A ONTOLOGY-BASED APPROACH TO SUPPORT THE IMPLEMENTATION OF CONCURRENT ENGINEERING IN THE INNOVATION PROCESS

Master Thesis

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Master of Science in Technology and Innovation Management

Submitted by

Dipl. Ing. Edgardo Moreira Barahona

Advisors:

Prof. Dr. Dietmar Wikarski

Dr. Andreas Giesenhagen

University of Applied Sciences of Brandenburg
Department of Economics

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Abstract

This thesis proposes of a technological solution to facilitate the management of the innovation process based on Concurrent Engineering (CE) as a strategy, Quality Function Deployment (QFD) and FMEA (Failure Mode and Effects Analysis) as integrating methods, and finally TRIZ as a problem-solving technique.

The motivation derives from the demanding conditions that business organizations have to face. The scenario is such that companies must develop products, services and processes and simultaneously improve quality, reduce costs and reduce product development time. The implementation of CE as management philosophy is analyzed in this master thesis as means to handle more efficiently development projects within the innovation process. Such development projects can serve as crystals for a company-wide continuous improvement system. This approach is thoroughly studied in this master thesis.

As means for integrating these methods, an ontology-based approach was developed. Considering the each of these methods must be implemented by interdisciplinary teams dealing with cross-functional processes and that their principal contribution is the generation of knowledge to the innovation process, such an approach was considered very appropriate for the integration of activities in the innovation process.

Moreover, the technological solution should add value to the activities performed with the knowledge management systems. These KM systems should be used as complementary knowledge distribution channels (complementary to project meetings, training programs, quality assurance programs, project management standards, etc.). Several requirements were defined for this solution. It should be compatible with tools and methods common to business activities. Also, technological solution should be relatively easy to develop and extend, and it should be compatible with the existing information systems in an organization. These requirements are fulfilled quite well by object-oriented applications. In this case, the new office suite from Microsoft was analyzed together with the first graphical modeling tool for the Semantic Web, SemTalk. Finally, the solution should be such that it will support the communication between disparate systems and formats. This requirement is satisfied by the XML communication standard and its presence in the desktop applications is discussed here as well.

Acknowledgements

"Tell me and I'll forget;

show me and I may remember;

involve me and I'll understand"

American saying

1 Introduction

Within the very volatile environments of modern markets, the complexity and costs of products and technologies are increasing steadily. Innovative products and services, as well as innovation in the development and optimization of industrial and organizational processes, are of crucial importance for most companies today. Furthermore, the interaction between customers, suppliers and competitors lead to ever-shortened product and technology life cycles. In this scenario, the product, service and process development communities have three main goals: improve quality, reduce costs and reduce product development time.

These conditions entail the need of control and improvement of the development process (predictability of results, problem-solving capabilities, decision-making competences, etc) bringing about the standardization of the innovation process and the integration of functions which are decisive for managers. The parallelization of activities (when possible) should also be implemented in the innovation process as to reduce and optimize the time-to-market factor.

In the methodology proposed here, it can be said that, on one side, the standardization problem of the innovation process (i.e. the difficulty to model processes which are triggered by and result in unpredictable events surrounded by uncertainty) can be tackled with the business process management paradigm, by firstly establishing the “is” state of the process and defining the “should” state and thus discovering the optimal process within a specific environment. On the other side, through knowledge management practices, one can deal with the input and output of the innovation process, framing it in a knowledge cycle, in which the activities involved are: creation, capture, organization, access and use of knowledge. By standardizing and optimizing the innovation process, the use and production of knowledge can be managed, monitored and thus optimized. The resulting knowledge will be used in problem-solving activities and decision-making, thus reducing the unpredictability and uncertainty. It must be emphasized here, that standardization is not meant as design workflows for innovation, but rather it defines a framework in which a domain expert or a group of experts can use knowledge more efficiently. In addition, too much standardization can lead to increased bureaucracy. Hence, it must be regarded in its entirety, from guidelines to compulsory arrangements and from rules to fixed detailed operations.

The methodology proposed here considers the integration of functions as a critical factor for the development of sophisticated products, complex services and complicated processes. Cross-functional processes are carried out by interdisciplinary teams and therefore it is crucial that the team must understand the whole process. They should then be able to take appropriate action within their specific domain. By electronic means (but not only!), the integration of information and knowledge from different domains could be made reliable enough to be trustworthy.

An analysis of the innovation process can result in the identification of activities that are not dependent on others, and thus they could be run simultaneously. But when activities are dependent on others, an early initiation of those dependent activities should in most cases also be possible. This occurs because not all information is required to start a new activity. The result of this approach, included in the proposed methodology, should be an accelerated execution of linked processes, but with the trade-off of a higher decision complexity. Furthermore, the parallelization of processes can result in the amendment of cost because of a lower number of errors. Communication problems and barriers between teams, departments and other members of the organization must be overcome before implementing this strategy.

Generally, it is said that the formation of a successful interdisciplinary team (like those working with concurrent engineering) can only be achieved through a continuous cycle of improvement. Hence, it is the author’s opinion that the implementation of concurrent engineering in the innovation process is a strategy for continuous improvement.

At the critical juncture where functional groups meet, development projects are a true test of an organization’s integrative abilities. [Clark, K & Wheelwright, S., 1995] An expected result (or maybe a need) of this approach over time is the greater involvement of more members of the organization in the innovation process. Therefore, it is very important to find mechanisms for focusing the creative skills and problem-solving capabilities which everyone has on a regular basis across the organization. The concept of continuous improvement – developed by the Japanese manufacturing industry – should be coupled with concurrent engineering and thus extending it to the entire organization.

This master thesis includes the implementation of two well-known methods in the product and service development communities. The Quality Function Deployment (QFD) method integrates customer demands with its technical requirements and the technical capacities of the producer. Meanwhile, the Failure Mode and Effects Analysis (FMEA) method, facilitates the prediction and prevention of harmful or unwanted situations during the entire life-cycle of a product. Both methods follow the three guiding principles of concurrent engineering: by integrating explicit and implicit knowledge from different domains of expertise, by standardizing the collected knowledge in a previously well-defined structure, and by parallelizing the engineering, manufacturing and commercial activities during the analysis and continuous reviews during the product's life-cycle.

As one can infer from the above considerations, at the heart of an effective product development, including services and process development, effective problem-solving and reliable decision-making are of essential importance in the innovation process. Decision-making is about identifying problems and possible alternative solutions, and then the best of them are chosen. In this way, it is possible to classify decision problems from the point of view of their degree of structuring. At one extreme, decisions are programmable when they repeat themselves and behave predictably. At the other extreme, when the phases of the decision-making process are weakly structured and the decisions are complex and innovative, the process can not be programmed. Between these two extremes, decisions can have a wide spectrum of degrees of structuring, repeatability and programmability. Meanwhile, from the point of view of problem-solving, problems can also be divided in two types: Those with *known solutions* and those with *no known solution* (i.e. the individual or the team has or does not have sufficient knowledge of a standard solution for working out the problem). The former can normally be solved using information found in technical literature or with acquired specialized knowledge on the subject. Problems with unknown solutions are called *inventive problems*. Although the latter normally belong to the field of psychology (see Wertheimer M, 1964), a technology-oriented method called TRIZ will be here presented to assist experts dealing with such problems and a technological adaptation of the method will be suggested.

As means for integrating these methods, an ontology-based approach will be proposed. Considering the each of these methods must be implemented by interdisciplinary teams dealing with cross-functional processes and that their principal contribution is the generation of knowledge to the innovation process, such an approach has been considered very appropriate. This assumption is based on the fact that an ontology can be used to represent subsets of a person's domain of knowledge, who uses a language for the purpose of talking about the domain. At the same time, an ontology can provide a controlled vocabulary of terms (language standardization) for individual methods, each with an explicitly defined and machine processable semantic. This ontology-based integration follows the conceptual schema approach, well-known for its contributions in integrated application design, development, and use.

1.1 Main objective and hypotheses

The main objective of this master thesis is to propose a technological solution to facilitate the management of the innovation process based on Concurrent Engineering (CE) as a strategy, Quality Function Deployment (QFD) and FMEA (Failure Mode and Effects Analysis) as integrating methods, and finally TRIZ as a problem-solving technique. The concept of continuous improvement will explain at an organizational level the benefits resulting from such approach, as well as the complexity of the interactions and the effort necessary for solving the problems that this concept brings about.

In order to reach this major objective, several questions and hypotheses are proposed and the analysis is directed to collect evidence to test the following hypotheses and to answer the questions:

Question N° 1:

Can the implementation of concurrent engineering in the innovation process improve or at least facilitate a continuous improvement within an organization?

> Hypothesis: In order to manage and maximize the continuous flow of knowledge in the innovation process and thus to maximize the competitiveness of an organization, three conditions must be fulfilled: parallelization, standardization and integration of activities.

Question N°2:

Can the concept of continuous improvement explain the high complexity of the interactions within knowledge-intensive activities of the innovation process as well as provide guidelines to manage them?

> Hypothesis: The innovation process consists mainly of cross-functional activities. A continuous improvement system seems to be necessary so that every individual member of the organization can contribute to the added-value chain in the innovation process.

Question N° 3:

Can an ontology-based approach be integrated in the innovation process through well-known product and service development methods (QFD and FMEA) so as to manage more efficiently and assist knowledge-intensive activities?

> Hypothesis: The concept of the conceptual schema for information systems has delivered important contributions to the computer sciences. The same concept can be applied to the knowledge-intensive activities in the innovation process using ontologies as conceptual schema and developing appropriate GUIs based on development methods like QFD, FMEA and TRIZ.

Question N° 4:

With the technology available today, is it possible to develop an ontology-based information system to manage more efficiently and assist knowledge-intensive activities within the innovation process?

> Hypothesis: The object-oriented technology can provide the means to develop and implement an ontology-based information system. The XML communication standard supports the communication between disparate systems and formats. XML is also now present in popular commercial office desktop solutions, which allows the normal user to separate information from presentation data. XML-based languages, which offer semantics to the XML syntax (e.g. RDFS) are available and some of them have received industry support.

This master thesis is structured in an attempt to answer the questions above. In chapter 2, the innovation process will be introduced by describing in a general way the complexity of its activities and to substantiate the necessity of a global management strategy. It discusses the possibility to implement concurrent engineering as a management philosophy for the innovation process. Later in the same chapter, the concept of a supplier-customer network is presented in order to understand where, why and how concurrent engineering can be extended to the entire organization by means of a continuous improvement system.

In chapter 3 three different well-known techniques in the product development communities are reviewed, that is Quality Function Deployment (QFD), Failure

Mode Error Analysis (FMEA) and the Theory of Inventive Problem Solving (better known as TRIZ from its russian acronym). These methods are considered here be the means to integrate concurrent engineering in the innovation process. Chapter 4 presents technological proposal for the integration of the reviewed techniques from chapter 3. This proposal follows an ontology-based approach for a computer-supported implementation of concurrent engineering. Finally, chapter 5 points out some conclusions and visions for future research and possible development.

2 Implementing Concurrent Engineering in the Innovation Process

Managing the innovation process is not an easy task. First of all, the variation of what people understand by the term *innovation* is broad. According to the author, one of the best definitions was given by Roberts (1987) "Innovation = invention + exploitation". This definition makes clear that innovation is about turning opportunities into new ideas and putting them into practice. There is no recipe for managing innovation, but management will always require a clear strategic approach. Therefore, managing innovation depends on:

- company's resources
- industrial organization and competition of the sector
- relation to customers, suppliers and public policy
- growth and dynamics of the market
- technological opportunities

It is important for every innovation strategy to determine what kind of innovation it is pursuing. Figure 1 resumes the different levels of innovation according to the perception of novelty or innovation in the eye of the beholder and where the innovation is applied.

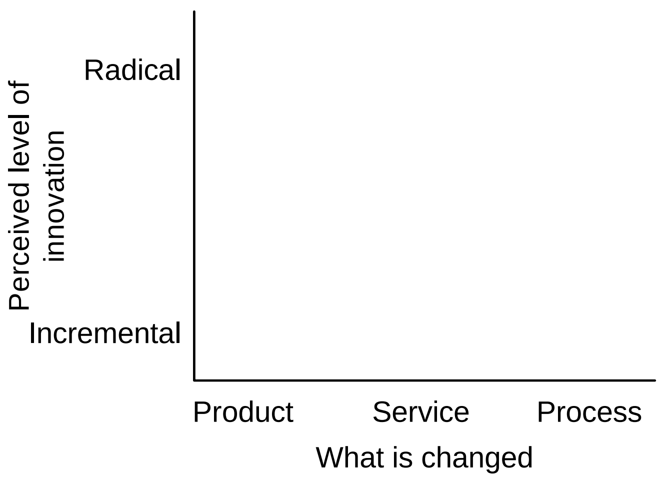


Figure 1: Dimensions of innovation space (Source: adapted from Tidd et al., 2001)

Even more than product or service innovation, it is process innovation which frustrates managers. Two aspects about managing innovation are often feared by them: Firstly, the cycle of process innovation is usually long-term, and secondly, it involves high risks. Both concerns are a response to the magnitude of organizational, cultural and technological change demanded by radical process innovation. Radical process innovation or business process re-engineering was an important approach in the 1990s, but it had less to do with bringing new ideas into the organization than performing an overdue revision and update of inefficient processes. This situation was a consequence of inattention and a lack of continuous review in the past. In other words, to avoid going through a painful, risky and long process of re-engineering, a continuous improvement process should be part of the innovation process. The success of process innovation depends upon a steady flow of changes resulting from regular review and fine tuning of the organization's processes. (Tidd et al, 2001)

There are many different models of the product innovation process with the monitoring of market opportunities or idea generation to its market introduction, but in fact each innovation process is unique. It does not follow per se routines and many events are unpredictable. However, Kleinschmidt, Geschka, and Cooper[1] proposed a model that can be regarded as a standard. This model has five steps and five milestones. Assuming that the reader is familiar with the innovation process, its steps are briefly described in the upper half of Figure 2.

An innovation process can be seen from two points of view, and thus one can group its activities in two ways. From the point of view of a project, the innovation process is characterized by cross-functional activities, as seen in the 5-phase model in the upper half of Figure 2. Meanwhile, one can also group the same activities in functional groups (see lower half of Figure 2). Within the functional groups sub-activities [2] can also be found. They will include mechanical engineering, purchasing, quality tests, legal activities, logistics, accounting, etc. Such sub-activities are more or less standardized and integrated among the routine processes of the company.

The success of the innovation process depends greatly on the integration of project activities and sub-activities, the coordination of activities and people, and an efficient exchange of information. Besides these requirements, in the innovation process both structured and unstructured processes take place at the same time. Unforeseeable results can occur and the communication and

[1] See Kleinschmidt, Elko J. et al, 1996, p. 52.

[2] See Berndes, Stefan, 128, in Scholz Reiter, B. and Stickel, E., 1996.

exchange of information are intensive, including internal or external partners and customers.

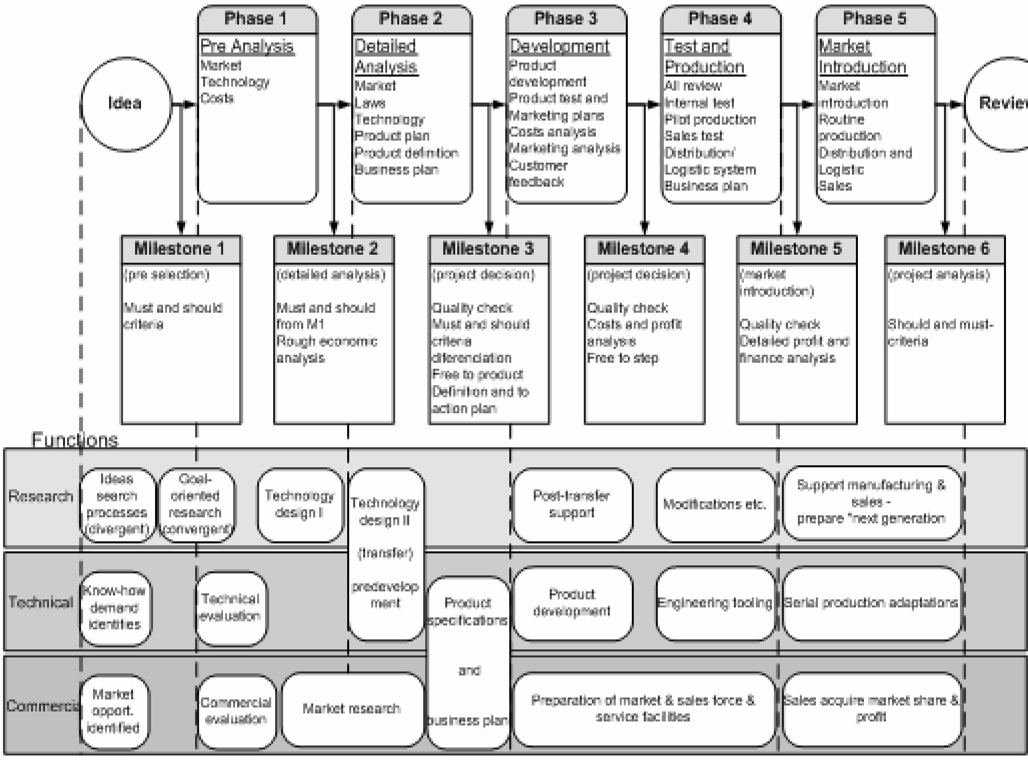


Figure 2: A linear representation of the innovation process. The upper half of the picture represents the innovation process from the point of view of a project, while the lower half shows it divided into functional groups. (Source: adapted from Kleinschmidt, Elko, et al, 1996 and Schmidt-Tiedemann, 1982)

By means of business process engineering, the innovation process can be considered as a typical case of a cross-functional processes[3], but also as a special case of business process, because it is open and creative[4], especially in the early phases of development projects, where uncertainty, doubts and chaos are characteristic.

It is the author's opinion, that the concept of concurrent engineering can be used to manage the interplay between designers, makers, sellers and users; all actors of the innovation processes sooner or later. As it will be further explained in this master thesis, concurrent engineering can also be used to reduce time-to-market for new products. This occurs as a consequence of an early identification and resolution of conflicts, since the actors are in constant interaction (continuous

[3] See Davenport, Thomas H., 1990, 9.

[4] See Berndes, Stefan et al, 129, in Scholz Reiter, B. and Stickel, E., 1996.

flow of information) during the entire process. Better information flow also brings new input to design at a stage in which they can be used to improve the design, rather than blaming different areas because they failed to pass on the information which could have helped avoid costly design faults.

Concurrent engineering emphasizes team work and cooperation, rather than the traditional structure of functional groups, each one pursing very different goals. The concept of continuous improvement reflects this approach and extends it to the entire organization by considering every member as a supplier and a customer at the same time, and stressing their dependency on each other. In this master thesis, the concept of continuous improvement will be introduced to better understand the interactions in the innovation process and how concurrent engineering can contribute positively to the entire organization as innovation becomes everyone's task.

2.1 Continuous improvement in the supplier-customer network

The basic relationship in a business organization can be defined as the supplier-customer relationship. It is the author's opinion that by first understanding the supplier-customer relationship, the eventual solution proposed in this thesis based on concurrent engineering will not only contribute positively and decisively to the innovation process, but by coupling it with the approach of continuous improvement it can be extended to the entire organization. For this reason, firstly, the concept of supplier-customer network will be discussed only enough to understand where, why and how a continuous improvement system can be applied to the activities of the organization. However, it is not the aim of this section to discuss specific metrics and statistical methods related to the supplier-customer network, but rather this will allow us to place the chosen methods in the business process management paradigm.

A business organization is constituted of different actors and the relationships between them. The actors and the relationships between them define functions within the organization, which aim to the accomplishment of the organization's purpose. Hence, it can be said that a business organization is a network of interdependent functions aiming at the organization's goal. The goals and objectives define how the functions are diffused and assigned horizontally and vertically throughout the system to individuals (members of the organization). Outwardly the business organization is a closed system, but inevitably, it interacts with its environment. The concept of a system will support the understanding of the factors that influence the performance of the person's activities (as individuals or groups) internally or outside of the business organization. In this case, we are interested in the supplier and customer roles, from an internal and external perspective. In other words, on the one hand, within the business organization the individuals will perform activities to satisfy internal customer requirements and at the same time, their requirements will have to be satisfied by internal suppliers. On the other hand, the business organization is a subsystem within a world system, where it will pay to satisfy the requirements of its customers, and itself will be the customer of other systems.

This concept cannot only be applied to the production of hardware and software (e.g. ideas, information), but also to the individuals performing in any line, service, or administrative work at every level in the hierarchy. This way of system thinking for business organizations was first introduced in the Japanese companywide quality control practices (see [Ishikawa, 1985], [Juran, 1988] and others).

2.1.1 Continuous improvement of the internal supplier-customer network

Within a processing system that produces goods or services, a member of the business organization will be in one of two roles depending on the production stage. Every stage is the supplier of the subsequent stage and obviously the customer of the one preceding. The output of each stage should have an added value to the output of the previous stage. The person carrying out the activity of adding value in each stage is the worker and he or she has the dual role of customer and supplier. The worker manages the resources at his or her disposal and controls the process. These resources are the inputs (equipment, tools, material, methods, information, and environment). The worker's personal skills, knowledge, intelligence and effort are considered resources because they add value to the input. Therefore, it can be said that there are two classes of inputs, those that will do the transformation process and may be consumed, and those that will be transformed into a value-added output. The outputs can be products or services or waste products. As the value adding process takes place higher in the hierarchy of the organization, the outputs become more complex along with their requirements. (See Figure 3)

In order to verify if the output requirements of the supplier match the input requirements of the customer, some kind of feedback between them must take place. This feedback will contain information to be used in the producer's decision-making concerning the output (e.g. what characteristics of the output should be measured and controlled) and concerning the process (e.g. what can be changed to reduce processing time). This information is called *critical outcomes* and usually they derive from very few characteristics. As the processes take place higher in the hierarchy these measurements are more complex and infrequent, becoming indexes and composites. Furthermore, with the purpose of regulating a process stage there must be internal feedback consisting of the necessary information needed to control the process stability and the output uniformity. (See Figure 3)

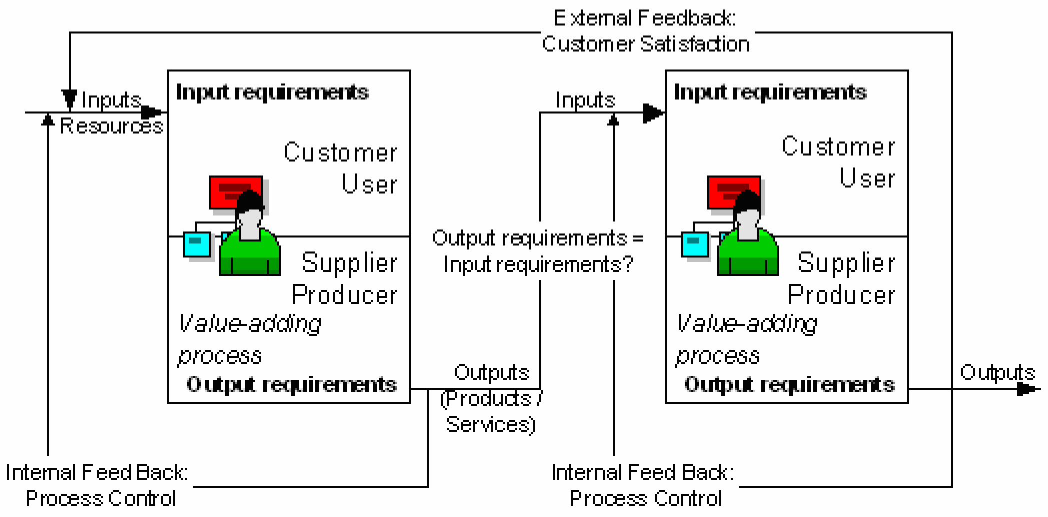
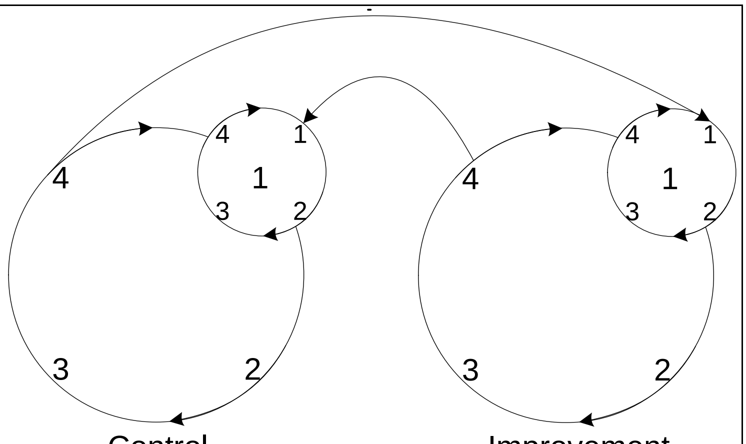


Figure 3: Process system components and dual role of process manager in an internal supplier-customer network.

