

POLITECNICO DI MILANO

Facoltà di Ingegneria dei Sistemi



POLO REGIONALE DI COMO

Master of Science in Management, Economics and Industrial Engineering

Proposal of  
Knowledge-Based Engineering methodology for  
Mass Customization

Supervisor: Prof. Ing. Marco TAISCH

Assistant Supervisor: Dott. Sergio TERZI

Submitted by: KIYAN VADOUDI

Matricola: 754687

**Academic Year 2011-2012**

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**“TO MY FAMILY”**

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# Abstract

This thesis aims to introduce a Knowledge Based Engineering (KBE) Methodology that tackles Mass Customization (MC) from a knowledge management perspective and attempts to propose a systematic framework to implement and modify the process of Mass Customization, based on best practice with storing the past data as experiences, geometry and data that relate to a specific product family. This process is the result of providing support and appropriate automation of repetitive and routine design tasks with integrating huge sources of expertise in order to perform the multi disciplinary tasks.

The main effort about this methodology is the first step (Knowledge Management) that includes identify, Justify and capture of the knowledge from production, process and market. Based on the methodologies exist in literature, I prepare this methodology that includes eight steps. Each step characterized from several subclasses and tried to introduce the methodology as a general framework. This methodology is a combination of two big areas, Knowledge-Based Engineering (KBE) and Mass Customization (MC) , Thus, validation of it will takes more than a usual time for thesis.

More in detail the proposed Methodology from one side is base on the logic of existing KBE methodologies such as MOKA (Methodology and tools oriented to knowledge based engineering application) and KNOMAD (Knowledge nature for optimal multidisciplinary analysis and design). From the Mass Customization side is base on the logic of product family architecture (Module or Building Blocks).

The forces of the model are its ease to use, providing a consistency process of developing and maintaining KBE methodology for implementing MC and reduction in lead-time and cost in the design process.

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## *Sintesi*

*Questa tesi si propone di introdurre un Knowledge Based Engineering (KBE) Metodologia che affronta Mass Customization (MC) dal punto di vista di gestione della conoscenza e tenta di proporre un quadro sistematico per implementare e modificare il processo di personalizzazione di massa, basata sulle migliori pratiche con l'archiviazione del passato dati come esperienze, geometria e dati relativi a una famiglia di prodotti specifico. Questo processo è il risultato di fornire un supporto adeguato e l'automazione di operazioni ripetitive e di routine con l'integrazione di fonti enormi di competenza, al fine di svolgere i compiti multi-disciplinari.*

*Lo sforzo principale di questo metodo è il primo passo (Knowledge Management) che include identificare, Giustificare e la cattura della conoscenza della produzione, di processo e di mercato. Sulla base delle metodologie esistono in letteratura, preparo questa metodologia che comprende otto passaggi. Ogni fase caratterizzata da diverse sottoclassi e ha cercato di introdurre la metodologia come un quadro generale. Questa metodologia è una combinazione di due grandi aree, Knowledge-Based Engineering (KBE) e Mass Customization (MC), quindi, di validazione si vuole più di un tempo usuale per la tesi.*

*Più in dettaglio la metodologia proposta da un lato è la base sulla logica delle attuali metodologie KBE come MOKA (Metodologia e strumenti orientati alla domanda di ingegneria basata sulla conoscenza) e KNOMAD (la natura della conoscenza ottimale per l'analisi e la progettazione multidisciplinare). Dal lato Mass Customization è la base sulla logica di architettura famiglia di prodotti (Modulo o Building Blocks).*

*Le forze del modello sono la sua facilità di utilizzo, fornendo un processo di coerenza di sviluppare e mantenere la metodologia per l'attuazione KBE MC e riduzione dei lead-time e dei costi nel processo di progettazione.*

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# Executive Summary

## **Key Words:**

Knowledge Management, Knowledge-Based Engineering, Mass Customization

## **1. Introduction**

This thesis aims to introduce a Knowledge Based Engineering (KBE) Methodology that tackles Mass Customization (MC) from a knowledge management perspective and attempts to propose a systematic framework to implement and modify the process of Mass Customization, based on best practice with storing the past data as experiences, geometry and data that relate to a specific product family. This process is the result of providing support and appropriate automation of repetitive and routine design tasks with integrating huge sources of expertise in order to perform the multi disciplinary tasks.

The main effort about this methodology is the first step (Knowledge Management) that includes identify, Justify and capture of the knowledge from production, process and market. Based on the methodologies exist in literature, this proposed methodology includes eight steps. Each step characterized from several subclasses and tried to introduce the methodology as a general framework. This methodology is a combination of two big areas, Knowledge-Based Engineering (KBE) and Mass Customization (MC) , Thus, validation of it will takes more than a usual time for thesis and because of this time limitation, I validate the first step (Knowledge Management) and hope that the opportunity facilitate for me to validate completely the model in future.

