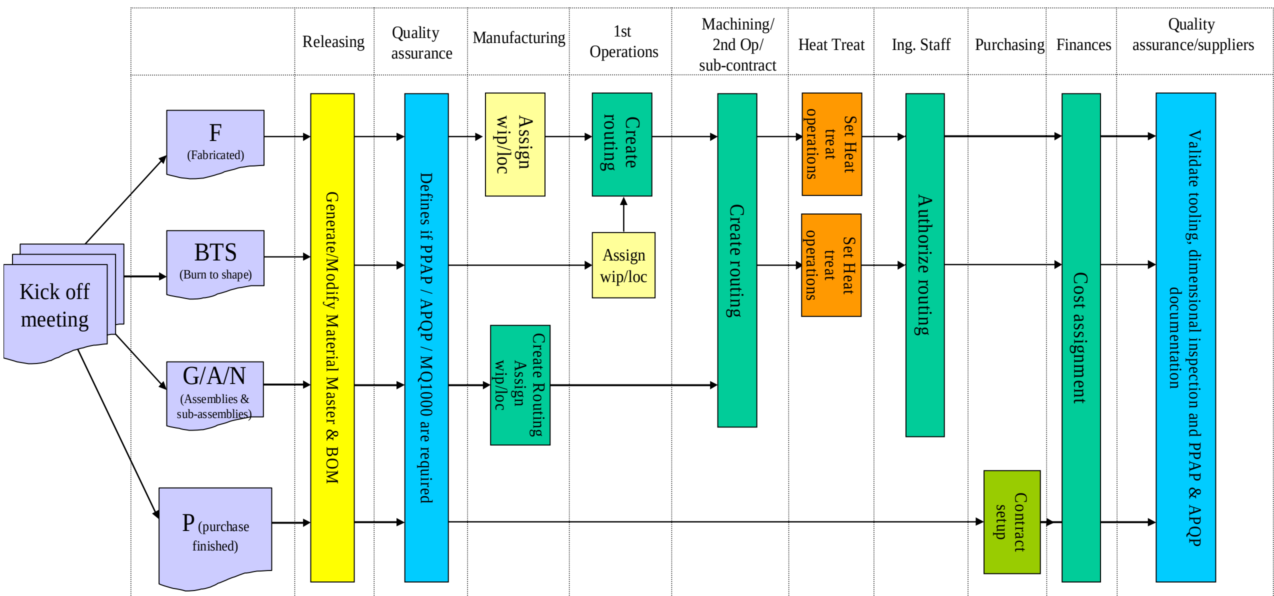


Figure 4.3 Maxcim deployment map

c. Metrics gathering/definition.

Some metrics were proposed by the users, such as process time, past due, amount of part numbers processed, part numbers pending by area and user responsible.

d. Information formats definition.

For this development information formats were not defined. Due that this option was not considered at the time that was developed.

e. Integration and Communication System (ICS) decision made and development.

Based on customer requirements and lack of a Maxcim developer, the best option was to create a Workflow Management System (**WFMS)** by finding a third party supplier who could offer this development.

The development was performed by the personnel of the systems development group within the Caterpillar Information and Technology (IT) division, who, taking in count the communication system already established worldwide within the company called "Lotus Notes" (figure 4.4), proposed the development of the WFMS as part of a database where information could be stored and retrieved by users at any moment.

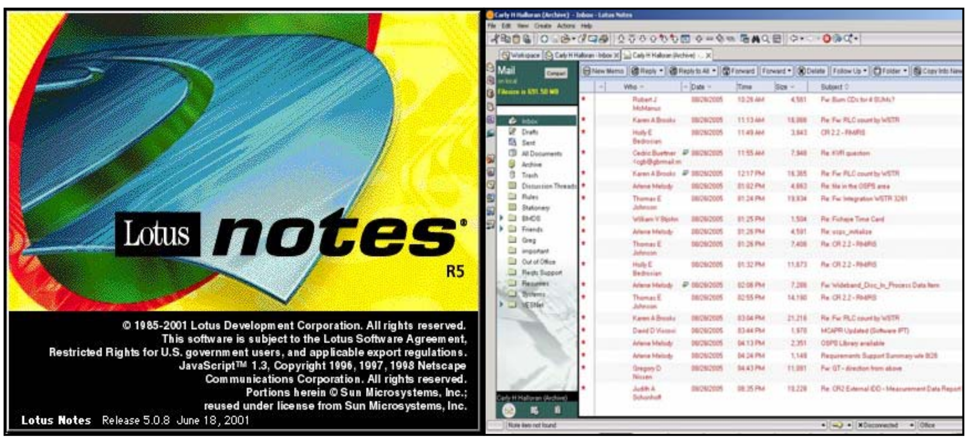


Figure 4.4 Lotus Notes system by IBM®

To create this WFMS in Lotus Notes, a Lotus Notes tool called "Domino Designer" was required. This tool enables IT system experts to create, program, and design custom-made databases that can fulfill customer needs and requirements about integration and communication.

After eight months of developing and testing with the IT group by the project core team, the first Integration and Communication System for PLM, ERP, and KM was finished, with the name of "e-Master File," which could be seen in figure 4.5.

Detailed information about the capabilities, structure, and design of the e-Master File can be found in Appendix 8.

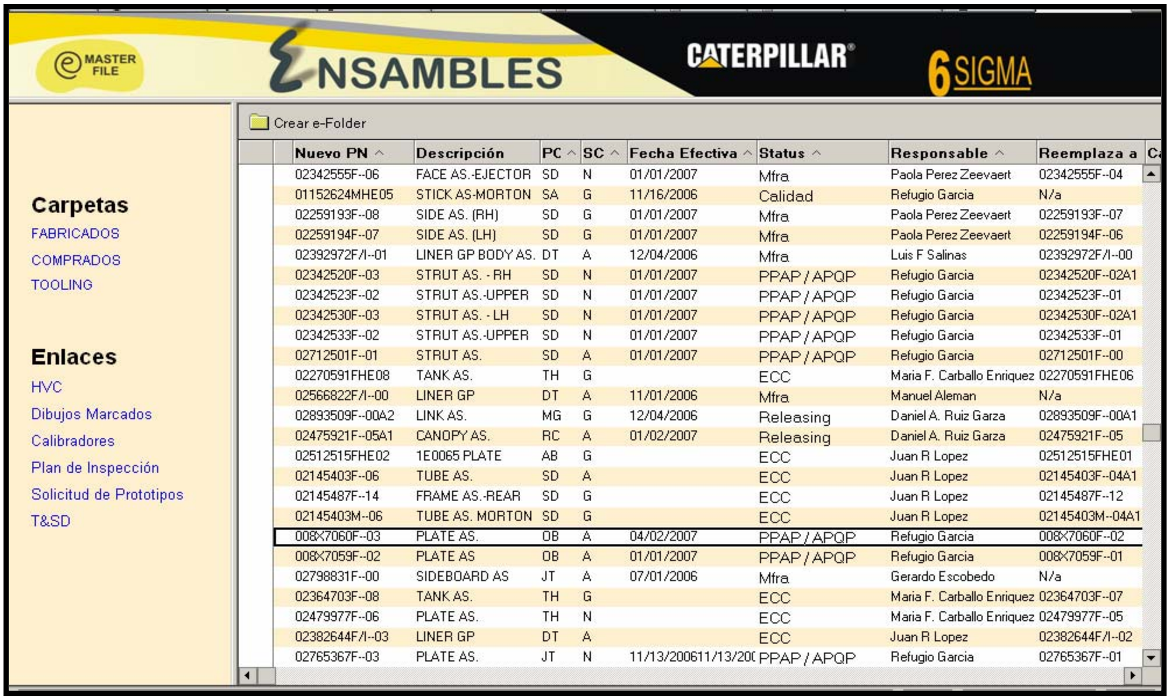


Figure 4.5 WFMS "e-Master File"

III. ICS Implementation "The Reflect" stage

a. Implementation for System Tests.

The system was partially implemented in a pre-production simulation environment where all capabilities were proved, by performing error-provoking tests applied to data and the workflows with differing variables and scenarios.

b. Compare the New System with the as-is.

In the as-is the PLM processes were carried out by project management follow up. Now the usage of these tools can continue under the new "e-Master File", which is designed to track the stages that must be performed in order to fabricate a product.

Formats were created to record a user's knowledge and expertise as a repository for every product processed and because this, were defined some mandatory field for the e-Master File, and the user is forced to share this knowledge. This same knowledge could be used by incoming generations or as reference for other product development projects.

The only disadvantage is that some critical data must be entered twice, once in Maxcim and again in the e-Master File.

IV. ICS Control and evaluation "The Evaluation" stage (*To be*…evaluation)

a. System Integration Test (SIT – Only for team members).

For the e-Master File development, the core team and the end users performed few tests were to validate the different scenarios for which the product could pass through. These were: the prototype, pilot, and production scenarios according to the PLM stages. Three different workflows were defined for all types of products in the company: 1) Components fabricated in house, 2) Sub assembly, shipping levels and phantoms sub-assemblies and 3) Purchased finished material.

For each scenario, the variant of new product introduction and the engineering change was considered. With these variants, the three kinds of products and the PLM stages were needed to perform more than eighteen *System Integration Tests*.

b. End user training.

A training session was used with the areas involved, where the system was presented for all three types of products, and since most of the end users participated in the SIT, the training has continued since that step of the methodology.

c. User Acceptance Test (UAT – For end users).

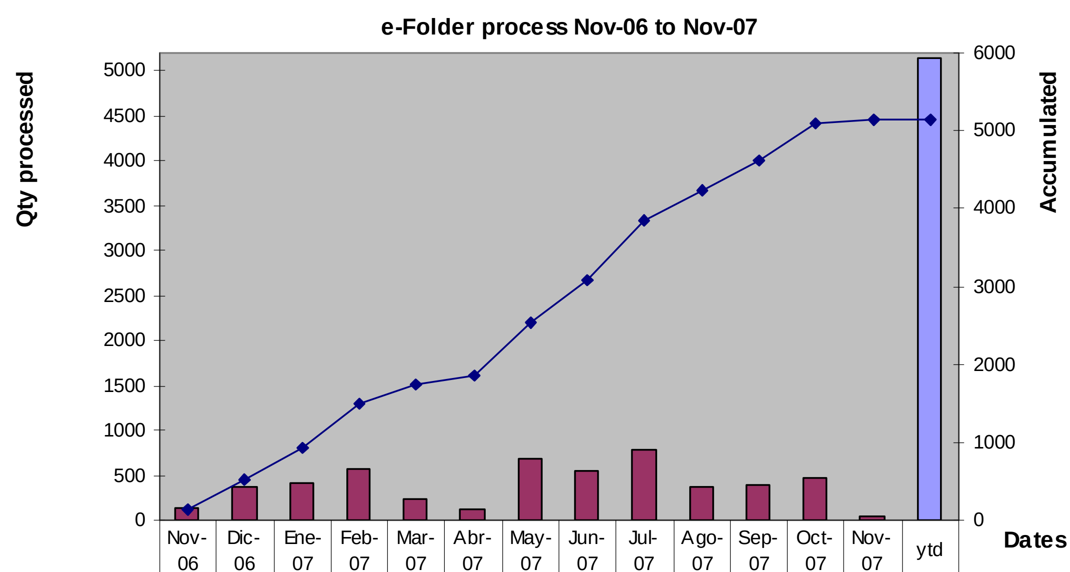
The only point that was performed was a sign off for this step of the methodology since the needed tests were already covered in the development, SIT, and end user training steps.

d. Launch and Release the IC System (On-Line).

The e-Master File, as an integration and communication systems, was finally released to production in November 2006, where the different areas involved began to use the systems to control the PLM process and data entrance into Maxcim, thereby generating documents which are left in the e-master file as information and knowledge.

e. Integration system Control.

Since the system was released, some improvements have been implemented according to users' ideas that were analyzed, accepted and put into place. In figure 4.6 shows how the system has grow up in one year of its usage.



	Nov-06	Dic-06	Ene-07	Feb-07	Mar-07	Abr-07	May-07	Jun-07	Jul-07	Ago-07	Sep-07	Oct-07	Nov-07	ytd
Part number	147	365	421	570	233	125	678	541	780	380	383	478	35	5136
Accumulated	147	512	933	1503	1736	1861	2539	3080	3860	4240	4623	5101	5136	5136

Figure 4.6 Usage of e-Master File for Maxcim

During the first month that the system was released, 147 products where processed including all types of products (fabricated in-house, assemblies, and purchased finished) and through the different stages of the PLM as prototype, pilot, and production, giving a total of more than 5100 products processed for November 2007.

4.3. Case Study Two (CS2): CMSA-SAP®

Caterpillar Inc. is facing one of its most important business transformations, since it is changing from its current ERP systems into a more sophisticated ERP system called SAP r/3® (figure 4.7). All facilities worldwide are working on the development and implementation of this new ERP in order to be fully integrated and working in a common business environment.

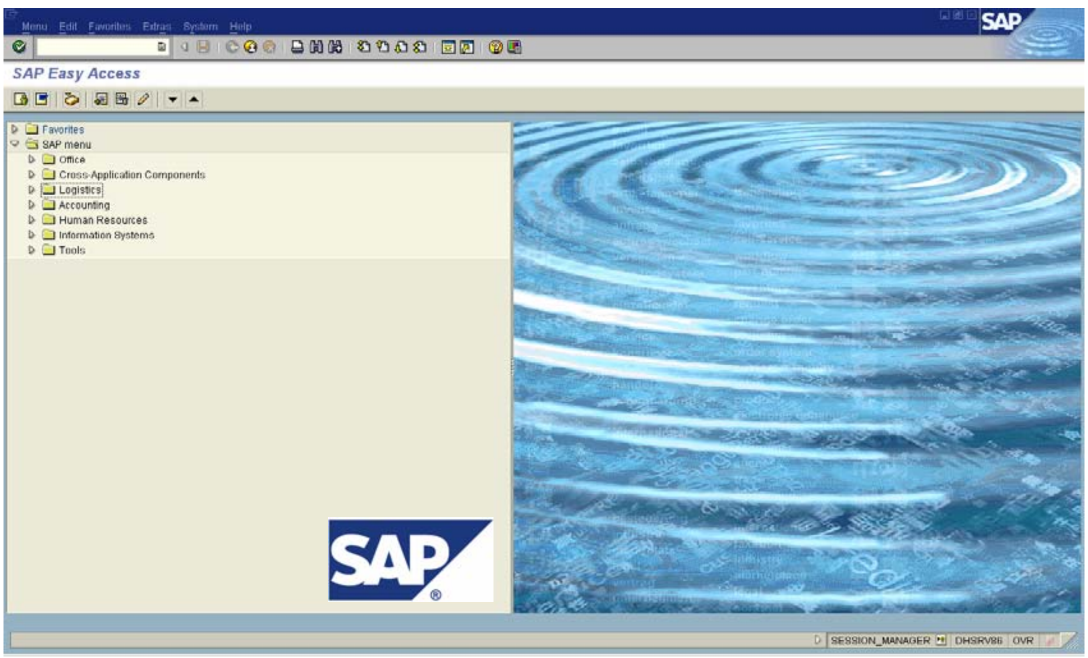


Figure 4.7 SAP/r3® easy access screen

This process started in early 2006 with the successful implementation in the Caterpillar Asia-Pacific Division facilities (China and Australia). For 2007, Caterpillar Mexico's Torreon Facility will enter into this large business change by discontinuing the use of its current ERP system, "Maxcim" (referred in case study one), and implementing the more sophisticated ERP, SAP®.

Due to this change, its ERP system should be limited as all modules of the scope; all related processes and systems that interact with Maxcim must be considered as part of this improvement in order to updated or modified according to the new ERP requirements.

The second study case is the implementation of the Integration and Communication Methodology (ICM) proposed in order to support the Business Transformation generated with the implementation of SAP®, thereby carrying out and ensuring the integration and communication that must exist between the new ERP system, the virtual PLM process, and the Knowledge Management in addition to all the ICM objectives defined at the beginning of this chapter.

Because of the company's organization and requirements are similar to the steps performed in the previous Case Study, they will be used again in the second circle of the learning evolution circles as part of the action research methodology (figure 4.8).

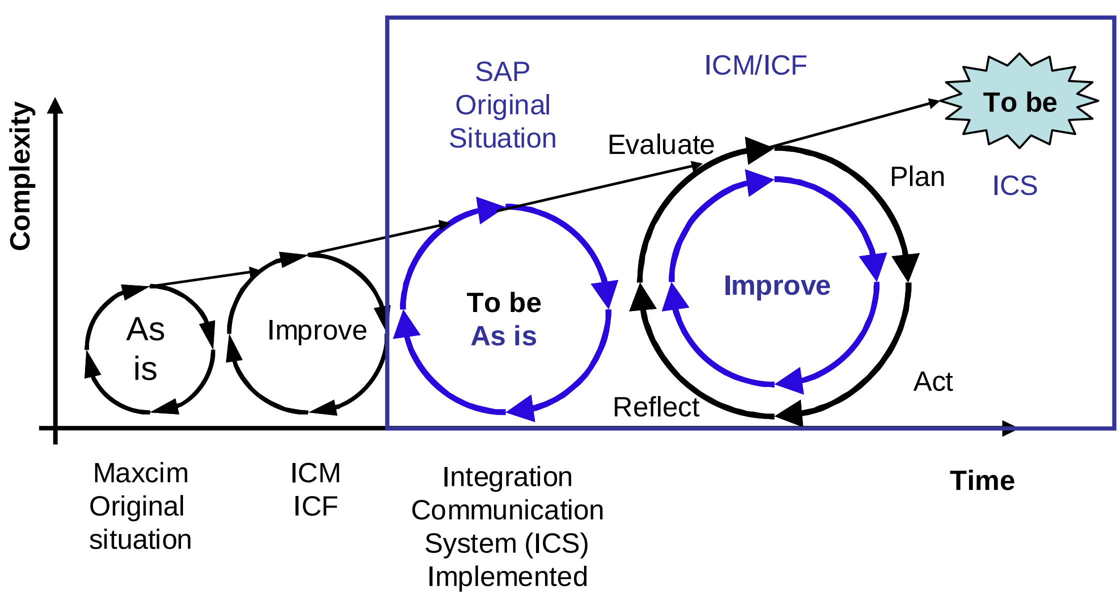


Figure 4.8 Second Circle of the Learning Evolution Circles

4.3.1. CS2: Methodology and Framework application

I. Customer Requirements Definition (*As- Is*) "The Plan" stage

a. Pre-evaluation of the company

The case study "CMSA-SAP®" passed the pre-evaluation stage, which means that the methodology can be applied to improve the integration and communication between the ERP (in implementation process), their virtual PLM process, and KM. The pre-evaluation format filled out for this case study can be found in Appendix 6.

b. Integration level desired is established.

Using figure 3.11 in the ERP axis, SAP obtains 2 points for all modules related to production, sales and distribution, and finances. In the PLM axis, because of the previous case study, it could be said that there is a system that control the PLM process in all the stages, and then 3 point will be given. This makes a total of five points for the Integration Level Index referred to the PLM and ERP.

From diagrams 3.12, the KM_{ERP} gets 3 point since SAP does not have enabled the KM module, but, from the previous case study, it was developed, for the KM_{PLM} point of view, Caterpillar Mexico, with the system developed, now has a system that controls the PLM stages and knowledge generated by this process, and taking into account that the information related to PLM projects are archived by team leaders, KM_{PLM} obtains six points. That makes a total of 9 points.

Now using chart 3.1, enter first with the values of 5 for PLM and ERP and 9 for $KM_{PLM/ERP}$ yields the value of 62.50 which, according to the index integration scale, this results in an integration level of MEDIUM because 62.50 is between 41 and 71 from the scale.

Since the integration level of MEDIUM is acceptable, and, based on the fact that the company does not have investment plans for SAP's workflow module because of its high cost of development (more than $100 KUSD according to Accenture consultant). For the purpose of this case study, to maintain the actual level or to increase it with the application of an interface would be accepted.

c. Define the areas and process involved

As in previous case, the three stages of the PLM process, (the prototype, pilot, and production stages) for fabricated components, purchased finished components, sub-assemblies, phantom assemblies, and shipping levels were defined, with the same consideration for product design stage as support.

Same areas who participated in the previous case study are: releasing, quality assurance, supplier's quality, purchasing, manufacturing, first and second operations, machining process, heat treatment, paint and finances. However since SAP configuration is not the same as Maxcim, other areas such as requirements, distribution, and traffic must be considered too. Once again, the releasing area will be defined as the area for carrying out the control and coordination of this methodology, as it was defined in the case study one.

d. Define the area's requirements.

The same requirements that were defined for Maxcim are used for this development: communication between the areas in the PLM stages, accuracy of data processed in the Maxcim system, process time and customer feedback, involvement in synchronization, technical knowledge about the products and process, obsolete and surplus material inventory avoidance control, quality service to customers, and effective delivery date definition in conjunction with "team works".

e. Define data or information to integrate.

A translation of terminology must be performed to move from Maxcim to SAP. The data from table 4.2 was defined as key data according to new SAP terms and PLM stages:

Material Number	Plant Specific Material Status	Profit Center
Description	Valid From date	CC Phys. Inv. Indicator
Gross & Net Weight	MRP Type	Purchasing Group
Spanish Description	MRP Controller	Standard Price
QM Control Key	Procurement Type	
MRP Group (Source Code)	Production Scheduler	

Table 4.2 Key data from SAP

II. ICS development: "The Act" stage

a. Process mapped against PLM.

Similar to the previous case study and according to figure 3.5 almost all of the different PLM stages are covered, however since the company does not control the design and development of the product stage, this will be excluded, and the PDM will be used as the tool to get data and information related to products.

b. Deployment Map (Mapping the process to integrate).