Process control serves to prevent undesired and adverse changes and to ensure a stable state. It is also unquestionably the search for process improvement by planning and creating beneficial and desirable changes. W.E. Deming – American statistician, educator and consultant who advocated his work to develop quality-control method's in Japan's industrial production system after World War II – developed a *personal communication* concept to relate the worker to the process control and improvement activities. [Juran, 1988] This concept is depicted in a four-stage cycle called Deming's PDCA cycle (also called Shewhart's cycle), where PDCA stands for *Plan-Do-Check-Act*. (See Figure 4)



1. Plan	- Define internal customer requirements - Develop output requirements and measures - Establish feedback loops and other control plan elements - Plan the work (process sheets, process models, etc.)	- Form project team - Identify improvement opportunity as gap between current and desired situation - Plan the change (e.g. on-line or off-line experiment)
2. Do	- Execute plan - Collect process data (observations, measurements)	- Make the change - Collect data
3. Check	- Analyse data - Decide on actions (do nothing; identify & remove assignable causes of sporadic variations; adjust)	- Analyse results - Observe effects of the change - Assess what was learned
4. Act	- Take action determined in Step 3 - Go to Step 1 of control cycle or to Step 1 of improvement cycle to remove chronic problems.	- Go to Step 1 of control cycle to hold gains or to Step 1 of improvement to continue the investigation

Figure 4: Plan-Do-Check-Act (PDCA) processing system management cycle (Source: Juran, 1988)

In industrial mass production, the labor force is usually unskilled and the workers only participate in the “Do” stage of the cycle by executing the plan designed by managers and engineers. Inspectors have the task of checking their work, of collecting the data and handing it over to managers. The latter are responsible for deciding whether the process is running optimally or if it needs improvement. In this case, the learning process is not optimal, because the generated knowledge is dispersed but incomplete in each member of the process cycle. Therefore, the workers are not able to control and maintain the process. In addition, the work becomes meaningless because they have no idea about the purpose of the work (and therefore they have no sense of accomplishment). Finally, they cannot participate in improvements plans. Although white-collar workers are considered a skilled work force, this pattern is also valid for them in many cases.

The PDCA cycle addresses these problems by assuming that each single worker or employee can perform at every stage of the cycle. As stated at the beginning of this section, each individual needs to have control over his or her resources to manage them in what he or she thinks is the most efficient way. For that, both kinds of feedbacks (customer satisfaction and process control feedbacks) have to reach the worker or employee. Higher-level employees perform in the four stages as well. However they have other kind of resources than those mentioned for the workers. They can use organizational resources (i.e. outputs – products and services – from the organization) such as staff, service support and administrative functions, which do not report to him or her.

The small PDCA cycles in the planning stage correspond to activities such as search and identification of suppliers and customers to form teams to do the control and improvement processes. If the teams are to perform control functions usually done by a supervisor, they must have the opportunity to do significant decision-making. They can establish the process output requirements and link them to the supplier's capabilities. They must be able to do self-inspection and implement the changes within the team. These activities in Deming's PDCA cycle clearly represent a learning and improving process.

The two principal beneficial consequences for the human resource after applying this concept in the internal supplier-customer network are:

1. He or she understands the relationship between his or her own behavior and the process outputs. The learning process is enhanced and he or she gains a sense of accomplishment of goals.

2. He or she knows their contribution to the goals and objectives and understand the purpose of the organization. The sense of collectiveness (teamwork) within the organization is enhanced and organizational learning is improved (in a narrower sense of organizational learning as the sum of individual learning).

On the other hand, process improvement becomes a systematic approach inside the organization. The typical results of this approach include increased customer satisfaction, higher quality, waste reduction, increased productivity and faster processes. Furthermore, the creation of teams can produced high-quality outputs.

In other words, a team is more likely to bring up innovative solutions because the idea generating and evaluation processes used by groups can produce results, usually not possible by combining the ideas and efforts of people working alone.

In order to make this concept work, the normative and strategy management levels have to embrace continuous improvement as one more of the organization's philosophies. That means, that the uppermost levels of management must not only clear the way of barriers to implement it, but above all ensure that a change in the way of thinking occurs towards a knowledge-based organization.

Several are the obstacles or barriers to clear before implementing a continuous improvement of the process system. In hierarchical bureaucratic organizations, it can be very difficult that their members understand their organization as a network of persons in interdependent supplier-customer relationships. In such organizations, the separateness between the objectives of different departments hampers the linkage with the overall business purpose and goals. Communication problems aggravate the ineffectiveness of the organization since the establishment of common understanding can be impossible. The lack of adequate communication means (e.g. formal and informal personal communication, documentation, statistical tools, graphical techniques, etc.), shortage of training programs, inadequate appraisal system, lack of trust, etc. make it more difficult to achieve the organization's goals.

2.1.2 Continuous improvement of the external supplier-customer network

As it was said before in this section, outwards the business organization is a closed system, but inevitably, it interacts with its environment. A business organization itself is part of a marketplace, where other organizations or individuals take the dual role of customer and supplier. Hence, the basic scheme of the external supplier-customer network is analogous to the one of an internal supplier-customer network.

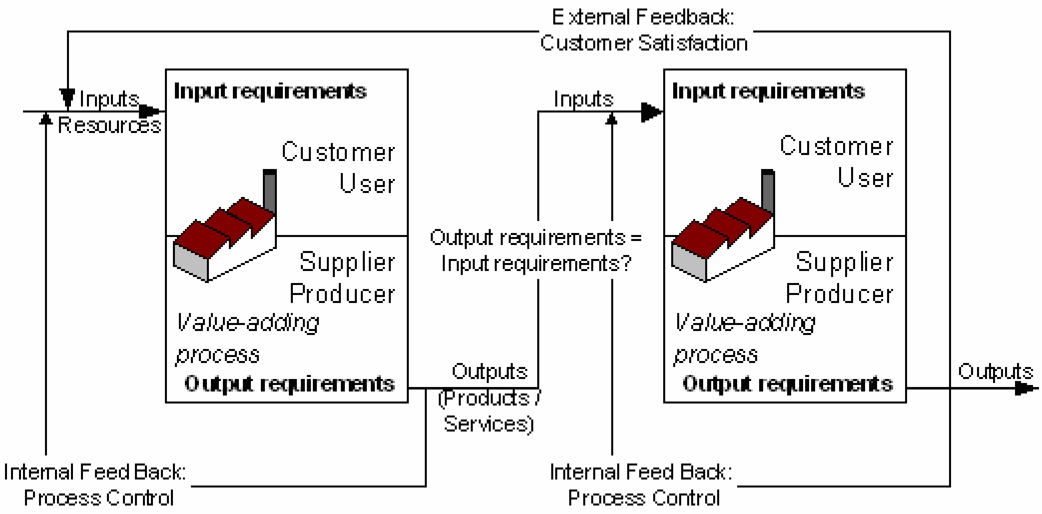


Figure 5: Process system components and dual role of an organization in an external supplier-customer network.

Crucial differences between both networks lie on time and space properties of the process system. Usually the distance separating the organizations in an external network is larger than in an internal network. The time necessary, before the outputs of a given organization reach their customers, is usually more in an external network than in an internal one. The two latter points are nowadays sometimes relative. Some organizations are restructuring themselves by selling some of their sections – becoming then external suppliers or customers – or acquiring former suppliers and integrating them in the organization. In addition, internal customer-supplier networks are becoming distributed throughout the world thanks to advances in communication and information technologies.

An external customer-supplier network is generally known as the **supply chain**. The supply chain is a sequence of suppliers, warehouses, operations, and retail outlets. [Stevenson W.J., 1999]. Figure 6 shows a typical supply chain for a manufacturer and for a service organization. Although being very important, we will not consider the telecommunications networks and financial service organizations in this analysis of the supply chain, since they handle mainly intangible products and thus escaping to the scope of this study.

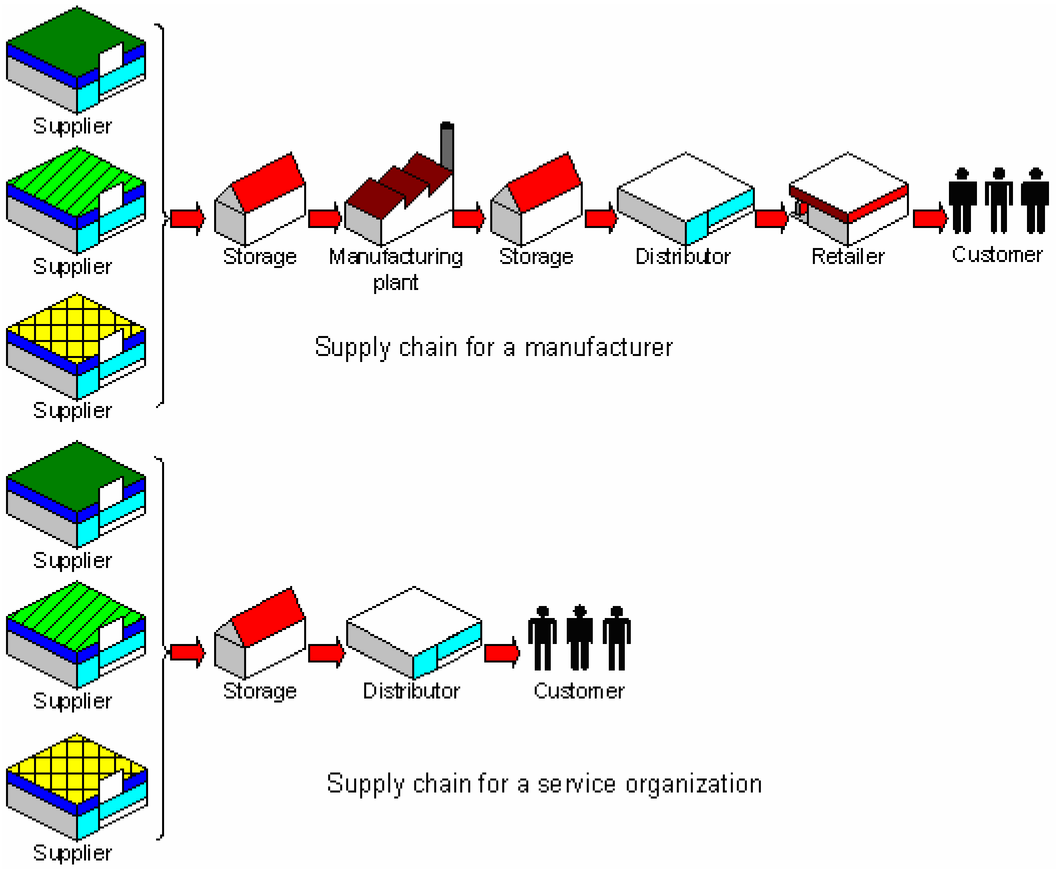


Figure 6: Typical supply chains for a manufacturer and a service organization.

In the figure above the different elements of a typical supply chain can be seen. Each elements carries out a particular activity, i.e. purchasing, manufacturing, transportation and warehousing. Moreover, each element contributes to the value-added chain. It can be argue that warehouses or retailers do not add value to the product. Nevertheless, in order to reach the customer, they must provide logistic services and thus contributing to the chain.

Supply chain management deals with three kinds of integration in the supply chain. Firstly, the above mentioned activities concern the **functional integration** of the supply chain. In addition, these activities must be also integrated in across geographically dispersed actors of the supply chain, i.e. a **spatial integration**. Finally, a hierarchical planning or **intertemporal integration** is concerned with the merging of these activities over strategic (resource acquisition decisions in long-term planning), tactical (resource allocation decisions in medium-term planning), and operational (short-term execution decisions) horizons. Intertemporal integration considers also with the need to optimize the life cycle of a product's supply chain, i.e. through the stages of design, introduction, growth, maturity and retirement.

Supply chain design refers to decisions regarding the facilities owned and operated by the company and the company's relationship with its suppliers. The business organization is not only concerned with the costs of acquisitions, but also with their quality and the responsiveness and the flexibility of the supplier. These criteria determine the input and output requirements of the customer and supplier respectively. The communication channels for the definition and feedback of these requirements depend on the type of relationship between customer and supplier. [Shapiro J.F., 2001] classifies the supplier-customer relation as an **arms-length** or an **alliance** relationship.

The arm-length relationship is defined by a short-term contract between supplier and customer based primarily on price without guarantees for follow-on work. The contract specifies very explicitly on which terms and conditions the supplier and customer interact. Usually the customer does not restrict himself to only one supplier of an item, but instead, several suppliers will have to compete to keep their costs low and the customer can impose quality and delivery standards to the suppliers. [Shapiro J.F., 2001]

Instead, the alliance relationship is defined by a flexible long-term contract. The supplier and customer work closely solving problems to their mutual satisfaction, even by redesigning products. Usually alliances are more expensive in direct costs of procurement, but they represent lower contract monitoring and negotiation costs with multiple suppliers. Very important indeed is that alliance relationships allow the business organization to direct its attention of product quality and integration of the supply chain management. [Shapiro J.F., 2001]

To stay within the focus of the process system described in the sections before, the supply chain is here framed within the concept of the value-added chain. By studying the three types of integration described before, i.e. functional, spatial and intertemporal integration, under the perspective of the value-added chain, the business organization is in the position to apply a continuous improvement process system. The value-added chain allows the business organization to recognize that a successful implementation of the organization's strategy is only possible through the careful coordination of the activities at a operational level. An organization that controls their value-added chain costs better than its competitors will very probably increase their competitive advantage. In addition, it will be better able to differentiate their products by providing superior quality, customer service, product variety, etc.

[Porter M.E., 1985] says that the value-added chain (he calls it **value chain**) consists of nine categories of activities (see Figure 7). **Primary activities** are those that create the product or service, deliver and market it, and provide after-sale support. These activities include inbound logistics, operations, outbound logistics, marketing sales, and service. These primary activities are able to perform through the **support activities.** They provide inputs and the infrastructure needed. Support activities include the organization infrastructure, human resource management, technology development and procurement.

[Shapiro J.F., 2001] adds to the support activities two new activities, that is information technology and supply chain management. Figure 7 shows that the latter support activities are becoming more and more important (i.e. a larger portion of the support activities) in the value-added chain. There are basically the two: a technological change and an organizational change within the business organization. As explained before, the integration of all levels of planning – strategic, tactical und operational – is needed for a continuous improvement process. Advancements in information technology makes it possible to create modeling systems that help management cope with an overabundance of transactional data and to understand what this data means, to facilitate the integration of strategic, tactical and operational decision-making.

[Porter M.E., 1985] adds that the linkages among the activities in the business organization lead to competitive advantage by optimizing and coordinating them efficiently. The organization's ability to transfer skills or expertise (knowledge) and the ability to share activities among similar value-added chains (e.g. different business units) may create synergy. Again, here information technology facilitates the redesign of business process and the revision of managerial incentives schemes to promote and facilitate competitive strategies based on data, models and modeling systems. The optimization and coordination of the value-added chain will result in competitive advantage based on product differentiation if the cost of differentiation is justified. In other words, the modeling systems must identify cost-effective plans that sustain the business organization's superior level of customer service, quality, or some other differentiating factor. [Shapiro J.F., 2001]

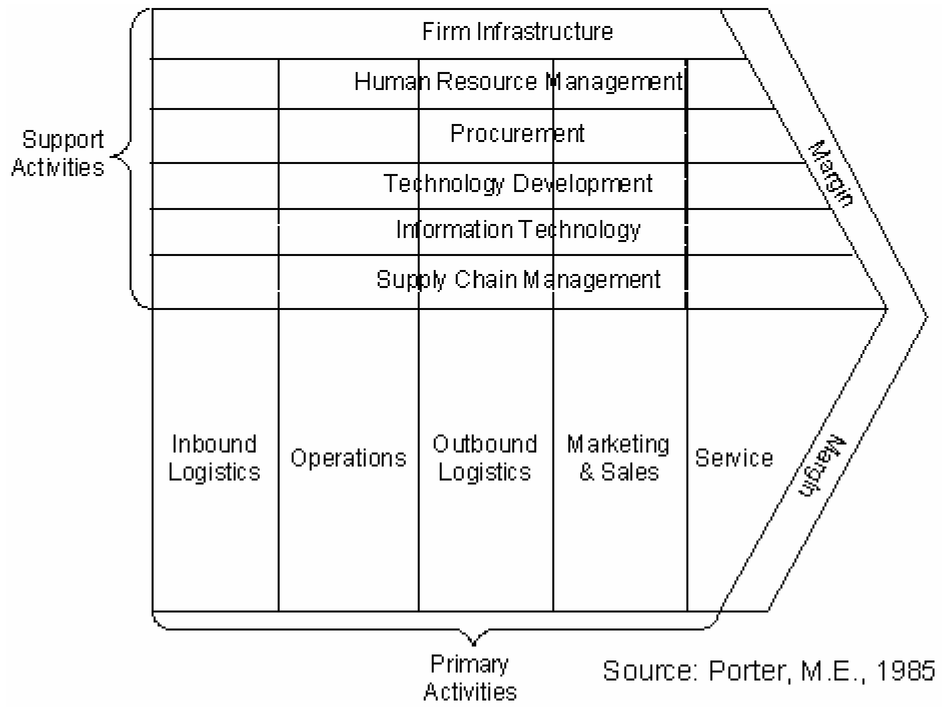


Figure 7: The value-added chain. (Source: adapted from Shapiro J.F., 2001)

As in the case of the internal supplier-customer network the process control of the supply chain (external supplier-customer network) aims to prevent unwanted and disadvantageous changes. But since normally the conditions of the marketplace(s) in which the business organization performs are always changing, the organization has to strive to ensure a process improvement by planning and creating beneficial and desirable changes.

The information technology has solved the problem of an overabundance of transactional data, its processing and its storage for the supply chain management. Also, it has allowed to formalized and streamlined operational processes. Furthermore, IT enables now the implementation of applications to optimize the throughput of products based on expected demand as well as material and capacity constraints. Much of this has been done using primarily statistical information and procedures enabling some managers or “experts” to analyze and to interpret these data. They are the ones that take corrective actions when exceptions occur. However, experienced managers know that in supply chains a single and located exception seldom occurs and that obvious fixes often have longer-term, unintended consequences.

By defining holistically the solution scope for resolving supply chain issues, business organizations can manage adaptively their supply chain. They strive to avoid unintended consequences by approaching their supply chains as interactive systems, not as functional silos. Second, they have a proactive bias toward how issues are actually resolved. They continuously achieve sustainable improvements through a focus on preventing fires, not on fighting them. [Lee H. & Amaral J., 2002]

The concept of the PDCA cycle (see Figure 4) can be also applied to the supply chain to introduce a continuous improvement process. Once the external customer requirements are defined, the output requirements and metrics are developed, the feedback loops, and process sheets and models are established, the execution of the supply chain process can begin. Immediately transactional data can be collected and exceptions can be identified. Users need to understand the potential root causes, the alternative courses of actions available, and the impacts of such alternative actions. This should enable prompt reaction to the performance exceptions with corrective actions. But once responses have been defined, it is only through flawless and timely execution of such responses that companies achieve performance improvement. These responses should then be documented, and the system should be updated with data and information regarding both the occurrence and resolution of the performance exceptions. The responsive actions could, in some cases, result in new definitions of exceptions, business rules, and business processes. Hence, a continuous process of validation and updating is needed in the cycle.

A sound statistical process control is critical in the supply process control and improvement, but an appropriate communication with the appropriate personnel within as well as outside of the organizations is as important. For a successful implementation of a continuous improvement process in the supply chain, information must be not only available to managers, but also disseminated to appropriate people across the organization so they can understand issues, evaluate alternatives, and take appropriate action. Furthermore, it requires education of the people on the needs and approaches of continuous improvement in and out of the organization, the creation of a collaborative environment, and the assignment of accountability to the appropriate people. The following table summarizes this improvement approach:

Table 1: Continuous improvement approach. (Source: adapted from Lee H. & Amaral J., 2002)

Improvement Area	Problem	Continuous improvement concept.
People	Lack of communication, collaboration, and accountability slows down decision cycles	▪ Proactive, secure, and personalized notification of exceptions ▪ Information in context ▪ Collaborative decision-making and resolution of issues
Processes	Misaligned business processes conflict with corporate objectives	▪ Establishment, validation, and modification of business rules and thresholds across the organization ▪ Alignment and management of cross-enterprise processes ▪ Decision and knowledge capture
Systems	Critical information is locked in disparate systems	▪ Timely and normalized data from relevant enterprise systems ▪ Aggregated, synchronized, and correlated data and trends ▪ Flexible disaggregation of data for quick diagnosis

2.2 Concurrent Engineering (CE)

The Merrian Webster dictionary defines the word 'Concurrent' as "operating or occurring at the same time; running parallel" It suggests as synonym the word 'Convergent' meaning "specifically: meeting or intersecting in a point". On the other side, the same dictionary defines 'Engineering' as "the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people; the design and manufacture of complex products (e.g. software engineering). [www.webster.com]

The combination of both definitions gives us a hybrid definition, that could be read as:

> "The design and manufacture of complex products running in parallel and meeting or intersecting in a point (goal)".

We can derived three features about CE from this definition: **events and activities, which occur the same time** and **dynamically**, and that CE requires a **goal**. The activities take place through time and they can be of any kind (design, manufacturing, distribution, etc.) The goal can be a milestone (static goal) or a new invention from a R&D environment (a moving goal). To hold together these three properties of CE it is necessary to introduce 'communication' as a fourth feature.

Likewise, the industry defines concurrent engineering as a "systematic approach to the integrated design of products and their related processes, including manufacturing and support." [Gillen D.J, Fitzgerald E., 1991] Furthermore, CE has been described as "a cross-functional interdisciplinary activity that begins at the pre-natal stages of design and continues through production and product end of life" [Natale C., 1994] From both definitions is evidently that CE is not a 'off-the-shelf product', nor a strict process with defined steps. Rather, CE can be better described as a management philosophy, a way of approaching a situation.

Concurrent engineering – sometimes also called simultaneous engineering – is an approach that dates back to 1940, during the Second World War in the United States. Its origins can be very briefly summarized when the American Aviation Corporation won an order to develop 320 NA-73 fighter aircrafts from the British Air Purchasing Commission. The contract stated that the first prototype, NA-73X, was to be ready for testing in 120 days after receipt of contract. The engineers involved in the project opted to use novel concepts instead of proven and conservative designs although the limit of time. Only just after 102 days the first prototype was ready for test trials. The aircraft that became to be known as the US P-51 Mustang, which included very novel concepts at that time like laminar flow foils and a combined radiator housing-ejector nozzle that provided 300 pounds of jet thrust. In the design project 2800 drawings were produced, which represented around 600,000 hours of effort. Simultaneous activities and very efficient coordination were the key to success. [Ziemke M.C., Spann M.S., 1993]

War is not the motivation of this study and neither the reason to implement CE in most of the business organizations nowadays. During the last decade the life cycle of products and processes in different industry branches decreased while the complexity of products have increased steadily. In other words, business organizations have been faced with the problem of achieving a smoother transition from product design to production, and to decrease product development time. Furthermore, nowadays no business branch can avoid considering in some way the customer requests when designing their products or services. This has to be done always keeping in mind the actual capabilities and competences of the organization and its suppliers.

The initial CE concept was bringing design and manufacturing people together in the early design phases to develop simultaneously products and processes. CE has evolved into an organization-wide concept responding to the need of not only faster product development, but also to achieve quality and costs goals. It can be said that CE has as three main goals the following:

- shortening of product development time
- quality improvement
- cost reduction

Through the combination of technical, organizational and social aspects in the business organization, framed within the concept of CE, these goals are achievable. From a technical point of view, a framework to model, support, control and integrate processes and teams must be devised and implemented. Furthermore, an information management system should manage, change, release and store metadata related to the product. Finally, specific product information should be stored and be accessed in common product data model.

CE is characterized by being project oriented and heavily relying on teamwork, which requires an intensive exchange of information. Thus, when implementing CE the most important elements are people and the design of development processes – including suppliers and customers.

Management, from top down, must show a commitment to CE and support its implementation. CE could be introduced through pilot projects and therefore allowing the organization to gain from this trial group or gradually over different projects. Problems will arouse, but it must be kept in mind that it is not only the actual placement of the CE philosophy that has to change, but attitudes and policies on rewards and recognition must be changed, supporting collaborative methods over individual achievements.

In this way, we can say that success factors to promote the necessary communication and cooperation to implement CE in an organization are:

- Top management support of CE implementation.
- Reducing barriers among departments and hierarchies.
- Promoting interdepartmental cooperation and communication.
- Building up close linking between supplier and customer.

The whole management task has now shifted in emphasis, it is no longer directed towards getting the functions to achieve their tasks, but ensuring tasks are handled collaboratively, and helping the team with situations outside of the team sphere, i.e. with functions not in the concurrent sphere of influence. The manager's role is not so much directing what must be done, but helping the team work smoothly by diagnosing problems and potential conflicts within the team which may be caused by dependencies. Dependencies as harmful in CE, because when a team member is dependant upon another to continue an action, and is having to wait - this can lead to frustration. The situation must be discussed, understood and learned from. This will be eased as many dependencies will be recognized as knowledge expands and through discussion of critical issues at the requirements stage of the cycle.