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## **2. Literature review of Knowledge Management**

This chapter explains the importance of knowledge management methodologies to capture different types of knowledge in Product Development and then re-use them to reduce the errors that happening through manufacturing process.

### **2.1 Knowledge**

Knowledge is related with something or someone that can includes facts, information and skills that captured by education and experiences. Knowledge can be implicit that comes through practical skill and explicit from theoretical understanding. Russell Ackoff divided the classification of the human mind in to five categories: Data, Information, Knowledge, Understanding and Wisdom. He mentioned that the first four categories have connection to the past activities and deal with what has been or what is known But Wisdom dealing with the future because it include vision and design and because of this future estimation achieving Wisdom is not easy.

### **2.2 Knowledge Management**

Knowledge Management has a long history and is related to World War II. Harry Scarborough et al (1999, p.1) define KM as "any process or practice of creating, acquiring, capturing, sharing and using knowledge, wherever it resides, to enhance learning and performance in organizations". By the mid-1980s, the importance of knowledge as a competitive asset was apparent and by increasing the importance of organization's knowledge, the concern emerged about dealing by growing up by the amount of available knowledge in organization. The computer technology that cooperated so heavily to superabundance of information started to become part of the solution, in a variety of domains. There are six main drivers about Knowledge Management that play critical role in success of useful KM process:

- 
- The Wealth from Knowledge: A company's value depends on intangible assets, on their knowledge assets, intellectual capital and intellectual property.
  - Knowledge Interdependence: Cross-boundary interdependence between organizations: between the stakeholders such as customers, suppliers, partners etc.
  - Technology: Limits in information systems will drive Knowledge management.
  - Human resources issues: People capture their own knowledge, create value and maintain organizational memory and then they can leave.
  - Organizational learning and the Learning Organization: The pace of change nowadays requires continuous regeneration of an organizational knowledge base.
  - Innovation: Organizations must exercise their advantages through innovation, knowledge creation, knowledge sharing and application.

### **2.3 Explicit and Tacit Knowledge**

The distinction between explicit and tacit knowledge provides a field to understand the differences between computer-system and human-system about supporting of knowledge management process

Explicit knowledge is a type of knowledge that codified and conveyed to others through dialog, demonstration, or media such as books, drawings, and documents. This approach assumes that the useful knowledge of individuals in an organization can articulate. Explicit knowledge approach believes that organization can reach to this kind of knowledge through documents, drawings, standard operating procedures etc. Because of the nature of this knowledge, Information systems are usually play critical role in order to facilitate the dissemination of it over through organizations.

From the other side, Tacit of knowledge made up from practices, experiences wisdom and other intellectual property that are not recordable. This knowledge exists within our minds and is not possible to show as numbers or graphs."We know more than we can tell" is a sentence by Polanyi about tacit knowledge. Furthermore, there are two dimensions of tacit knowledge, the first is the technical dimension, which encompasses the 'know-how', the second is the

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cognitive dimension, which consists of beliefs, ideas and values which we often take for granted.

Nonaka introduced the theory of knowledge, which shows the interrelations between tacit and explicit knowledge within an organization. The results of these interactions are Socialization, Externalization, Internalization and Combination.

## **2.4 Knowledge-Based Engineering**

Knowledge-Based Engineering (KBE) is a combination of object-oriented programming, artificial intelligence, and computer aided design in order to capture product and process knowledge from inside and outside of organization to allow businesses to model engineering processes, and then use the model to automate all or part of the process. In the design domain, one of the technologies that support rapid modular design is Knowledge-Based Engineering (N. Wognum, A. Trappey, 2008).

### **2.4.1 The MOKA Methodology**

A number of KBE methodologies are available to support the development of KBE applications and systems. By far the most famous of these is the Methodology and software tools Oriented to Knowledge-Based Engineering Applications, or MOKA (Methodology and software tools Oriented to Knowledge based engineering Applications) methodology. This methodology, consisting of six KBE Life-cycle steps (Identify, Justify, Capture, Formalize, Activate and Delivery) and accompanying informal and formal models, is designed to take a project from beginning towards industrialization and actual use (Oldham, Kneebone, Callot, Murton, & Brimble 1999; Stokes, 2001). The important point about MOKA is that, focus lies with the ‘Capture’ and ‘Formalize’ steps of the KBE life cycle.