A deployment map (figure 4.9) was created based on the different areas involved in the processing of information and data generation for SAP according to the PLM stage and the type of product. For a complete overview of this deployment map refer to Appendix 7.

			Analisis de ECN	Generacion de Nesteo	Genera requi	Genera cotización	Da de alta vistas basicas		Creacion de Q-Info rec	Creacion de PO	Solicitud de PPAP	Genera BOM	Solicita PPAP	Solicita info a HT-Maq(2nd Op)-Pintura-Calidad (MIC) según sea necesario	
Releasing	**Clasificacion**	**MRP Group**	**ECC - Analista**	**Program**	**Calidad (desarrollo) de proveedores**	**Compras**	**Rel - MDM**	Sub_Proceso	**Calidad recibos**	**Compras**	**Calidad de proveedores**	**Releasing**	**Aseguramiento de calidad (Analista y planeador resp.)**	**Mfra (Soldes a y n/Assy esg)**	**1st Op**
Creacion de EDN asignando JOB o ECN	NPI (P/P*)	P003	x	x	ok	ok	ok		ok	ok	ok	x	x	x	x
	NPI (F/BTS)	F003	x	ok	x	x	ok		x	x	x	ok	a 1st Op (N/a F para CMSA)	x	ok
	NPI (G/A/N)	G005/A003/N003	x	x	x	x	ok		x	x	x	ok	a mfra	ok	x
	EC (P/P*)	P003	ok	x	ok	ok	x		ok	ok	ok	x	x	x	x
	EC (F/BTS)	F003	ok	ok	x	x	x		x	x	x	ok	a 1st Op (N/a F para CMSA)	x	ok
	EC (G/A/N)	G005/A003/N003	ok	x	x	x	x		x	x	x	ok	a mfra	ok	x

Figure 4.9 SAP® deployment map

c. *Metrics gathering/definition.*

Metrics were obtained from the last case study are used, such as process time, past due, amount of part numbers processed, part numbers pending by area and user responsible.

d. *Information formats definition.*

In this case study the format for general product information gathering was defined. This format presents a screen that shows the workflow status, comments, and general information. An example of this screen is presented in figure 4.10 and the full structure can be found in Appendix 6.

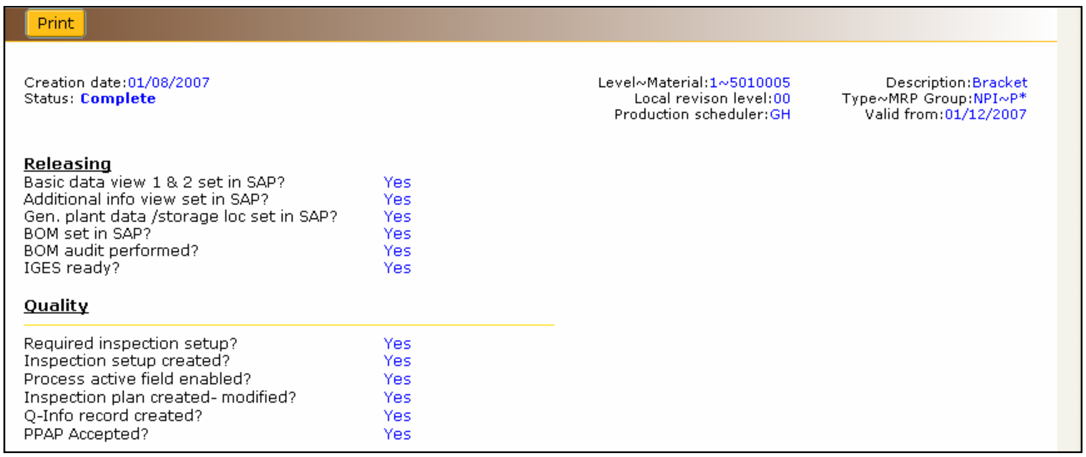


Figure 4.10 Information format screen

e. Integration and Communication System (ICS) decisions made and development.

Once again based on customer requirements, the cost of SAP development and the support and the experience gained from previous development, the best option was the creation of a new Workflow Management System (**WFMS)** by looking for a third party supplier who offers this development.

The new WFMS development was performed by a consultant firm called: "Steffanini" who specialized in system development. It took Steffanifi six months to produce the new WFMS (figure 4.11) using the same application as the last e-Master File, "Lotus Notes" with the support of the Domino Designer tool, the deployment map, and the customer requirements.

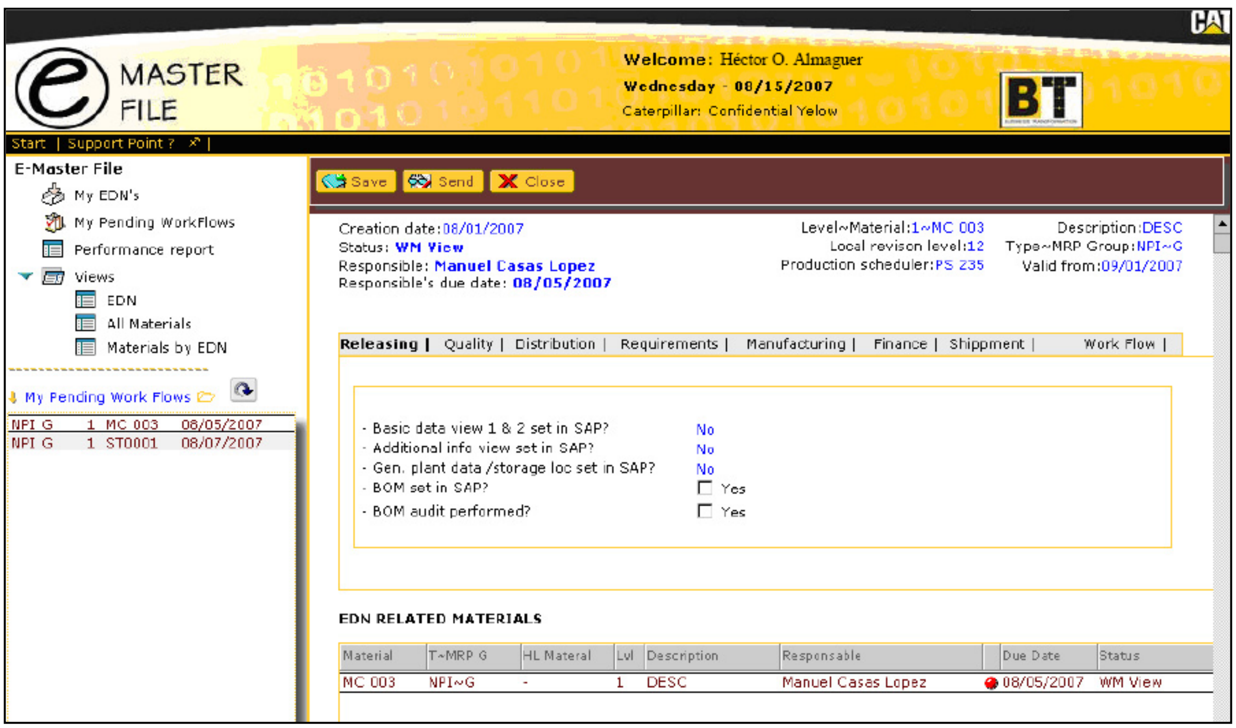


Figure 4.11 WFMS "e-Master File"

Detailed information about the capabilities, structure, and design of the new e-Master File for SAP can be found in Appendix 8.

III. ICS Implementation “The Reflect” stage

a. Implementation for System Tests.

The system was implemented in a pre-production simulation environment where, the capabilities were proved, when were performed “error provoked test” applied to data and workflows with different variables and scenarios.

b. Compare the New System with the as-is.

The new e-Master File covers all same stages of virtual PLM and the modules of SAP as the previous WFMS did for Maxcim, but with some improvements that were impossible to create in the old system. These improvements were obtained by post-implementation surveys applied to users from case study one, and are listed as follows:

- Reminder agent, that informs personnel responsible when the processing time assigned to them is almost finished as an e-mail, followed by a second message when the product processing is delayed;
- Format summary for easy printing and retrieval with primary information and knowledge from the people who processed a product;
- Continuous improvement mail box, and;
- Support Point creation with all documentation needed for new personnel training.

As in the original e-Master File, formats were created to record users’ knowledge and expertise as a repository for every product processed and, since these are mandatory field for the e-Master File, the user is forced to share this knowledge. This same knowledge can be used by the incoming generations or can be also used as reference for other product development projects.

Since this WFMS is not an interface with SAP, the primary disadvantage still remains the critical key data must be entered twice, once in SAP and then in the new e-Master File.

IV. ICS Control and evaluation "The Evaluation" stage (To be…evaluation)

a. System Integration Test (SIT – Only for team members).

For the new e-Master File development more than 70 test scripts were performed by the core team in order to validate all the variants for which the product could pass: the prototype stage, the pilot stage, and production stage according to the virtual PLM stages. Three different workflows models were defined according to the types of product used in the company: 1) Components fabricated in house, 2) Sub assembly, shipping levels and phantoms sub-assemblies, and 3) Purchased finished material.

For each scenario, the option of new product introduction and the engineering change, were considered. With these variants, the needed to perform more than 18 *System Integration Tests* as in the last development are justified.

b. End user training.

Four training session meetings were used to perform training to more than 85 people from the different areas involved, using some scenarios from the SIT.

c. User Acceptance Test (UAT – For end users).

Once that the training was completed, some end users were selected to perform the final tests in which the supervisor in charge of the area signed the official approval for the New Integration and Communication System (ICS) to go live.

d. Launch and Release the ICS (On-Line).

An overview of the new e-Master File as an integration and communication systems, was presented to the administration by explaining all the general capabilities of the ICS. It was ultimately released for production in August 2007 (at the same time that SAP entered to production), where the different areas involved began to use the systems to control the PLM process and data entry into SAP, thereby generating documents which will remain in the e-master file as information and knowledge.

e. Integration system Control.

Since the system was released, some improvements have been implemented according to user ideas that were analyzed, accepted and set in place. In figure 4.12, the increase in the system use since implementation is shown.

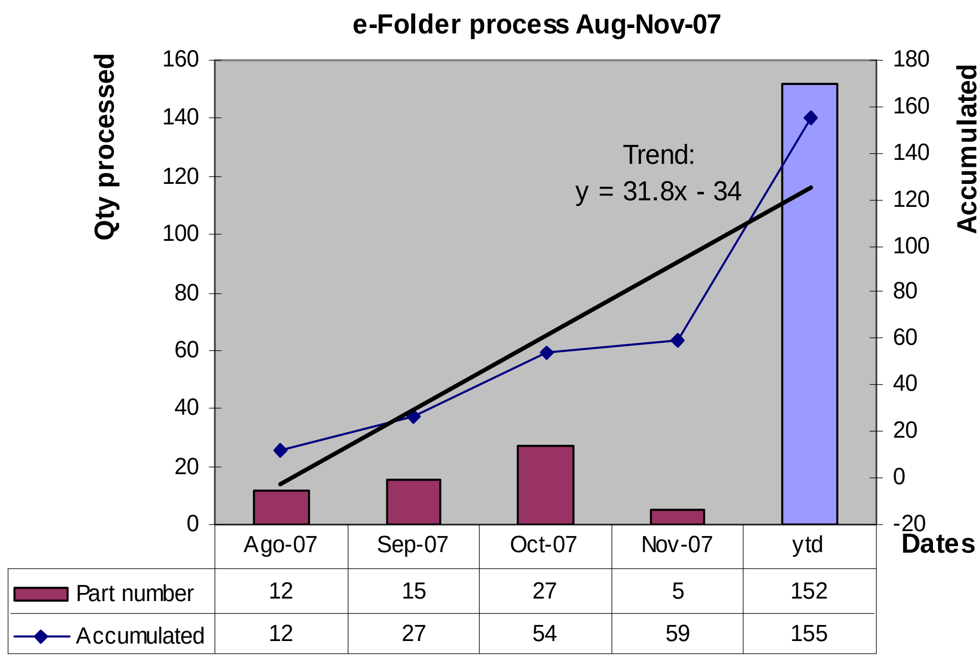


Figure 4.12 Usage of New e-Master File for SAP

In the first month, the system processed 12 products of their different types (fabricated in-house, assemblies, and purchased finished) through the different stages of the PLM such as prototype, pilot, and production, giving a total of more than 150[3] products processed to November 2007.

4.4. Summary

During this chapter, two experiments were presented as case study for the application of the Integration and Communication Methodology and Framework for ERP, PLM, and KM, in Caterpillar Mexico.

The first case study refers to a 25 years old, custom- made ERP system, "Maxcim", which has not had any software version updates during the recent years, making basic integration and communication nearly impossible. For this ERP, no technical support exists from the original suppliers, so no improvements or special developments were possible inside of this homemade ERP.

The methodology could be applied because to this experiment because has passed the pre-evaluation. PLM stages were adopted as virtual management since there is no software that controls this process inside the organization. Knowledge management was enabled with the support of a Workflow Management System (WFMS) developed by IT system experts from the organization as a way to communicate and integrate the people, process, data and information.

This ICS was developed in early 2006, and was implemented in November of the same year, called “e-Master File”, here every product type (component, assembly, in-house fabrication, purchased finished) is processed by this system. From its beginning to November, 2007, more than 5,100 products, which indicates that the system has been used by the users and the knowledge for each product is reordered inside the ICS.

The second experiment or case of study, was applied in the same company but in other facility (at Torreon, Coahuila), were according to action research and evolution learning cycles basic information was used for this development based on the previous experiment,

[3] The amount of the product processed is low compared with the case study one because in Torreon facility the volume o product is about the 25% from the total of the products in Monterrey facility.

but over its “to be” stage, changed in the “as-is” for this second experiment.

For second experiment, the ERP that was used was SAP® r/3, which was in the implementation process for which technical support existed from a consultants firm (Accenture) who has experience in implementations of this type. The cost of investment and complexity for the module that integrates PLM and KM was too high for the Caterpillar organization, so the decision was to perform a similar ICS based on the success of the previous development.

The methodology was applied by improving previous improvements from the first experiment. The usage of the experience gained helped the company to better understand its needs. This ICS was developed by a third party company (Steffanini), an expert in WFMS that supported the development (using Domino Designer programming), testing, and implementation of the ICS by improving upon the previous version of the ICS implemented in the organization.

CHAPTER 5

5. RESULTS, CONCLUSIONS AND FURTHER RESEARCH

5.1. Introduction

This chapter presents the finals results, conclusions and further research for the problem of communication and integration stated in chapter one based on the literature reviewed during chapter two and the hypothesis that was proposed for the solution of the problem. Using the Action Research and Six Sigma as the research methodologies, was made possible during chapter three, the creation of a framework and methodology that was applied as experiments in two different case studies in chapter four, yielding the results and conclusions that will be presented in the following section of this chapter as well as the possibility to extend this investigation on a further research will also be discussed during this chapter

5.2. Results

In chapter one, a series of objectives or goals where stated and for what that during the development of the thesis was necessary to solve, each goal and its respective result is presented as follow:

a. Explore and understand the integration and communication that could exist between: PLM processes and ERP systems and their impact to support knowledge, abilities, and expertise of the people involved; in order to define an Integration and Communication Model for theses three elements: PLM, ERP and KM.

In the figure 3.4 of the methodology chapter, the integration and communication model (ICMdl) was defined, which presents the three base elements KM, ERP and PLM in an integrative and communicative way within the model.

Knowledge Management was referred to as people because the people generate this knowledge that could be managed.

The ERP was referred to the data and information, that is entered by the people into the ERP, this is how knowledge is generated making the ERP work.

Finally, the PLM was referred to as the different processes defined as prototype, pilot, and production that, depending in which process were being developed by the company, some or all the PLM stages could be applied and different data and information should be entered by the people into the ERP, interrelating each element from the model.

The last portion is about the communication that is enabled based on the methodology developed by the company where the “Integration and Communication System” (ICS) is generated, whether the company decided to adapt an existing ERP system or PLM process or to develop a “Workflow Management System” (WFMS) that communicates and integrates all three elements of the ICMdl.

b. Develop a methodology that could be applied in any kind of industry that relies upon an ERP system already in place (PLM and KM could be handled in an informal way) based on the integration and communication model.

During chapter three, a methodology was developed with the support of the model generated (ICMdl) by using Action Research as “Learning Evolution Cycles,” and Six Sigma “DMAIC” methodology, and their respective tools. This Integration and Communication Methodology (ICM) was created using generic scenarios for which a company could be involved while developing new products or services.

SAP was used as the ERP base because this is the main ERP used in the world according to the main vendors of ERP chart from Appendix 1. The methodology consists of about four stages and 16 steps that must be fulfilled in order to develop and implement the Integration and Communication System (ICS) over the company or enterprise.

Some of these steps can be omitted according to the customer environment, requirements, and needs.

c. Apply the methodology proposed by the author and show how it has improved the “integration” and “communication” between ERP systems, PLM processes and people KM.

During chapter four, two experiments were presented as our case of studies for the application of the Integration and Communication Methodology and Framework (ICM and ICF) at Caterpillar México.

The first case study is refers to a 25-year old, custom-made ERP system, called "Maxcim", which has not had a software version update during recent years. This methodology was applied because the experiment has passed the pre-evaluation. PLM stages were adopted as virtual management since there is no software that controls this process inside the organization. Knowledge management was enabled with the support of a Workflow Management System (WFMS) developed by IT system experts from within the organization as a way to communicate and integrate the people, process, and data and information.

This ICS, is called “The e-Master File,” was developed in early 2006 and was implemented in November of the same year. More than 5,100 products have been processed by the first ICS implemented, which indicates that the users are using the system and that knowledge for each of the different products is recorded inside the ICS.

The second experiment or case study, was applied in the same company but in the Torreon, Coahuila facility, where, according to action research and evolutionary learning cycles, basic information that was defined for the previous experiment was used; however, now the “to be” stage from the first experiment becomes the “as-is” stage for this second experiment.

In the second experiment, the ERP used was the SAP r/3 (in the current implementation process) for which technical support exists by a consulting firm (Accenture) who has expertise in ERP implemented of this type. The cost of investment and the complexity for PLM and KM modules to be integrated was too high (more than $100 KUsd), so the decision was to carry out a similar ICS based on the success from the previous development.

The methodology was applied by improving upon previously implemented improvements of the last system. The development of a ICS was made by a third party company (Steffanini), experts in WFMS that support the development (using the same platform from the previous development), testing, and implementation of the ICS.

The implementation of the framework, model, and methodology succeeded over the two experiments even though the PLM was seen as virtual process because the company at least had an ERP in place or in process when an implementation or a workflow was developed.

d. Reach at least the three benefits proposed by Miller [Miller, K., 2005]: (a) consistent use of product and plant-related information by personnel in organizations throughout the enterprise; (b) reduce the time to bring new and enhanced products to market at a lower cost while improving quality; and (c) create and use common product-related terminology and processes throughout the business.

The ICS allowed the benefit of using plant-related information by personnel throughout the enterprise, because everyone could enter into the ICS and review all information, data, and comments related to the product during all stages of the PLM process.

This bring about the benefits of reduced time to bringing new and enhanced products to the market at a lower cost while improving quality, and creating and using common terminology and processes throughout the business.

The processing time was positively affected by reducing more than 50 % from the original time for all products and increasing the process capacity for all areas in the organization because all information is sequenced, well managed, and tracked.

For the second experiment, the process time increased because the people involved had to become accustomed to the new ERP system and to the new activities to be performed as compared to the previous development; however, thinking of this learning curve as part of the improvements for the second ICS that created a module, that could modify and adapt the process time for each stage of the process.

The people are using the system and, by doing this, they are creating and using the terminology defined, thereby covering both benefits proposed by Miller [Miller, K., 2005]; theses benefits can be seen in charts 5.1 and 5.2.

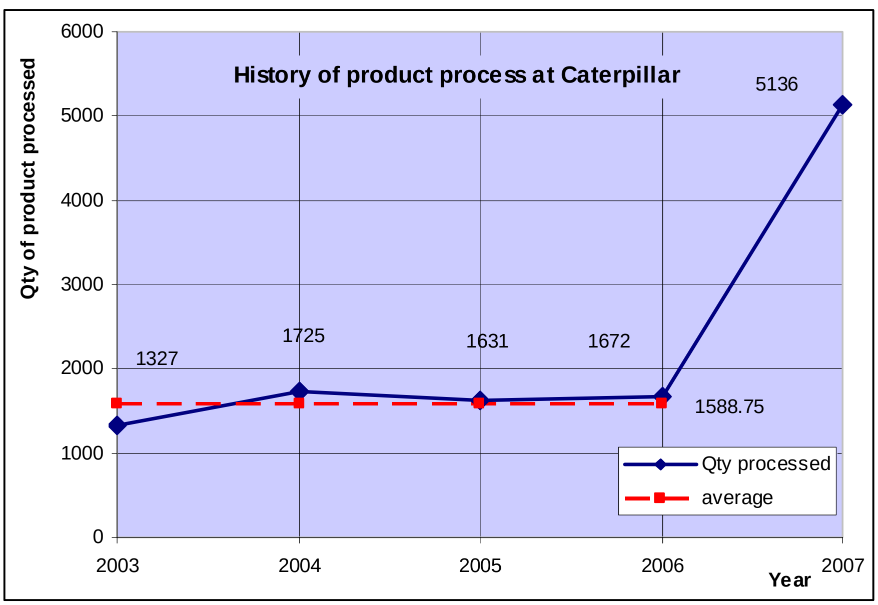


Chart 5.1 History of Product Process at Caterpillar

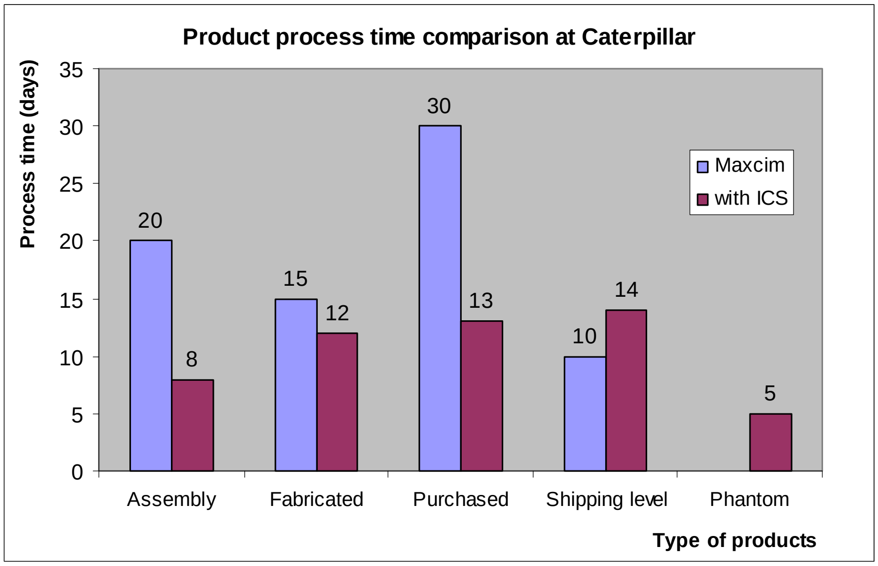


Chart 5.2 Product Process Time Comparison at Caterpillar

5.2.1. Other benefits

For the first case study, the limited experience of IT experts with WFMS was used to develop the ICS, where the only benefit was the elimination of the "master file" area, which was used to file the processed products information into cabinets.