At top down framework to support the implementation of CE is summarized in Figure 8:

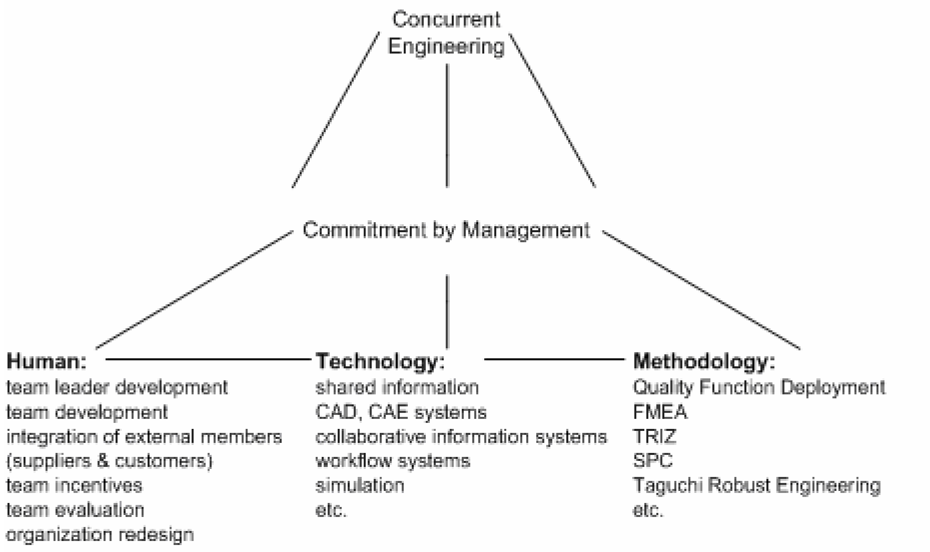


Figure 8: A framework for the implementation of concurrent engineering

2.2.1 Strategies to implement concurrent engineering

CE builds itself on top of three pillars or strategies: parallelization, standardization and integration.

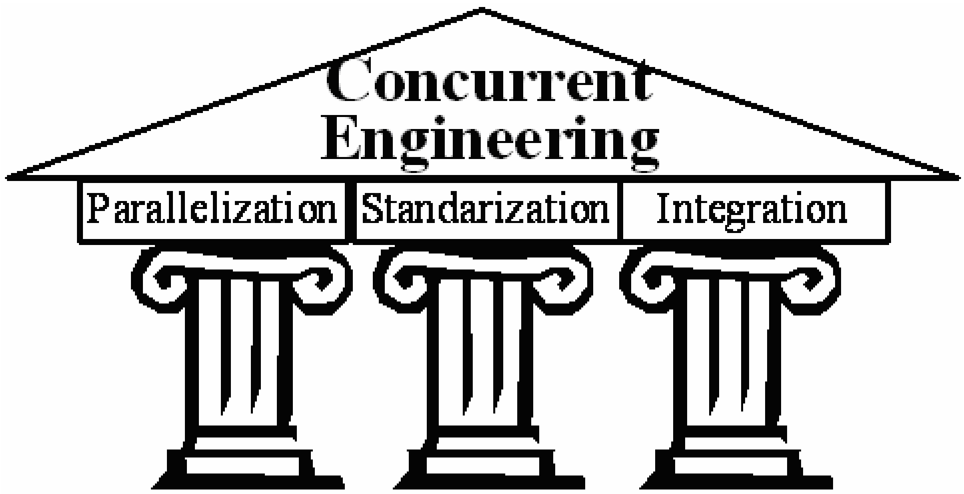


Figure 9: Three pillars of concurrent engineering.

With regard to innovation processes, parallelization implies the cutting and optimization of **time-to-market**. Basically, this means to carry out simultaneously activities that are "to some degree" independent from others. Usually in every process any activity is dependent from others, but this dependency is not an absolute rule. "To some degree" means then, that in practice some activities do not require full completeness and/or every product of an activity to be executed. The simultaneity of several activities should result in an acceleration of linked processes. In other words, by executing particular activities concurrently the critical path of the process (e.g. a project) must be reduced. The trade-off of this approach is an increased complexity of the decision-making processes, basically embodied in a more comprehensive information exchange between departments and/or teams. Although, there is much more uncertainty when running activities concurrently – due to the incompleteness of the information – the costs of correction or change of end products/processes are lower. This happens because the alterations can be done on-the-fly and not until the end of the process.

The objective of standardization in the innovation process must not be seen as the design of workflows for innovation, but rather to define a framework in which a domain expert or a group of experts can use of knowledge more efficiently. Standardization is meant to avoid the repetition and needless work and thus, allowing the taking of repetitive and similar decisions faster. This optimization should leave more time for innovation and creative activities and for management of unexpected events. Also, standardization can be very appropriate to facilitate organizational learning and the individual learning from existing experience of the organization and its environment. On the other hand, too much standardization can lead to increased bureaucracy. Hence, it must be regard in its whole extent, from guidelines to compulsory arrangements and rules to fixed detailed operations. Therefore standardization should be seen as:

- Structuring of process: Routine processes must be specified and generalized. Sequences of activities must be defined.
- Structuring of product: The products' systems, elements and construction kit can be standardized.
- Structuring of organization: The definition and optimization of communication channels and coordination means to overcome organizational barriers and cope with the amount of information exchange due to the implementation of CE.

As it was described before, the innovation process can also be seen as a value-added chain, where several departments of an business organization are involved in the development of products and services and their later exploitation. The allocation of tasks in different functional areas increases interface problems and thus, the loss of information. The reason for the loss of information is nonsynchronized timescales, different interpretation of tasks and ignorance of requirements of the internal or external customer. Integration means working in interdisciplinary teams, thinking and behaving in a process oriented way. The team must understand the whole process so that they are able to take appropriate actions within their specific domain. Like said before, information technology plays a very important role for the implementation of integration by handling large amounts of data, its processing and its storage.

Next, three different methodologies or techniques used in the implementation of concurrent engineering will be explained. These techniques were chosen to establish what value could they add to the different stages of the innovation process. Further in this study, it will be establish how to integrate them through state-of-the-technology.

3 Selected methods for the implementation of concurrent engineering

The aim of this section is to review three different well-known techniques in the product development communities in order to implement CE in the innovation process in any business organization. These techniques are *Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA) and the Theory of the Inventive Problem Solving (TRIZ).* In Figure 10 these methods are mapped to the innovation process. Thereby, is also the intention of this review to establish what value these methodologies could add to the stages of the innovative problem solving process.

The chosen methods can be placed within the concept of concurrent engineering. The QFD method supports the rendering of the customer demands into product and service characteristics. Meanwhile, when the aim is the detection of potential errors in the subsequent domains of product and service development, an on-the-run evaluation of products, services and processes can be done by the implementation of the FMEA technique. Moreover, TRIZ (the Russian abbreviation for “Theory of Inventive Problem Solving”) provides systematic methods for solving technological problems.

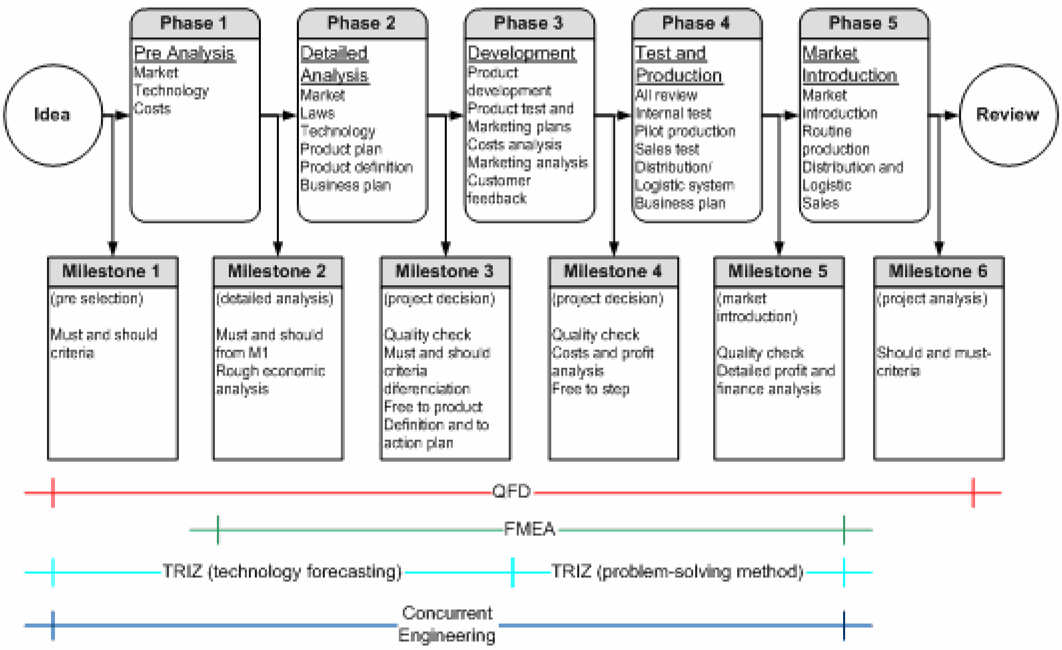


Figure 10: Linear representation of the innovation process and product innovation methods (Source: adapted from Kleinschmidt, Elko, et al, 1996)

3.1 Quality Function Deployment (QFD)

Due to the important role that quality plays in every activity of the product and service development and its later exploitation QFD was chosen as one of the techniques to be revised in this master thesis. Quality function deployment (QFD) is a method used to identify critical customer attributes and to create a specific link between customer attributes and design parameters. [Clark, K & Wheelwright, S., 1993]

QFD's basic concept goes back to Japan in 1966 where Yoji Akao conceived this technique. It was in 1972 when for the first time QFD was implemented at the Mitsubishi Heavy Industry shipyards in Kobe. Five years later Toyota adopted the QFD philosophy and since then they implement it consistently. In 1981 Ford was the first American corporation to implement QFD successfully. Shortly after companies like Kodak, Hewlett Packard, Xerox and Digital Equipment began using QFD. Nowadays, QFD is requested for a customer oriented development certification in the QS-9000 (American quality assurance standards).[Klein B., 1999]

The most important contributions of QFD are: [Klein B., 1999]

- Establish quality management and a customer oriented philosophy in the business organization.
- Intensify teamwork and motivate the worker to think and act consciously responsible.
- Nurture of an open communication and information
- Establish clear, coordinated and measurable goals.
- Loss reduction in the entire value-added chain through preventive planning of every service, product and process.
- Continuous reduction of the time-to-market
- Systematic documentation of the processes in the business organization.
- Early input of expert knowledge in the planning stage of development.
- Permanent development and improvement of quality.

The process of QFD involves constructing one or more matrices referred as quality tables. The first of these tables is the so called House of Quality (HoQ) (see Figure 11). It displays the customer's requirements along the left and the development team's technical response to meeting those needs along the top.

The matrix consists of several sections or submatrices joined together in various ways that contain interrelated information.

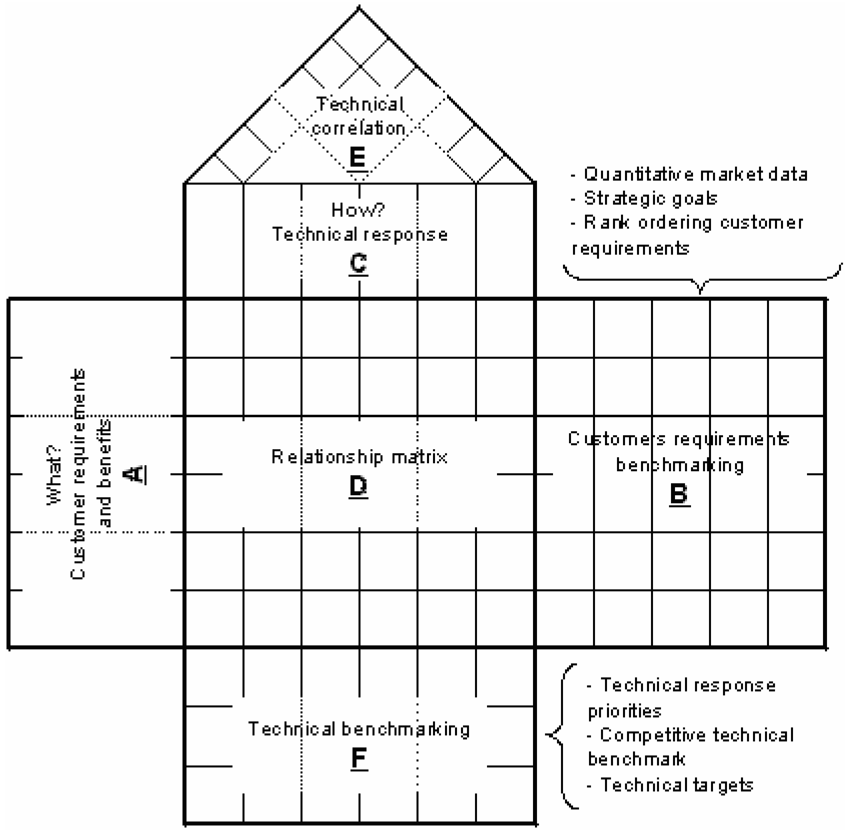


Figure 11: QFD House of Quality. (Source: Klein B., 1999)

Each of the labeled sections is a structured expression of the product or process development team's understanding of an aspect of the overall planning process for a new product, service or process.

Section A contains a structured list of the customer requirements (i.e. wants and needs). The structure is usually determined by qualitative market research. The data are in the form of a tree diagram that is obtained by methods such as a Voice of Customer exercise.

Section B contains three main types of information:

- Quantitative market data: Three columns indicate the requirement's importance to the customer, customer satisfaction performance and competitive satisfaction performance.
- Strategic goal setting for the new product or service: Here is indicated the level of customer performance being aimed for and the improvement ratio required. The two columns are usually called goal and improvement ratio or factor.

- A computation for rank ordering the customer wants and needs: Under this main category the ability to sell the product or service, overall importance to the development team of each customer requirement and cumulative normalized raw weights are normally captured. These three columns are unique selling point, raw weight, and normalized raw weight.

Section C contains in technical language the description of the product or service they intend to develop (i.e. the technical quality attributes). This is normally generated or deployed from the customer requirements in section A. It is important to note that there will probably not a one-to-one correlation between the user requirements and the technical solutions offered.

Section D contains the development team's judgments of the strength of the relationship between the items in A and the technical response in C.

Section E contains the technical development team's assessment of technical correlation between the items in the technical response. This section is usually called the roof of the House of Quality.

Section F contains the computed rank ordering of the technical responses, based on the rank ordering of the customer requirements from section B and the relationships in section D. It also includes comparative information (benchmarking) on the competitors' technical performance. The technical performance targets are as well here indicated.

The House of Quality has a primary intention to integrate development and quality planning. Nevertheless, the HoQ will also serve to connect the different operational stages in the innovation process together. The following diagram shows the HoQ cascade to integrate the different stages in product development.

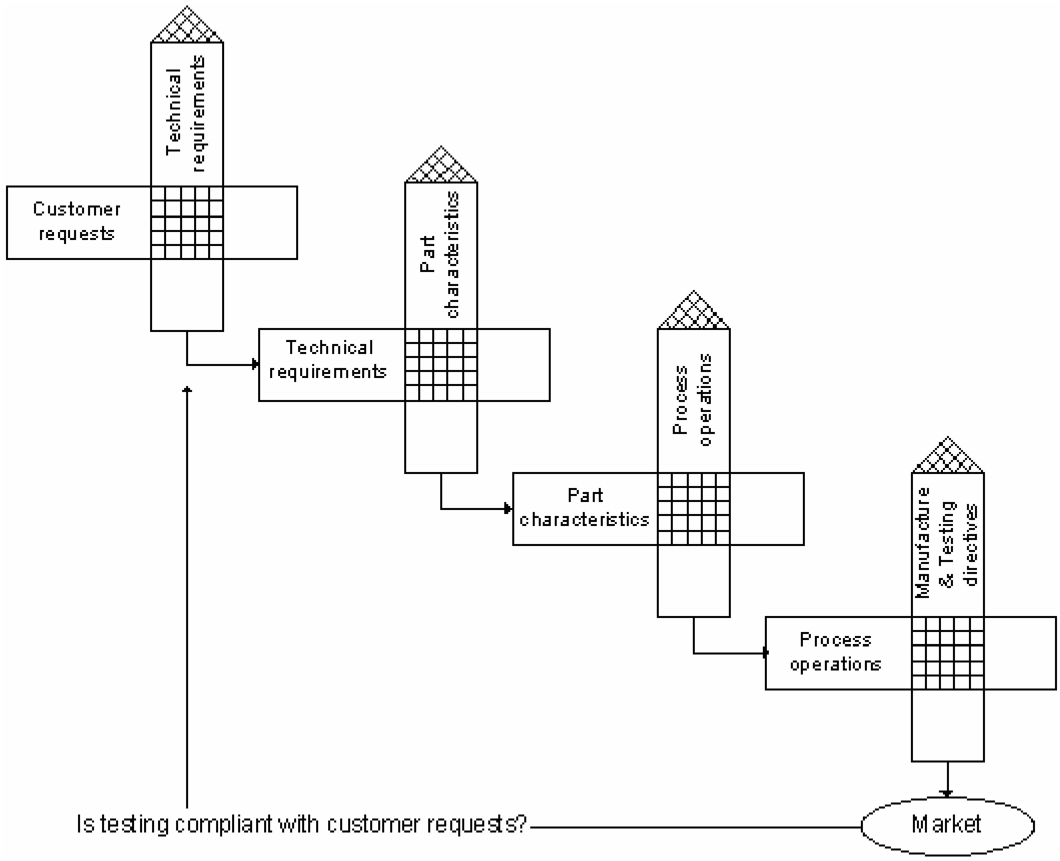


Figure 12: Transformation of customer requests into product attributes until market introduction. (Source: adapted from Klein B., 1999)

1. Product planning: the product profile is defined by the quality attributes and targets.
2. Concept planning: the system concept – including its construction parts – is developed. The team works out the design attributes with their technical and economical targets.
3. Process planning: the process conditions and their respective technological targets are here defined.
4. Manufacture and test planning: this stage is defined using available standards and the relevant manufacture and test attributes.
5. Further marketing program variables can be compared with manufacture attributes (not included in Figure 12)

3.1.1 QFD for Business Process Optimization

The majority of the business organizations use QFD in product or service development. Nevertheless, because quality is an universal endeavor, actually QFD should be also applicable to business processes of every kind. In this case, an internal customer takes the external customer's role and his or her requirement are to be satisfied by an internal supplier (see section 2.1.1). Therefore, the House of Quality must be adapted to circumstances where people are handling at a immaterial level. (see Figure 14) Understanding the processes is the first step to evaluate how quality management could have an effect on them. Using modeling tools one can define business process as business processes models to actually see and understand them. The specification of a business process definition enables an enterprise to express its business processes so that they are understandable to members of the organization or other enterprises, but also to some extent, to machines. Therefore, the integration of business processes within an enterprise or between enterprises should be possible.

A business process describes in detail how trading partners take on roles, relationships and responsibilities to facilitate interaction with other trading partners in shared collaborations. The trading partners participate in internal or external value-adding activities. (see section 2.1) The interaction between roles takes place as a designed set of business transactions. Each business transaction is expressed as an exchange of electronic business documents.

Although business practices vary from one organization to another, most activities can be decomposed into business processes that are more generic to a specific type of business. This analysis, using business modeling, will identify business processes and business information meta models that can likely be standardized.

Figure 13 shows the basic modeling procedure of a business process. It begins by gathering the requirements and information that are relevant to the specific business process. All this information is presented in documents that are then analyzed.

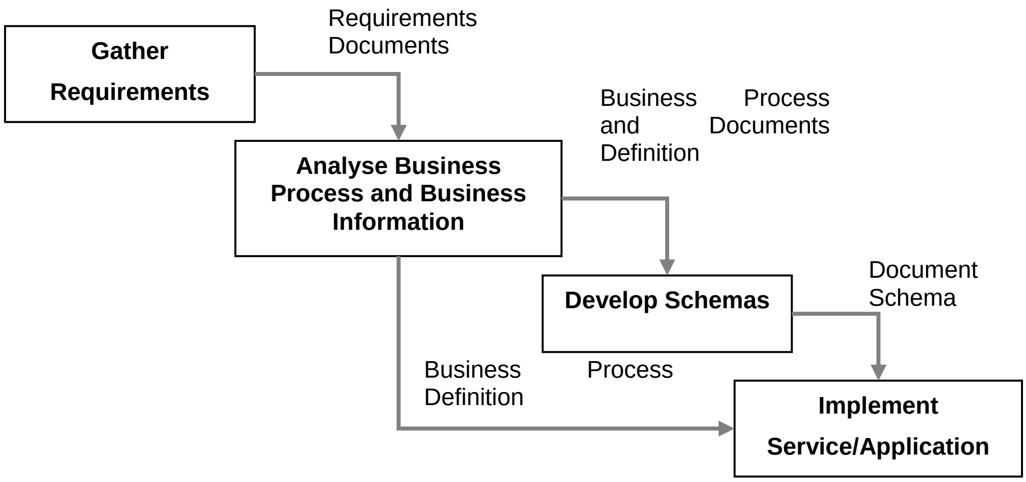


Figure 13: Modeling process of a business process (Author)

This information can come from a wide variety of sources depending on the business process to be modeled. From this analysis two results will emerged. One of them is the business process definition and the other is the business process documents. The business process definition alone or together with the business process documents can be implemented.

Business process models are likely to be composed of several abstraction levels. We can consider the most abstract layer to be the first layer or parent process layer. Thus, the last layer should be a refinement of the processes and activities – i.e. subprocesses. To each subprocess resources can be assigned, tasks designated and communication channels defined.

For the implementation of QFD it is very probable that a very detailed level of detail must be reached. The application of QFD to business processes takes distance from the technical product QFD, because in this case, bilateral requirements are to be functionally worked out and the number of combinations is sometimes much larger than in a product. The product HoQ cascade can not be applied in the business process QFD, since single requirements of business processes must be matched against each other.

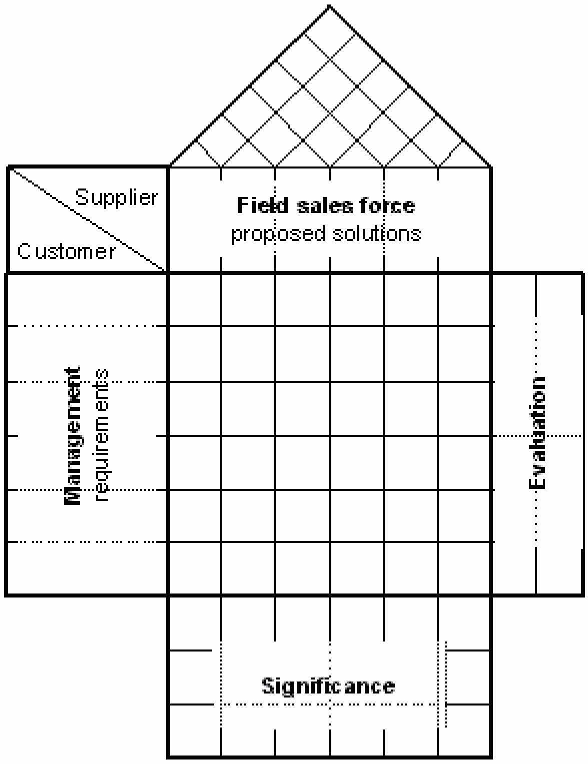


Figure 14: House of Quality for business processes (Source: Clark K.B., Wheelwright S.C., 1995)

Companies have not applied QFD to business processes basically because of the great effort needed to reach the necessary level of detail. However, for the past 20 years more and more organizations are standardizing their business process for reasons mentioned before, resulting in that half the work to implement QFD has already been done. In many cases, business process models are available so that an analysis using QFD can reveal which business processes are critical for a higher customer satisfaction and subject to an optimization. The HoQ matrix allows the common user to visualize relationships between different business processes even though they might have no clear connection in a business model, e.g. interdepartmental processes.

Another important reason to perform such practices is that up to 80% of an organization's knowledge is found within business process and its human resources. (Clark K.B., Wheelwright S.C., 1995) Nevertheless, generally only those processes and activities that prove to be decisive to competitiveness of the organization should be considered for a QFD application.

3.1.2 QFD Implementation

The implementation of QFD breaks usual organization structures from sequential product development process. Instead of handling the developing product from one department or functional team to another, QFD requires that teams from different functions meet in order to agree on the specifications in the matrix. This brings as a result a clear communication and translation of customers requirements into an operational product or service. The major steps in building the House of Quality interaction matrices are:

1. Identify the requests of potential customers and other stakeholders and measure their importance.
2. Identify potential customer perceptions or positioning of competitors relative to the new product. It will indicate opportunities for competitive advantage along with benefits, according to their relative importance.
3. Identify design and engineering elements (attributes) that affect the customer requests.
4. Estimate the potential impact of the quality attributes on the customer requests through a ranking system.
5. Correlate the quality attributes to revise the overall performance integrity of the product.

This procedure is analogous for the other necessary matrices for the different stages of the product or service development process.

A cross-functional team is indispensable to execute a QFD exercise. Ideally, the team should include members from all major areas of product development (marketing, manufacturing, purchasing, process engineering, cost accounting, etc.) Very important for a successful implementation of QFD is absolute top management support. QFD programs demand tremendous efforts, especially at initial stages, due to large amounts of marketing research and other information needed to complete the different matrices. Maintaining team commitment and participation with open communication and discussion might prove to be also difficult in long projects.

3.2 Failure Mode and Effects Analysis (FMEA)

This section introduces the topic of potential Failure Mode and Effects Analysis (FMEA) and gives general guidance in the application of the technique. Because of the general focus of this study is to state the importance of a continuous improvement of products, services and processes in the innovation process whenever possible, the need for using the FMEA as a disciplined technique to identify and help minimize potential concern is as important as ever. Although it can be argued that the FMEA generates no innovation, it is a well known technique in the product development community and therefore, it is the author's opinion that it can be and should be coupled with other techniques like QFD, TRIZ, etc. to produce a synergy between them.

The FMEA technique dates back to 1949 when the document titled "Procedures for Performing a Failure Mode, Effects and Criticality Analysis" was published the United States Military as procedure MIL-P-1629. The FMEA technique is included in the Advanced Product Quality Planning (APQP) which is in accordance to the QS 9000 (the automotive analogy to ISO 9000 developed by the Chrysler Corporation, Ford Motor Company, and General Motors Corporation to ensure a standardized supplier quality). (see www.fmeca.com)

The goals of the FMEA technique are:

- Recognize and evaluate the potential failure of a product or process and its effects.
    - Early recognition of critical components and weak points. It is specially important in product innovation and development processes.
    - Eliminate or reduce the probability of the potential failure through proper means.
- Document the development process.
    - Increase of the clearness in the product's construction (product transparency).
    - Risk evaluation using the previous experiences.
    - Determination of responsibilities for improvement and correction measures.
- Optimization of the manufacturing strategy.

- Reduction of development time and activities (less development loops).
- Generation of synergies through a methodical teamwork of experts.

Three basic FMEA types can be distinguished according to the product's development phase. With a System-FMEA one examines the functional efficiency of each component in relation with the entire system. Correspondingly, also the interfaces between each component are here analyzed. The goal of the Construction-FMEA is to look at potential failures of each of the product's components during their conception, construction, manufacturing and assembly. Finally, the Process-FMEA deals with potential failure causes during the production process.

3.2.1 FMEA Implementation

FMEA input should be a team effort. Usually, the responsibility for the preparation of the FMEA is assigned to an individual, but a team of experts from each production domain should be formed (e.g., design experts, analysis & testing engineers, manufacturing and assembly experts, as well as service, recycling, quality, and reliability knowledgeable individuals).

The responsibility, coordination and execution of a FMEA lies usually in the hands of a designated engineer. He/she is also responsible of preparing the corresponding documentation and updating it with the latest results of the group discussion. The responsible engineer must assure that all recommended actions have been implemented or adequately addressed. To keep a sufficient concentration on the analysis a session should no last more than 2 hours. In some cases, it can be very important that a team is constituted with knowledgeable individuals from their departments, but having the same hierarchy.

All along a FMEA the following three questions must be answered:

1. Will a failure of the system result in intolerable/undesirable loss? If NO, document and end the analysis. If YES,
    a. Divide the system into its subsystems. At each level of analysis, interfaces should be considered as system elements at same that level. Ask this question for each subsystem: Will a failure of this subsystem result in intolerable/undesirable loss? If NO, document and end the analysis. If YES,

   b. Divide each subsystem into its assemblies. Ask this question for each assembly: Will a failure of this assembly result in intolerable/undesirable loss? If NO, document and end the analysis. If YES, continue this questioning through the subassembly level, and onward – into the piece-part level if necessary.

2. For each analyzed element, what are the Failure Modes?
3. For each Failure Mode, what are the Failure Effects?

3.2.2 FMEA Procedure

In this section, the basic steps in implementing a FMEA will be described. The responsible engineer has at their disposal a number of documents that will be useful in preparing the FMEA. The process begins by developing a listing of what the design is expected to do, and what it is expected not to do, i.e., the design intent. Customer wants and needs, as may be determined from sources such as Quality Function Deployment (QFD), known product requirements and/or manufacturing/assembly/service/recycling requirements should be incorporated. The better the definition of the desired characteristics, the easier it is to identify potential failure modes for preventive/corrective action.

The results of each step are to be registered in a FMEA form sheet (see Figure 30).

1. **Identify system of interest and register basic information**

   In the header of the FMEA form sheet a designated team member will capture the essential data for an unambiguous identification of the product. This includes:

   - System identification: Object name, number of each system element as well as version information (model, year, etc.)
   - Identification of participating departments: Those departments, that are responsible for the implementation of the FMEA and their delegates are to be specified.
   - Identification of targets or aims to be protected: The targets can be personnel, product, environment, equipment, productivity, etc.

2. Develop system analysis

2.1. Identify system scope: Physical boundaries, operating phases and other assumptions made (e.g., as-is, as-designed, no countermeasures in place) have to be defined.

2.2. Develop system block diagram: The system block diagram is developed by determining the potential failure mode of each element and decompose them when necessary. The system decomposition is better done by answering the three basic FMEA questions. (See pg. 39) The diagram illustrates the primary relationship between the items covered in the analysis and establishes a logical order to the analysis. Copies of the diagrams used in FMEA preparation should accompany the FMEA.

2.3. Determine consequences (effects) of each failure mode: The effects of the failure are described in terms of what the customer might notice, the target to be protected and experience . The effects should always be stated in terms of the specific system, subsystem, or component being analyzed. The hierarchical relationship between the component, subsystem, and system levels must be kept in mind.

In a real technical system it is important if the failure:

- denotes a safety hazard
- means non-compliance to regulations
- implies a function breakdown
- limits the performance

It is unimportant for the technical system if the failure:

- is a normal wear out without resulting in a malfunction
- is aging-related and results in the displacement of the characteristic curve of a system.

Furthermore, it must be distinguished between failure consequences for a person or for the actual system.

2.4. Determine possible failure cause: The cause should be listed as concise and complete as possible so that remedial efforts can be aimed at pertinent causes. Experience has demonstrated that failure causes are best found if one looks for causes related to:

- design faults

- manufacture faults
- assembly faults

3. Evaluate failures modes

The failure mode analysis is over after investigating their causes. Now the project team will evaluate the risk implied in each failure mode and the appropriate correction measures for each of them. Furthermore, testing and prevention measures exert direct influence on this evaluation as we will see next.

3.1. Determine testing and prevention measures

Prevention measures are all those already existing and applied procedures to diminish the occurrence of a failure or fault. These measures are related to the present condition of the system and they consider the current development and quality assurance state, as well as all the available knowledge on the system.

It can be considered as testing measures all those procedures aimed to discover failures and faults.

3.2. Determine fault occurrence probability

From this analysis an occurrence probability index (OP) for each failure mode should be derived. (For an example see The FMEA designated engineer or moderator should ensure that the determination of the occurrence probability is made totally independent from the significance of the failure. Prevention measures are to be considered all the time in this phase.

3.3. Determine probability of discovering the fault

The testing measures must be taken into account when assessing the probability of finding the probable faults. This means that only those faults, that can be detected before delivery, will be analyzed. For those faults and failures that derived from erroneous interpretation of hypotheses (e.g. wrong requirement profile, wrong life cycle curve) there is no possibility of being discovered. (For an example see C).

3.4. Determine severity of the consequences

The significance of the aftermath of each failure mode in relation to a specific target is here assessed. This means that every failure cause with the same consequence for a specific target will receive the same assessment. Therefore, to each potential consequence of a failure mode a severity index must be assigned. Again here, the assessment must be done independently from the occurrence and discovery probabilities. (For an example see C).

3.5. Calculate Risk Priority Index (RPI)

The Risk Priority Index results from the multiplication each of the indexes of the previous assessment (RPI = O_P * D_P * S). This index represents a measurement of the risk that a failure mode implies.

4. Determine if risk is acceptable.

Failure causes with a high RPI should be specially considered. The RPI provides a corresponding priority rank for the optimization. Nonetheless, independently from the RPI each individual index should be considered if:

- a high O_P is encountered. The failure mode occurs very frequently and thus, it should have the highest priority.
- a high D_P is encountered. The high probability of discovering a failure mode may indicate design weak points.
- a high S is encountered. The failure mode is critical for the customer or the corresponding target. Radical modifications (e.g. design modifications) are to be considered.

5. Develop countermeasures and optimize concept.

According to each individual evaluation and RPI the project team or the corresponding department must develop countermeasures and improvements. The new concept must be evaluated again following the same procedure described above.

3.3 Theory Inventive Problem Solving (TRIZ)

As a rule, people face one of two types of problems, those with generally known solutions and those with no known solution ('known' meaning, that the individual or the team has sufficient knowledge of a standard solution for the problem). The former can normally be solved using information found in technical literature or specialized knowledge acquired on the subject. These solutions follow a general pattern of problem solving and therefore from the standard solution a particular for the problem can derived. Problems with unknown solutions are called inventive problems. They usually fall in the field of psychology. Great inventors like Thomas Edison used the trial-and-error method to solve these problems and to come out with inventions, but it is clear that such methods can be very inefficient. Furthermore, experts dealing with innovative problems face what is called psychological inertia, i.e. the considered solutions remain within the inventor's experience. Hence, if the solution lies outside the inventor's knowledge domain, it might never be discovered.

The late Russian engineer Genrich S. Altshuller studied for decades the situations mentioned above. He believed that solving complex inventive problems could not only depend on psychological stimulating procedures, inborn abilities or exhaustive methods like trial-and-error. After screening thousands of patents, searching for recurrent patterns and principles independent of their application field and classifying them according to different criteria, he was able to develop a method to assist experts dealing with such problems. He developed a theory which he called TRIZ, an acronym for the Russian words Teoriya Resheniya Izobretatelskikh Zadatch (in English "Theory of the Solution of Inventive Tasks/Problems"). He proposed a systematic technological approach that could guide the expert to the ideal solution step-by-step through broad solution space. He also suggested that the procedure has to be repeatable, reliable and not dependent on psychological tools. The method must to be able to access knowledge bases and to add knowledge to them.

3.3.1 TRIZ and technology forecasting

The first part of Altschuller's contribution is in the field technology forecasting. If an expert can anticipate (to some degree) which should be the next step in the evolution of a product and sometimes even its technological evolution, he or she is in a better position to making decisions and to solve future problems.

Altschuller was able to classify the patterns of behavior in a new way and relate them to other technological indicators. At the end he developed a set of eight principles or laws called ”Technology Evolution Laws”.

By applying these laws to a ”system” the following questions can be answered:

1. Where is our product in its technological evolution?
2. What should come next?
3. What kind of innovation should be the most adequate?
4. What approach towards the next technology should be taken?

The following are the Eight Laws of Technology Evolution:

1. Stepwise Evolution

Like a product has a life cycle the technology behind it had also an embryonic stage, a birth, a childhood, then adulthood, maturity and finally death. The embryonic stage is when a system does not yet exist, but important conditions for its emergence are being developed. Birth can be defined as when a new system appears due to high-level invention, but development is slow. During the childhood society recognizes value of the new system. In the adult stage resources for original system concept end. As maturity comes the next generation of system emerges to replace original system. Before death comes some limited use of original system may coexist with the new system.

Altschuller saw that when the grade of maturity or performance of a technology vs. time is plotted a S-curve results. (See Figure 15) This is no astonishing discovery, but what really distinguished his investigation was that under the same transition in time other parameters also maintained a constant behavior. These parameters are level of innovation, number of inventions and profit.

To understand the first parameter – level of innovation – it must be said before that Altschuller, after studying thousands of patents, found out that statistically the level of innovation can be grouped in the following way.

Table 2: Level of innovation (Source: Terninko, J., 1998)

Level	Degree of inventiveness	% of solutions	Source of knowledge	Approximate # of solutions to consider
1	Apparent solution	32%	Personal knowledge	10
2	Minor improvement	45%	Knowledge within company	100
3	Major improvement	18%	Knowledge within the industry	1000
4	New concept	4%	Knowledge outside the industry	100,000
5	Discovery	1%	All that is knowable	1,000,000

a. Level one. Routine design problems solved by methods well known within the area of expertise. No invention is needed.

b. Level two. Minor improvements to an existing system, by methods known within the industry. Usually solution is found with some compromise.

c. Level three. Fundamental improvement to an existing system, by methods known outside the industry. Contradictions are resolved.

d. Level four. A new generation that uses a new principle to perform the primary functions of the system. Solution found more in science than in technology.

e. Level five. A rare scientific discovery or pioneering invention of essentially a new system.

The level of innovation can be also correlated to the number of inventions in the same time period. It seems to be logical that as the innovation grows in maturity, the number of improvements will start growing at different paces. In the early stages of the technology, the number of innovations will grow, but relatively slowly. This happens probably because not enough knowledge is yet available or there are up until then unsolved technical problems. The public awareness towards the technology is rather low and therefore investment is rather scarce to produce fast improvements. When the technology reaches the adulthood means also that the number of inventions will grow, but mainly through improvements which represent a lower level of innovation. The flow of investments increases until the end of the maturity. At these moment no improvements in the technology seem to be necessary and a radical change is needed.

The profitability, i.e. the state of producing earnings, of a certain technology also changes through its life cycle. At early stages, as seem before, the technology lacks the necessary investments to mature faster because the costs are to high when compare with a immediate return as profit. A larger degree of risk is seem in the technology, but will change once the barriers are overcome and the public awareness grows. During the maturity stage the profitability will start declining, because probably the number of products in the market is too high meaning bigger competition or another technology is taking the share of the market. (See Figure 15)

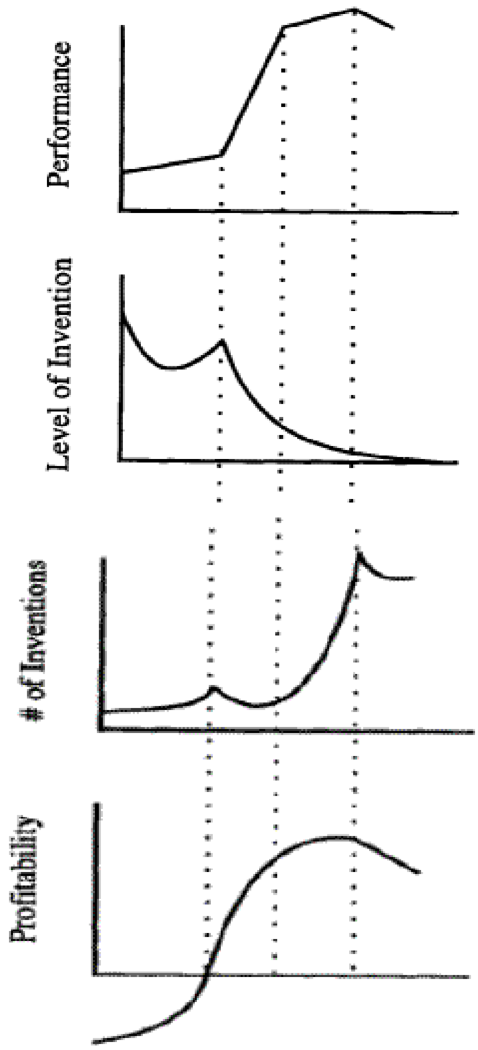


Figure 15: S-curves (Source: Terninko, J., 1998)

2. Increasing Ideality.

The second law of Technology Evolution states that a technical system will develop in direction of a higher Ideality. (see Terninko, J., 1998). An ideal system is understood as a system in which a desired function is available through the already existing resources. The following equation represents this concept:

$$\text{Ideality} = \frac{\sum \text{useful functions}}{\sum \text{harmful functions}} = \frac{\sum \text{benefits}}{\sum \text{costs} + \sum \text{harm}}$$

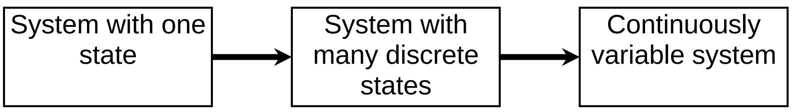
This law helps the technology policy maker by forcing him or she to identify the useful (positive) functions and compare them to the costs and harm they produce. It is clear that it can be very difficult to quantify these parameters. In such a case the person in charge has to develop a priority list to guide himself or herself in the following steps to take. [5]

3. Uneven development of subsystems.

Every subsystem and every element of a system has its own evolution. Some of them will evolve slower than the others and therefore slowing down the further development of the system. The key issue here is to understand the relationships between each function and how they affect the main function. It is always recommended to start from the weakest component of the system. [6] . (see Terninko, J., 1998, f.p. 91)

4. Increasing dynamism and controllability

TRIZ's fourth law of evolution says that every technical system moves in direction of an increase of dynamic, flexibility and control. . (see Terninko, J., 1998, f.p. 95) The use of alternative materials, processes, reactions, etc. should always be considered to provide the system with a larger degree of adaptability, flexibility and control.



[5] TRIZ offers tools to understand and reach a solution near the ideality. Such tools are the contradiction analysis and the innovation checklist.

[6] The problem formulation method that TRIZ offers is an ideal tool to apply here.

5. Increasing complexity, followed by simplicity through integration

This law states that technological systems evolve in a general direction from mono-systems to bi- or poly-systems. Usually a system originates as a mono-system, because at this moment only an application seems obvious or necessary. Bi-systems and poly-systems offer greater degrees of adaptability, flexibility and control (the law mentioned before). As seen in the figure Figure 16 several forms of bi- a poly-systems are possible. A bi-system (B-S) can have a single or multiple functions. Two identical subsystems with only one function is a homogeneous B-S. When a single function is performed by two different subsystems, then we are taking about a shifted B-S.

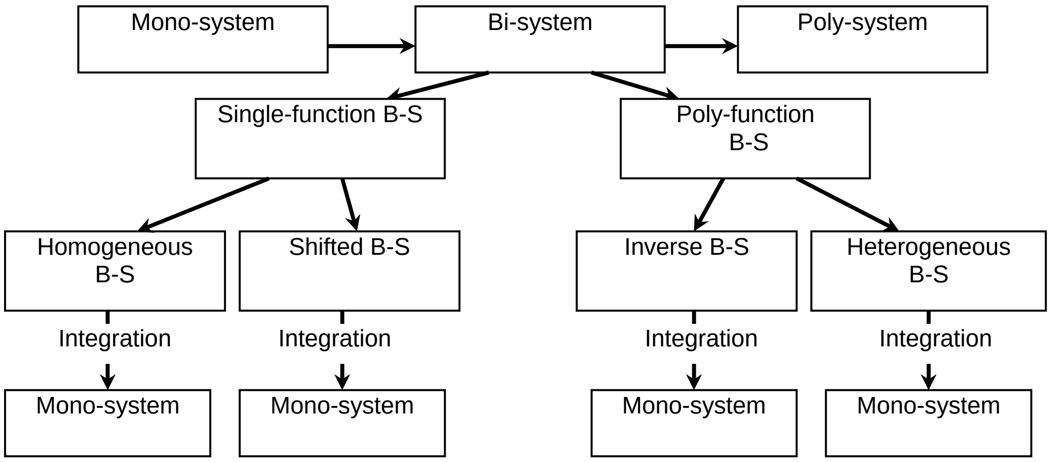


Figure 16: Transition from mono-system to poly-system (Source: Fey, 1999)

A bi- or poly-system can also have more than one function (poly-function system). The effectiveness is also increased when different components are put together in such systems. A heterogeneous bi-system is the result of two different subsystems in one. The second case is called inverse bi-system and it is the product of two opposite subsystems.

The next step in the evolution is the transition to a convoluted bi- or poly-system. Convoluted means that the different functions are integrated in time (i.e. a new mono-system). The key issue here towards technology forecasting is the awareness that a system can become more efficient through its combination with other systems. . (see Terninko, J., 1998)

6. Evolution with symmetric components and targeted non-symmetric components.

In technological evolution the combination of matching and mismatching parts in a system has increased very often the efficiency of the system. Trying to maintaining a solid symmetry in a system can mean that only the undesired or harmful functions are been emphasized.

7. Transition from macrosystems to microsystems using energy fields to achieve better performance or control.

This law states that technological systems evolve in the direction of increasing the fragmentation of their elements. As a system is in a higher fragmentation level the system's control is more precise and adaptive.

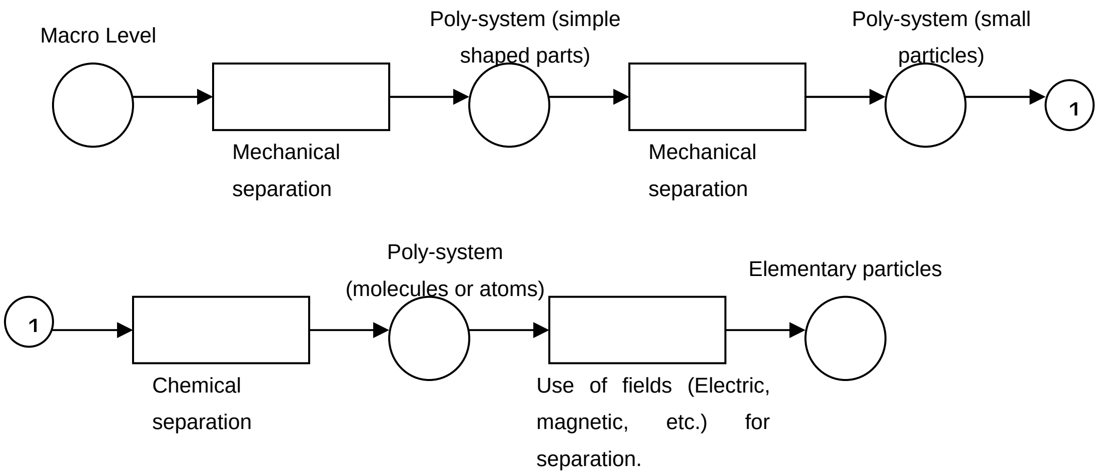


Figure 17: From Macrosystems to microsystems

8. Decreasing human involvement with increasing automation.

As a result of technological evolution this law stated the human being will have less interaction with technology. Routine processes done by humans are done now and more often in the future by technical systems.

3.3.2 TRIZ as a problem solving method

The problem solving method developed by Alshuller is composed of a series of tables and algorithms that still today are been studied, complemented and developed by different researchers around the world. The following are some the main problem-solving methods in the TRIZ methodology:

3.3.2.1 Innovation Check-List

The goal of the Innovation Check-List is to assist expert(s) with the exact definition of a problem. It has been said that a good defined problem is half the solution.

A prerequisite of this method is to have a very clear understanding of the innovative system that is going to be modified or the structure to be improved and its background. Precise documentation of all the important aspects is also necessary. Therefore, the Innovation Check-List has the form of a questionnaire and each of the questions has to be as detailed and specific as possible. It is recommended that the preparation of a Innovation Check-List must be done in teamwork and a working session should last from 4 to 8 hours.

In most of the cases technical language should be replaced by general or generic terms, because technical vocabulary generally brings implicit a probable solution that could cause a mental block when finding an alternative and better solutions.

Every system has a set of information that has to be fully understood at the moment of applying it modifications with the goal of making improvements. The following is a summary of this information:

1. Primary Useful Function

The main function of the system (and as well as other existing functions) should be expressed or formulated by an active verb and its subject and object.

2. Existing or desirable system structure

The system structure has to be described in detail. This is achieved by using statistical conditions and drawings. Every subsystem has to be included and its relationships to the system clearly detailed.

3. Functional description of the system (how it works)

A functional description of the system based on its “primary positive function” is necessary. Also, the interactions between the system and its subsystem are here depicted.

4. System environment

How the system interacts with its surroundings (other systems) will be here described.

The description of the system’s environment must contain:

- each system with which negative or positive interactions exist.
- those systems with which no direct interaction exist, but under certain conditions this could happen.
- common systems in which our system is considered as a subsystem or a component.
- the natural surroundings of our system.