It is expected to use this space area as offices for managers or meeting rooms for the company in the 2008. This improvement saves the company $22 KUsd according to the evaluation of space performed by the construction area expert of the company, because the floor per square meter is valuated in $44 usd/m^2 and the area to be released is about 500 m^2.

The paperwork (table 5.1) of the information that need to be saved in folders as printed hard copies, including the folder avoids about $5 Kusd a year, based on the average amount of 1,500 products processed per year (chart 5.1); this gave a $27 Kusd or $297,000 pesos as the total savings gathered for the company and reported in the form of 6 Sigma project.

Concept	Cost (Usd)
Product Drawing	0.5
Nesting	0.3
Engineering notification	0.3
Fabrication routing	0.9
Standard process	0.9
Nesting	0.5
Total	3.4

Table 5.1 Paperwork Printing Expenses

For the second case of study, because the ICS was developed by a third party company, it was an expense about $22 KUsd; however, compared to the quotation from the SAP consultant for the development of ERP, PLM, and KM integration and communication by integrating the Workflow SAP module (WF) is more than $100 KUsd, there is a cost avoidance, according to 6 Sigma methodology, of about $78 KUsd for the company. Table 5.2 contains the summary of the two case study benefits.

	Investment (Usd)	Benefits (Usd)	
Case Study 1	$ -	$ 27,000	
Case Study 2	$ 22,000	$ 78,000	
Total	$ 22,000	$ 105,000	
	Net Benefits	$ 83,000	Usd
		$ 913,000	pesos

Table 5.2 Case Studies Benefits

After two years invested for the two projects' development based on the methodology, with an obtained benefit about $83 KUsd that contribute to the achievement of Six Sigma value proposition as one of the Goals for Caterpillar.

The rejection due to lack of information from previous stages is registered now, new product introduction is beginning to be launched on time, and people feel more involved in the process, since they are tracked as part of every project.

5.3. Conclusions

During the development of this thesis, people were skeptical about the integration that could exist between the different systems and process such as ERP and PLM, and even more skepticism existed if the Knowledge Management was included because of how does these three elements could be included in a model to show the interrelation inherent to them. The model was defined, as well as the framework and methodology to implement an integration and communication system in any industry.

In both experiments, were the methodology was exposed, it could be said that the users have adopted still are using the ICS as the way to integrate and communicate the ERP modules from the ERP against the PLM stages in prototype, pilot, and production processes every time that it is needed. By doing so, their tacit knowledge, based on data and information, is transferred into explicit knowledge that could be accessed by any other user within the organization at any time.

For both experiments, PLM was handled as a “virtual” process since there is not a formal tool to manage this process at Caterpillar Mexico, as well as KM, which is not considered as part of the culture (people leave the company and their expertise and knowledge goes with them).

The methodology was applied by measuring the level of integration by proving the effectiveness of the methodology when the second case study was in development, and it was compared with the previous case study. The level of integration increased from low to medium according to the measurement system generated by the author.

The ICS that was developed and implemented for both experiments was in a Workflow Management System (WFMS) using Domino designer from IBM® Lotus Notes.

Finally, the “Communication and Integration of the PLM and ERP enabling the KM” could be possible, when it was applied, developed, and implemented in the company that sponsored this research. However this success could not be reached without the support of the people who participate in the two projects, by performing tasks for the application of the methodology or in the development or implementation of the ICS in order to achieve an adequate organizational integration and communication system by having the right information at the right time.

5.4. Further research

The efficiency of the Framework, Model, and Methodology with the implementation in two different facilities from Caterpillar was proven, where the PLM was referred to the methodology as a virtual process.

There is a need to prove that the methodology could be applied in other companies, looking to cover the "virtual PLM" with a real system that handles the PLM stages by trying to see if the methodology has the same success it has had for the two aforementioned experiments, focus on the Integration Level Index to prove their effectiveness.

The following applications of this methodology will be at Caterpillar Brazil during 2008 and at Caterpillar Inc. in the USA in 2009, where the learning evolution cycles will be extended to use the improvement from the first and second case studies and could be improved with a third and four experiments.

To complete "full business integration", the author propose to enable Customers integration and communication including CRM to the ICMdl, as well as applying Lean Manufacturing concepts and Concurrent Engineering to improve the performance of the systems, and ISO 9001 to improve the documentation of the methodology.

5.5. Summary

During this last chapter the results obtained for the problem and objectives stated in chapter one are presented, having as follows:

a. A model that supports the integration and communication between ERP, PLM, and KM was defined.
b. A methodology that could be applied in any industry that relies upon an ERP system already in place based on the integration and communication model was developed.
c. The methodology proposed by the author was applied and it was proved the integration and communication between ERP systems, PLM processes and people KM improvement by the usage of the ICS.
d. For both case studies the benefits of consistent use of product and plant-related information by personnel in organizations throughout the enterprise, and the creation and use common product-related terminology and processes throughout the business, by the ICS proposed by Miller were obtained [Miller, K., 2005]. But about the time reduction it was just for the first case of study because if is compared the first ERP system (Maxcim) against the ERP (SAP) system from the second case study the deployment map shows a long process time because the complexity of the ERP.

Indirect benefits were also presented obtained with the implementation of the methodology to both study cases about $83 KUsd.

The conclusions about the whole research on this thesis were presented, and were proved by the author that integration and communication could exist between two different concepts such as ERP and PLM, and how this integration and communication could be used as a way to manage the peoples' Knowledge, supported with the usage of Workflow Management Systems.

The author proposed as further research the application of the methodology and the development of an Integration and Communication System for Caterpillar Brazil in 2008 and Caterpillar Inc. in 2009, based in the good results from the two case studies. It was also proposed the integration of CRM and SCM, including Lean Manufacturing and Concurrent Engineering principles and tools to improve the ICS and ISO 9001 for the methodology documentation.

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AP. 1.1 Product and Process Development (PPD) key activities

Keys activities for product and process development success proposed by M. Rezayat [M. Rezayat, 2000]:

1. Designing to customer and business requirements.
2. Creating strong links with the supply chain; developing robust planning and validation processes.
3. Gathering requirements and expertise in the form of knowledge.
4. Planning for reusability of enterprise knowledge.
5. Formalizing the management of enterprise knowledge;
6. Following an integrated and controlled process;
7. Integrating known practices with new technologies;

AP. 1.2 Idealized set of PPD stages explanation

Explanation of the idealized set of stages in PPD (figure 2.2) defined by Edwards' article [Michaels, E.A., 1989]

How to continually come up with new ideas for your business? How to develop new ways of attacking problems? How to capture and assess these ideas and select them down to the ones that are worth investing more time and effort in? That's the objective of the **creativity stage**.

In **defining the product and process** stage, is when is asked, how do turn the idea from creativity stage into a real business opportunity and determine the necessary investment and expected return? This requires a number of questions to be answered. What is the market potential? Is it technically feasible to produce? What are the timescales? How will it affect existing products? How will the competition react? And so on. On this information the decision to go ahead and invest will be made.

Typically the early part of product and process developing looks at defining the customer requirements, followed by the translation into some form of prototype or pilot service. The key is that perceived customer needs are translated into possible solutions to these needs. In reality the design or **development of the product and process** will continue into subsequent stages as the product is refined to the point that could be released to the market.

Testing and finalizing the product sometimes is referred to as alpha and beta testing of products or better known as "prototypes and pilot" stage. It is the controlled release of the product, so that the sales, customer, manufacturing and support organizations can test and modify the product or the process. One outcome of this stage could be that the concept was wrong, there is no market, and the product should stop prior to committing to the expense of releasing it into the market.

Even a potential profitable new product can fail if it is improperly priced. Therefore, **pricing** strategies should be finalized as the prototype nears completion. Bear in mind that once implemented, pricing strategies are difficult to change.

Full product launch is probably one of the most difficult and expensive stages. It includes developing the market, the correct sales channels, ramping up the volume of business and supporting the product.

Then came the **management of the life cycle** for this product, were we could be ready to have from the decline of a product, extending its life, and some times, not to be considered. Unfortunately when this activity is not planned the need to develop new products is often triggered by falling sales. At this point there may not be enough time for new products to be developed.

AP. 1.3. Different software related to PLM stages

If we look again over figure 2.2, the first stage in the development of a product idea is the definition of its requirements based on the customer, the company and the market. From this, specifications of the products and major technical parameters can be defined. These kinds of task are often carried out using ***QFD, TRIZ*** or ***standard office software packages***. The second phase is where the detailed design and development of the products form starts, progressing to prototype testing, through pilot release to full product launch. We have to not dismiss that it can also involve redesign and ramp-up for the improvement of existing products during the process.

The main tool used for design and development is the ***Computer-Aided Design (CAD)***. This can be simple 2D Drawing / Drafting or 3D Parametric Feature Based Solid/Surface Modeling, Such software includes technology as Hybrid Modeling, Reverse Engineering, Knowledge Based Engineering (KBE), Assembly construction, etc. It could cover many engineering disciplines including: Mechanical; Electrical; Electronic and Architectural.

We already covered the design but, along with the actual creation of geometry there is the analysis of the components and product assemblies. Simulation, validation and optimization tasks are carried out using ***Computer-Aided Engineering (CAE)*** software, either integrated in the CAD package or stand-alone. These are used to perform tasks such as: Stress analysis, Finite Element Analysis (FEA); Kinematics; Computational fluid dynamics (CFD); mechanical event simulation (MES), and the like.

Here we can include ***Computer-Aided Quality (CAQ)***, which is used for dimensional tolerance analysis. Another task performed at this stage is the sourcing of bought out components, possibly with the aid of ***Procurement Systems.***

Once the design of the product's components is complete the method of manufacturing is defined. This third phase includes CAD tasks such as tool design; creation of ***Computerized Numerical Control (CNC)*** Machining instructions for the product's parts as well as tools to manufacture those parts, using integrated or separate ***Computer-Aided Manufacturing (CAM)*** software.

This will also involve analysis tools over process simulation for operations such as casting, molding, and die press forming. Once the manufacturing method has been identified ***Manufacturing Process Management (MPM)*** could be performed.

This MPM involves ***Computer-Aided Production Engineering (CAPE)*** or ***Production Planning (CAP/CAPP)*** tools for carrying out Factory, Plant and Facility Layout and Production Simulation. For example: ***Press-Line Simulation***, ***e-Factory*** and ***Industrial Ergonomics***; as well as tool selection management.

Once components are manufactured their geometrical form and size can be check against the original CAD data with the use of ***Computer-Aided Inspection (CAI)*** equipment and software. Parallel to the engineering tasks, sales product configuration, disposal and marketing documentation work will be taking place. This could include transferring engineering data (geometry, part list data) to a web based sales configurator and other Desktop Publishing systems.

The final phase of the lifecycle involves managing of in service information. Providing customers and service engineers with support information for repair and maintenance as well as (waste management/recycling information) this involves using tools as Maintenance Repair and Overhaul Management (MRO) software.

PLM is not just about business processes, it also include people and methods as much as software application solutions. Although PLM is mainly associated with engineering tasks, but it involves marketing activities such as Product Portfolio Management (PPM), particularly related to New Product Development Introduction.

At the engineering department level this is the domain of ***Product Data Management (PDM)*** software; for corporate level is the ***Enterprise Data Management (EDM)*** software; it is typical to see two or more data management systems within an organization, working as the repository of information for PDM.

AP. 1.4 PLM Benefits and Characteristics

According to PLM expert Michael Grieves on his book [Grieves, M. 2006] said that "there are certain underlying characteristics that are an integral part of PLM, and need to be articulated for a deep understanding of the forces moving organizations to adopt PLM".

The characteristics mentions by Grieves are: singularity, correspondence, cohesion, traceability, reflectivity and cued availability. The definition of each characteristic it's explained on table ap.1:

Characteristic	Definition
Singularity	Have one unique and controlled version of the product data.
Correspondence	This refers to the tight relationship between a physical object and the data and information about that physical object.
Cohesion	The fact that there are going to be different representations or views of product information depending on the perspective of the product.
Traceability	It Is the ability to demonstrate that the path of a product's travel through time can be followed seamlessly back to its origin.
Reflectiveness	This term is directly related to the arrow in the Information Mirroring Model that connects the real space to virtual space and captures data and information from real space into virtual space, were a mechanism to change the information in virtual space is required.
Cued Availability	It is related to the arrow indicating the movement of information and process from virtual space to real space. The term cued indicates that such information and processes might or might not be requested, but they are presented, because of the current situation.

Table AP.1.1 PLM characteristics (adapted from Grieves, M. 2006)

By now there being explained a complete overview of PLM, including it definition of PLM and a detailed description of all stages of the model reviewed, the tools and characteristics. Edgar Ramon [Ramon, E. 2007] on his thesis includes some comments about the benefits of PLM; taking this as reference to presents the economic benefits that an enterprise or company could gain implementing a PLM strategy in table AP. 1.2

Increased revenue through:	• Faster introduction of new products to markets • Offering new, valuable features to customers • Avoiding being perceived as a commodity • Development of a product portfolio with more different capabilities.
Decreased product cost through:	• Reduced part counts and product complexity • Design for manufacturability • Reuse of existing technology platforms • Design for service.
Decreased product development cost through:	• Increased efficiency of designers • Increased overall efficiency of new product development projects • Increased success rate of new product development projects.

Table AP.1.2 PLM economic implementation benefits
(Adapted from Ramon, E. 2007)

This benefits can be verified in the reporting made by IBM PLM on Demand Business (IBM, 2005), which states that PLM's return on investment indicate high benefits in manufacturing industry. Manufacturing organizations with PLM initiatives developed are reporting 20% increase in design productivity and 50-80% reduction in the time required to modify complex design, ability to explore 50% more design options fostering innovation, conducting numeric control programming up to 10 times faster and machining up to 35% faster, 60% reduction in pallet manufacturing time, 40% decrease in the errors found at the final assembly stage, etc.

AP. 1.5 Factors for ERP supplier-consultant services selection

Factors that should be taken into account when choosing a provider should include the stability and history of the vendor, the implementation support they offer, the competence of the installers and the availability of third party additional products and potential for improvements to the selected ERP package [Somers, M. T. and Nelson, K., 2001]. The success of ERP systems also depends on the service level of the supplier of ERP.

AP. 1.6 ERP Benefits

ERP is now considered to be the price to pay, to enter in the running a business, and being connected to other enterprises in a network economy used to create “business to business” or electronic commerce [Boykin, 2001].

Potential benefits including drastic declines in inventory, breakthrough reductions in working capital, abundant information about customer needs, along with the ability to view and manage the extended enterprise of suppliers, alliances and customers could be hole integrated [Chen, 2001].

In manufacturing sector, ERP implementation has reduced inventories any where from 15% to 35% [Gupta, 2000].

The fundamental purpose of an ERP is to offer support to the clients of the business, fast times of answer to its problems as well as an efficient management of information that permit takes it opportune of decisions and decrease of the total costs of operation.

Among the most important attributes of ERP [Nah *et al.* 2001, and Soh *et al.* 2001; Alanis, M., *et al.*, 2005] are its abilities to:

- Automate and integrate business process across organizational functions and locations.
- Enable implementation of all variations of best business practices with a view towards enhancing productivity.
- Share common date and practices across the entire enterprise in order to reduce errors.
- Produce and access information in a real-time environment to facilitate rapid and better decisions and cost reductions.
- Optimization of the business processes.
- Access to right information, in the right time (up to date).
- The possibility to share information among all the modules-areas of the organization (integration between departments)

- Elimination of unnecessary data and operations.
- Reduction of times and cost of processes.
- Increase profitability while maintaining product quality.
- Decrease total costs: order processing, material handling, distribution, direct labor, overhead, etc.
- It's a good reason to re-engineer business processes.

The traditional application systems, which organizations generally employ, treat each transaction by separately. They are built around the strong boundaries of specific functions that a specific application is meant to provide for. ERP stops treating theses transactions separately as stand alone activities and considers them to be a part of interlinked processes that make up the business [Gupta, 2000].

AP. 1.7 Main ERP vendors

Business information systems can be either designed as custom applications or purchased as off-the-shelf standard solutions. The development of custom applications is generally expensive and is often plagued by uncertainties, such as the selection of appropriate development tools, the duration of the deployment cycle, or the difficulties involved in assessing cost.

Therefore, companies are radically changing their information technology strategies by purchasing off-the-shelf software packages instead of developing IT systems in-house [Holland and Light, 1999].

Out of more than 100 ERP providers worldwide, SAP, Oracle, JD Edwards, PeopleSoft and Baan – collectively called the "Big five" of ERP software vendors – control approximately 70 % of the ERP market share (Figure 2.12). [Mabert, *et al.,* 2001].

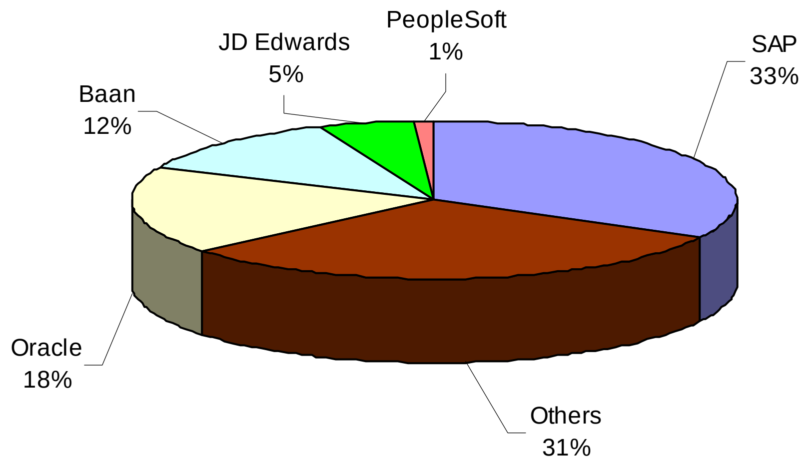


Figure AP. 1.1 the "Big five" ERP vendors at 2000
[Mabert, *et al.*, 2001]

AP. 1.7 Knowledge hierarchy elements definition

a. Data

There is no doubt that the fundamental input of any intelligent and knowledge system is data. The data have as characteristics that are discreet and objective about in fact and events. Nevertheless, they do not say anything about their importance or relevance for that event [Davenport and Prusak, 1998]

So "data" is the raw material that is used to generate useful information and helpful knowledge, which is, in another extreme, a vital input for decision making and problem solving.

Karen Giannetto and Anne Wheeler [Giannetto and Wheeler, 2001] mention that the organizations can retain data in many forms, but they need certain form of orchestration or application to be useful. The utility of the data acquired and the interpretation or contextualization that the receiver gives, is just then when this data is transformed into information.

b. Information

The data become information when its creator adds meaning. Davenport and Prusak mention that the word "inform" or "to report" signifies originally "to give form" and the information is capable of forming the person that obtains it, providing certain differences in his interior or exterior.

Therefore, strictly speaking, it is the receiver, and not the transmitter, the one who decide if the message that has received is really information. Inside the processes utilized to carry out the transformation of data the following were found:

- **Contextualize data**: Purpose is known why the data were generated.
- **Categorize data**: It is known the units of analysis of the main components of the data.
- **Calculate data**: The data may have been analyzed mathematics or statistically.
- **Correct data**: The errors have been eliminated of the data.
- **Condense data**: The data have been able to be summarized of more concise form.

K.M. Wiig [Wiig, K.M., 1993] in the article of Silke Bender and Alan Fish [Bender & Fish, 2000], mention: “the people transform the information in knowledge when they add their personal experiences, values and beliefs”.

c. Knowledge

It was established in the article of Bender and Fish [Bender & Fish, 2000] that “the knowledge is originated inside the person, to be configured based on an initial inventory of knowledge and the intake of new information, the knowledge formed by an individual will differ from another person receiving the same information” by Fahey and Prusak [Fahey, L. and Prusak, L., 1998], and to make this happened, they also defined:

- **Information comparisons**: how the information about a private situation with other situations can be compared and get similar connections?
- **Information consequences:** what implications have the information for the decisions and the actions?

- **Information connections:** how a proportion of knowledge with other factors is related?
- **Information conversations:** what think the other people about same information?