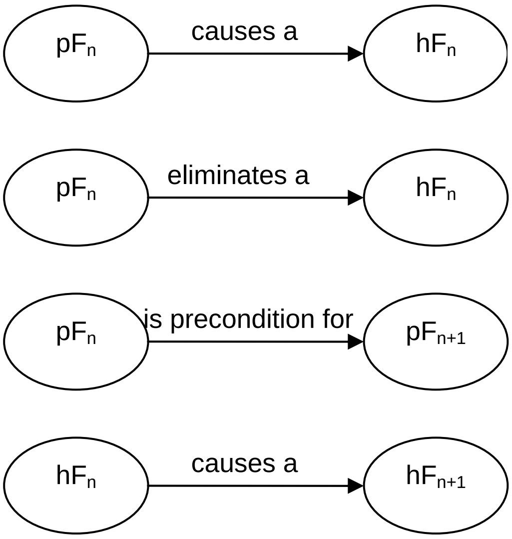
5. Available resources

Available resources in the surroundings of a system are often overlooked. According to TRIZ, the available resources can be grouped as follows:

- material resources
- field resources
- functional resources
- information resources
- time resources
- space resources

6. Problem definition

All the information that has to do with the problem within the system must be collected. A problem must be understood as any inadequate, harmful, undesired condition that needs to be improved. To be able to understand the problem it is necessary to have a very clear the relationships between the primary positive function and the harmful functions. In other words, the expert(s) must describe how the considered harmful functions work and how they affect the system. The relationships between “positive functions” and “harmful functions” are of the following kind.



- A positive function (pF) causes a harmful function (hF). (Will the positive function also have harmful effects?)
- A positive function will cause the elimination of a harmful function.
- A positive function is necessary for another positive function to happen.
- A harmful function causes another harmful function.

Figure 18: Relationships between positive and harmful functions

The system will admit changes up to some point. The limit depends on the development situation of the system as well as the relation profit – cost that the modification represents.

The development history of the problem must be recorded. At what point of the system development did the problem(s) occur. This will help to define alternative development paths to avoid the problem.

The information collected before should be allow the selection of a solution criteria. The criteria could be technical, economical, time, etc. It is a good idea to make a list of the systems' elements which would be modified through the selected criteria.

It is very common that other systems with similar problems have already been analyzed and maybe a solution has found. It is useful to collect this information even though the solution was not reached and to ask oneself why not. The documentation about earlier attempts to solve the problem will allow us to refine the criteria to be used.

3.3.2.2 Contradiction analysis

The contradiction analysis is a method through which a problem can be abstracted and it's solution can be found with the help of abstract principles.

TRIZ recognizes two categories of contradictions:

Technical contradictions are the classical engineering “trade-offs”. The desired state cannot be reached because something else in the system prevents it. In other words, when something gets better, something else gets worse. Classical examples include

• The product gets stronger (good) but the weight increases (bad);

• The bandwidth increases (good) but requires more power (bad);

• Service is customized to each customer (good) but the service delivery system gets complicated (bad);

Physical contradictions are situations where one object has contradictory, opposite requirements. Everyday examples abound:

• Surveillance aircraft should fly fast (to get to the destination) but should fly slowly to collect data directly over the target for long time periods;

• Software should be easy to use, but should have many complex features and options;

• Training should be thorough and not take any time;

The TRIZ research has identified 40 principles that solve the **Technical contradictions** and four principles of separation that solve the **Physical contradictions**.

The first obvious question that arises is "How can an innovation problem be structured through a contradiction?" To answer this, it is necessary to look back into the Innovation Check-List that TRIZ offers us. From this list the following three basic questions can be formulated:

Q.: Which is the principle positive function of the system?

Q.: What should be improved in the system?

Q.: Which is the origin of the problem?

If a car is taken as an example (car = system) and as answer for the first question it is found that speed to travel from one place to another is the principle function, it can be said that the more speed is what should be improved. Then the answer of the third question could be that more speed means the burning up of more fuel.

Through abstraction of the system, two contradictory functions are found: Speed and use of energy. A more powerful motor will be the answer to make the car faster, but that should also mean that the car will use more fuel (energy). A third function (power) has been introduced in the system and as expected it increments the contradiction's magnitude between the first two functions.

When the problem is formulated through contradictory conditions in it's system the question that arises is: ”What could happen if….?”, being this the beginning of the solution. The question ”What is wrong here?” should be avoided.

The TRIZ patent research classified 39 features or parameters for technical contradictions. (See Table 3 Once a contradiction is expressed in the *technical contradiction* form (the trade-off) the next step is locate the features in the Contradiction Matrix. Figure 19 shows a piece of the matrix.

Table 3: 39 Technical parameters

Parameter	Parameter	Parameter
1. Weight of moving object	14. Strength	27. Reliability
2. Weight of stationary object	15. Duration of action of moving object	28. Measurement accuracy
3. Length of moving object	16. Duration of action by stationary object	29. Manufacturing precision
4. Length of stationary object	17. Temperature	30. Object-affected harmful factors
5. Area of moving object	18. Illumination intensity	31. Object-generated harmful factors
6. Area of stationary object	19. Use of energy by moving object	32. Ease of manufacture
7. Volume of moving object	20. Use of energy by stationary object	33. Ease of operation
8. Volume of stationary object	21. Power	34. Ease of repair
9. Speed	22. Loss of Energy	35. Adaptability or versatility
10. Force (Intensity)	23. Loss of substance	36. Device complexity
11. Stress or pressure	24. Loss of Information	37. Difficulty of detecting and measuring
12. Shape	25. Loss of Time	38. Extent of automation
13. Stability of the object's composition	26. Quantity of substance/the matter	39. Productivity

	A	B	T	U	V	W	X	Y	Z	AA
1		Worsening Feature → Improving Feature ↓	Illumination intensity	Use of energy by moving object	Use of energy by stationary object	Power	Loss of Energy	Loss of Substance	Loss of Information	Loss of Time
10	**8**	**Volume of stationary object**		-		30, 6		10, 39,		35, 16, 32
11	**9**	**Speed**	10, 13, 19	8, 15, 35, 38	-	19, 35,	14, 20,	10, 13,	13, 26	
12	**10**	**Force (Intensity)**	-	19, 17, 10	1, 16, 36, 37	19, 35,	14, 15	8, 35, 40, 5		10, 37, 36
13	**11**	**Stress or pressure**	-	14, 24,		10, 35, 14	2, 36, 25	10, 36, 3,		37, 36, 4
14	**12**	**Shape**	13, 15, 32	2, 6, 34, 14		4, 6, 2	14	35, 29, 3,		14, 10,
15	**13**	**Stability of the object's composition**	32, 3, 27, 16	13, 19	27, 4, 29, 18	32, 35,	14, 2, 39, 6	2, 14, 30, 40		35, 27
	14	**Strength**	35, 19	19,	35	10,	35	35,		29, 3,

Figure 19: Section of the Contradiction Matrix. Selected rows and columns from the Contradiction Matrix. The numbers in the cell refer to the principles that have the highest probability of resolving the contradiction.

Find the row that most closely matches the feature or parameter you are improving in your “trade-off” and the column that most closely matches the feature or parameter that degrades. The cell at the intersection of that row and column will have several numbers. These are the identifying numbers for the Principles of Invention that are most likely, based on the TRIZ research, to solve the problem: that is, to lead to a *breakthrough* solution instead of a trade-off. The principles are usually accompanied by examples from a variety of industries. The design or problem solving team uses both the text and the examples, and examples from their own previous applications, to develop a solution. For a complete version of the Contradiction Matrix and a list of “The 40 general Principles of TRIZ”, please refer to the additional files in the CD accompanying this master thesis.

Physical contradictions are based on opposite and excluding conditions of a system's component or function, which are applied to a unique function. Three ways to formulate physical contradictions are available. They are based on functions, properties or elements of the system:

a. Based on a function which must take place in order to reach the desired result, but at the same time it can not take place to avoid harmful or undesired effects.

b. To reach the goal, a specific property of the system must have a specific value, but to avoid the undesired or harmful effects the same property must have the opposite value.

c. To reach the goal, a specific component or element is needed, but to avoid unwanted or harmful effects it can not be present.

When using the TRIZ research findings, in general the most comprehensive solutions come from using the physical contradiction formulation, and the most prescriptive solutions come from using the technical contradiction. In terms of learning, people usually learn to solve technical contradictions first, since the method is very concrete, then learn to solve physical contradictions, then learn to use both methods interchangeably, depending on the problem.

TRIZ has 4 classical ways to resolve physical contradictions:

1. Separation in time

   The basic idea in of this principle is to allow the contradictory requirements, but in different periods of time. As an example, we can remember earlier versions of software applications, e.g. Microsoft Excel. The user had to install the complete software package before doing either simple functions like adding values in from columns or realizing complex mathematical operations. Now, because the spectrum of functionalities offered by Excel is much larger, you have the possibility only install what really need, when you need it (e.g. Add-Ins) and thus saving storage and processing capacity in your computer.

2. Separation in space

   This principle basically says that contradictory requirements should happen within different spaces. Consider the first workstations or personal computers. Their principle function is still the same now, but they were extremely uncomfortable and they consume a lot of desktop space. By separating the screen, disk drives, keyboard, the use of space is more efficient and undoubtedly more comfortable.

3. Transformation of a substance (material) or separation by changing the conditions.

As the title says one can solve a physical contradiction by changing the conditions within the system and thus allowing the contradictory requirements simultaneously. For example, take the flash of a camera. A flash is necessary to improve the quality of the photograph under certain conditions. The “red eye effect” is caused by the same flash producing the negative notorious effect that we all know. By using a less powerful flash fractions of a second before using the principle flash, the eye can change biophysically and adjust itself to the new source of light, and so preventing the red eye effect.

4. Transformation of a structure or separation within a system und its parts.

   Parts of a system can undergo transformation to allow contradictory conditions simultaneously. A bicycle chain is a good example. A chain has to be stable and strong, but also very flexible. Instead of using a single metal element to provide the necessary strength, the chain is made up of small elements (chain links) that provide the same strength, but are also much more flexible.

3.3.2.3 Substance-Field Model (Su-Field Model)

The Su-Field Model is one of the most important tools that the TRIZ theory offers. The Su-Field Model is based on the possibility to express every system by a field and two substances. The field can have any form in its widest meaning. Technically speaking a field is usually a physical field – thus a mechanical, thermal, chemical, electrical, magnetic, gravitational, etc. field. One of the substances will affect the other substances by means of the field. The former substance receives the name S_2. The modified substance is called S_1. The relationship between the components of a Su-Field Model is represented by lines and arrows. (see Fig.)

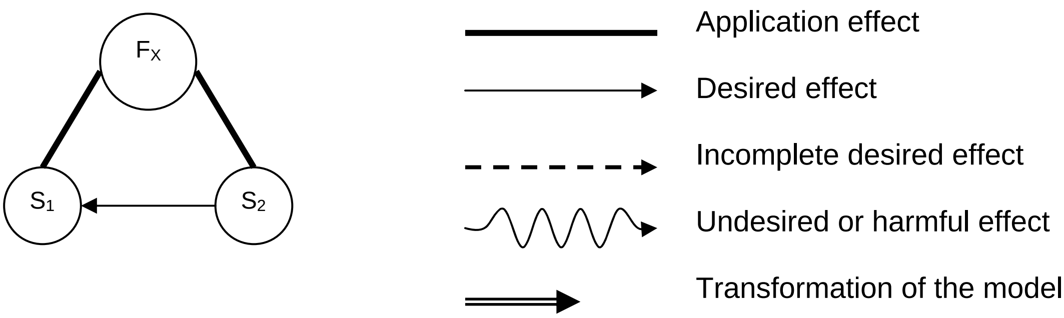


Figure 20: Basic components and relationships of the Su-Field Model

A system can be in any of four states. The ideal state is when the system is a complete. A system can also be an incomplete system, a complete but inefficient or a complete but a harmful system. The goal of any solution is to change the later three systems into a complete system. This goal can be achieved by replacing any element of the system, by introducing new elements or new systems. TRIZ provides 76 Standard Solutions, which should assist the expert(s) transform a the faulty system into a complete one. Just like the name says it, this list of standard solutions should work as basis for the generation of ideas leading to a specific one. The following flow diagram represents the procedure of the Su-Field Analysis. Steps 1 to 4 are clearly the analytic phases of the analysis. On the other way steps 5 to 7 are carried out with the help of knowledge-based tools (bases).

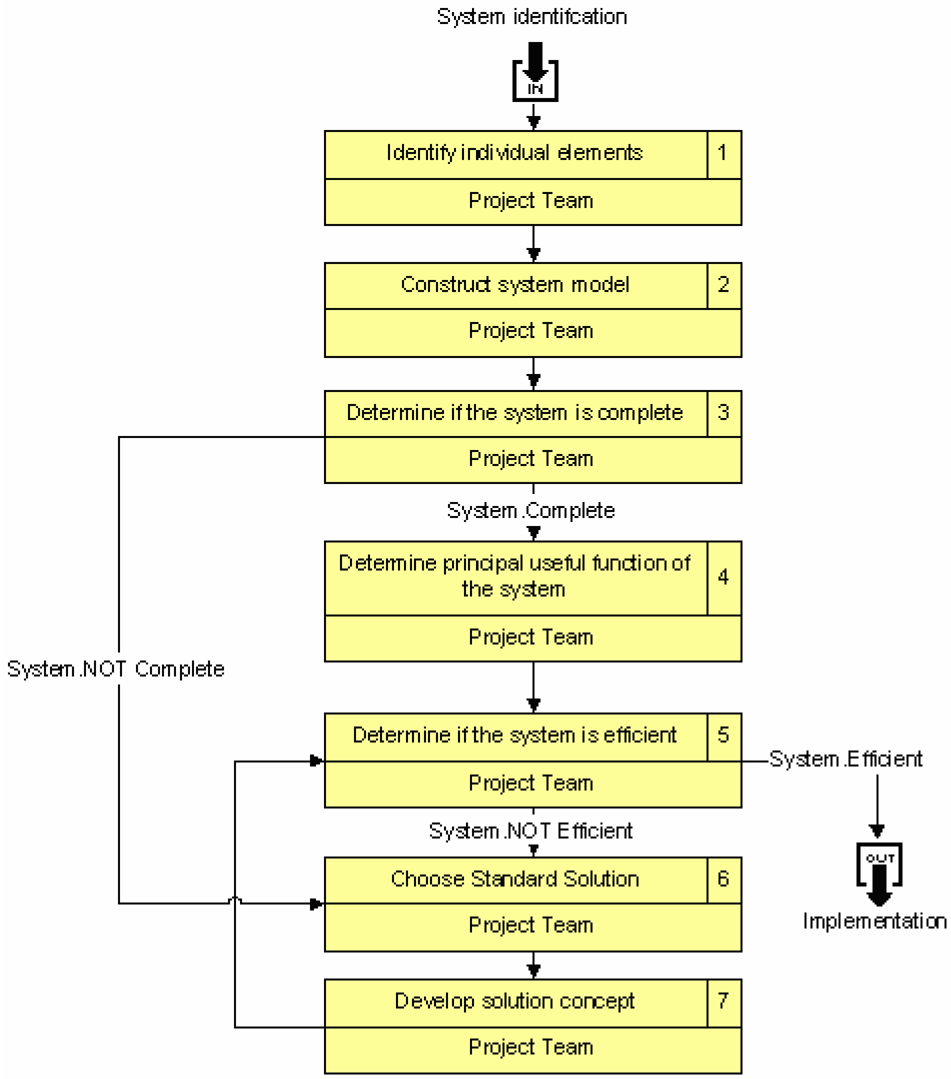
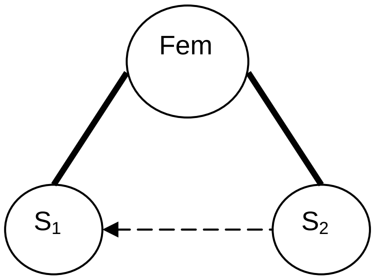


Figure 21: Procedure of the Substance – Field Analysis

For example, one can say that in a “mobile” society a fixed net has become an incomplete system, because it does not offer the freedom of movement as a wireless system. In fact a fixed net can be represented as follows:



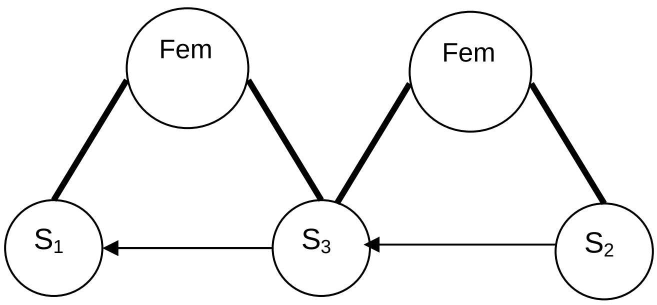
Fem: electromagnetical field

S_2: Cable

S_1: Information (software)

Figure 22: Incomplete software distribution system. (Wireless subsystem) (Source: Own interpretation)

By analysis of the “76 Standard Solutions” (see supplementary file in the accompanying CD) an innovative approach was taken to solve this incomplete system. The introduction of a third element or substance could be also effective (instead of changing the field for example). If the third element could transform the signal coming through the cable into a signal receivable by an antenna, then the system would be complete. This third element will be called “Bluetooth”, which is the combination of a transistor and a chip.



Fem: electromagnetic field

S_2: Cable

S_3: Transistor + Chip “Bluetooth“

S_1: Information (software)

Figure 23: Complete software distribution system. (Wireless subsystem) (Source: Own interpretation)

4 An ontology-based integration of the selected methods

Every product reflects the organization and the development process that created it. Companies that develop successful products are themselves coherent and integrated. This coherence is evident not only at the level of structure and strategy, but more important at the level of day-to-day work and individual understanding. Companies with organizational integrity possess a source of competitive advantage that others can barely match.

Developing and maintaining organizational integrity and thus, product integrity is becoming everyday more difficult. In the last two decades, the increasing international competition, rapid technological advances and sophisticated demand from the customer have made the road to become a leader more and more rough and difficult in two contradictory ways. On the one hand, an organization must build and refresh its individual areas of knowledge and expertise so that it does not fail to keep up with the pace of competition. On the other hand, it must find the way to get the always changing combination of disciplines work together in an also always changing competitive world.

Although most organizations continue to be structured in functional groups, the cross-functional organization is gaining ground as being more suitable for especially product development projects. But those organizations which have restructured themselves by cross-functional processes, have discovered how difficult it is to integrate various disciplines and still to maintain functional excellence. In other words, managers have to realize that the issue of core capabilities (which determine the competitiveness of an organization) is not just about creating or having them, but more important is to coordinate them to produce synergy. In addition, each capability consists of four elements, which must be also managed and integrated: [Clark, K & Wheelwright, S., 1995]

- Knowledge and skills – technical know-how and personal “know-who”.
- Managerial systems – tailored incentive systems, in-house educational programs, or methodologies that embody procedural knowledge
- Physical systems – plant equipment, tooling, and engineering work systems that have been developed over the years and production lines and information systems that constitute compilations of knowledge

- Values – the attitudes, behaviors, and norms that dominate the organization.

In the previous chapters, three different methods (QFD, FMEA and TRIZ) were introduced, which were conceived to integrate better the capabilities in modern organizations. These three methods have in common that they must be performed in cross-functional groups dealing, of course, with cross-functional processes. They have proven to be very successful in many projects, but probably there are many projects in which they have failed because they were not appropriately applied.

The distinguishable characteristic of this proposal is the implementation of an ontology-based approach to produce the desired synergy between the methods. As a result of this synergy, a continuous improvement in the organization and with its surroundings should be accomplished in time.

4.1 What is an ontology?

First of all, an ontology is here understood as a catalog of the types of things that are assumed to exist in a domain of interest from the perspective of a person who uses a language for the purpose of talking about the domain. The types in the ontology represent the *predicates*, *word senses*, or *concept and relation types* of the language when used to discuss topics in the domain. The combination of logic with an ontology provides a language that can express relationships about the entities in the domain of interest. Sowa J.F., XXX

For the purpose of this study, an ontology will be considered to be the conceptual schema of an integrated system. The ontology will be a standardized way of encoding all pertinent knowledge about an application domain. In Figure 4 an integrated system is unified by a conceptual schema or ontology at the center. The user interface calls the knowledge base for query and editing facilities, and it calls the application programs to perform actions and provide services. Then the knowledge base supports the application programs with facilities for data and knowledge sharing and persistent storage. The conceptual schema binds all three circles together by providing the common definitions of the application entities and the relationships between them. Sowa J.F., XXX

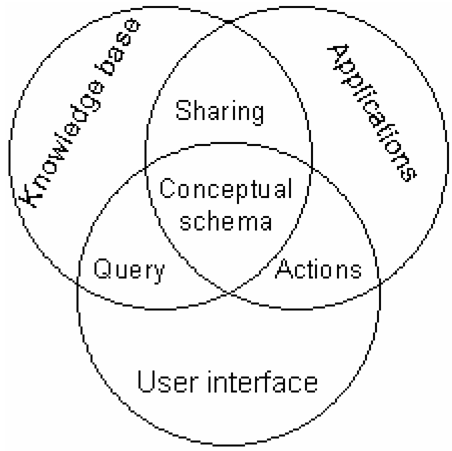


Figure 24: Conceptual schema as the heart of an integrated system (Source: adapted from Sowa J.F., XXX)

The concept of the conceptual schema has been around for some time now. It has been very important for integrated application design, development, and use, but there are no full implementations. Fourth generation languages (4GLs), object-oriented programming systems (OOPS), and the tools for computer-aided software engineering (CASE) are results of this concept. Each of them enhances productivity by using and reusing common data declarations for multiple aspects of system design and development. Unfortunately, none of them has achieved the ultimate goal of integrating everything around a unified schema.

The Semantic Web is the latest attempt to integrate all the world's knowledge. One of its major contribution has been the XML (eXtendible Mark-up Language) as the common syntax for everything. The XML standard is published and maintained by W3C, the consortium that maintains many of the standards for the World Wide Web. XML uses tags to define elements in a document. Since XML only provides the structure to define tags and their relationships, the user specifies his or her tags according to the information to be publish in the document. That also means, that XML is a way of sharing information with other users and machines, but it imposes no semantic constraints on the meaning of these documents.

For the sake of standardization, the XML schema defines specific tags and relationships that each data element in a document can contain and it can be created by a user, a company, or at the industry level. Thus, XML schemas can be created to define and qualify content for virtually any application .

To express that, that has been marked-up with the XML notation, RDF provides a simple semantics for this datamodel. To express more semantics the RDF Schema is a vocabulary for describing properties and classes of RDF resources, with semantics for generalization-hierarchies of such properties and classes. Furthermore, the scientific community have developed a subset of first-order logic called description logic. Languages like DAML and OIL are two versions of description logic and recently both languages have been combined in OWL. OWL adds more vocabulary for describing properties and classes: among others, relations between classes (e.g. disjointness), cardinality (e.g. "exactly one"), equality, richer typing of properties, characteristics of properties (e.g. symmetry), and enumerated classes.

4.2 Creating ontologies for the proposed methods

The first step in creating ontologies for development projects using QFD, FMEA and/or TRIZ is to define the meta models of each method. A meta model is the description of the object classes and their relationships. They provide a controlled vocabulary of terms, each with an explicitly defined and machine processable semantic. Although they are also an ontology, please do not confuse them with meta ontologies, which capture the representation primitives used to formalize knowledge in a given knowledge representation family or system.

Ontology building is a process. The usually accepted stages through which an ontology is (at least for the purposes of this study) built are:

1. identify the purpose and scope of the ontology
2. build the ontology by capturing knowledge, coding knowledge and reusing appropriate knowledge from existing ontologies,
    a. capture knowledge by identifying key concepts and relationships in the domain. A precise unambiguous text definitions have to be produced for such concepts and relationships. Finally, terms are identified to refer to such concepts and relationships.
    b. code knowledge by explicit representing the captured conceptualization in some formal language. This is done by using some representation ontology language to create the code.
3. evaluate the ontology technically
4. document the ontology by reporting in a document and along the implementation, what was done, how it was done and why it was done.

The purpose of our ontologies was described all along section 2.1 and the beginning of this section. Summarizing the purposes very briefly, it can be said that the ontologies should allow the integration of cross-functional activities. An ontology can provide a controlled vocabulary of terms for each method and the domain of knowledge under discussion. Thus, each ontology will have an explicit defined semantic besides being also expressed in a machine processable semantic.

Knowledge acquisition can begin, for instance, with brainstorming and meetings with domain experts. This is actually a middle-out approach to produce the conceptual model of the ontology, instead of a bottom-up or top-down approaches. A middle-out approach begins by conceptualizing and defining the concepts that are more highly connected to other concepts since these are the most difficult to be correctly and accurately defined. Other sources of knowledge are technical documentation, interviews and workshops.

The idea of using methods like QFD and FMEA to populate ontologies is supported in the fact, that they were not designed by or intended for the use of the AI community (which has nothing wrong, but their ‘language’ and ‘Denkstrukturen’ are not those of the industry), but rather they were designed within the industry and with the purpose of simplifying the work of its people. Said in other words, the same human resources working in development projects will be populating their ontologies. This is very important because initial costs of building ontologies can appear to be high, as specialists usually are expensive people. The simple preconditions for doing this is that modeling must be made extremely easy and add a personal benefit to their daily work. Additionally, personal goals have to reflect the efforts spent on this knowledge management activity. [Fillies, et.al., 2002]

The meta model must be done by a modeler with working experience on the proposed methods or with close assistance and supervision from experts in development projects. Using a graphical tools like SemTalk and Visio the building of such ontologies is very easy. SemTalk is built on a RDFS-like XML data structure. Standard RDFS has been enriched by diagramming information and object oriented features like methods and states. Optimized structures for basic inferences such as inheritance and graph traversals are also included. [Fillies, et.al., 2002]. Figure 25 shows an example of the QFD meta model developed with SemTalk using UML class notation.

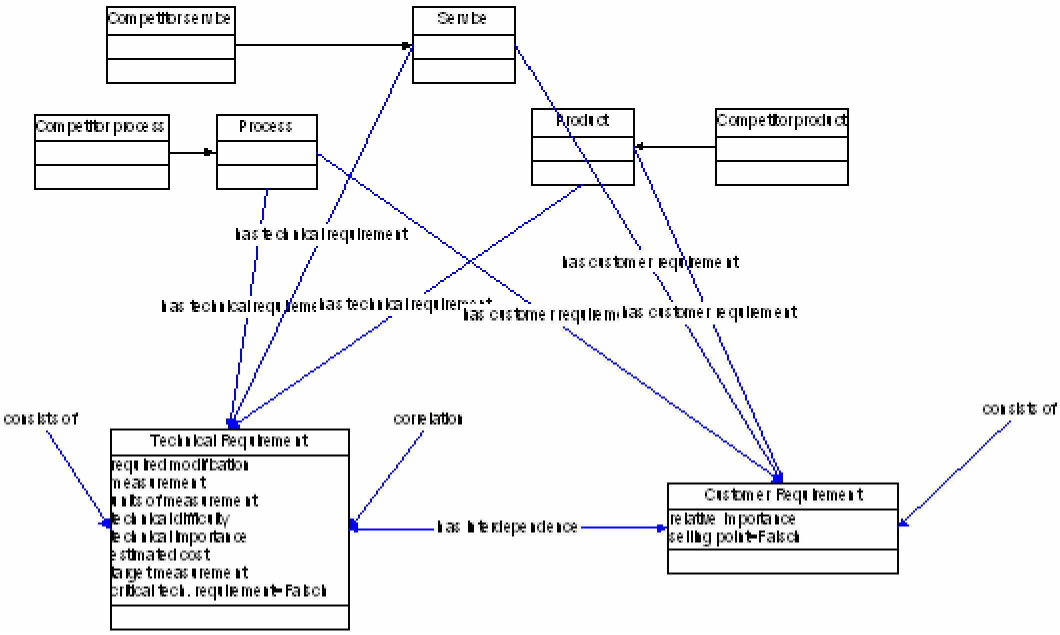


Figure 25: QFD Meta model

In this way, the project team has a very basic modeling language. The specific ontologies (i.e. the application ontologies[7]) using the meta model above, can be also populated using modeling tools like SemTalk, but that will take distance from the usual working style or habits of industrial experts in development projects. Therefore, a graphical user interface (GUI) needs to be developed according to the proposed methods. In other words, the GUI has to be such, that at the time of entering data in a House of Quality, a FMEA Worksheet or a TRIZ Innovation List Questionnaire the experts will not notice that they are really populating an ontology.

Considering the available technology, the ontologies should be stored using the Semantic Web format OWL. Libraries of ontologies can be published and made available for use in other development projects and/or in future stages of an ongoing project. This will be explained in the following sections.

4.3 Computer-supported QFD, FMEA and TRIZ

It is the author's opinion that any computer support for the reviewed methods should not be limited to an appropriate Graphical User Interface (GUI), although it has great importance. Like explained before, ontologies will bind knowledge bases with the GUI and the applications. A knowledge-based method, that is supported by an information system, must facilitate not only the capture of explicit

[7] Application ontologies describe knowledge pieces depending on both a particular domain and task. Therefore, they are related to problem solving methods.

and implicit knowledge through an appropriate GUI, but also its transformation into a machine-understandable notation. Furthermore, the knowledge will be publish as reference models (of processes, products, services, standards, etc.) in an information network (e.g. Internet or an intranet) so the users can make use of it in different tasks. It must be also subject to update, modification and validation from authorized persons in a decentralized way.

To achieve these goals, a integrated system is here proposed. As mentioned before, SemTalk will be used to develop models were a direct involvement of the industrial experts is not needed (e.g. meta models). An appropriate GUI for FMEA, QFD and TRIZ must be developed. The following are prototypes of such GUIs.

4.3.1 The Graphical User Interface

The QFD methodology was explained in section 3.1. An appropriate GUI should guide the user through the well define steps of this methods. It should allow the immediate view of the relationships between the requirements and their attributes as well. Since the users will always compare two types of requirements, and at the same time each one can be subdivided into more specific requirements, two tree structures facing each other seems to be an appropriate visualization strategy. (See Figure 26).

With the QFD Editor GUI the user(s) will populate ontologies while he or she collects the information from QFD sessions, as the GUI matches the previously prepared QFD meta model (see Figure 25). Both kinds of requirements can be saved in separate tables in an MS Access database, so they can be reused separately in other projects. Concepts, including their relationships, attributes and other information captured during a QFD session will be stored in an ontology database, specifying context information for this purpose (e.g. project name, date, stage in the QFD cascade, etc.) In this way, these ontologies will serve as reference models for subsequent activities, like queries, process modeling, reporting, etc.

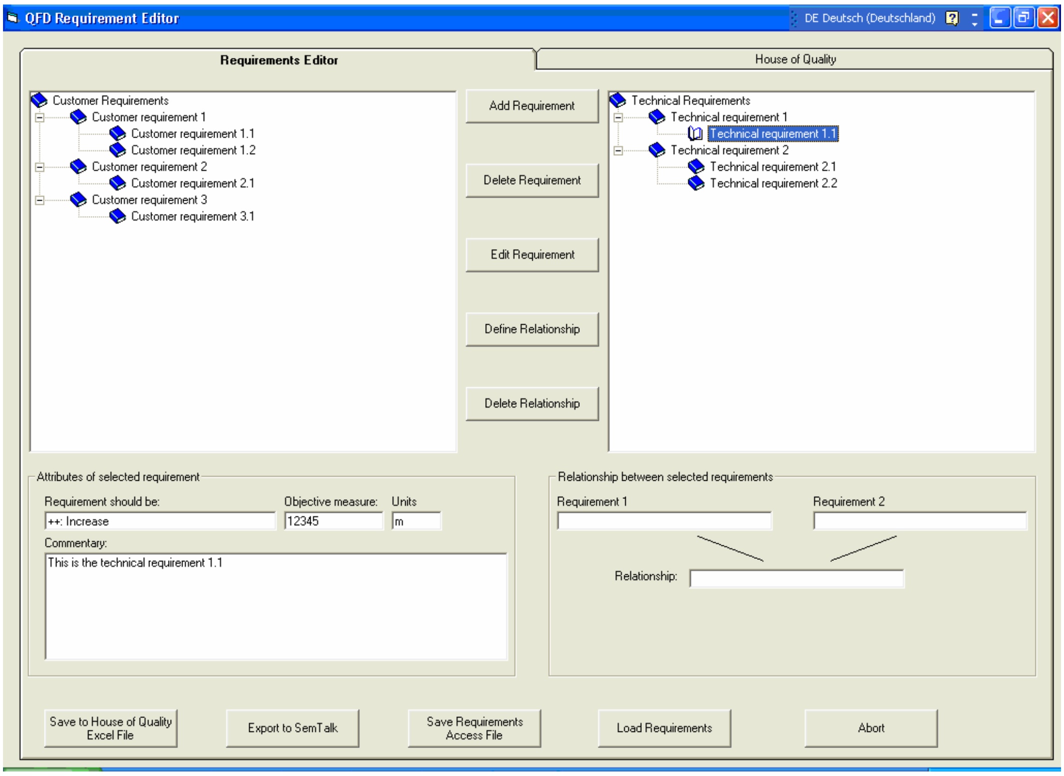


Figure 26: QFD Graphical User Interface – Requirement Editor (Author)

To display the results of the requirements analysis, a House of Quality using a MS Excel spreadsheet is the best and easiest way to do it. Moreover, SemTalk has included in its functionalities an "Excel import", which makes it very easy to transform the HoQ into an ontology. In order to do that, the information in the HoQ must reorganized and classified in form of lists corresponding to the different classes, attributes and relationships. This reorganization is done simultaneously by the same editor. The SemTalk application to import the information of an Excel table is available as a open-source macro in an Excel template, which can be modified to match specific meta models of the different methods.

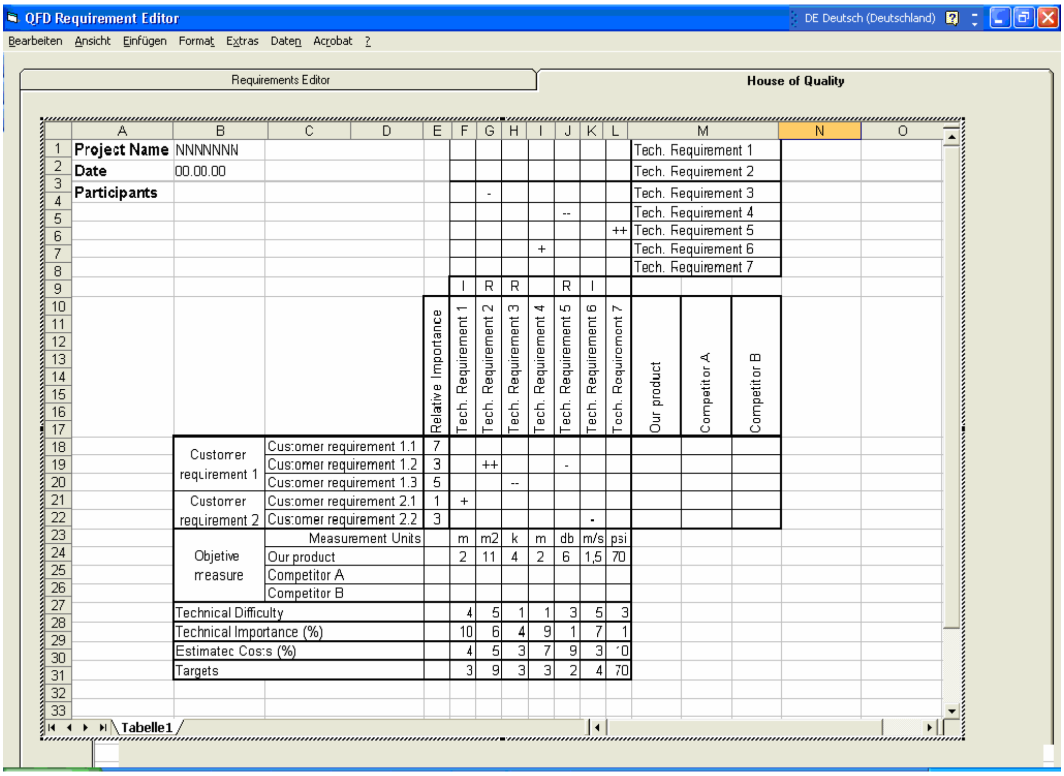


Figure 27: QFD Graphical User Interface – House of Quality (Author)

The FMEA GUI follows the same principle of the QFD GUI. A tree structure determines the relationships between the potential failure, the potential consequence of the failure and the probable cause of such a failure. The first children of the tree structure are the system/functions which are being analyzed. They can be imported from a Access database or Excel table containing the system breakdown (refer to section 3.2). The system breakdown will be done previously in SemTalk using a FMEA meta model and template. (See Figure 28)

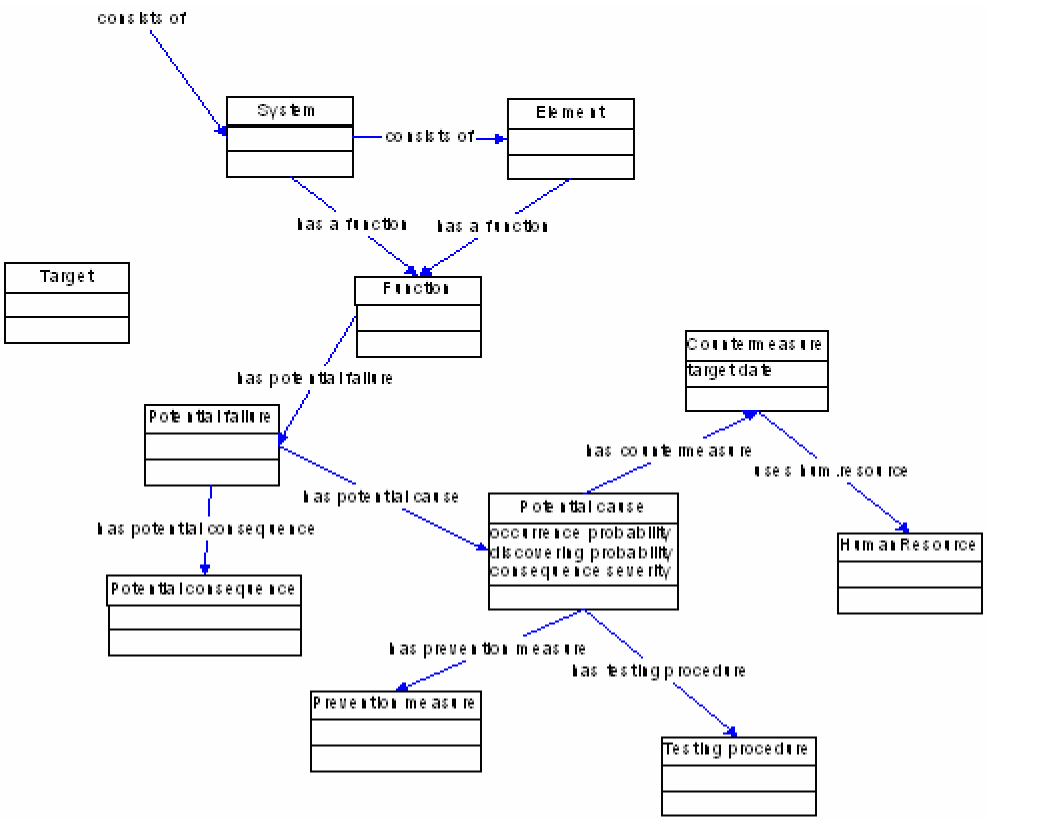


Figure 28: FMEA meta model (Author)

The user(s) select the system/function on which the want to apply a FMEA analysis. Next, they will enter the information that arouses from the FMEA session with the corresponding experts. The tree structure is developed during the FMEA session. (See Figure 29)

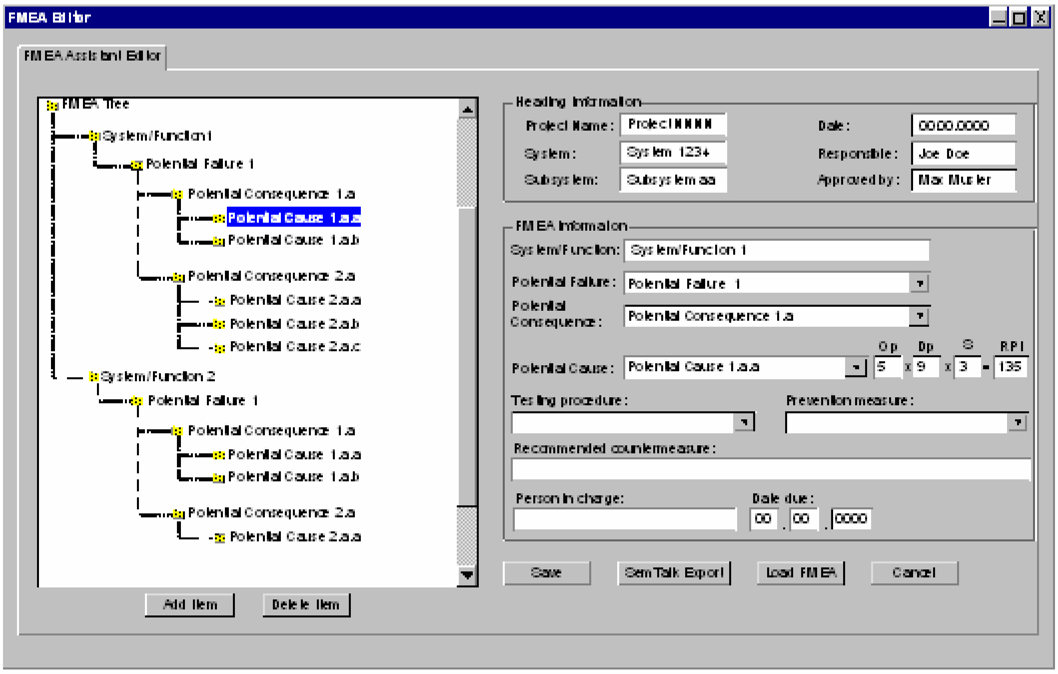


Figure 29: FMEA Graphical User Interface – FMEA Editor (Author)

The information collected in the FMEA Editor will be presented as a typical FMEA worksheet using an Excel template (see Figure 30). The procedure to turn this information into a model is analogous to the procedure explained for the QFD GUI.

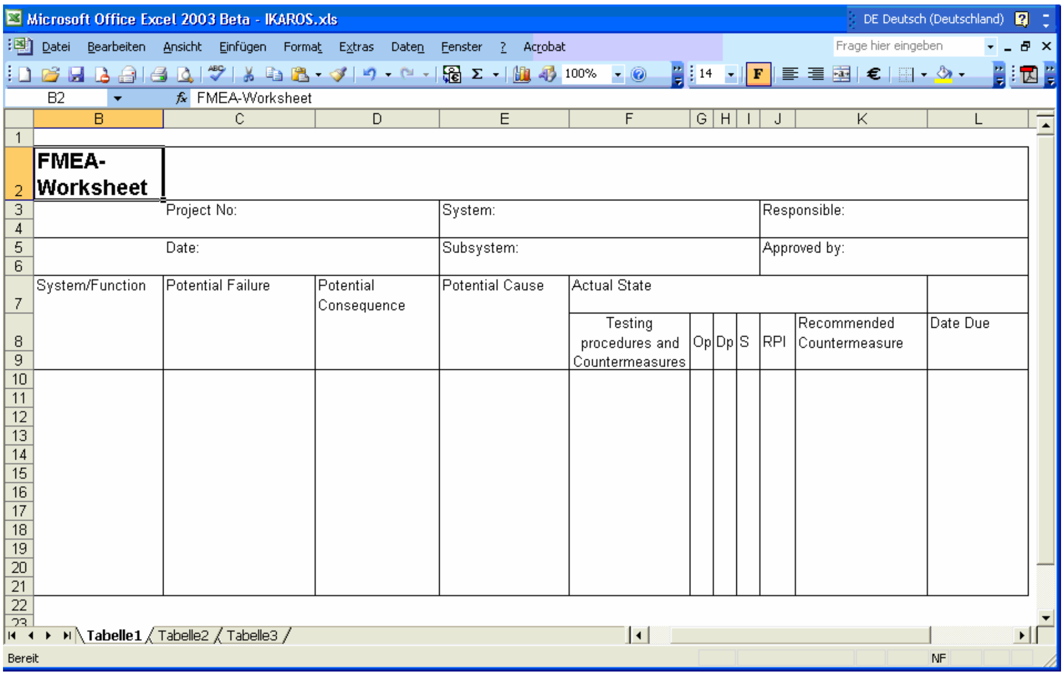


Figure 30: FMEA Graphical User Interface – FMEA worksheet template (Author)

The case of TRIZ is somehow different. The information collected with the two previous GUIs will provided most of the information required for applying the TRIZ methodology when needed. In order to reuse the ontologies, rather than using a merging strategy, a integration strategy will be used.

Merge is the process of building an ontology in one subject reusing two or more different ontologies on that subject [Pinto et al. 1999]. In a merge process source ontologies are unified into a single one, so it usually is difficult to identify regions in the resulting ontology that were taken from the merged ontologies and that were left more or less unchanged. On the other hand, integration is the process of building an ontology in one subject reusing one or more ontologies in different subjects [Pinto et al. 1999]. In an integration process source ontologies are aggregated, combined, assembled together, to form the resulting ontology, possibly after reused ontologies have suffered some changes, such as, extension, specialization or adaptation. In an integration process one can identify in the resulting ontology regions that were taken from the integrated ontologies. Knowledge in those regions was left more or less unchanged.

In this specific case, the integration is achieved with the use of three central concepts in each of the three meta models, that is “System”, “Element” and “Function”.

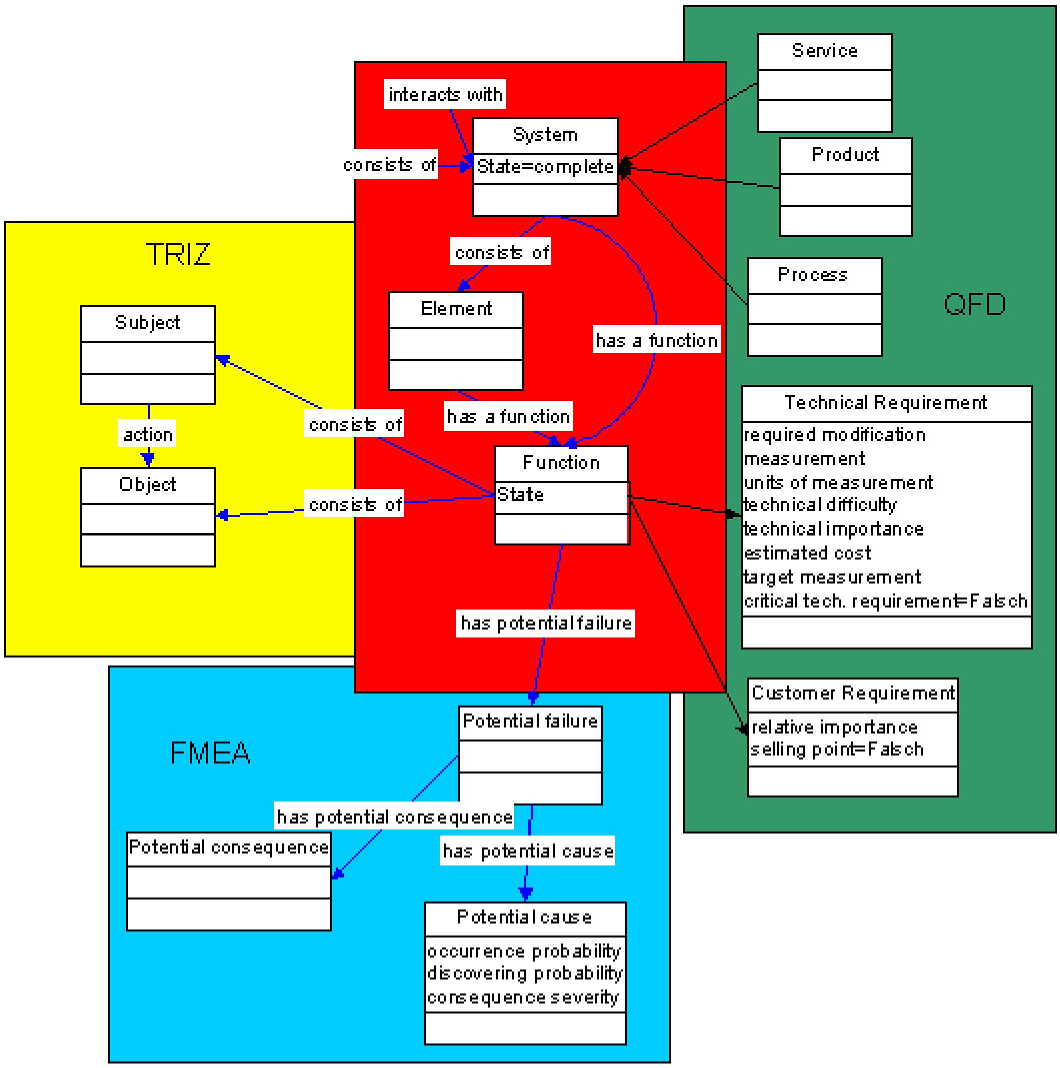


Figure 31: Integration of the QFD, FMEA and TRIZ meta models. The red section in the middle indicates the common concepts which allow the integration. Only sections of the meta models are shown.

Using the TRIZ GUI, the user(s) will only select a specific information on which he or she wants to apply the TRIZ method. This information originates from a QFD or FMEA exercise and it was saved as an ontology. With the aim of applying the TRIZ problem-solving method, the concept selected will be a “Function” for which a problem has to be solved. In the same GUI the user will record the necessary information for the TRIZ analysis. For example, out of a QFD exercise the user(s) decided that a customer requirement is very important, but a very negative relationship between two technical requirements needs to be eliminated before satisfying it. Using a TRIZ GUI the user(s) will load or enter the necessary information about the concerned system and the particular problem. The problem definition is done with SemTalk according to the problem definition method explained in section 3.3.2.1.