The knowledge inside the organizations is not only found inside documents or stores of data, but also this in organizing routines, processes, practical, and norms. When the knowledge in an area is enriched during a long period of time, the person that possesses becomes him in an "expert" in that area.

d. Dexterity or "expertise"

The dexterity or "expertise" is deeper than the knowledge in certain area that has been enriched for a long time period, education and training is built for the constancy of the person [Bender & Fish, 2000]. Unlike information, expertise cannot be transferred to other individuals; it must be developed from their own knowledge [Sveiby, K.E., 1997].

AP. 1.7 SECI model, Knowledge conversion example

With ***socialization*** a manager can learn the tacit secrets of conducting market research from a senior manager (tacit to tacit). Through ***externalization***, the manager can then translate these secrets into explicit knowledge (tacit to explicit) and communicate it to subordinates (explicit to explicit). The subordinates then standardize (by ***combination***) this knowledge and put it into a marketing report. Finally, through ***internalization***, experience gained from conducting market research, enriches the manager's own tacit knowledge base.

AP. 1.8 Business Practice Factors for ERP and PLM integration

Integration between PLM and ERP is as much than integrating processes, it's also about change management, it about transferring data from one application to another. Integration requires addressing the transfer of information and management control of business processes.

Information may need to flow across PLM and ERP boundaries and several times through the course of the processes. Effective integrations must address how a business will work, as well as what data will flow, were, process automation should be embedded within the integration whenever is possible since that automation will significantly reduce non-value-added activities. Understanding how a specific business operates is a key step to successful integration of PLM and ERP [CIMdata, 2005].

AP. 1.9 Technology Factors

There are many technology factors to be considers [CIMdata, 2005], includes:

- The type of information to be integrated.
- The processes to be supported.
- The type and complexity of integration required.
- The tools and methods to be used to create and maintain the integration.

Product structure and BOM exchange are normally the first integration to be taken. Other potential integration points between PLM and ERP include (but are not limited to) supplier details, inventory and stocking information, cost data, manufacturing processes and routings, vendor lists, part and component classification data, and item master data. Defining the scope of integration also means determining the level and direction of data flow between PLM and ERP.

For some information, a one-direction exchange of information may be all that is needed (example: moving cost information from ERP to PLM9. In other instances, a bi-directional exchange of information may be required.

For all integrations, information needs to be consistent between both PLM and ERP. This includes maintaining information integrity, information states, information replication, defined attributes, metadata and consistent use of standards.

Not all information must be exchanged between PLM and ERP. In some instances, providing access to the information that resides in the other domain may be sufficient, incorporating access to PLM and/or ERP could provide this exchange.

AP. 1.10 Approaches to Development Factors

There are multiple approaches that a company can take to accomplish integration between PLM and ERP [CIMdata, 2005]. Each approach will provide different levels and complexity of integration, functionality, scope, cost of implementation and support. Companies need to select the best approach based on their specific needs, future plans, current infrastructure, and estimated cost.

There are three primary methods used for PLM and ERP integrations, and each has advantages and disadvantages, strengths and weaknesses, increasing capabilities deliver higher benefits but generally at a higher cost.

• Encapsulation is a relatively simple solution (implementation can be done within person days) and is easier to implement than either interface or integration.
• Interface is more difficult to implement (implementation can be done within person weeks).
• Integration is the most difficult to implement (implementation may require person months to person years).

AP. 1.11 Examples of integration development between ERP and PLM

MSI article [MSI, 2004] explain about how the customer “Wave7”, wanted a PLM solution to process their engineering changes, and a way to quickly transfer information about those changes to the item master list in their ERP system (Hans Hartmann, VP of operations for Wave7). The item master list must be up-to-date to ensure that Wave7's customers are getting the latest version of a product whenever they place an order.

Situations like this are forcing PLM vendors to build ways of linking their solutions to ERP systems. Michael DeLapa, a VP with Arena Solutions said "we offer various ERP integration options, including fully automated, turnkey integration or semi-automated integration”, which could hosts Wave7's PLM system.

Another vendor, PTC, included a similar module in the most recent release of its Windchill PLM package, and its story explains why users have waited so long for these out-of-the-box integration tools to surface. Robin Saitz, a VP at PTC, said, “it took roughly 18 months to develop this solution, which works with one specific version of the R/3 ERP suite from SAP”, Saitz also mention that, PTC made this first integration module compatible with SAP because the majority of its customers use that ERP system, but PTC plans solutions that work with other ERP packages because the problem of integrating PLM and ERP is a major industry issue. "The fact is, different activities take place with PLM and ERP systems," Saitz explains, "but there is a great need for those systems to share data. Typically, this data transfer has taken place through a manual process or some homegrown, point-to-point method of integration that is expensive and time-consuming." [MSI, 2004]

Another example of integration was at Millennium, Marty Etzel, Director, e-Business at Millennium mention "We licensed the entire mySAP.com suite, which is a cross-enterprise solution for everything from CRM and supply chain management [SCM] to product lifecycle management [PLM], knowledge management portals and enterprise buyer capabilities" [Anonymous, 2007].

The home page of “Business wire” expose a paper were the company “Infor” announced built-in integration between its industry leading PLM solution, Infor PLM Optiva, and Infor ERP LX. Rory Granros, Infor’s director of industry and product marketing for Process Industries mention that “Integrating LX with Optiva enable quick respose to market fluctuations and consumer demand”.

Another company, IBM [IBM, 2005] announced on his paper, that IBM has enhanced its PLM Express portfolio, created specifically for mid-sized manufacturers, with two new offerings: PLM Express for Business Integration and PLM Express for Machining. PLM Express for Business Integration links ERP and PLM to optimize the sharing of critical product and materials information.

This integration will help to organizations start their on-demand journey by increasing both horizontal integration between ERP and PLM processes, and vertical integration between design and manufacturing; thus, this systems will be able to respond faster to changing customer requirements and to bring products to market quicker with improved quality and more innovation [IBM, 2005].

Chuck Stickles, Vice President of Enterprise Solutions said that “this integration will help to optimize the sharing of information and data related to product and material amongst all enterprise teams involved in product development” [IBM, 2005]

The company UGS’ Collaborative has made the link between Teamcenter PLM Portfolio and mySAP Business Suite. The Teamcenter Gateway for the mySAP Business Suite has been redesigned to include pre-configured workflows representative of best practices for using both Teamcenter and SAP. Predefined workflows, handlers and data mappings facilitating accelerated implementation for all customers [UGS, 2006]

AP. 2.1 Action Research

Action research is known by many other names, including participatory research, collaborative inquiry, emancipatory research, action learning, and contextual action research, but all are variations on a theme. Put simply, action research is "learning by doing."

A group of people identifies a problem, do something to resolve it, see how successful their efforts were, and if not satisfied, try again. While this is the essence of the approach, there are other key attributes of action research that differentiate it from common problem-solving activities that we all engage in every day. A more succinct definition is:

Action research, aims to contribute both to the practical concerns of people in an immediate problematic situation and to further the goals of social science simultaneously. Thus, there is a dual commitment in action research to study a system and concurrently to collaborate with members of the system in changing it in what is together regarded as a desirable direction.

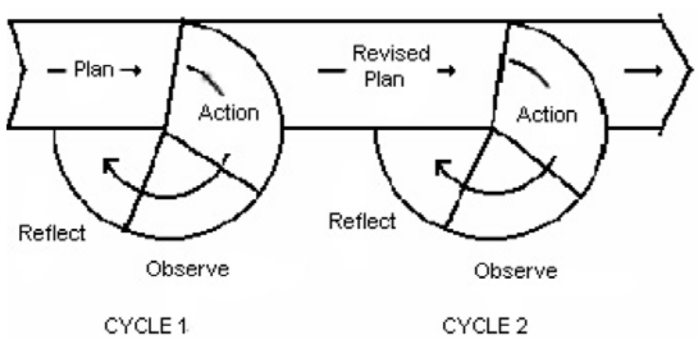
Accomplishing this twin goal requires the active collaboration of researcher and client, and thus it stresses the importance of co-learning as a primary aspect of the research process.

What separates this type of research from general professional practices, consulting, or daily problem-solving is the emphasis on scientific study, which is to say the researcher studies the problem systematically and ensures the intervention is informed by theoretical considerations.

Much of the researcher's time is spent on refining the methodological tools to suit the exigencies of the situation, and on collecting, analyzing, and presenting data on an ongoing, cyclical basis.

Several attributes separate action research from other types of research. Primary is its focus on turning the people involved into researchers, too-people learn best, and more willingly apply what they have learned, when they do it themselves. It also has a social dimension; the research takes place in real-world situations, and aims to solve real problems.

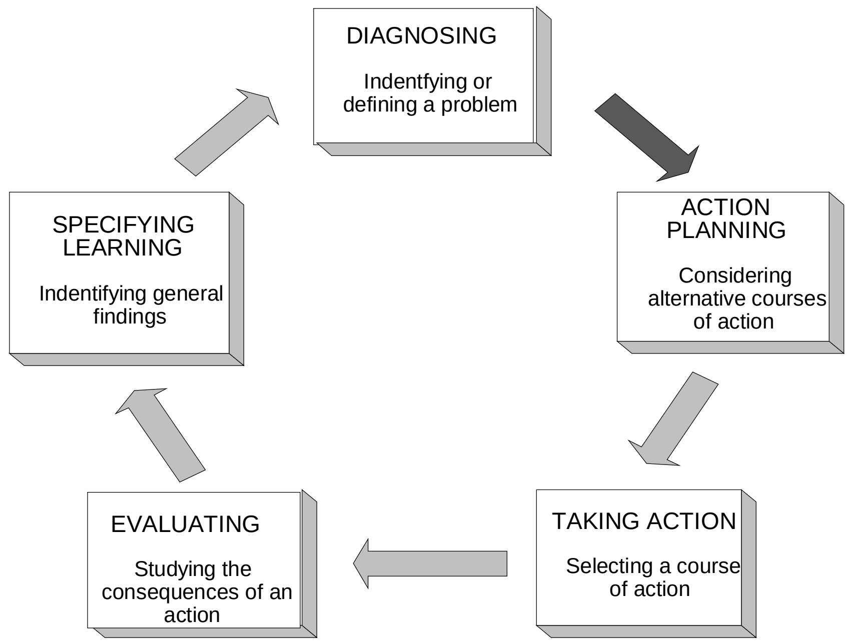
Finally, the initiating researcher, unlike in other disciplines, makes no attempt to remain objective, but openly acknowledges their bias to the other participants. Stephen Kemmis has developed a simple model of the cyclical nature of the typical action research process (Figure AP.2.1). Each cycle has four steps: plan, act, observe, and reflect.



AP. 2.1 Simple Action Research Model (from MacIsaac, 1995)

Gerald Susman (1983) gives a somewhat more elaborate listing. He distinguishes five phases to be conducted within each research cycle (AP. 2.2). Initially, a problem is identified and data is collected for a more detailed diagnosis. This is followed by a collective postulation of several possible solutions, from which a single plan of action emerges and is implemented.

Data on the results of the intervention are collected and analyzed, and the findings are interpreted in light of how successful the action has been. At this point, the problem is re-assessed and the process begins another cycle. This process continues until the problem is resolved.



AP. 2.2 Detailed Action Research Model (adapted from Susman 1983)

AP. 2.1.1 Principles of Action Research

What gives action research its unique flavor is the set of principles that guide the research. [Winter, 1989] provides a comprehensive overview of six key principles shown at AP. 2.1 Table:

Reflexive critique	The principle of reflective critique ensures people reflect on issues and processes and make explicit the interpretations, biases, assumptions and concerns upon which judgments are made. In this way, practical accounts can give rise to theoretical considerations.
Dialectical critique	A dialectical critique is required to understand the set of relationships both between the phenomenon and its context, and between the elements constituting the phenomenon. The key elements to focus attention on are those constituent elements that are unstable, or in opposition to one another. These are the ones that are most likely to create changes.

Table AP. 2.1 Main Principles of Action Research

Collaborative Resource	The principle of collaborative resource presupposes that each person's ideas are equally significant as potential resources for creating interpretive categories of analysis, negotiated among the participants. It strives to avoid the skewing of credibility stemming from the prior status of an idea-holder. It especially makes possible the insights gleaned from noting the contradictions both between many viewpoints and within a single viewpoint. Participants in an action research project are co-researchers.
Risk	The change process potentially threatens all previously established ways of doing things, thus creating psychic fears among the practitioners. One of the more prominent fears comes from the risk to ego stemming from open discussion of one's interpretations, ideas, and judgments. Initiators of action research will use this principle to allay others' fears and invite participation by pointing out that they, too, will be subject to the same process, and that whatever the outcome, learning will take place.
Plural Structure	The nature of the research embodies a multiplicity of views, commentaries and critiques, leading to multiple possible actions and interpretations. This plural structure of inquiry requires a plural text for reporting. This means that there will be many accounts made explicit, with commentaries on their contradictions, and a range of options for action presented. A report, therefore, acts as a support for ongoing discussion among collaborators, rather than a final conclusion of fact.
Theory, Practice, Transformation	For action researchers, theory informs practice, practice refines theory, in a continuous transformation. In any setting, people's actions are based on implicitly held assumptions, theories and hypotheses, and with every observed result, theoretical knowledge is enhanced. The two are intertwined aspects of a single change process. It is up to the researchers to make explicit the theoretical justifications for the actions, and to question the bases of those justifications. The ensuing practical applications that follow are subjected to further analysis, in a transformative cycle that continuously alternates emphasis between theory and practice.

Table AP. 2.1 Main Principles of Action Research (continuation)

Action research is used in real situations, rather than in contrived, experimental studies, since its primary focus is on solving real problems. It can, however, be used by social scientists for preliminary or pilot research, especially when the situation is too ambiguous to frame a precise research question. Mostly, though, in accordance with its principles, it is chosen when circumstances require flexibility, the involvement of the people in the research, or change must take place quickly or holistically.

It is often the case that those who apply this approach are practitioners who wish to improve understanding of their practice, social change activists trying to mount an action campaign, or, more likely, academics who have been invited into an organization (or other domain) by decision-makers aware of a problem requiring action research, but lacking the requisite methodological knowledge to deal with it.

AP. 2.1.2 Evolution of Action Research

Kurt Lewin is generally considered the 'father' of action research. A German social and experimental psychologist, and one of the founders of the Gestalt school, he was concerned with social problems, and focused on participative group processes for addressing conflict, crises, and change, generally within organizations. Initially, he was associated with the Center for Group Dynamics at MIT in Boston, but soon went on to establish his own National Training Laboratories.

Lewin first coined the term 'action research' in his 1946 paper "Action Research and Minority Problems", [v] characterizing Action Research as "a comparative research on the conditions and effects of various forms of social action and research leading to social action", using a process of "a spiral of steps, each of which is composed of a circle of planning, action, and fact-finding about the result of the action".

Eric Trist, another major contributor to the field from that immediate post-war era, was a social psychiatrist whose group at the Tavistock Institute of Human Relations in London engaged in applied social research, initially for the civil repatriation of German prisoners of war. He and his colleagues tended to focus more on large-scale, multi-organizational problems.

Both Lewin and Trist applied their research to systemic change in and between organizations. They emphasized direct professional-client collaboration and affirmed the role of group relations as basis for problem solving. Both were avid proponents of the principle that decisions are best implemented by those who help make them.

By the mid 1970s, the field had evolved, revealing 4 main 'streams' that had emerged, Traditional, Contextural (action learning), Radical, and Educational Action Research.

Traditional Action Research	**Contextural Action Research (Action Learning)**
Traditional Action Research stemmed from Lewin's work within organizations and encompasses the concepts and practices of Field Theory, Group Dynamics, T-Groups, and the Clinical Model. The growing importance of labour-management relations led to the application of action research in the areas of Organization Development, Quality of Working Life (QWL), Socio-technical systems (e.g., Information Systems), and Organizational Democracy. This traditional approach tends toward the conservative, generally maintaining the status quo with regards to organizational power structures.	Contextural Action Research, also sometimes referred to as Action Learning, is an approach derived from Trist's work on relations between organizations. It is contextural, insofar as it entails reconstituting the structural relations among actors in a social environment; domain-based, in that it tries to involve all affected parties and stakeholders; holographic, as each participant understands the working of the whole; and it stresses that participants act as project designers and co-researchers.

Radical Action Research	**Educational Action Research**
The Radical stream has a strong focus on emancipation and the overcoming of power imbalances. Participatory Action Research, often found in liberationist movements and international development circles, and Feminist Action Research both strive for social transformation via an advocacy process to strengthen peripheral groups in society.	A fourth stream, Educational Action Research, where professional educators should become involved in community problem-solving. Its practitioners, not surprisingly, operate mainly out of educational institutions, and focus on development of curriculum, professional development, and applying learning in a social context. It is often the case that university-based action researchers work with primary and secondary school teachers and students on community projects.

Table AP. 2.2 The 4 main 'streams' of Action Research

AP. 2.1.3 Action Research Tools

Action Research is more of a holistic approach to problem-solving, rather than a single method for collecting and analyzing data. Thus, it allows for several different research tools to be used as the project is conducted. These various methods, which are generally common to the qualitative research paradigm, include: keeping a research journal, document collection and analysis, participant observation recordings, questionnaire surveys, structured and unstructured interviews, and case studies.

AP. 2.2 Six Sigma

Based on Nadia Hernandez [Hernandez, N., 2002] research about Six Sigma taking Arthur Jay definition of Six Sigma, were states that:

> The methodology Six Sigma is oriented to results, with a focus in projects of quality [Jay, 2001]. It is a way to measure and obtain results in favor of the elimination of defects in the products, and is directly connected to the customer's requirements.

Jay also explained that Six Sigma is a system of the better practices, developed by Motorola in 1987, whose objective is to reduce the variation and to eliminate the defects. This quality improvement philosophy extensively has been diffused and adopted by other businesses of world class, such as: G.E., Allied Signal, Sony, Polaroid, Dow Chemical, FedEx, Dupont, NASA, and Caterpillar, among others.

According to Brey [Brey, 2001], the methodology of Six Sigma emphasizes an intelligent blending of the wisdom of the organization with proven statistical tools to improve both the efficiency and effectiveness of the organization in meeting customer needs.

Its application requires of the intensive use of tools and statistical methodologies (mostly) to eliminate the variability of the processes and to produce the results expected, with the possible minimum of defects, low costs and maximum customer satisfaction.

The term Six Sigma comes from the relation that exists between the variation of a process and the requests of the client related to the process. A process with a curve of capacity tuned up for Six Sigma, is capable of producing with a minimum of to 3.4 defects for million of opportunities (DFMO), what its equals to a level of quality of the 99.9997%

AP. 2.2.1 Six Sigma benefits

Currently the technology is available for everyone; the leadership in competitiveness is oriented to exceed the expectations of the client and efficiency of the companies.

Six Sigma is an investment in intellectual capital of the companies. The creativity, the permanent learning and the increase of competences that supposes the Six Sigma process is an additional benefit for the businesses. Since the tangible point of view, these are some of the benefits:

1. Reduction of costs and variation in the process for the project.
2. Aid to improve the delivery and action of the quality.
3. It Provides information that permits manipulate critical variables.
4. Develops processes and strong products.
5. Could get quickly improvements.
6. It permits the best knowledge of the processes.
7. Aid to good understanding of the customer requirements.
8. Aid to increase the levels of customer satisfaction.

In general, Six Sigma is an improvement administration system that seeks:

Obtain dramatic improvements	The projects are focused in obtaining improvements of the 50%, 40% or 30% on the metric critic selected in 4-6 months.
To have a focus al client	The product is based on what desires the client and finally, the quality of a product or service is measured from the customer satisfaction.

Table AP. 2.3 Six Sigma main goals

To Obtain financial results	The utilities of the savings generated by means of the projects can be palpated in the first 6-8 months. Each project selected should have an important financial impact.
To Decide in facts and data	The methodology Six Sigma is based 100% in the data: there is a not decision by instinct. The statistical tools employ a very important role to verify each supposed one and to validate each decision. The goal of Six Sigma is to help the people and the processes to aspire in delivering free defects product and/or services.

Table AP. 2.3 Six Sigma main goals (continuation)

AP. 2.2.2 Tools utilized in the Six Sigma methodology

Six Sigma utilizes an extensive range of tools (especially statistical) that commonly are employees for some areas, such as, the traditional Quality, TQM, among others. Some of these tools are mentioned subsequently:

Design tools	Design of Experiments (DDE), Strong Design and Analysis of Failures and Effects (AMFE).
Production and quality	Histograms, Diagram of Pareto, Diagram of Ishikawa, AMFE, SPC (Statistical Control of Processes) and DDE.
Others tools	Processes of Continuous Improvement, Design / Redesign of Processes, Map of processes, Analysis of Varianza, Integral control Panel, The Voice of the Client, Creative Thought, and Management of the Processes.

Table AP. 2.4 Six Sigma main tools

AP. 2.2.3 DMAIC Methodology

One of the central ideas of Six Sigma is to attack the problems with definite projects employing elements coached and specialized in the solution of problems and statistical analysis of data. In general, Six Sigma seeks to solve a practical problem with a practical solution, utilizing statistical tools. This description is shown graphic in the figure AP. 2.3.