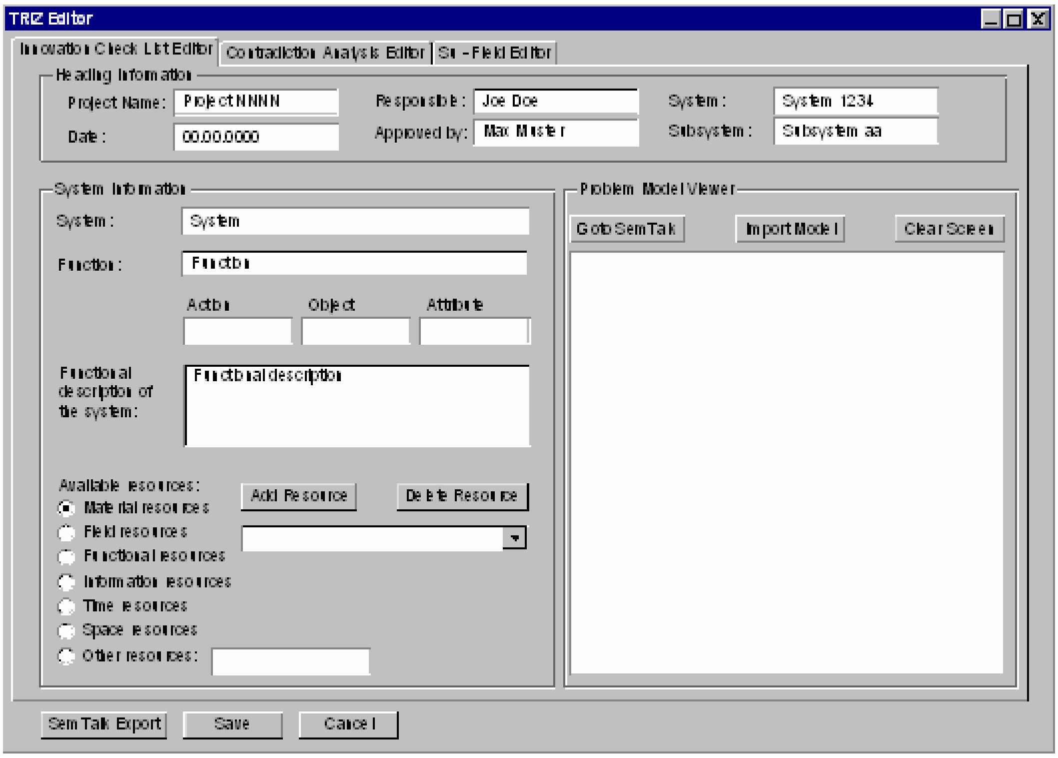


Figure 32: TRIZ Graphical User Interface – Innovation Check List Editor (Author)

The Contradiction Analysis Editor and the Su – Filed Editor are two alternative GUIs with the aim to assist the expert(s) finding a solution for the problems defined with the previously shown GUIs. As explained in sections 3.3.2.2 and 3.3.2.3 both methods try to formulate the considered problem with a new approach. In this way, the search of a solution for analogous problems should a least suggest an analogous solution. Therefore, the important aspect of these methods is not the graphical user interface, which in both cases should run under SemTalk, but rather the knowledge base and the query procedure for such a knowledge base.

4.3.2 Knowledge Bases

[Debenham J.K., 1998] defines a Knowledge-Based System (KBS) as a system that represents an application containing knowledge and has been designed, implemented and possibly maintained with due regard for the structure of the data, information and knowledge. Knowledge for KBSs is basically expressed as declarations and it can be acquired by humans or automatically derived using abductive, deductive, and inductive techniques [Omelayenko B., 2000].

KBSs are applied directly to concrete problems of a real-world domain in concrete situations on a daily basis by domain users or experts. KBSs are based on competence models rather than performance models because it is the contained knowledge what matters and not its behavior. Since the solutions for pragmatic problems are highly context and situation dependent, a KBS must be extremely flexible to maintain and develop. These characteristics make the maintenance of KBSs and the evaluation of their competence very difficult to perform. [van de Velde W. et al, 1994].

All semantic structures, as well as the data that identifies document sources (e.g. document titles and URLs) will be stored in a KB. SemTalk can store models as knowledge bases somewhere on a webspace. Very important is that the models and thus the knowledge bases are expressed using a common syntax like XML. In this way, the retrieval and display of information depends only on the interface used. Another advantage of this approach lies on the reuse of other KBs published as webspaces as well. Online lexica and domain-relevant knowledge bases are already available for public use as webspaces. Some examples include WordNet[8], the DAML ontology library, the GALEN medical ontology, etc. The DARPA[9] ontology library which contains about 250 ontologies about a wide range of subjects. The ontologies have been written in OWL or DAML+OIL.

Very interesting is the case of WordNet, which is an online lexicon with contains English nouns, verbs, adjectives and adverbs. They are organized into synonym sets, each representing one underlying lexical concept. Different relations link the

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[8] WordNet® is an online lexical reference system whose design is inspired by current psycholinguistic theories of human lexical memory. WordNet was developed by the Cognitive Science Laboratory at Princeton University under the direction of Prof. George A. Miller. http://www.cogsci.princeton.edu/~wn/

[9] The DARPA Agent Markup Language (DAML) Program officially began in August 2000. The goal of the DAML effort is to develop a language and tools to facilitate the concept of the Semantic Web. http://www.daml.org/ontologies

synonym sets. With SemTalk, one can reference online this lexicon, allowing the user to e.g. introduce on-the-fly synonyms, hyponyms, hypernyms, meronyms[10], and other semantic relations natural to the human memory. It is probably unnecessary to mention that e.g. problem-solving activities can take advantage of such functionalities. After an expert has clearly stated a problem, he or she will abstract it and will search for a standard solution for it. The term abstraction process can be underpinned with online lexica like WordNet emulating the human reasoning process. The next step, that is deduction of a specific solution for the problem can be assisted by this technology in the same way.

SemTalk includes a Wizard to support the user during the modeling process. The Wizard 'keep an eye on' the modeling process and he will offer suggestions about whether the user is actually rebuilding models that already exist on the Semantic Web. The user can develop an ontology which can be linked to various RDFS data sources. Each class in the ontology can be linked to a class in another model, and thus entire ontologies can be generated from externally shared models. Each class can be identified and located using its URN. The Wizard is supported by a Crawler, which looks independently or on request if such terms were already used in a published ontology and creates index files for the Wizard. The Crawler looks not only in the local file system but also in the Semantic Web for available sources of knowledge in the format RDFS. Furthermore, the Wizard checks the terms being modeled after a given set of rules about writing like upper/lower case, detecting synonyms and in the investigation of situations where the inheritance structure appears to be incorrect. and checks in the Internet. [Fillies, et.al., 2002]

An ontology that has been published as a webspace, or a whole collection of them, can accessed by inference engines like Ontobroker™ or Cerebra™. The idea behind, is that one day computers will have access to structured collections of information and sets of inference rules that they can use to conduct automated reasoning. [Berners-Lee T. Hendler J., Lassila, O. 2001]

Ontobroker[11] is a commercial inference engine, which can use knowledge models and data from different sources to answer queries. It is a main memory deductive, object oriented database system. New knowledge can be derived with Ontobroker by evaluating the axioms in the knowledge models. In the same way

[10] Hyponym is a word that is more specific than a given word (relation *is a*). Hypernym is the opposite of a hyponym. Meronym is a word that names a part of a larger whole (relation *has a*).

[11] Ontobroker is available from ontoprise GmbH, http://www.ontoprise.com

Ontobroker can check the consistency of the available models. It runs as a middleware system and thus may be used by a variety of applications as an information delivering base. [Fillies, et.al., 2002]

Ontobroker may be used in three different ways: i) it may be used as a separate application which reads input files containing facts, rules and queries, which then evaluates the queries and finally prints the answers, ii) it may be used as a server which reads input files containing facts and rules and which then evaluates queries sent to the server and sends the results back and iii) it may be used as a library for integrating inferencing services in own applications. Ontobroker integrates the access to different information sources like databases, keyword based search engines etc. It reads various input formats like XML, OXML, RDF(S), F-Logic, Prolog. Thus it provides a homogenous access to an inhomogeneous set of information sources and input formats. (www.ontoprise.de: Ontobroker Tutorial).

It is possible to make queries with SemTalk and Ontobroker using its query language F-Logic and by sending a list of possibly relevant knowledge bases to an Ontobroker server. The server returns a list of XML encoded solutions to the query. Each variable binding in a solution can be a reference to an object in a knowledge base. The user can insert objects into SemTalk directly from the URNs provided in the result set. [Fillies, et.al., 2002]

Cerebra is a Description Logic based inference engine with reasoning support for the Semantic Web recommendation OWL[12]. Such an engine is required to support the creation and maintenance of large scale ontologies. With Cerebra the user loads an ontology that exists locally or remotely, or make use of an ontology that has already been loaded into the Cerebra Server™. If requested to load the ontology, Cerebra Server™ will fetch that ontology from a given URL, and parse the expressed information, constructing an internal model of the explicit ontology. At the time of parsing, the ontology is checked for the OWL syntax and errors are reported back to the client applications.

OWL ontologies are constructed so that a given ontology can import concepts and relationships from other ontologies that exist on the web. Cerebra Server™ will automatically follow all of the import clauses that exist, providing a central unification of a distributed set of ontologies and concepts. The import functionality

[12] OWL is not a real acronym. It should stand for "Web **Ontology** Language" but the W3C working group decided to use the word OWL.

can be tuned to a specific implementation through use of Construct™ to only import a given set concepts or relationships from a designated imported ontology, which prevents massive document loads. Construct™ was developed in collaboration between Semtation and Network Inference. It is a OEM version of SemTalk for Cerebra that supports axioms according to the OWL specification using graphical symbols and advanced reasoning. Cerebra's engine detects inconsistencies in respect to specified axioms like disjointness or equivalence using Description Logic. Cerebra Server uses XQUERY as query language and Construct as interface and thus, the approach is very similar as the one explained before for Ontobroker.

4.3.3 Applications

From the previous sections of this chapter a series of requirements can be derived in order to choose or create the most appropriate applications to achieve the objectives of this thesis. The applications should be permit:

- the representation of real world entities without distorting and decomposing them.
- the re-use or extension of existing software.
- the use of development of environments, which include tools for the creation of interfaces and their fast prototyping without having to completely recode them.

Object-oriented applications fulfill these requirements quite well. Such applications are constituted by objects with specifically defined features, which communicate between themselves by message passing. Objects have a static and a dynamic aspect. The state or the static aspect of the object is defined by means of instances, variables and attributes, while the dynamic aspect or behavior of the object correspond to the operations that can be performed on the object.

Following the object-oriented architecture, Microsoft introduced in 1994 the Visual Basic controls, which are known today as ActiveX. Microsoft promotes the use of the object-component model (COM) for the efficient management of distributed objects and the incorporation of these into compound documents[13]. Microsoft

[13] A compound document is an electronic document that can contain diverse components. Each component is an independent, autonomous object, capable of cooperating with other objects in a distributed system with the intention to provide a globally available service to the application.

offers a wide variety of environments such as Microsoft Word, Excel, Access, Visio, Visual Basic, etc. were these controls are available.

For this reason, the Microsoft Office products have been chosen as the main applications for the proposed methodology and Microsoft Visual Basic is the natural choice as the programming language to develop the different interfaces considered in this proposal .

Moreover, an appropriate application should support the communication between disparate systems and formats. By communicating in real-time, the systems should be able to share that data, streamlining the process of exchanging information between PCs and back-end systems, and allowing the creation of integrated business solutions across the organization and between internal and external business partners. This can be now achieved with the industry-supported XML standard.

Although many business processes rely on XML for data exchange and transaction processing, and even supposing that the necessary servers and architecture are in place on the Internet and at the enterprise level, XML is yet to be exploited on the desktop. The key to implement XML in end-user scenarios is to separate content from presentation in desktop applications.

In this way, the new office suite from Microsoft, MS Office 2003, is the first set of new office solutions and applications in which XML plays a significant role. For example, a document in MS Word 2003 can be saved using a native XML file format, which fully represents a Word document without the loss of Word formatting. This means that a developer can very easily detach presentation data without having to worry about hindering the experience for users.

To do that, the user has to annotate or tag the information in the document using the XML notation separately from the presentation data. XML uses tags to define specific elements within a document. They will define the document’s structural elements and the meaning of those elements. XML contains no predefined tag set, making it an extremely flexible meta-language, but as a rule business processes need information to be standardized for further processing. XML schemas define the set of tags and the rules for applying XML tags in a document. Schemas define the structure and type of data that each data element in a document can contain and can be created by a user, a company, or at the industry level. Thus, XML schemas can be created to define and qualify content for virtually any application. Hence, XML documents are text-based, structured, and platform-independent, which can be opened and operated on by a range of editing programs (e.g. MS Office 2003 applications) and integrated into automated business processes.

The philosophy behind this new feature in MS Office 2003 is that a common user will be able to annotate his or her documents, generating XML files without doing any programming. In that way the MS Office applications can be used as:

- an XML editor for customer-defined schemas
- a content management and repurposing tool
- a structured data editing tool
- a data reporting tool

These features are indeed very important for the proposed system, but they are not enough. Marking-up documents with an XML notation is only a process of capturing information. The XML Schemas are very useful to control and validate the data elements in the document, but they say nothing about the relationships that the document elements have between them nor about their relationships with other documents. SemTalk can be use to create the XML Schemas for specific projects according to the methods proposed, but until this information is not transformed into a ontological notation like RDFS, DAML or OWL it can not be reused as knowledge. In other words, the resulting XML documents can only be useful for knowledge reuse, if a network of terms (i.e. an ontology) has been built by people who understand the domain of knowledge. In this way, SemTalk and the interfaces proposed above add value to the knowledge generated within projects (e.g. development projects). Figure 33 illustrates the architecture for this system.

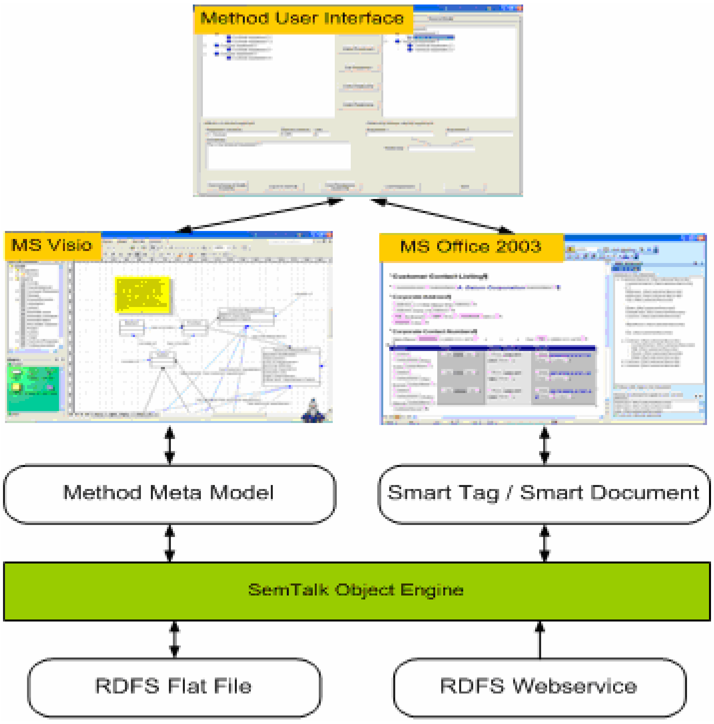

Figure 33: Proposed architecture using SemTalk as central element.

With the technology described previously the process to transform the captured information in distributed models should be the following: (see also Figure 34)

1. The user captures the project-related information using the appropriate GUI (QFD, FMEA, etc.).
2. MS Office 2003 applications are used to present the information according to each method. (QFD → House of Quality [e.g. MS Excel Spreadsheet] ; FMEA → FMEA Worksheet [e.g. MS Excel Spreadsheet], etc.)
3. The information is detached from the presentation data. The user interfaces create a separate file where the information is arranged so that it can be imported by SemTalk. (Currently we are using SemTalk Excel Import)
4. The information is imported by SemTalk and arranged graphically into a model. The model can be edited, integrated to other models, or complemented with more information. With the approval of the project coordinator, the model can be published in the Internet or in company's intranet as a webspace.
5. Models can be reused to develop: [Fillies, et.al., 2002]
    - Business process models.

- Project specific glossaries.
- Company wide glossaries.
- Further models.

6. Selected terms can be used to create XML schemas. They can be used to define Smart Documents for project or company related activities. XML Schemas can be used to validate project data.

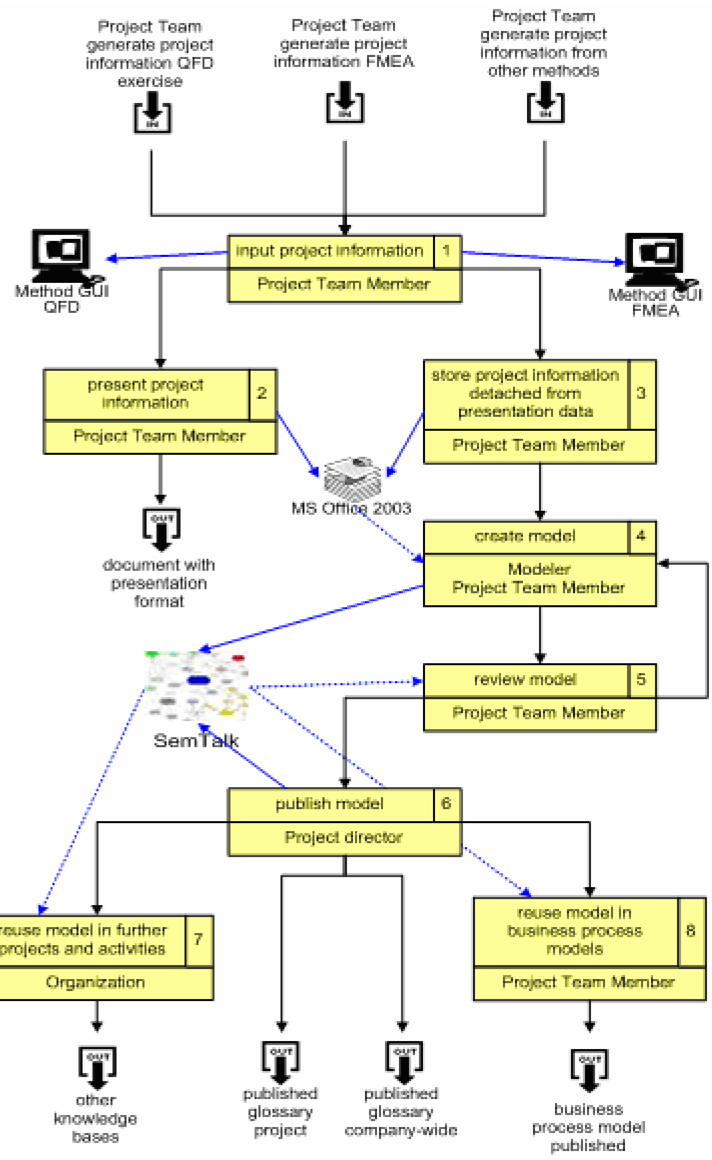

Figure 34: Transforming captured knowledge into reusable knowledge.

SemTalk takes advantage of the presently available Smart Tag technology in Office XP to create awareness of available terms in published ontologies (indexed models) in real-time document editing. While editing the SemTalk Class Recognizer Smart Tags will check if terms found in Word documents, Outlook emails, MS Project plans or Excel spreadsheets have been already modeled.

Once a term has been recognized it will be underlined with purple dots and it will offer the user a series of options like to jump to the model in SemTalk or browse the model in an Internet browser. The user will immediately see a graphic representation of the term and its related terms.

In MS Office 2003 the Smart Tag technology has suffered modifications and SemTalk is yet to adapted them to its SemTalk Class Recognizer. Smart Tags in MS Office 2003 will offer new features, but among them two can be of importance to our approach. Now Smart Tag action menus now can be altered at run time. This can be very interesting to point exactly at models by using their real names. Until now, a SemTalk Smart Tag will only show this options mentioned above. But if the same term has been used in different models it would be preferable to choose a model which better represents the term in its context. For example, the user can choose to see the term in a QFD related model (if available) or in any another methodology used in the project. The second interesting new feature involving Smart Tag action menus is the ability to create cascading menus. Action can be logically grouped by hierarchy to make it easier for users to find related actions, shorten the overall menu length, or simply consolidate actions under one heading so they are separated from other action handlers.

MS Office 2003 has a very interesting new functionality for our proposal. The Smart Tag metaphor has been extended to a document level in what is called Smart Document technology. With the Smart Document technology templates for development project reports can be created and made available to project members. As users enter information, the task pane is automatically updated to offer relevant content that may be instructional and/or functional. For example, the user is entering data about the results of a mechanical test for a new product, the task pane will show the corresponding fields that need to be fill for such test, as well as the units and ranges allowed. The validating information has been modeled previously with SemTalk and has been exported as XML Schemas. The report will be marked-up as the user enters the data. This information can be easily expressed in Excel tables for further calculations.

The solution developer can take advantage of an existing document or create a new document to build a Smart Document solution. The document must be attached to an appropriate XML schema, which is then used as the basis for marking it up with the corresponding XML elements. Once the document is prepared, developers use the Smart Documents API to build the automation that drives the solution. The code will control the document directly or it could interact with server-side processes, such as retrieving data or routing the document (or its contents) to a back-end system to complete the solution.

The API for creating Smart Documents is very similar to the Smart Tags API on which it is based. The developer can reference the API with Visual Basic. Although Smart Documents and the code behind them are closely related, they exist independently of each other, and thus they can benefit from reusing other common components beyond the project.

5 Conclusions

In the first chapters of this master thesis (chapters 2, 3, 4 to be exactly) a theoretical substantiation was given to support hypotheses 1, 2 and 3 and to answer the corresponding questions. In Chapter 5 a technological solution for hypotheses 3 and 4 was proposed and partially developed. Next, the hypotheses will be remembered and discussed in order to reach a set of conclusions for each hypothesis.

<u>*Hypothesis N° 1:*</u> *In order to manage and maximize the continuous flow of knowledge in the innovation process and thus to maximize the competitiveness of an organization, three conditions must be fulfilled: parallelization, standardization and integration of activities.*

In chapter 2 evidence was given to demonstrate that the innovation process is a truly cross-functional process. The complexity of products with a high added value requires the participation of members out of almost every functional group in the organization. Specially during the development stages of the innovation process experts with very different areas of expertise must converge and integrate their knowledge (physically and now sometimes virtually with the help of modern IT technology) to analyze requirements, discuss capabilities and define products, services and processes. The flow of knowledge will vary in intensity depending on the degree and on the subject of the innovation, but in any case the flow of knowledge will require an efficient management to yield the best results. Moreover, people must work in continuously more demanding scenarios where the life cycle of products and technology is shorter everyday, competition is globally distributed and the interaction between supplier, customer and competitor increases simultaneously. Companies have to do more, in less time, reduce costs, and offer products with a better quality to remain competitive.

Although each innovation process is unique, a management philosophy for it must aim to create a framework to standardize and integrate the flow of ideas and information without kidnapping creativity. The aim is that everyone participating in the innovation process will understand the goal being pursued, they will comprehend their role in the process, allowing them to make better decisions individually and ultimately as a team to accomplish the goal. This is only possible when comprehensive knowledge is given to them.

Within the innovation process the parallelization of activities makes possible a reduction of the time-to-market. Usually knowledge-intensive activities can be triggered before all the information necessary to perform the activity is available. Moreover, parallelization and a continuous flow of information will allow an early identification and resolution of conflicts. Even new ideas to improve the design can be implemented at run-time, and not until the end meaning high modification or repair costs or even losing the opportunity to the first-to-market.

Parallelization, standardization and integration of activities are the basic principles of concurrent engineering. CE must be understood as a management philosophy and not a precisely defined technique. Although, concurrent could mean simultaneous, the concept concurrent engineering should be better identified with the idea of simultaneous activities converging to a goal(s). Communication is the factor holding together the three basic elements of CE. Excellence in managing the communication in CE projects will determine the success of it. Thus, knowledge-intensive activities of innovation process will benefit of an appropriate implementation of CE.

Hypothesis N° 2: The innovation process consists mainly of cross-functional activities. A continuous improvement system seems to be necessary so that every individual member of the organization can contribute to the added-value chain in the innovation process.

Also in chapter 2 it became evident that the innovation process is a continuous process in today's modern business organization and that at one moment or the other every member will have a role in its success or failure. The development of products, services and processes usually is carried out as projects, but the benefits of implementing concurrent engineering in those projects can be also extended to the entire organization. With this aim, the author considers that first of all the business organization must be perceived by its members as a system. The basic relationship within this system can be defined as the customer-supplier relationship. Therefore, by carrying out their corresponding activities the members will create a customer-supplier network. The functions in this network are distributed so that the goals of the organization are accomplished.

Furthermore, the way in which the business organization interacts with its environment, including customers and suppliers constitutes an external customer-supplier network.