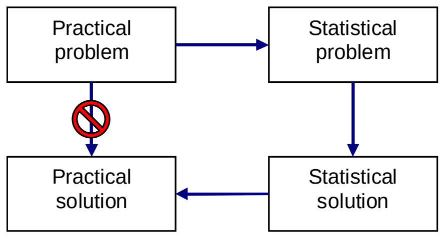
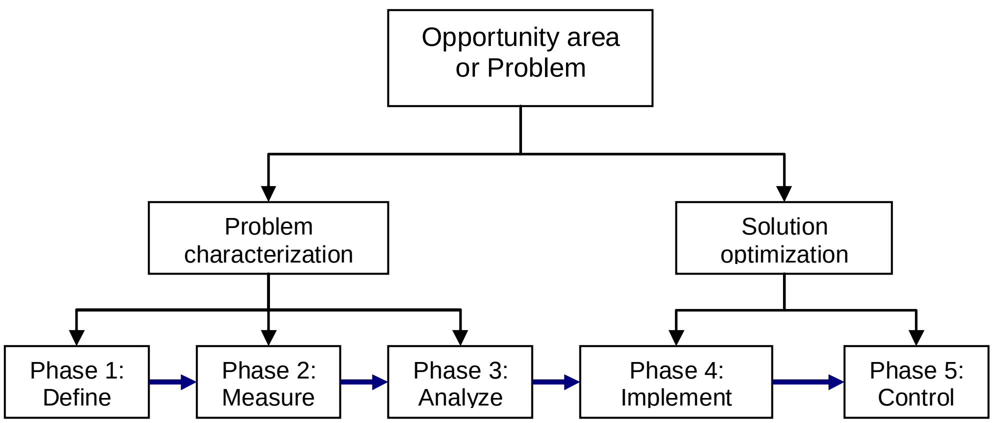


Figure AP. 2.3 Six Sigma Problem Solving Focus

This focus is found supported by a methodology of improvement called with the acronym DMAIC. This methodology is a standard process for the solution of problems utilized in diverse company and is comprised of five phases: Define, Measure, Analyze, Implement and Control. Figure AP. 2.4 shows these phases:



AP. 2.4 DMAIC phases

All the Six Sigma projects should pass for each one of the five phases, although the content of each one can vary due to the own nature of the project. Subsequently the description of each phase is shown:

Phase 1: Defining.

Define the team of work, the clients of the process, its needs and requests and create a map of the process [Eckes, 2001].

In this first phase of the implementation of the methodology of Six Sigma the team of work is defined, and before beginning with the activities, the roles of each one of the members should be defined, subsequently is presented the roles, that should cover the teams of implementation of Six Sigma:

a. Champion of the team: normally the owner of the process, or that this deeply involved inside the process to improve.
b. The team leader: business leaders that are classified like Black Belts, Green Belts.
c. Team Consultant or Master Black Belt.

Inside the first phase of implementation, three essential elements are considered, without which cannot continue:

1. Create the scheme of the team; which contains the following elements:
   - The specific case of the organization.
   - The approach of the problem.
   - The reach of the project.
   - The objectives and the goals.
   - The time of the project.
   - The roles and the responsibilities.
2. Identifying the clients of the project, its needs and requirements.
3. Creating the process map for the project.

Phase 2: Measure

Identify the main metrics of the efficiency and effectiveness of the organization and to transfer them to Six Sigma concept [Eckes, 2001].

The quality is quantifiable, and should be quantified. To measure the quality one must express it in numbers and act in function of the values measured; these two so simple principles give rise to a methodology of continuous improvement of the quality. These two values fulfill the fabrication of products, as for the installment of services and for the design of new products.

To establish a Six Sigma systematic is necessary establishing certain parameters of measure that will contribute the sigma value to the processes, products, suppliers, workshops, departments and in general of all the areas that be desired to quantify. A very useful way and commonly utilized in the methodology to express the values, is by the usage of a graphic in function of the time.

During the development of this step, is very important the knowledge of statistics, due to that the measurements are established in the principles of the same one. It fits to mention, that the previous thing it's because in most of the productive processes statistical distributions can be determined. Some general rules to select the variables that should be measured could be:

a. Important variable for the business (product characteristics, content of labor and materials including scrap and cycle time).
b. That what is profitable to improve and those variables that you desire to modify with the usage improvement programs.
c. Those variables that have to guarantee that the programs in motion giving results.
d. The necessary variable usage to guarantee that the improvements will long last.

Phase 3: Analyzing

During the analysis the work team determines the causes of the problems that need to be improved [Eckes, 2001]. This third phase of the implementation of Six Sigma is considered like the most important one. And it is focused to discover the existential reasons of the problem. The objective of the analysis is that the work teams determine and validate the root causes of the problem, inside the project.

There are two types of analysis that are commonly utilized by the work teams and that in the majority of the occasions they combine to obtain better results.

The first type of analysis is the analysis of data, that considers all the data that were collected or were defined in the phase of measurement, and subsequently they are analyzed. The second type of analysis is the processes analysis; here the process is examined where the problems is found.

A tool extensively utilized inside this phase is the root cause analysis, which begins with a brainstorm, for subsequently transform into a diagram causes and effect.

Phase 4: Implementing

It is the sum of activities carried out to generate, select and implement the solutions [Eckes, 2001]. In this part of the methodology the team should be focused in the elimination and decrease of the problem cause or root causes defined in the analysis phase.

The employed methodology in this part is similar to it utilized in the phase the analysis, therefore develops a brainstorm to generate different options, for later select one or two of theses ideas. The selection criterion is developed by the work team champion, depending on the reach of the solutions that were contributed, in the brainstorm. Different forms exist to determine which is the solution or solutions that are considered to implement as projects of improvement; all these are you considered by the work team, in such way that the most viable one could be selected.

Controlling

Assure the changes through the time" (Eckes, 2001). Two important types of control in an improvement project exist, the quantitative control and the qualitative one.

The control this based on the standardization capacity of the changes carried out in the processes and in the rate of production or generation of the new processes.

An useful way to maintain in control the processes is by of the utilization of graphics, that have the purpose to alert to the personnel involved in the process the changes that this have through the time, these changes can be false alarms, or well, could be changes that are presented in the process and that has to be analyzed to avoid any variation.

AP. 3.1 Integration model (ICMdl) elements explanation

Following it is explained how the author interprets two of the three element from the Integration and Communication Model (ICMdl) in the figure 3.4, the PLM and the ERP.

AP. 3.1.1 *The Process element (PLM)*

a. Prototype process:

The aim of this process is test the product or concept, looking to fulfill customer needs and requirements for which was designed. The production time should be very short; the cost of fabrication should be high and the quantities to produce should be punctual (low quantities depending o the product and the kind of test needed), no specialized tooling, machines or fixtures are required in this process. If product does not fulfill customer needs, a redesign process should be made trying to solve the problem and the cycle starts over again.

b. Pilot process:

The aim of the pilot stage is to test the production line, once that the product passed the prototype process, now is time to develop the production line that will be used once that start the production process. For this process, the production time, cost of fabrication, should be as real as the one that will be defined for production process, with the only difference that an investment in specialized tooling, machines or fixtures that support production should be done. The quantities to produce must be the necessary to test the production line.

c. Production (and ramp-up) process:

The aim of the production process is start with normal production according to a plan defined against customer requirements or demand. This production process start wit low demand as a "ramp up", start growing up until the maturity or normalization is achieved then with the passing time the life cycle ends with the product declination or disposal stage (this stages is out of scope for this thesis as it was mention in chapter 1)

AP. 3.1.2 *The Data-Information element (ERP):*

An example of this data could be seen in table AP.3.1 that presents main ERP areas and their generic main data.

Material master data (MM)
Material number
Material description
Material status
Valid from dates
Lead times
Production type
Procurement type

Production and planning data (PP, QM, PM)
Bill of materials (BOM)
Fabrication routing
Quality information record
Contracts of vendors
Production orders
Quality inspection program
Plant maintenance program

Sales and Distribution (SD, IM, WM)
Demand
Sales orders
Purchased orders
Inventory
Storage locations

Others (TR, PS, IS, IT, WF, etc.)
Treasure
Project system
Industrial solutions
Information technology
Workflow

Human resources (HR)
Personnel general information
Personnel schedules
Paycheck control
Vacations

Finance and Controlling (FI, CO)
Bank keys info.
Product cost
Product price

Table AP.3.1 ERP areas and their generic main data

AP. 3.2 Work Flow Management Systems (WFMS)

For Workflow Management Systems (WFMS), with the modeling of a workflow, it is possible analyze a whole process and visualize how it works. This model also helps to identify possible information flow problems, duplicated activities and unnecessary activities, as well as showing which are the core activities and resources.

Today's business environments make indispensable for a company to deal with complex business processes, where a workflow management system is a system able to support an automatic, efficient execution of the business processes.

A business process is the execution of a series of activities that leads to the achievement of a measurable business result (undertaken in pursuit of a common goal, and aligned with corporate objectives). The result may be the creation of a product or service, or an intermediate component that contributes to the creation and delivery of products or services, either directly or indirectly.

A WFMS in general is a software system that defines, creates, and manages automated business processes. The WFMS helps users involved in a business process to carry out their tasks following certain business logic [Hyerim and Yeongho, 2002]. This means that the WFMS should have a process model representing the business logic.

A process model consists of a number of activities and their precedence relations. Once a process model is set up, the WFMS automatically assigns activities to individual users based on the model.

By logging in the WFMS, a user can identify a task list that the user has to carry out. The system assists the user by delivering task related information including due date, process name, priority and status of task, input and output files, and methods and techniques (software based tools and human processes).

These tasks are presented on a user interface for WFMS clients. On completing the task assigned, the user notifies the WFMS of the results. Then, the WFMS proceeds to the remained part of the process by assigning the subsequent task to the other relevant users.

The benefits of WFMS are many and diverse, depending on the organization's goals. In the table AP. 3.1 are presented some examples:

Faster work completion	If a process has a lot of paper-based activities, Workflow can reduce the time it takes to accomplish tasks. Automating processes and moving documents electronically virtually eliminates the time required to move paper around partners.
Gains in productivity	For Workflow participants, a WFMS saves valuable time by helping work organization and set priorities (based on priority, due date, or most time sensitive tasks). Work arrives with all the supporting information, and the required indications to execute a task.
Improvements in process control	Workflow is a powerful knowledge management tool for standardizing the organization's processes (consistency and quality) while providing great flexibility for modifying and improving them.
More effective collaboration	Over time, the process definitions can become for the organization or the industrial networks, a storehouse of "best practices", which can be shared across the extended enterprise.

Table AP. 3.1 WFMS Benefits

AP. 3.2.1 WFMS Vendors

A complete list of Workflow Management System vendors announced at internet is presented in table AP. 3.2.

3G Interactive	Hatton Blue Limited	The Salamander Organization Ltd
Action Technologies Inc.	IBM Corporation	Sherwood Government
Advantys	Insession Technologies	Singularity
Aliroo – Solutions for Workflow Security	Image Fast Software Systems Inc.	Staffware Ltd
Avatar Group Inc	Imagesoft Corporation	Star Information Technology
Bizagi	JTS Limited	Steffanini
Blueridge Technologies	LanCept	Taligent
CASEwise Systems	LaserData	TeamWARE
CHALEX Corp	Lexign	Technology Deployment International, Inc. (TDI)
Computron Technologies	Logical Software Solutions	Technology Economics Inc.
Drala Software Inc	Memetex, Inc.	The Workflow Automation Corporation
DST	Metaphase Technology, Inc.	Timephaser Corporation
DynaFlow Modeling & Workflow Solutions Inc	Metastorm	Unisys Netherlands
Electronic Image Designers, Inc.	Micrografx, Inc.	W4
FloSuite	NHANZ Ltd	WindFire Technology
FileNet Corporation	Novius Group	Workflow, Inc.
Fornax	Oak Grove Systems	Workgroup Technology
Fujitsu Software Corporation	Pallas Athena BV	Worktiviti
Global Enterprise Managers, Inc. (GEM)	Proforma	Quask
GFI Ltd.	ProcessSoft	HandySoft Corp
Groiss Informatics GmbH	Promatis	

Table AP. 3.2 WFMS Vendor List

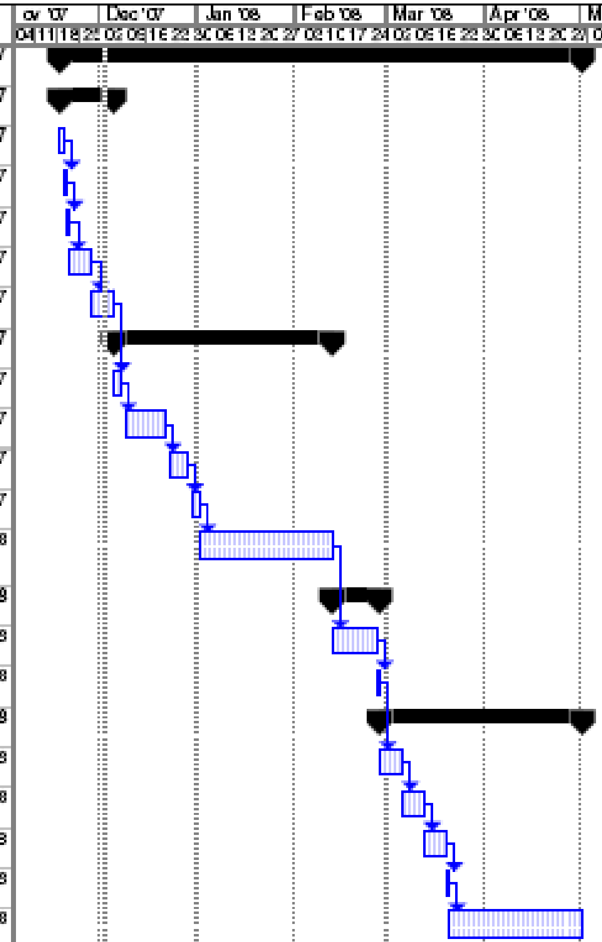
AP. 4.1 Integration and Communication Methodology Project

Appendix 4

Integration and Communication Methodology (ICM) Project

ITESM

ID	Task Name	Duration	Start
1	Integration and Communication Methodology (ICM) - Project	119 days	Mon 19/11/07
2	The Plan stage (As- is model definition)	13 days	Mon 19/11/07
3	Pre-evaluation of the company.	1 day	Mon 19/11/07
4	a. Integration level desired is established.	1 day	Tue 20/11/07
5	b.Define the areas and process involved.	1 day	Wed 21/11/07
6	c.Define the area's requirements.	5 days	Thu 22/11/07
7	d.Define data or information to integrate.	5 days	Thu 29/11/07
8	The Act stage (measure, analyze and develop)	49 days	Thu 06/12/07
9	a.Process mapped against PLM.	2 days	Thu 06/12/07
10	b.Deployment Map (Mapping the process to integrate).	10 days	Mon 10/12/07
11	c.Metrics gathering/definition.	5 days	Mon 24/12/07
12	d.Information formats definition.	2 days	Mon 31/12/07
13	e.Integration and Communication System (ICS) decision made and development.	30 days	Wed 02/01/08
14	The Reflect stage (To-be model improved and implemented)	11 days	Wed 13/02/08
15	a.Implementation for System Tests.	10 days	Wed 13/02/08
16	b.Compare the New System wit the as is.	1 day	Wed 27/02/08
17	The Evaluate stage (evaluation and control of the system)	46 days	Thu 28/02/08
18	a.System Integration Test (SIT – Only for team members).	5 days	Thu 28/02/08
19	b.End user training.	5 days	Thu 06/03/08
20	c.User Acceptance Test (UAT – For end users).	5 days	Thu 13/03/08
21	d.Launch and Release the ICM System (On-Line).	1 day	Thu 20/03/08
22	e.Integration system Control.	30 days	Fri 21/03/08



Project: Appendix 4 ICM Project.mpp
Date: Mon 03/12/07
MS Project Example

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

Times and Dates are estimated and for research purposes only

Page 1

Developed by:
Héctor Oziel Almaguer Vela

AP. 5.1 History of Caterpillar México

In all kind of Enterprise, "customer's satisfaction" it's one of the most important objectives were the way to do this is by delivering the highest quality products faster while complying with global standards in a low cost. A clear example of this "customer satisfaction" focus can be appreciated in one of the most important construction enterprises around the world, Caterpillar.

Caterpillar Mexico, S.A. de C.V. was founded at Monterrey, Nuevo León in the 1962 under the name of Caterpillar Mexicana, S.A. de C.V. were the company used to distribute spare parts and service parts. In 1981 changed its name to CONEK (Construction and Equipment) in a join venture with CYDSA (Celulosa y Derivados S.A. de C.V.) where CONEK was in charged of the fabrication for small components.

In 1994 Caterpillar Inc. become the major partner of the joint venture and CONEK change once again its name to what is know as today as Caterpillar Mexico, S.A. de C.V. also know as CMSA, being the main concern the metal-mechanic fabrication focus on components and assemblies fabrication for the heavy weight construction industry

Figure AP. 4.1 Caterpillar México S.A. de C.V. (CMSA)

In 1999 Caterpillar México expands his production and initiates the construction of a new plant in the City of Torreon, Coahuila, initiating activities in the 2002 under the name of Caterpillar Torreon S.A. of R.L. also known as CATO.

Figure AP. 4.2 Caterpillar Torreon S. de R.L (CATO)

As much CMSA as CATO form part of the Latin America Division of along with the plants of Argentina and Brazil where its main clients, that at the same time also form part of the corporation Caterpillar are found in Illinois, EU.

One of the projects but ambitious for Caterpillar Mexico is the change of its current ERP system known as Maxcim, implemented among 25 years ago, emigrating to a current and more sophisticated system, the SAP R/3® (Systems Application and Products), where besides the many activities to carry out inside the project, the control, the interpretation and transfer of the adequate information becomes a critic process, not alone in the period of implementation, but in the work days after the implementation, adapting terms and the know-how translating them in the new parameters and requests for this system.

AP. 6.1 Questionary for the pre-evaluation of the company

Company name: ________________________ Interviewed:
Industry sector: ________________________ Name ____________________
Foundation date: ______________ Position: ____________________

Instruction:
Answer the following questions before starts with the application of the "Methodology for ERP and PLM integration with a Knowledge Management base"

1. Does the company has or will have an ERP system?
   - □ Yes ---- Goes to question number 2.
   - □ No ---- End of the process, this company is not eligible for the application of the methodology.

2. If the answer was "yes" select one of the following ERP system:
   - □ SAP
   - □ Baan
   - □ People soft
   - □ Oracle
   - □ JD Edwards
   - □ Other (explain): ______________________________

3. Does the company has or will have a PLM system?
   - □ Yes ---- Goes to question number 3.
   - □ No ---- The need of a virtual PLM development is needed based on Product and Process Development (PPD) stages.

4. If the answer was "yes" what is the name of the PLM system:

   ____

5. What is the actual level of integration for the systems?

	Integration Level	Explanation:
□	No integration	
□	Loose integration (low)	ERP modules and PLM stages operate by separate, there is not a formal sequence in place, and mayor of the knowledge in processes is explicit.
□	Horizontal/vertical integration (medium)	ERP modules and PLM stages are partially integrated, there is sequence in place, and mayor of the knowledge in processes is explicit but there is some tacit.
□	Full integration (High)	ERP modules and PLM stages are fully integrated, there is a formal but in some times inflexible and not fully adaptable sequence of the process, and mayor of the knowledge in processed in explicit form (in this case the ERP vendor and PLM vendor are the same).

6. Does the company has or will have a Knowledge Management system?
   - □ Yes
   - □ No Why? ______________________________

7. What is the level of integration desired by the company? (according to question 5)

   ____

8. Additional comments:

   ____

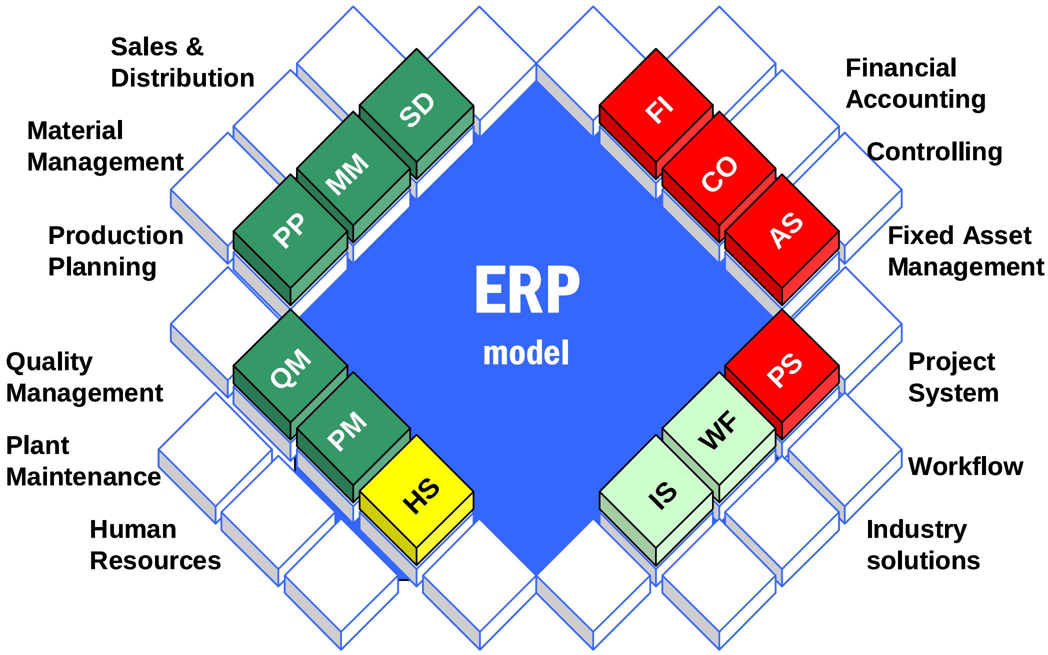
   ____

Questionary performed by: ______________________________ Date: __________

AP. 6.2 Pre-evaluation reference-models of the company

Reference models to compare current ERP and PLM systems.

AP. 6.2.1 ERP model



Check all modules or areas that fit or could be interpreted for the Company (reference definition of each element from the table 2.1, in chapter 2).

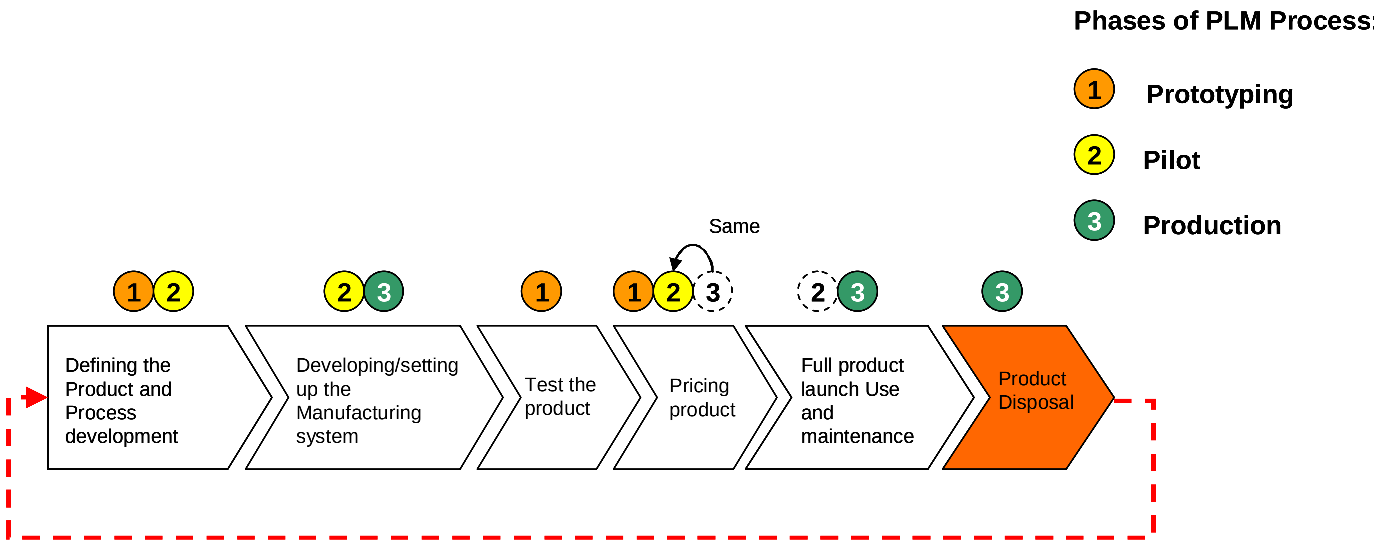
Sales and Distribution	□	Yes
	□	No
Material Management	□	Yes
	□	No
Production Planning	□	Yes
	□	No
Quality Management	□	Yes
	□	No

Plant Maintenance	□	Yes
	□	No
Human Resources	□	Yes
	□	No
Financial Accounting	□	Yes
	□	No
Controlling	□	Yes
	□	No

Fixed Asset Management	□	Yes
	□	No
Project System	□	Yes
	□	No
Workflow	□	Yes
	□	No
Industry Solutions	□	Yes
	□	No

AP. 6.2.2 PLM model (based on Aca's PLM model)

PLM Diagram: represent the stages for which a product can pass over the product development: 1) Prototyping, 2) Pilot, and 3) Production.



Check all stages that were applied to the Company.

Product/Process definition stages	□	Yes
	□	No
Manufacturing System(develop/setup)	□	Yes
	□	No

Testing of the product	□	Yes
	□	No
Pricing de product	□	Yes
	□	No

Product launch-use-maintenance	□	Yes
	□	No
Product disposal	□	Yes
	□	No

AP. 6.2.3 Integration Level Index Definition

a). From the figure 3.8 the possible combinations that can be obtained are:

PLM	ERP	PLM+ERP	
0	0	N/a	Methodology no appply
1	0	N/a	Methodology no appply
0	1	1	
1	1	2	
1	2	3	
1	3	4	
2	1	3	
2	2	4	
2	3	5	
3	1	4	
3	2	5	
3	3	6	

Figure 3.8						
PLMip + ERPidi						
0	1	2	3	4	5	6

This is the upper section of the table 3.4

b). From the figure 3.9 the possible combinations that can be obtained are:

KM ERP	KM PLM	$KM_{ERP}+KM_{PLM}$
0	0	0
1	1	2
1	3	4
1	6	7
3	1	4
3	3	6
3	6	9
6	1	7
6	3	9
6	6	12

Figure 3.9
$KM_{ERP}+KM_{PLM}$
0
2
4
7
4
6
9
7
9
12

This is the left section of the table 3.4

c). Now multiplying the results of the combination from incises a) and b), the following chart is obtained:

	PLMip + ERPidi						
$KM_{ERP}+KM_{PLM}$	0	1	2	3	4	5	6
0	0.00	1.00	1.00	1.00	1.00	1.00	1.00
2	0.00	2.00	4.00	6.00	8.00	10.00	12.00
4	0.00	4.00	8.00	12.00	16.00	20.00	24.00
7	0.00	7.00	14.00	21.00	28.00	35.00	42.00
4	0.00	4.00	8.00	12.00	16.00	20.00	24.00
6	0.00	6.00	12.00	18.00	24.00	30.00	36.00
9	0.00	9.00	18.00	27.00	36.00	45.00	54.00
7	0.00	7.00	14.00	21.00	28.00	35.00	42.00
9	0.00	9.00	18.00	27.00	36.00	45.00	54.00
12	0.00	12.00	24.00	36.00	48.00	60.00	72.00

The orange value of 1 is left because the option that in the company could not be a PLM formal process which could be handled as a virtual process with the minimum points.

So if the value of 72.00 could be used as the maximum value and expressed as a factor of integration divided by 100, the Integration Level Factor (ILF) of 0.72 is obtained.

d). Using the ILF dividing the result from incise c), the Integration Level table is obtained:

	Figure 3.8						
Figure 3.9	PLMip + ERPidi						
KM_{ERP}+KM_{PLM}	0	1	2	3	4	5	6
0	0.00	1.00	1.00	1.00	1.00	1.00	1.00
2	0.00	2.78	5.56	8.33	11.11	13.89	16.67
4	0.00	5.56	11.11	16.67	22.22	27.78	33.33
7	0.00	9.72	19.44	29.17	38.89	48.61	58.33
4	0.00	5.56	11.11	16.67	22.22	27.78	33.33
6	0.00	8.33	16.67	25.00	33.33	41.67	50.00
9	0.00	12.50	25.00	37.50	50.00	62.50	75.00
7	0.00	9.72	19.44	29.17	38.89	48.61	58.33
9	0.00	12.50	25.00	37.50	50.00	62.50	75.00
12	0.00	16.67	33.33	50.00	66.67	83.33	100.00

And in order to establish the Integration Level Index to classify from: no integration, low, medium or mid, and high integration, it was created the following ranks based on the values that could be obtained from the previous chart:

Integration level index	
0	No integration
1-40	Low integration
41-70	Mid integration
71-100	High integration

AP. 6.3 ERP model

In figure AP. 6.1 and 6.2 are presented examples of the control charts and metrics that could be used for the methodology:

Monthly process time by area
(in days)

Area: Releasing

Month	Qty of products	Proces time
Jan	157	20.2
Feb	122	20.9
Mar	183	21.6
Apr	180	22.3
May	121	23.2
Jun	143	23.7
Jul	98	20.2
Aug	230	25.1
Sep	-	-
Oct	-	-
Nov	-	-
Dec	-	-
Ytd	1234	22

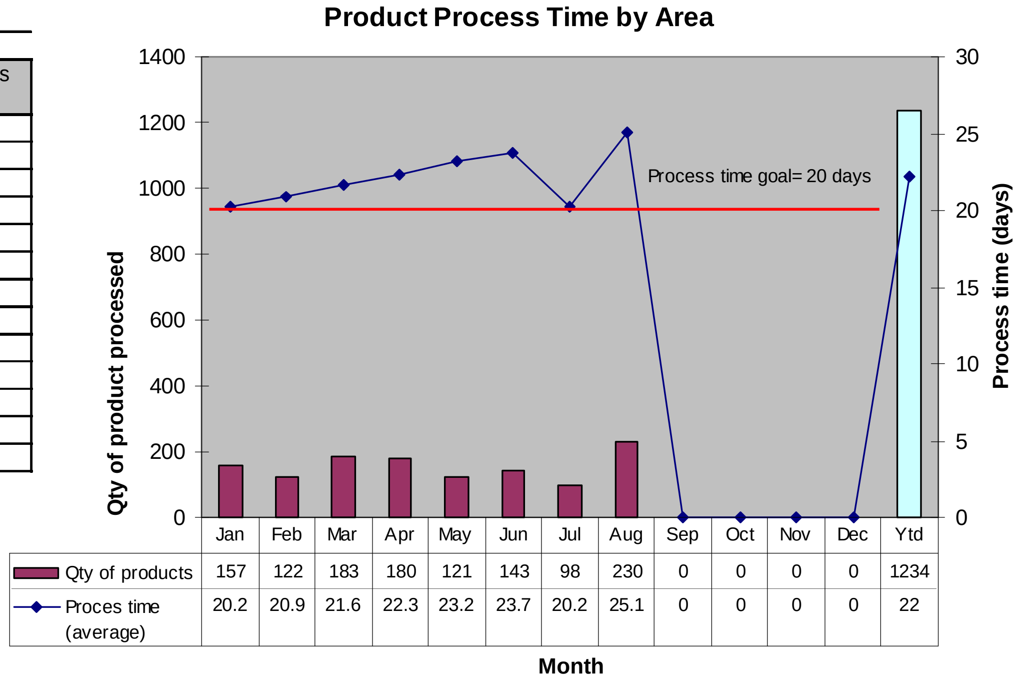


Figure AP. 6.1 Monthly process time and qty. for product (example)

Processing performance by area

Month: November 2007

Area	Pending issues	Processed	Total
Releasing	13	184	197
Finances	27	140	167
Purchasing	5	15	20
Manufacturing	47	98	145
Requirements	12	23	35
Distribution	23	5	28

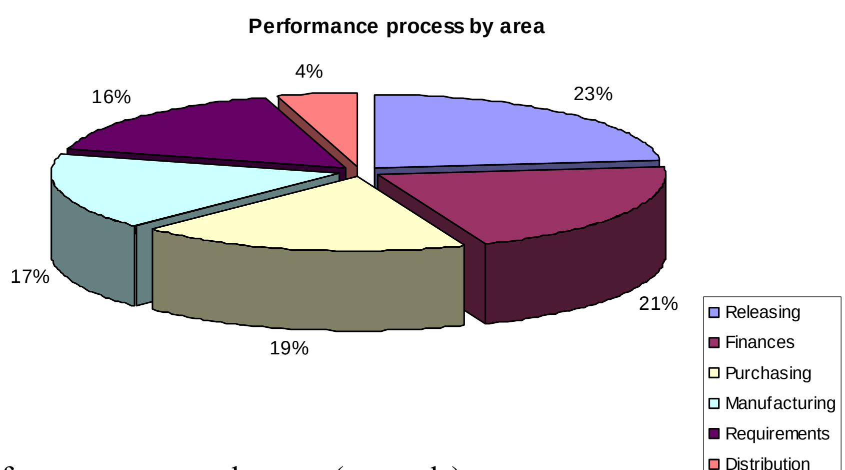


Figure AP. 6.2 Performance process by area (example)

AP. 6.4 Knowledge Management Formats

Following are presented two examples of the tool developed for the second case study to enable Knowledge Management based on the WFMS

e-Master File   Caterpillar: Confidential Yellow   19/11/2007 04:20:59 p.m.

Creation date:22/08/2007
Status: **Routing setup**

Level~Material:1~MC-2582654/03A1
Local revison level:03
Production scheduler:SF
Old material number:2582654

Description:PLATE
Type~MRP Group:EC~F
Valid from:03/09/2007
Revision level:03
ECN:200000002890

Releasing

Eng. change reason:
Slot (B1) Changed from 2 x 13.5 x 53.5 to 2 x 13.5 x 63.5

Effective date 03/09/2007
Basic data view 1 & 2 set in SAP? Yes
Additional info view set in SAP? Yes
Gen. plant data /storage loc set in SAP? Yes
BOM set in SAP? Yes
BOM audit performed? Yes

Quality

Required inspection setup? Yes
Inspection setup created? Yes
Quality management view set done in SAP? Yes
Confirm PPAP request to supplier? Yes

Distribution

Warehouse management view set in SAP? Yes
General plant data storage view extended? Yes
Store location stock view extended? Yes

Requirements

Will the material be on sale? No
MRP view set in SAP? Yes
Work scheduling view set in SAP? Yes

Manufacturing

Finance

WORK FLOW

Area	Sequence	Name	LT	Due date	Real date
Releasing	EC Analysis	Ernesto Moreno	3	08/25/2007	8/22/2007 12:56:39
Programming	Nesting	Juan A Caldera	4	08/29/2007	PM
Releasing	BasDat view	Jose A. Santos Aguirre	2	08/31/2007	8/22/2007 4:15:21 PM
Quality	QM View	Alejandro Olvera	1	09/01/2007	01/09/2007 2:58:07
Distribution	WM View	Victor E. Rodriguez	1	09/02/2007	p.m.
Requirements	Sales-MRP View	Karla M. Rodriguez	1	09/03/2007	10/15/2007 08:18:48
Releasing	BOM creation	Rodriguez	3	09/06/2007	AM
Quality	PPAP request	Jose A. Santos Aguirre	2	09/08/2007	10/15/2007 03:13:13
Manufacturing	Routing info req.	Alejandro Olvera	4	09/12/2007	PM
Finance	Cost setup	Gerardo A. Lugo	3	09/15/2007	25/10/2007 02:27:41
Quality	Tool order setup	Maria E Garcia	2	09/17/2007	p.m.
Requirements	Customer info rec	Alejandro Olvera	3	09/20/2007	25/10/2007 02:57:48
Finance	Price setup	Karla M. Rodriguez	4	09/24/2007	p.m.
Requirements	Schd agrmnt	Rodriguez	2	09/26/2007	11/14/2007 08:12:48
		Maria E Garcia			AM

Figure AP. 6.3 Product General Information Format

AP. 6.5 Customers survey format

CATERPILLAR MEXICO S.A. DE C.V.

Como una forma de conocer la opinión de nuestros clientes, sobre la calidad en el servicio prestado por el área de ___________________, se ha desarrollado la sig. encuesta para la cual le solicitamos que sea lo más sincero que pueda ya que nos interesa conocer nuestras áreas de oportunidad para poder mejorar nuestro servicio.

	Calificación				
Pregunta	2 mala	4 pobre	6 regular	8 buena	10 excelente
1. ¿Cómo calificas la calidad del servicio brindado por el área de ________ en relación con el tiempo de respuesta?	□	□	□	□	□
2. ¿Cómo calificas el tiempo de respuesta a tus solicitudes de trabajo?	□	□	□	□	□
3. Cuando existe la necesidad de proyectos urgentes, ¿Cómo consideras que aplica el sentido de urgencia la gente de _______ para cubrir esa necesidad?	□	□	□	□	□
4. ¿Cómo consideras la comunicación entre tú y el personal del área para evitar demoras en el desarrollo de los proyectos?	□	□	□	□	□
5. ¿Cómo consideras la comunicación entre tú y el coordinador de cambios de ingeniería para lograr implementaciones efectivas de cambios de ingeniería?	□	□	□	□	□
6. ¿Cómo calificas la seriedad prestada a tus necesidades por parte del área de ________________?	□	□	□	□	□
7. ¿Cómo calificas el nivel de conocimientos del área de ______________________ para la realización de sus funciones?	□	□	□	□	□
8. ¿Cómo considera la confiabilidad de que sus requerimientos serán satisfechos por el área de __________?	□	□	□	□	□
9. ¿Cómo considera la forma de dirigirse hacia usted (respeto) por parte del área de _________________?	□	□	□	□	□
10. En general ¿Cómo calificas el servicio brindado por el área de ________________?	□	□	□	□	□
11. ¿Qué recomendaciones le das al área de PCC para mejorar sus servicios?					

For this thesis was evaluated the areas of Product Change Control (PCC) in both cases studies because that areas are in charged of the PLM and processing coordination. Following are presented the result for the areas, which were classified by the own PCC team members.

AP. 6.5.1 Customers survey results (SIPOC) analysis

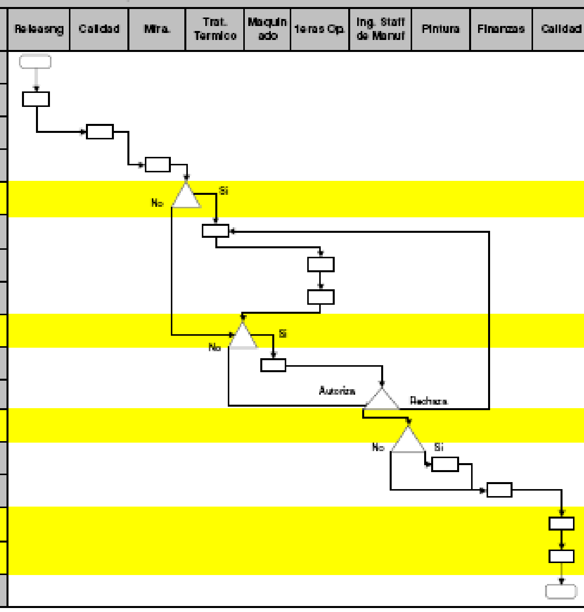
It was used the Six Sigma SIPOC tool to represents every concept that was defined by the PCC team based on the result of the survey.

Suppliers INPUT	Process	OUTPUT
Mensajes, necesidades o requerimientos de cambios de ing,. y NPI's	COMUNICACIÓN	Información efectiva, juntas
Cantidad de números, captura de datos, dibujo, definición de source code, base de datos de auditorias, EDS,	VERACIDAD	Bill de materiales, peso bruto, neto, acero ligado, resultado de auditorias, pending flag, source code, modelo, fecha efectiva, start y close date del bill, posteo
Fecha de recibido, fechas efectivas, liberación de información EDS, cantidad de números de parte, tiempos muertos, tracking system, tiempo de nuestros clientes (ing, programación, compras, requerimientos, mfg) .	TIEMPO DE PROCESO y DE RESPUESTA A CLIENTES	Fecha de procesado, fecha efectiva, tiempo de ciclo de cambio
Comunicación con clientes, seguimiento en juntas, análisis de cambios de ing. y npis	INVOLUCRAMIENTO SINCRONIZACION	Implementación efectiva de npi y cambio de ing. interacción con otras áreas
Aptitudes de personal, capacitación en procesos del área, conocimiento de producto a cargo, involucramiento con otras áreas, conocimientos afectación y/o interrelación de procesos	CONOCIMIENTO TÉCNICO	Seguridad en trabajo, mejores resultados, satisfacción de los clientes, personal mejor capacitado
Cambios de ingeniería y/o estatus (PF), cambios de modelos y series, cancelaciones de proyectos, compras excesivas, sobre inventario, sobre producción, cancelación de pedidos en corto, malas negociaciones	EVITAR MATERIAL OBSOLETO	Material obsoleto, destrucciones de material, perdidas y gastos para el negocio (nacionalización, subcontrato de personal para destrucciones)
Necesidades de cliente, llamadas, consultas, mensajes, actitud , disponibilidad, sentido de responsabilidad, empatia	CALIDAD EN SERVICIO	Cliente satisfecho, trabajo de calidad, retrabajos
Requerimiento de cliente, análisis de cambio, confirmación de fechas de NPI's	FECHAS EFECTIVAS	Fecha efectiva planeado e implementada correctamente, negociación o acuerdos con cliente

In this section are presented the flowcharts or workflow developed for both case study. Note: the flow charts are presented in the original language (Spanish)