A essential condition for this approach is that every member of the internal or the external customer-supplier sees himself or herself performing in both roles all the time. This implies that each member is aware of their responsibility and importance in achieving the goals of the organization. He or she must received constant feedback from its internal customers to facilitate the management of the available resources and make appropriate decisions. Furthermore, acting as a user and as a provider, he or she will have to constantly control that the outputs of their effort to meet the input requirements of other members in the added-value chain.

Such interactions can be easier managed in small groups like those of development project teams. A successful development project team, which is interdependent on each other, requires different tools such as an ongoing monitoring of dependencies and task interrelationships to see where certain tasks may be falling behind schedule (or even going too far ahead) or not meeting the defined requirements. Therefore, the formation of a successful team is a continuous cycle of improvement.

Development projects can be used to experiment the implementation of management techniques (e.g. QFD and FMEA), which could be later extended as a management philosophy to several departments and maybe finally to the entire organization. Concurrent engineering can be initially applied in several development projects using different management techniques. Subsequently an evaluation can determine the best way to implement it and transform it in a company-wide continuous improvement system. One of the technical reasons to experiment first in development projects is that initially the employment of continuous improvement system will require a higher cash expenditure with less visible output in comparison to the older functional approaches, where financial allotment is more evenly distributed. This may cause resistance from higher management levels eager to see immediate benefits.

The switch from a traditional function orientation to a concurrent engineering approach could be a key factor in the implementation of continuous improvement system; especially since most members of a development project team will not be working on the CE project all the time and must return to functional working for other tasks. This will put considerable strain on the group and also on the individuals, but must be persevered with to attain greater long term synergy. In the same way, as team members alter their work perceptions, they will affect all those around them so that people not involved with concurrent engineering at that time can be exposed to the basic principles which may lead to an easier transition into the wider organization and reduces the risk when a fundamental, culture changing technique is introduced.

External customers and suppliers also play an important role in the implementation of a continuous improvement system. Continuous interaction with customers and suppliers (even including them as team members in development projects) has proven to be a worthy practice. Having customers there when the requirements are forged is vital in CE to ensure that quality goals are set correctly. The setting of requirements may be the longest individual component of the whole delivery process, but time spent here can be more time and costly resources saved later in the cycle. The relationship between supplier and organization must be also addressed in a new way where both are to an extent reliant upon one another. Their relationship should aim to prevent unwanted and disadvantageous changes, which become more probable in marketplace(s) where conditions are always changing. Both parties should direct their efforts to ensure a process improvement by planning and creating beneficial and desirable changes. A common advantage of including both external actors in internal activities is that they will usually contribute with valuable and sometimes critical knowledge for achievement of the project goals and thus contribute to the organization purposes.

<u>*Hypothesis N° 3:*</u> *The concept of the conceptual schema for information systems has delivered important contributions to the computer sciences. The same concept can be applied to the knowledge-intensive activities in the innovation process using ontologies as conceptual schema and developing appropriate GUIs based on development methods like QFD, FMEA and TRIZ.*

The concept of the conceptual schema and the concept of ontologies are not new. Both have been present since the 70's in different fields of computer science like AI or database systems. Taking advantage of the maturity of these approaches they were considered very appropriate to develop a new approach to manage more efficiently knowledge-intensive activities within the innovation process. To underpin this approach two well-known product and service development methods, QFD and FMEA, were selected and integrated together following the ontology-based approach.

Ontologies have shown to be the right answer to the structuring and modeling problems arising in knowledge management. They provide a formal conceptualization of a particular domain that can be shared by a group of people (in and between organizations). Ontologies provide a sound semantic basis for the definition of meaning. They are typically used to provide the semantics for communications among humans and machines. Therefore, they are also a means to provide the kind of formal semantics needed in sophisticated KM systems and can represent the conceptual backbone for the KM infrastructure.

Ontologies used to be an exclusive subject of the AI communities, but with the idea of a new layer for the Internet called the Semantic Web, ontologies are being discussed in not only academic circles, but also everyday with more interest in the industry and even by normal users. A Semantic Web (if ever developed) will probably have deeper and more widespread consequences on our everyday activities than the present World Wide Web. Until now, an Internet browser only presents us information as a book contains letters and images. A Semantic Web should allow the communication between humans and machines at a semantic level.

With the actual state-of-the-art technologies, the first signs of a Semantic Web are already visible. These semantic islands in the Internet are being created at academic and industry level to a support KM systems and activities. Therefore, it is considered very appropriate to use the same Semantic Web technology assist knowledge-intensive activities within the innovation process. The author considered very necessary for the acceptance of a technological solution of such an approach that the effort of using it will be minimal. The user of this solution should notice as little as possible the activity of populating ontologies and thus consider it as their daily work. Additionally, personal goals have to reflect the efforts spent on this knowledge management activity. Considering that the QFD and FMEA methods are being used since decades in development projects and the their acceptance has been proven by development experts, they were selected to try this approach. The use of other methods and techniques could be also considered, but always following the idea that technology must be adapted to human activities and not vice versa.

It must be mentioned here, that the author's effort was mainly concentrated in learning and understanding the management methods and their implementation in real-world activities. Once they were mastered, the effort to build the ontologies was considerably less. One of the major reasons was the use of a graphical modeling tool 'SemTalk' to create object and process models. With SemTalk, modeling ontologies takes a big step away of AI activities and a bigger step closer to every day activities in the industry. This does not make the tool less powerful, rather just the opposite, since it allows itself to be reconfigured in order to meet the requirements of customers from a wide spectrum of business fields.

Even though, it can not be assumed the industry experts will be able to model ontologies and processes in SemTalk. Usually expert modelers are in charge of these activities to maintain a higher degree of consistency between models. The idea of using specially designed GUIs in combination with SemTalk arouse after searching for a way to reduce the step of translating the results of product development meetings, where e.g. QFD was used to define relationships between quality requirements, technical attributes, process requirements, etc., to a language that a modeler will understand. A modeler will be always necessary to check consistencies, for example when integrating two or more ontologies or using an object model to develop a process model.

Ontologies will play the role of binding not only the knowledge coming out of product development projects using different methods, but also the knowledge bases, the GUIs and the applications, included in a KM system.

<u>Hypothesis N° 4:</u> *The object-oriented technology can provide the means to develop and implement an ontology-based information system. The XML communication standard supports the communication between disparate systems and formats. XML is also now present in popular commercial office desktop solutions, which allows the normal user to separate information from presentation data. XML-based languages, which offer semantics to the XML syntax (e.g. RDFS) are available and some of them have received industry support.*

One of the main objectives of this master thesis was to demonstrate, that with the help of tools and methods common to business activities in many organizations, a comprehensive approach to knowledge management is possible. For the author it became clear that it was as important to define as a requirement that the technological solution should be relatively easy to develop and extend, and it should be compatible with the existing information systems in an organization. Moreover, the technological solution should add value to the activities performed with the information tools. These information systems should be used as complementary knowledge distribution channels (complementary to project meetings, training programs, quality assurance programs, project management standards, etc.)

These requirements are fulfilled quite well by object-oriented applications. The most popular desktop office solution, Microsoft Office, can be used to develop applications which would pose few effort on the users to learn and use these applications in daily activities.

SemTalk was developed as an add-on of Visio, not only but because Visio is fully programmable. The other members of the MS Office suite share also this feature. Furthermore, in MS Office 2003 version, new features are now available, of which the proposed technological solution could take advantage. They include the possibility of separating completely information from presentation data using XML and allowing the validation and standardization of this information through tailored made XML schemas.

A weak point of this master thesis was the lack of programming abilities by the author to develop thoroughly the prototypes of the technological solutions proposed. This also meant that this proposal has not been tested in real-world activities, but because it was completely conceptualized with existing technology, there is the confidence it could be made real.

The degree of acceptance by real-world user was not tested. This is of critical importance, but again it was thought to maintain the working habits of experts. The aim is to assist them in such a way that they would not notice the effort to communicate their knowledge and reuse knowledge from other sources, but rather to experience the results of doing it.

The reader might be asking himself or herself, why was TRIZ included in this master thesis. One of the original ideas pondered in this approach was to design a decision support system or an expert system to assist experts solve inventive problems in technical fields. Actually, this was the initial motivation that triggered this study. The concept of ontologies emerged during the study of a combination of several approaches from Cybernetics I and Cybernetics II: Cybernetics I in the sense of order, computer science and AI tries to develop tools for concrete practical problem solving whereas Cybernetics II tries to create interconnected models that take into account technological, scientific and cognitive requirements.

Very basic but very complex models were done using the UPML (Unified Problem-solving Method description Language) framework approach developed by Dieter Fensel and colleagues [Fensel et al, 2002]. The approach considered the use the UPML framework as support to define the reasoning process of a knowledge-based system and TRIZ will be used to guide the “reasoner” (expert or manager) through a more efficient reasoning process. Moreover, the UPML framework was chosen to formalize TRIZ, because UPML supports modularity and reusability of the components of a knowledge-based system and their use for future Web Services in the Semantic Web.

After writing an article about this approach (which was in fact never published) the author decided to abandon the enterprise mainly because the UPML framework lack the maturity and the support from applications. One month ago, a researcher working for the Stanford University, Dr. Monica Crubezy, posted a tab plug-in that supports UPML for the modeling tool Protégé. Furthermore, UPML has been has been given the ‘Recommendation’ status by the W3C. The formalization of TRIZ with the UPML language can be an interesting subject for future research. Its acceptance in the industry will only happen when tools like SemTalk can be used to develop easy-to-use applications.

The approach proposed in this master thesis can be benefit from TRIZ by using subsets its methodology classify knowledge from development projects in an alternative way. The ’39 Technical Parameters”, the ’40 General Principals of TRIZ’, etc. as classification systems, that together with ad-doc search methods for solutions can benefit the work of experts when dealing with very difficult technical problems. Future research and development can be focused of creating TRIZ knowledge bases and studying the best ways to extracted knowledge from such KBs. The study should include the possibility of developing rules for inference machines according to TRIZ, as well the use of agents to search KBs. A truly interesting web service for the Semantic Web could be based on TRIZ to search huge KBs (like patent databases) and propose solutions for technical problems. The article written on UPML is included in the accompanying CD for those interested in this idea.

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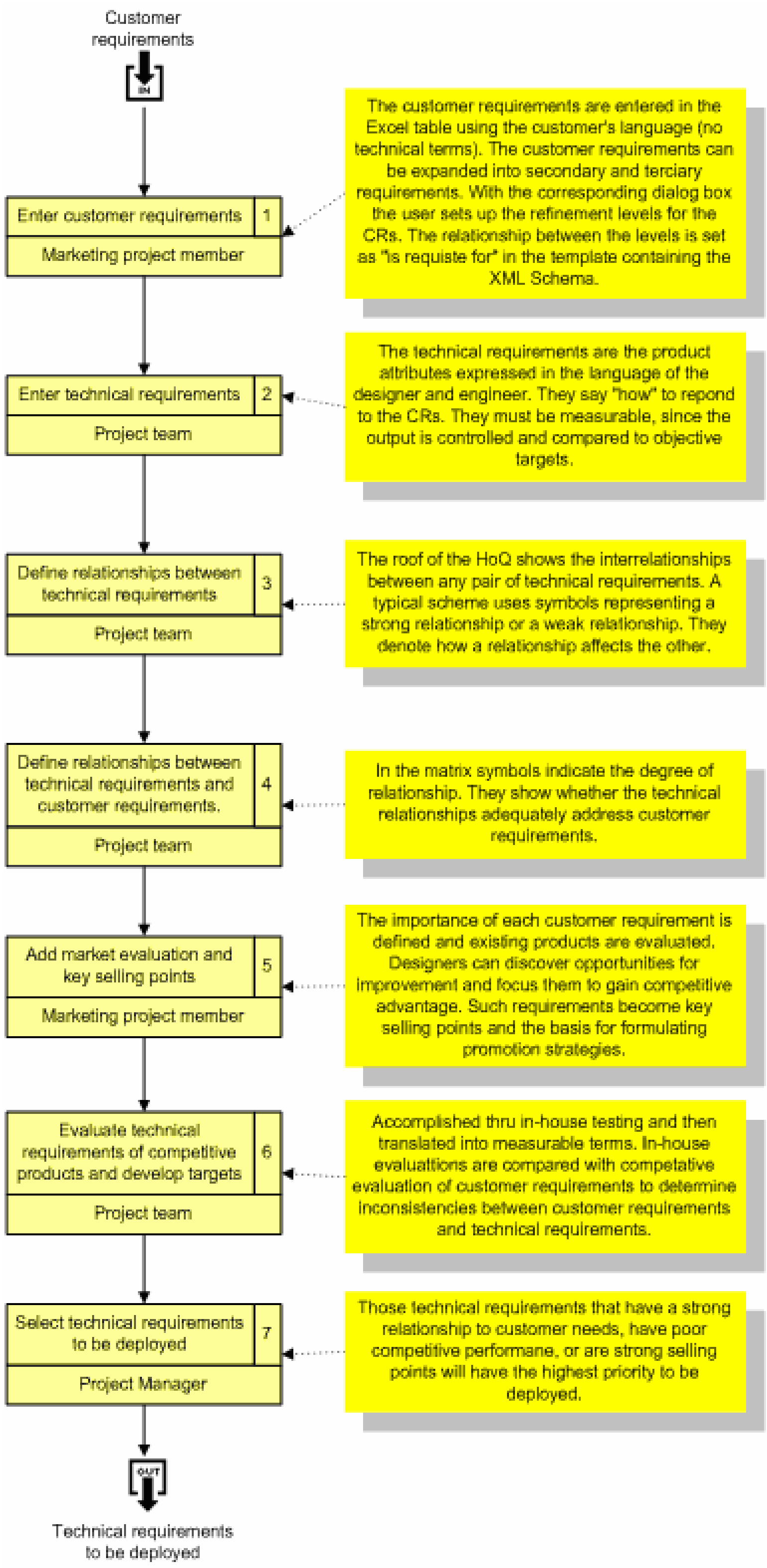
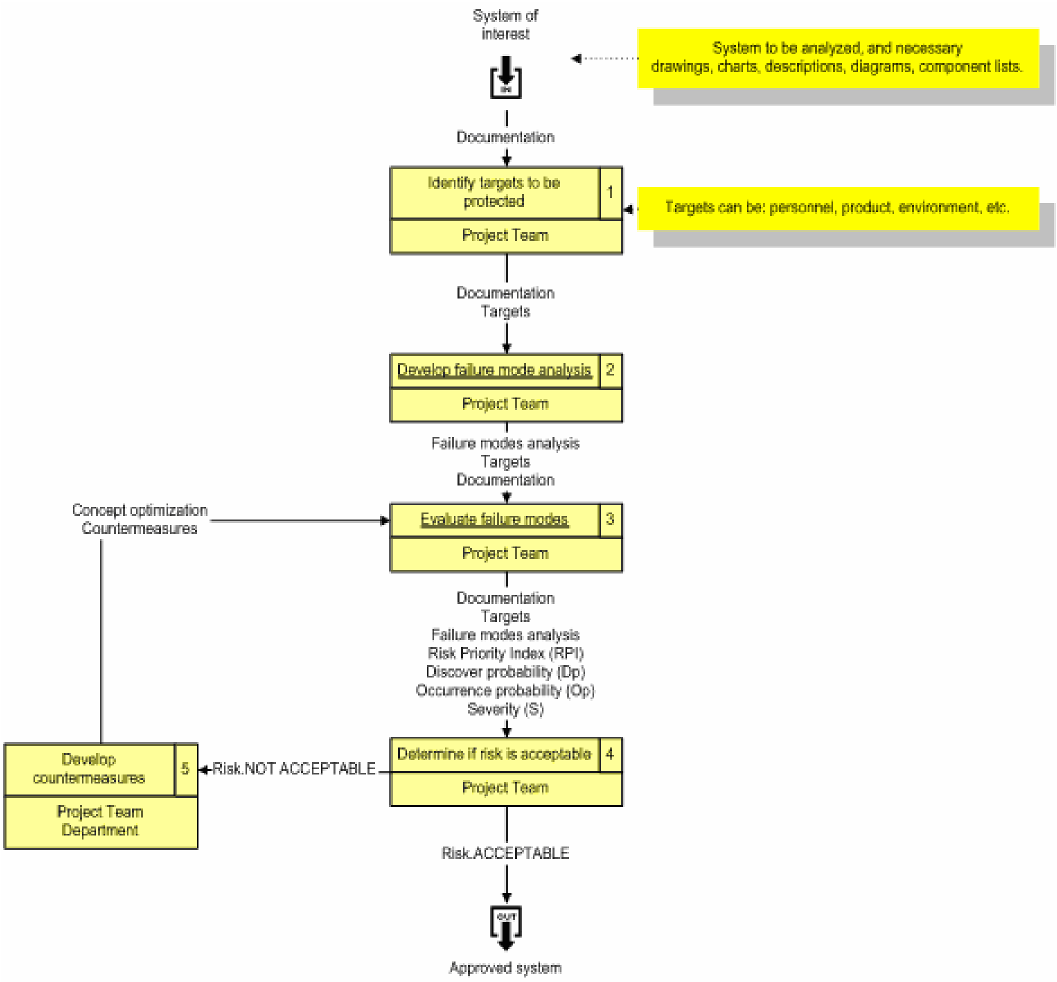
Appendix A: The QFD Process

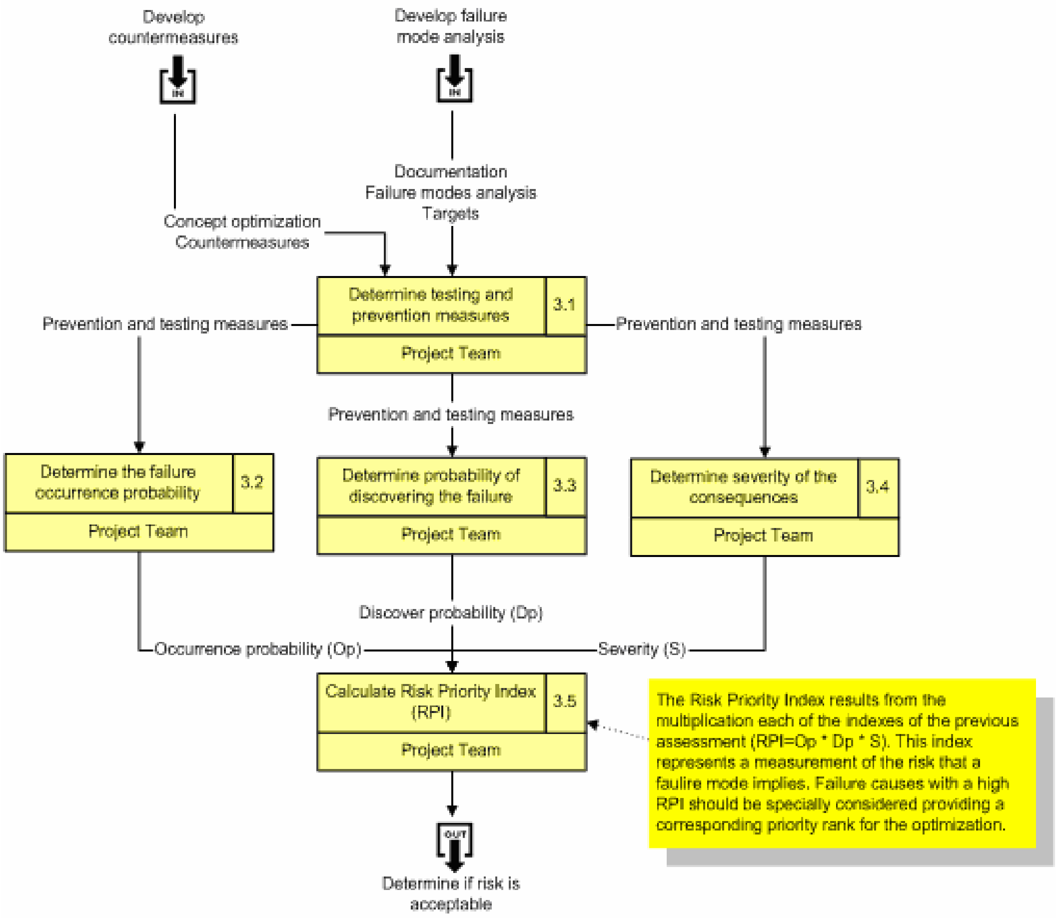


Appendix B: The FMEA Process

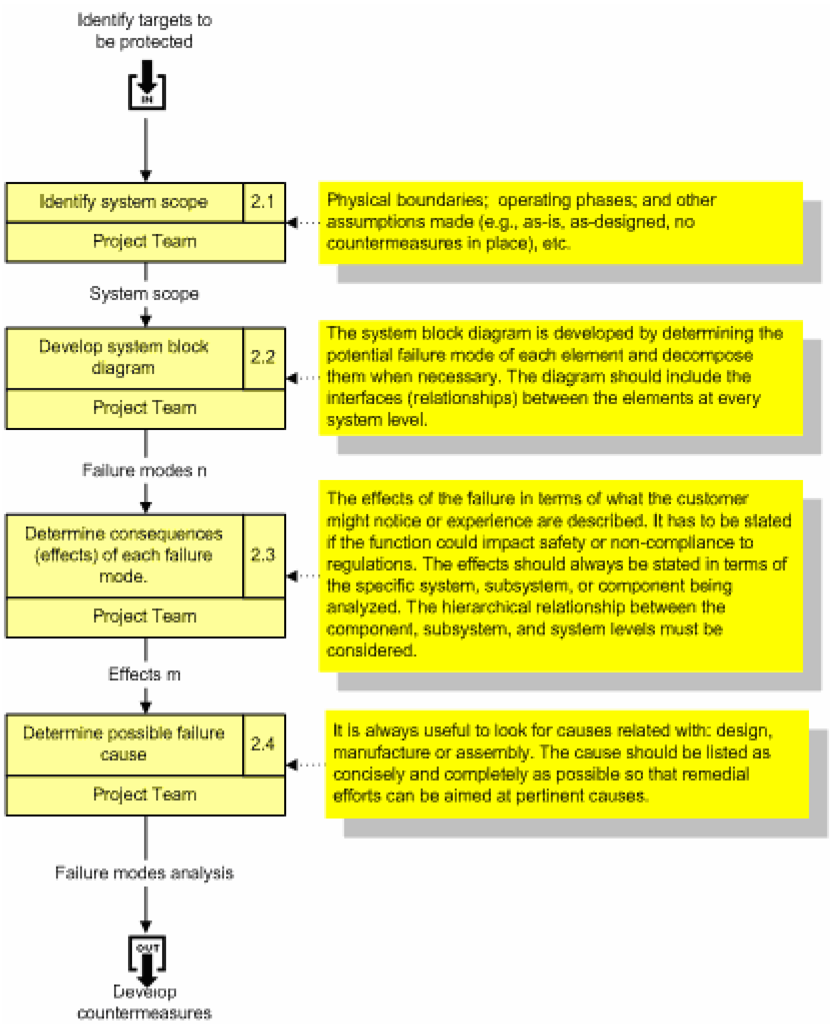
Process



Evaluate failure modes



Develop failure mode analysis



Appendix C: Example of Occurrence, Severity and Discovery Evaluation (FMEA)

Criteria	Rank		Frequency	Evaluation
Occurrence	Improbable	It is improbable that a failure will occur. The fault cannot happen during construction.	0	1
	very low	The system is reviewable and known. In general, it corresponds to previous designs for which low figures about failures and faults are known.	< 1 / 10000	2 - 3
	Low	In general, the system corresponds to previous designs for which proportionally low figures about failures and faults are known.	< 1 / 2000	4 - 6
	Moderate	In general, the system corresponds to previous designs that in the past have caused difficulties repeatedly.	< 1 / 100	7 - 8
	High	In a large extent, it is very probable that failures or faults will happen.	< 1 / 2	9 - 10
Significance	No consequence	It is improbable that a failure will have perceivable consequences on the system.		1
	Insignificant	The customer will be slightly affected. The system will suffer minimal consequences.		2 - 3
	medium-serious failure	Customer dissatisfaction. The fault means no unplanned visit to the workshop.		4 - 6
	serious failure	Customer annoyance. Unplanned visit to the workshop.		7 - 8
	very serious failure	The entire system fails.		9
	safety hazard	The failure implies a safety hazard.		10
Discovery	High	The functional failure will be discover.		1
	Moderate	Obvious failure symptom. Discovery probability > 99.7%		2 - 5
	Low	The failure symptom cannot be easily discovered.		6 - 8
	very low	Hardly detectable failure symptom.		9
	Improbable	The symptom cannot be or will not be checked.		10

Erklärung

Brandenburg, den 1. December 2006

Hiermit versichere ich, dass ich das hier vorliegende Werk selbständig verfasst und keine anderen Quellen und Hilfsmittel benutzt habe. Außerdem erkläre ich, dass diese Arbeit in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegt wurde.

Dipl. Ing. Edgardo Moreira Barahona

Matrikelnummer FHB 20002814