AP. 7.1 Deployment Map for experiment 1 - Maxcim

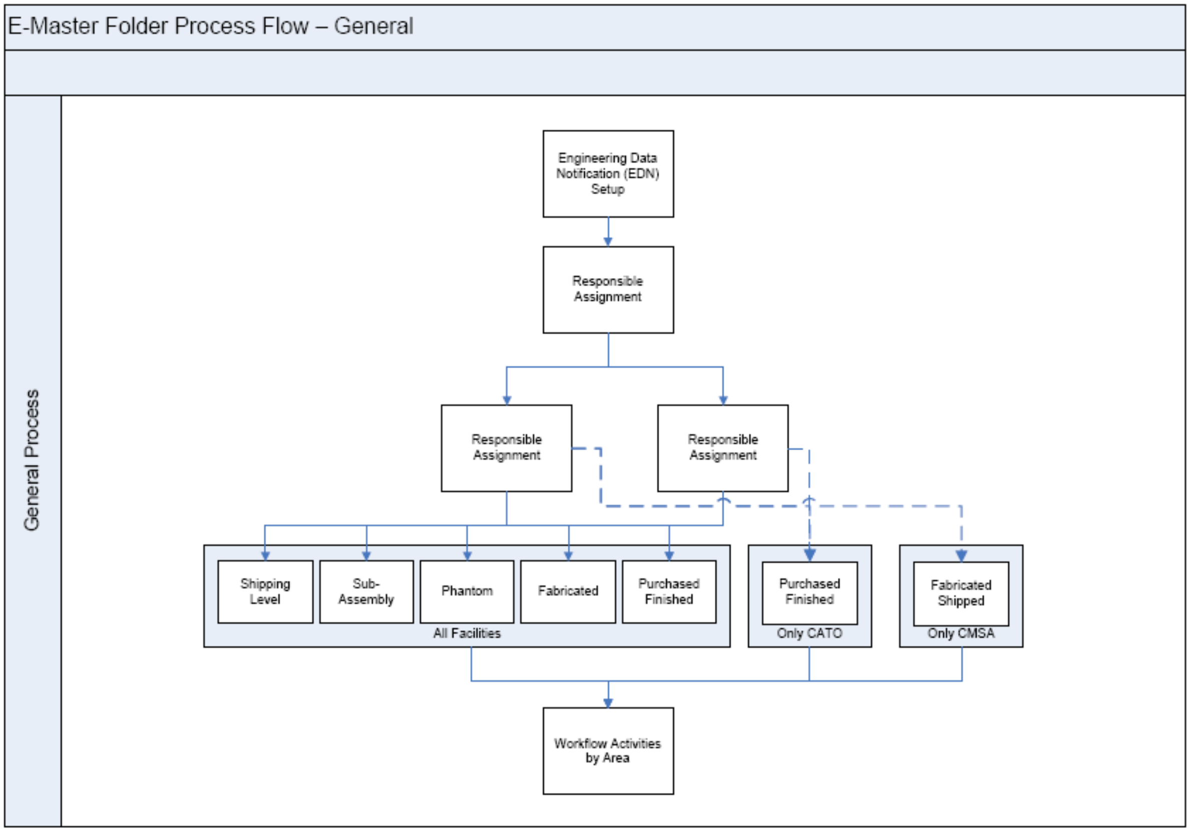
Deployment Map Process

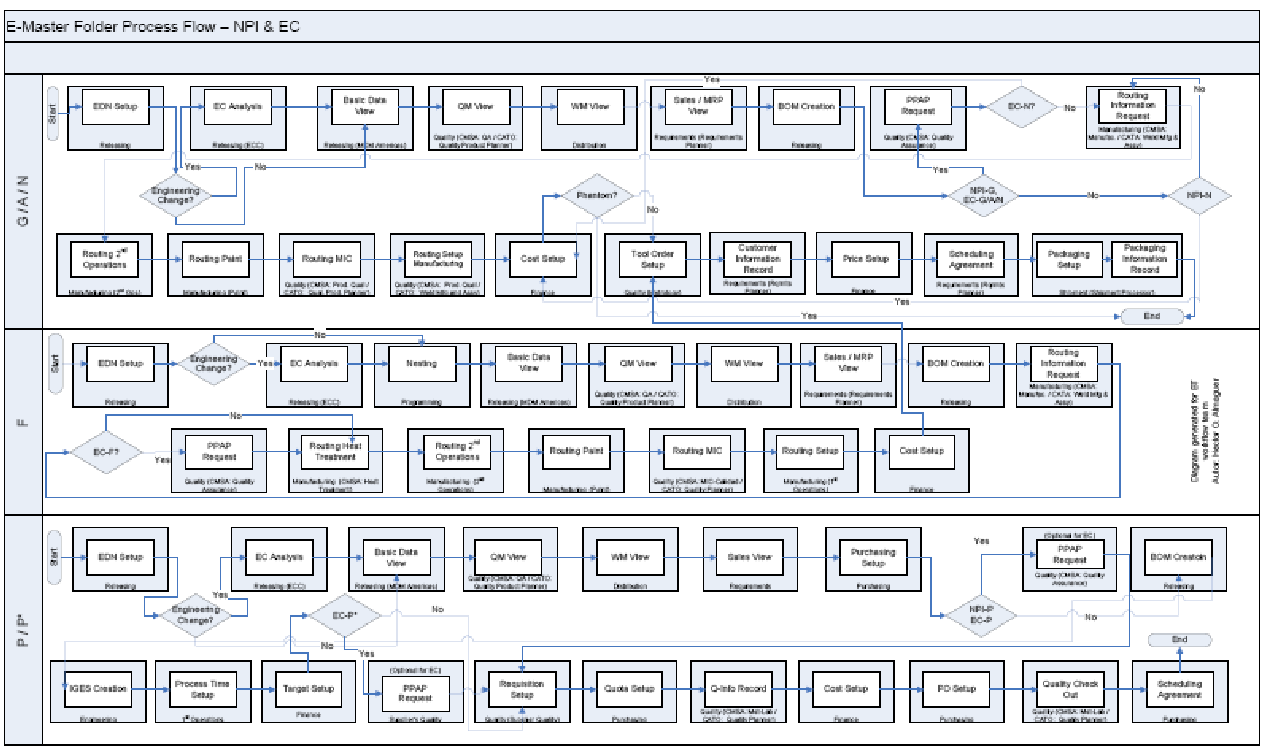


#	Actividad / Area	Tiempos de Procesamiento (min): Tiempo Original	Tiempo mejorado	Costos de procesamiento (pesos): Costo por hora por empleado	Costo de procesamiento actual	Costo de procesamiento mejorado	% Optimización
1	Generar folder electronico (e-Folder)		10				
2	Define si requiere Tratamiento Termico y/o Pintura	480	5	$ 50.00	$ 400	$ 67	98%
3	Define si requiere PPAP / APQP		30				
4	Asigna localizacion fisica del material	240	15	$ 93.75	$ 375	$ 94	94%
5	Requiere Tratameinto Termico?	N/a	0	N/a	N/a	N/a	N/a
6	Genera ruta de Trat. Termico	480	40	$ 93.75	$ 750	$ 500	92%
7	Define si requiere Maquinado	20	15	$ 56.25	$ 19	$ 5	25%
8	Genera ruta de ensamble/corte	960	40	$ 56.25	$ 900	$ 600	96%
9	Requiere Maquinado?	N/a	0	N/a	N/a	N/a	N/a
10	Genera ruta de Maquinado	480	40	$ 93.75	$ 750	$ 500	92%
11	Autoriza/Rechaza rutas de produccion (TT, Maq. y ensamble/corte)	60	15	$ 106.25	$ 106	$ 27	75%
12	Requiere pintura?	N/a	0	N/a	N/a	N/a	N/a
13	Genera ruta de pintura	240	40	$ 56.25	$ 225	$ 150	83%
14	Asigna costo del producto	120	20	$ 93.75	$ 188	$ 63	83%
15	Acepta documentación de calidad	N/a	0	N/a	N/a	N/a	N/a
16	Rechaza documentacion de calidad	N/a	0	N/a	N/a	N/a	N/a
17	Cierra el folder	10	5	$ 50.00	$ 8.33	$ 1	50%

	Tiempo Original	Tiempo mejorado	Costo de procesamiento actual	Costo de procesamiento mejorado		
Min	9088	275	$ 3,721	$ 2,005	Costo por numero de parte	96.97
Hrs	151	5	$ 1,116,250	$ 601,458	Costo al mes	96.97
Dias	19	1	$ 13,395,000	$ 7,217,500	Costo anual	96.97

AP. 7.1 Deployment Map for experiment 2 - SAP





AP.8.1 Integration and Communication System Structure for Experiment 1 - Maxcim

Following are presented some screenshots from the ICS implemented for the case study 1 (Maxcim)

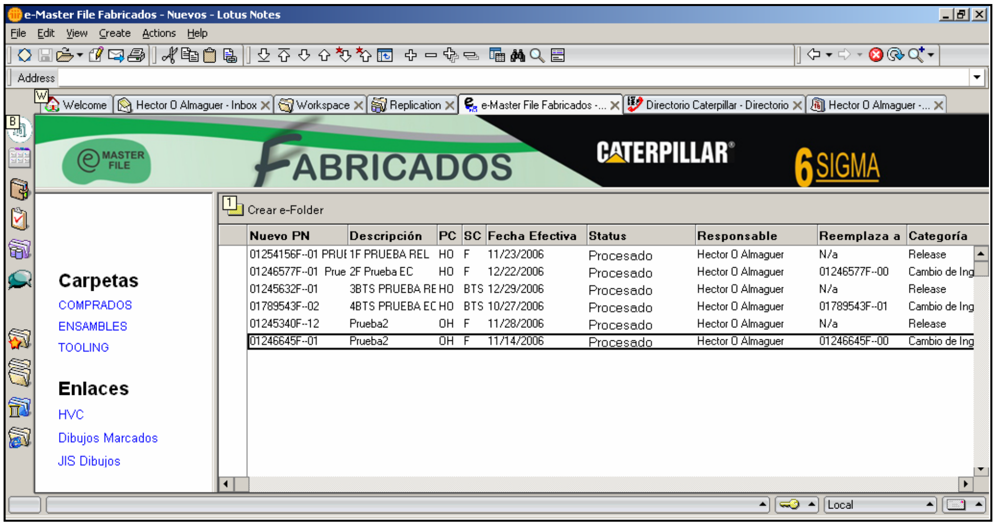


Figure AP 8.1   e-Master File main screen

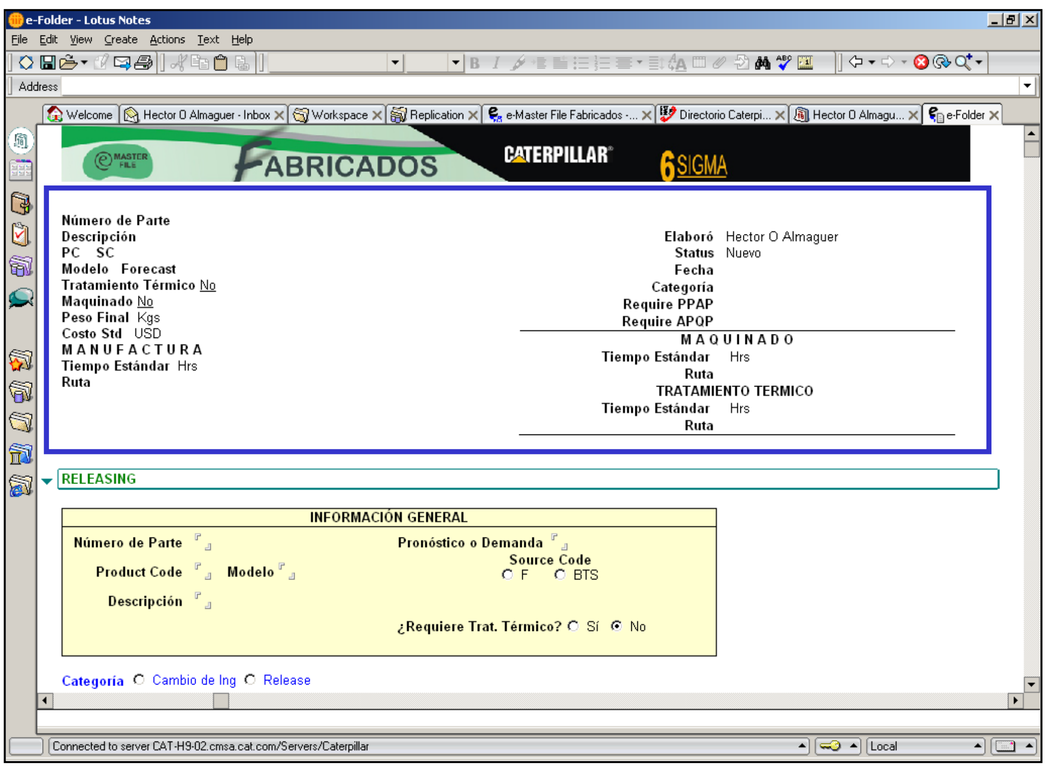


Figure AP 8.2   Data set-up section (general information)

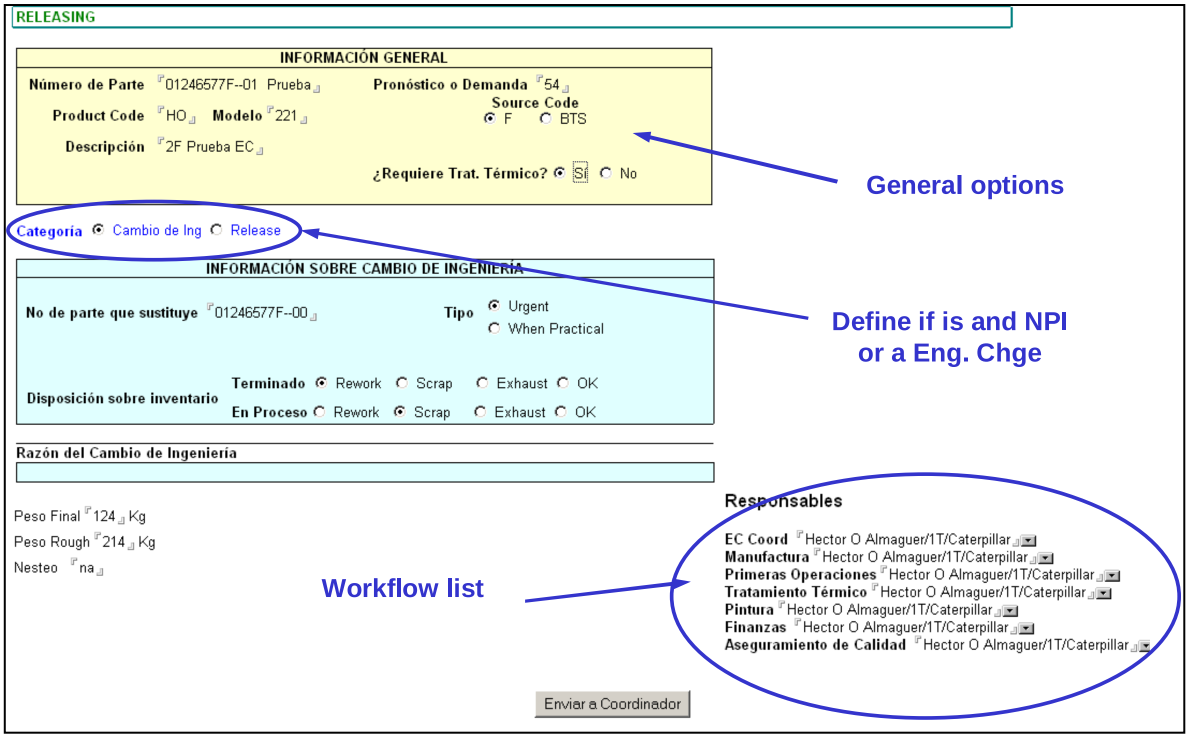


Figure AP 8.3 Personnel-workflow set-up (general information)

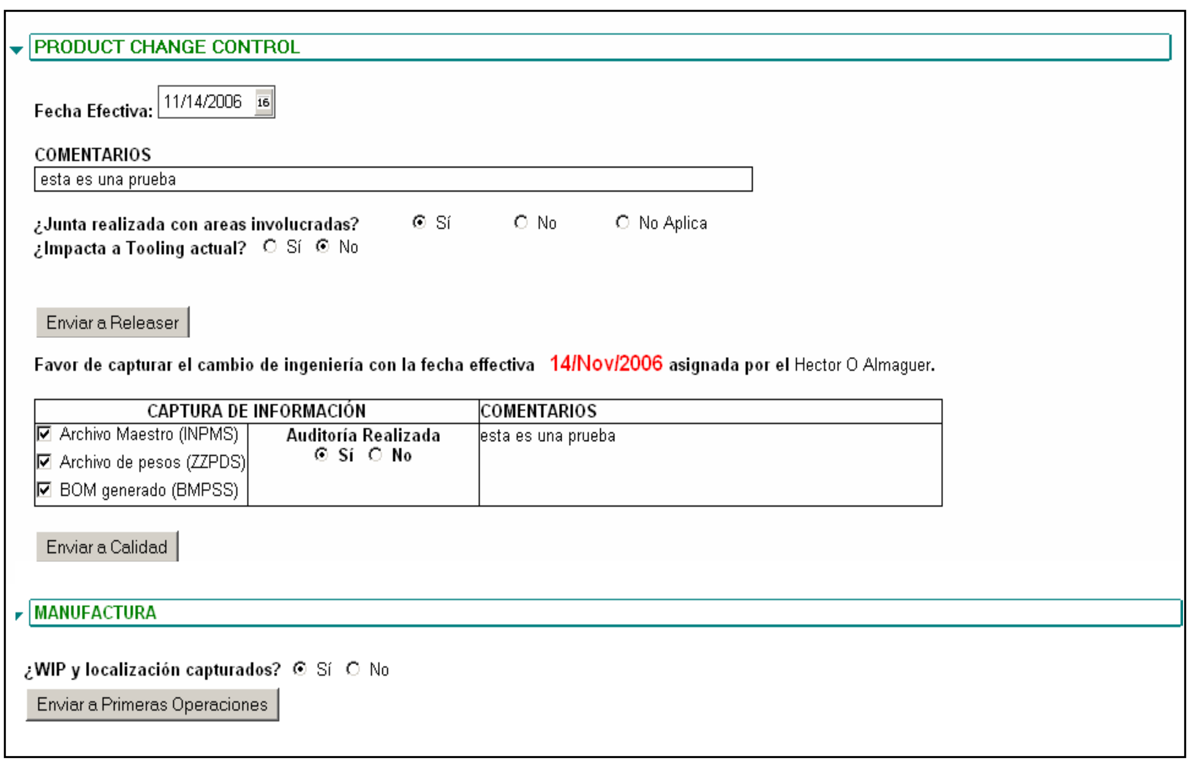
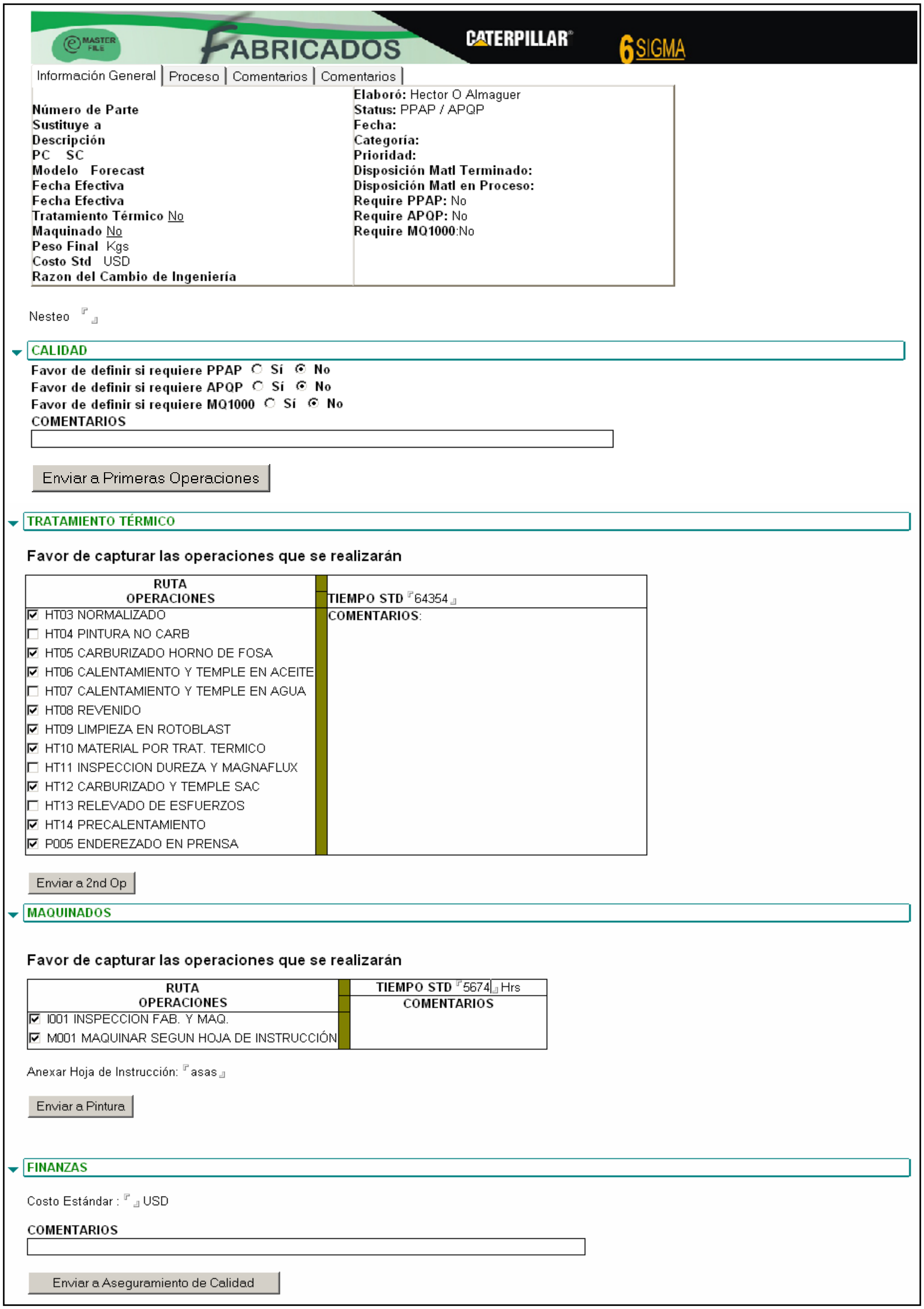


Figure AP 8.3 Information of the areas who participate in the workflow



FABRICADOS CATERPILLAR 6SIGMA

Información General | Proceso | Comentarios | Comentarios

Número de Parte
Sustituye a
Descripción
PC SC
Modelo Forecast
Fecha Efectiva
Fecha Efectiva
Tratamiento Térmico No
Maquinado No
Peso Final Kgs
Costo Std USD
Razon del Cambio de Ingeniería

Elaboró: Hector O Almaguer
Status: PPAP / APQP
Fecha:
Categoría:
Prioridad:
Disposición Matl Terminado:
Disposición Matl en Proceso:
Require PPAP: No
Require APQP: No
Require MQ1000: No

Nesteo

CALIDAD

Favor de definir si requiere PPAP ○ Sí ◉ No
Favor de definir si requiere APQP ○ Sí ◉ No
Favor de definir si requiere MQ1000 ○ Sí ◉ No
COMENTARIOS

[Enviar a Primeras Operaciones]

TRATAMIENTO TÉRMICO

Favor de capturar las operaciones que se realizarán

RUTA OPERACIONES	TIEMPO STD 64354
☑ HT03 NORMALIZADO	COMENTARIOS:
☐ HT04 PINTURA NO CARB	
☑ HT05 CARBURIZADO HORNO DE FOSA	
☑ HT06 CALENTAMIENTO Y TEMPLE EN ACEITE	
☐ HT07 CALENTAMIENTO Y TEMPLE EN AGUA	
☑ HT08 REVENIDO	
☑ HT09 LIMPIEZA EN ROTOBLAST	
☑ HT10 MATERIAL POR TRAT. TERMICO	
☐ HT11 INSPECCION DUREZA Y MAGNAFLUX	
☑ HT12 CARBURIZADO Y TEMPLE SAC	
☐ HT13 RELEVADO DE ESFUERZOS	
☑ HT14 PRECALENTAMIENTO	
☑ P005 ENDEREZADO EN PRENSA	

[Enviar a 2nd Op]

MAQUINADOS

Favor de capturar las operaciones que se realizarán

RUTA OPERACIONES	TIEMPO STD 5674 Hrs
☑ I001 INSPECCION FAB. Y MAQ.	COMENTARIOS
☑ M001 MAQUINAR SEGUN HOJA DE INSTRUCCIÓN	

Anexar Hoja de Instrucción: asas

[Enviar a Pintura]

FINANZAS

Costo Estándar : USD

COMENTARIOS

[Enviar a Aseguramiento de Calidad]

Figure AP 8.3 Information of the areas who participate in the workflow (continuation)

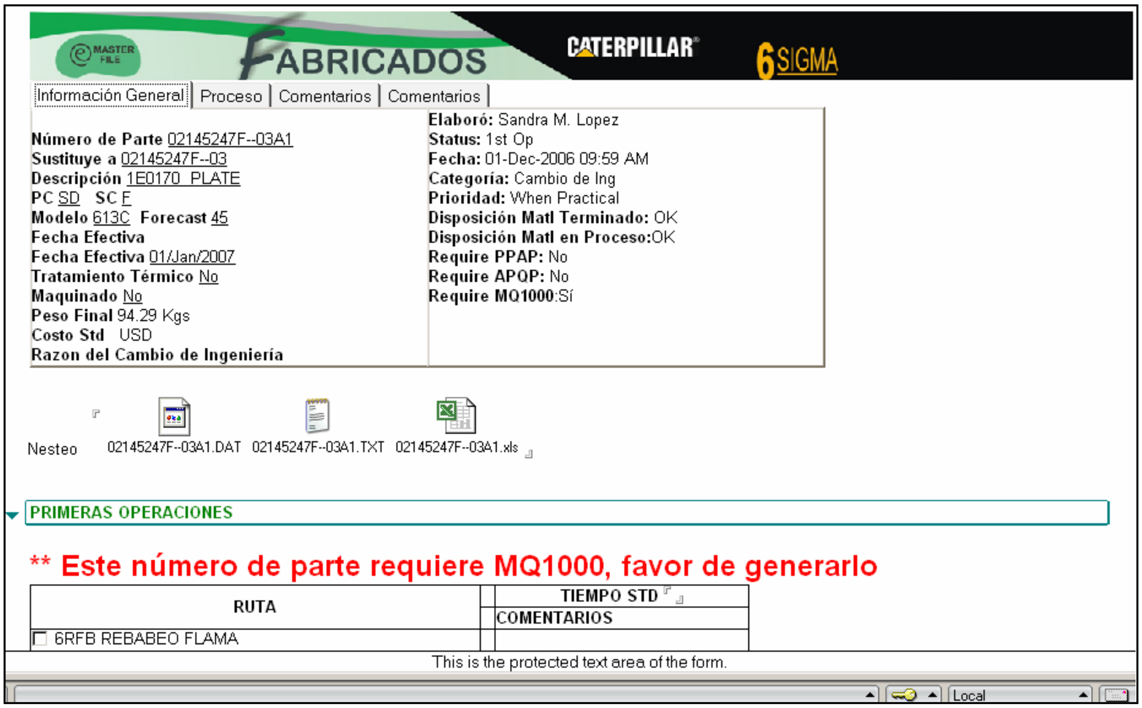


Figure AP 8.4 Product General Information section (knowledge)

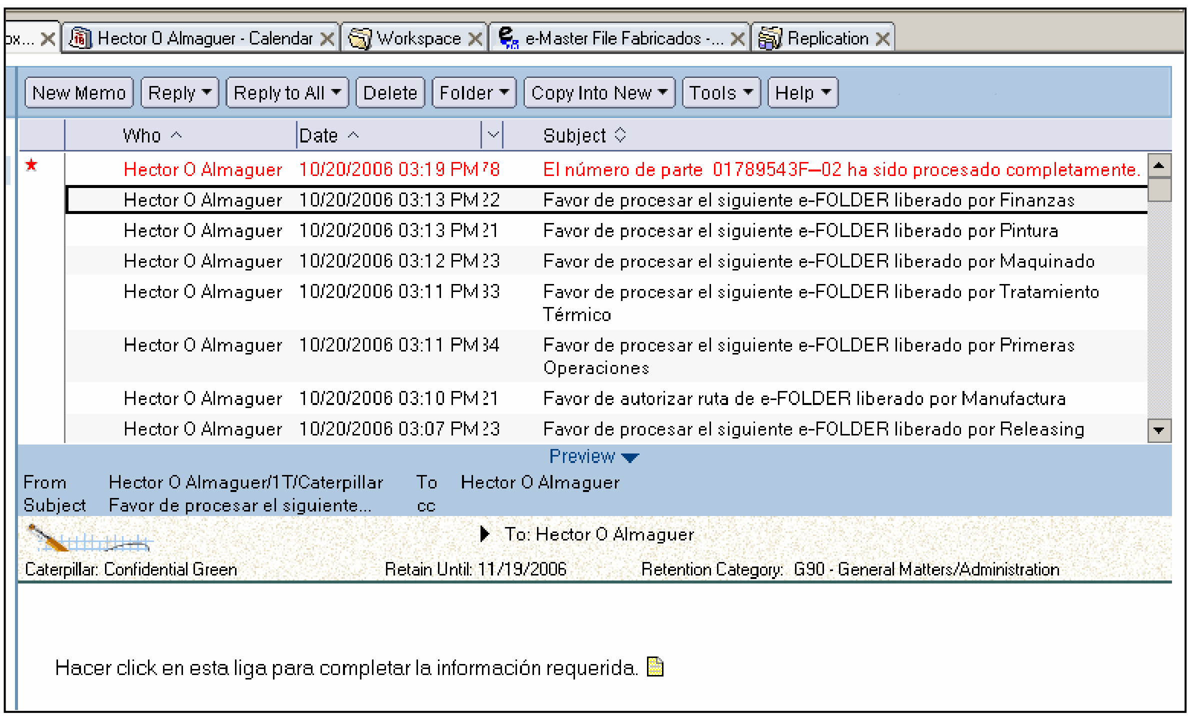
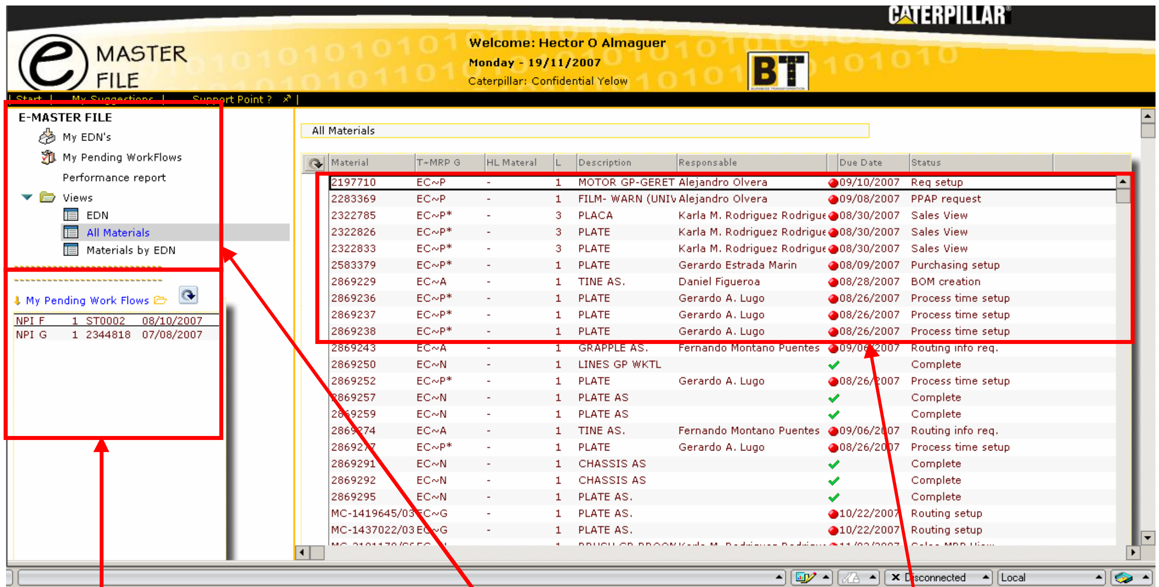


Figure AP 8.4 Notifications generated automatically

by the ICS and send to personnel responsible

AP.8.2 Integration and Communication System Structure for Experiment 2 - SAP

Following are presented some screenshots from the ICS implemented for the case study 2 (SAP)



Pending product to be processed

Menu for visualization and product setup

Product list (in process by area and completed)

Figure AP 8.5 Main screen

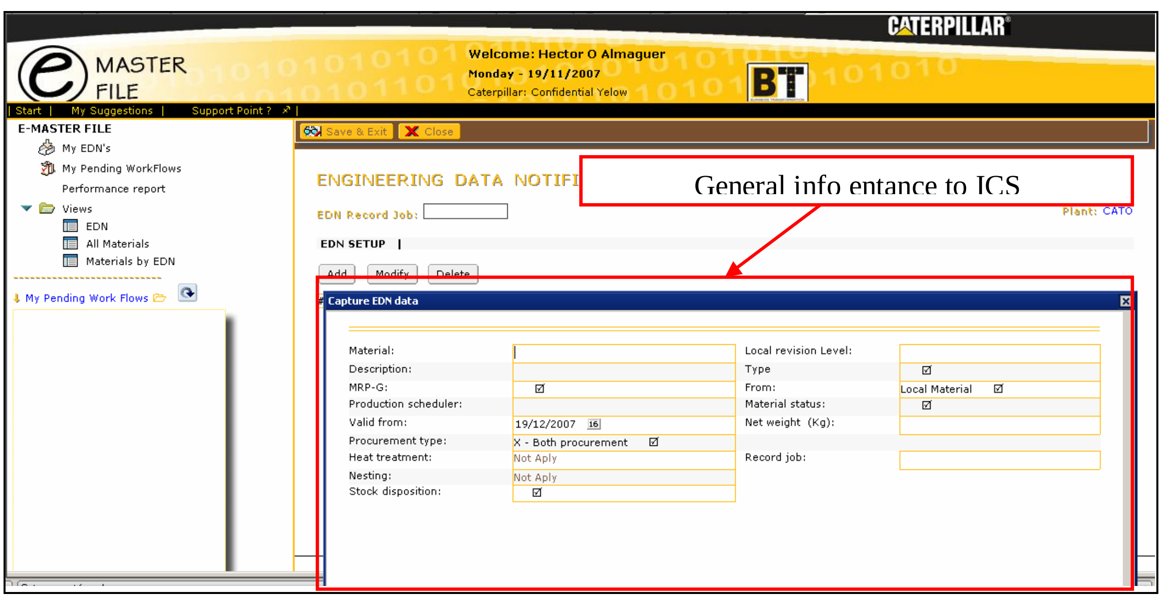


Figure AP 8.6 General info setup and data entrance to ICS

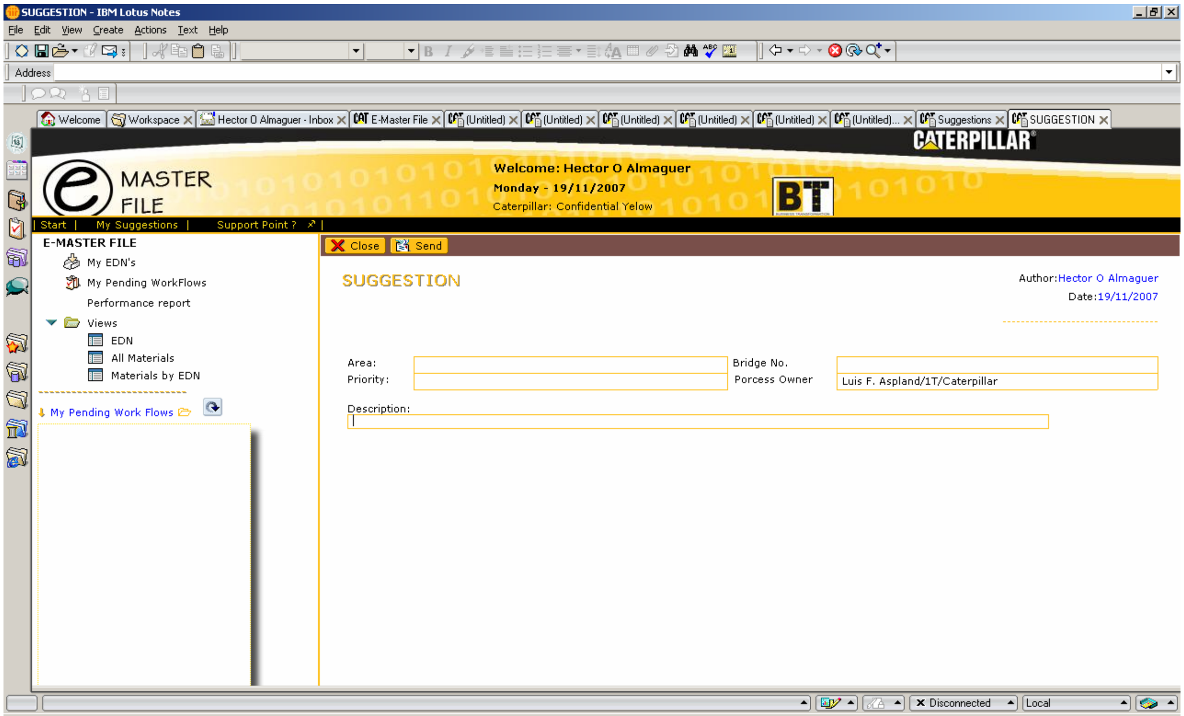


Figure AP 8.7 Area designed for continuous improvement as the suggestion area

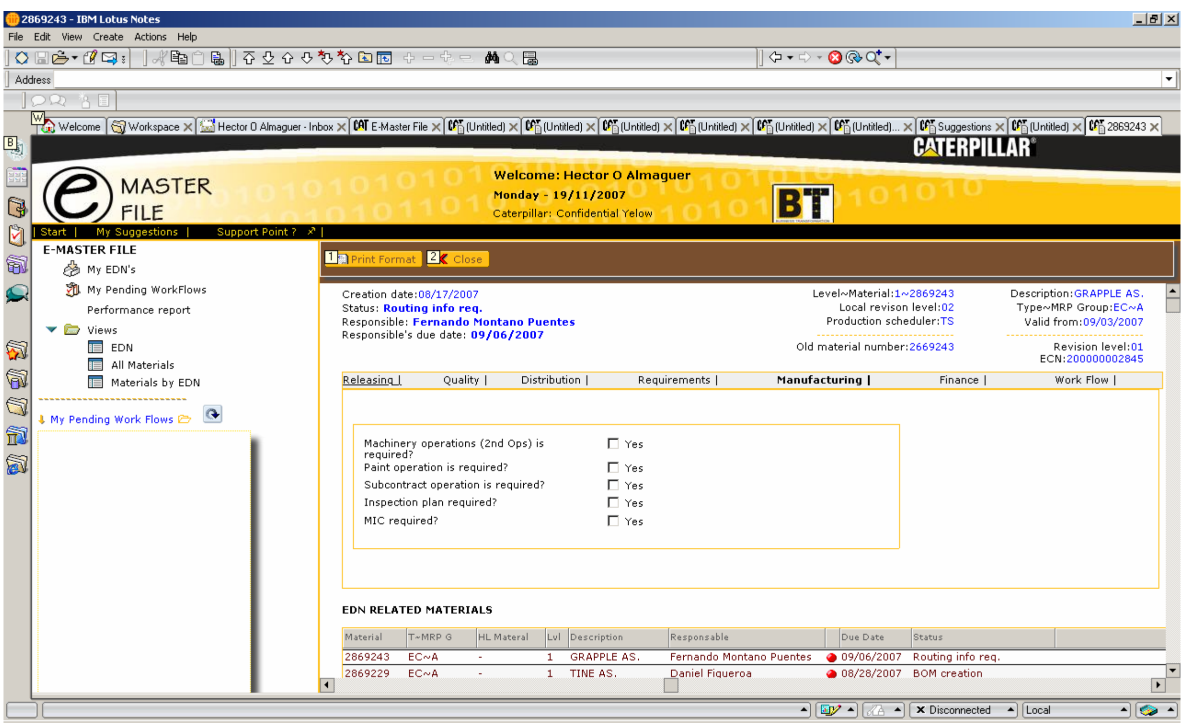


Figure AP 8.8 Example of the screen that is filled out with the personnel assigned

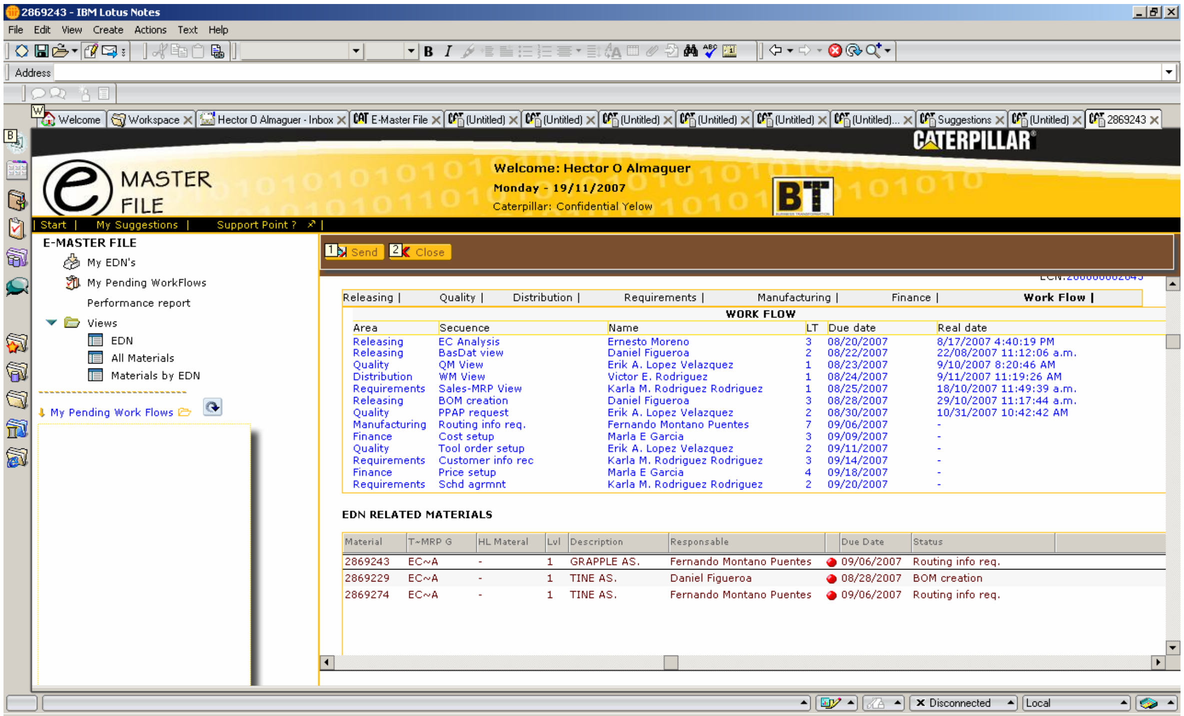


Figure AP 8.9 This section presents the list of all the personnel involved in the workflow for this product

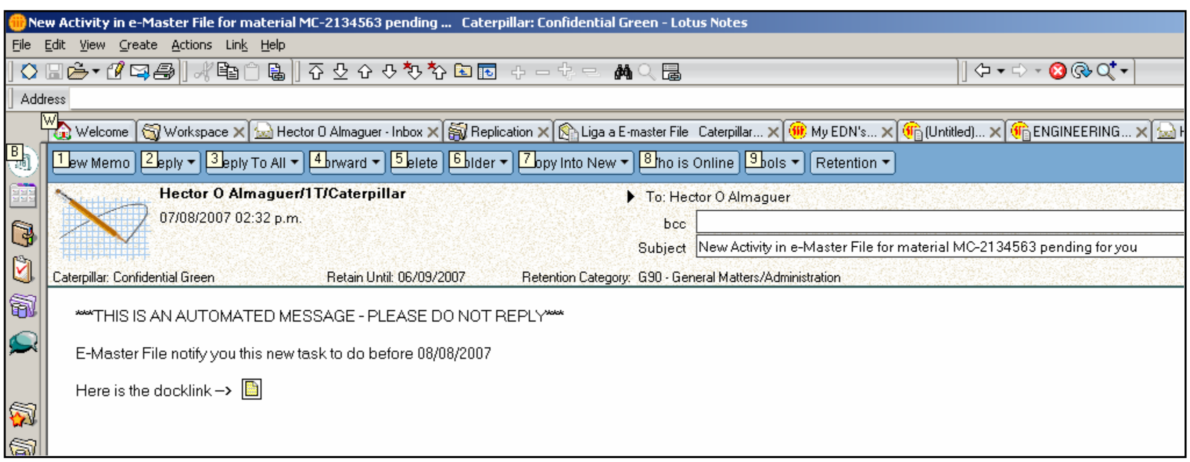


Figure AP 8.9 As in fist ICS a notification is send by Lotus Notes to people in the workflow