### **2.4.2 Design Engineering Engine (DEE) methodology**

The DEE includes of three major elements. The first is concerned with the design process, which includes multidisciplinary optimization. This element supports the



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parameter values to the second major element of the DEE that is the Multi-Model Generator (MMG). The MMG is a modeling framework and generates the Report File that uses the product model parameter values from the initiator by compounding with formalized domain knowledge to generate product models. These fed to the third major element of the detailed analysis modules (DDE) that calculate the design implications on a virtual per-discipline basis. Finally, the loop closed by analyzing the Data files in a Converge & Evaluator, which checks for mathematical validity and requirements compliance in a multidisciplinary procedure. (Van der Laan et al. 2006).

#### **2.4.3 Current Shortcomings of KBE**

There are five major deficiency about KBE have been funded from previous studding

- Case-based, ad hoc development of KBE applications
- A tendency toward development of 'black-box' applications
- A lack of knowledge re-use
- A failure to include a quantitative assessment of KBE costs and benefits
- lack of a (quantitative) framework to identify and justify KBE development

### **3. Literature review of Mass Customization**

Nowadays, customer's demand specifications are about high quality, low price and customized products and these factors increase the competition between companies. About twenty years ago, this competition was in prices, but today the main competitions are about product variety and speed to market. Hence, Mass Customization intrinsically makes high-value-added products and services possible through premium profits derived from customized products. In the MC model, value is creating by people, designing of product, combining the supplier competencies, establishing supplier networks, and ensuring customer satisfaction.

Beside many challenges about MC, keeping cost low as possible, achieving high quality for high quantity products and satisfaction of customers on time are

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some more important issues about this subject. Furthermore, modularization of products and processes, ability of using knowledge-based software to configure products and flexible automation for manufacturing process are hint points to enable MC.

### **3.1 Shifting from Mass Production to Mass Customization**

In the 1960s, Mass Production began to breakdown for many companies in many industries and finally until 1980s it was fully into management consciousness (Pine 1993). Firm started to face choice of continues process mass production or being innovative. Continues improvement and MC have shown that companies can overcome the tradeoffs through two broad categories of product process matrix that are product change and process change. The right pass from mass customization requires forms to transform it capabilities and processes fundamentally. There are four different organizational designs together with the four approaches to customization in organization.

- Mass Production
- Invention Design
- Achieving Mass Customization
- Continuous Improvement Design

### **3.2 Main components of Mass Customization**

Mass Customization composed from many different parts. Some of them have root inside of company and some outside. With paying attention to the field of methodology that has root in knowledge management engineering, three main components are: Co-Design and Customer Involvement, Modularity and Fit Preference.

### **3.3 Technical Challenges about Mass Customization**

The requirements of mass customization depend on three aspects: time-to-market (quick responsiveness), variety (customization) and economy of scale

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(volume production efficiency). In order to achieve this balance, three major technical challenges identified as follows.

- Maximizing Reusability
- Product Platform
- Integrated Product Life Cycle

### **3.4 Design for Mass Customization**

The effort in Mass Customization is to include the rule of customers in the development of product life cycle with making the connection between customer needs and capabilities of a company. The main stress of design for mass customization is to elevate the current practice of designing individual products to designing product families. In order to product differentiation customization we can characterize what is needed for customers and then perform these requirements by configuring and altering well-established building blocks hence we can named the product family architecture (PFA) and another as PFA-based product development life cycle (PFA-PDLC) as two fundamental concept underpinning DFMC.

#### **3.4.1 Product Family architecture for Mass Customization**

There are three kinds of approaches widely used for representing architecture and modularity of product family: 1) product-modeling language (Erens et al. 1997), 2) graphic representation (Ishii et al. 1995; Agarwal and Cagan 1998), and 3) module or building block (BB) (Tseng and Jiao 1996; Gero 1990; Fujita and Ishii 1997; Rosen 1996). The product modeling language offers little aid for design synthesis and analysis, graph structure does not have ability to model the product family constraints but a model specifically tailored for representation of a product family architecture is the building block model, which is derived from the concept of using modules to provide varieties.

### **3.5 Benefits of Mass Customization**

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Mass Customization carries several advantages for manufactures and customers. Improvement on flexibility, maximum utilization and maximum availability of automated material handling system as well as strategies to ensure on time delivery has been considered as significant due to the trend of Mass Customization.

## 4. The Proposal of the model

The proposed model is based on Knowledge based engineering (KBE) methodology that tackles mass customization from an engineering perspective and attempts to propose a systematic framework to realize mass customization. The main objective of this model is to use the KBE methodologies in order to develop configuration systems to modularize products to reduce the lead-time and cost of mass production by capturing the products and processes knowledge and provide a consistency process of developing and maintaining KBE application.

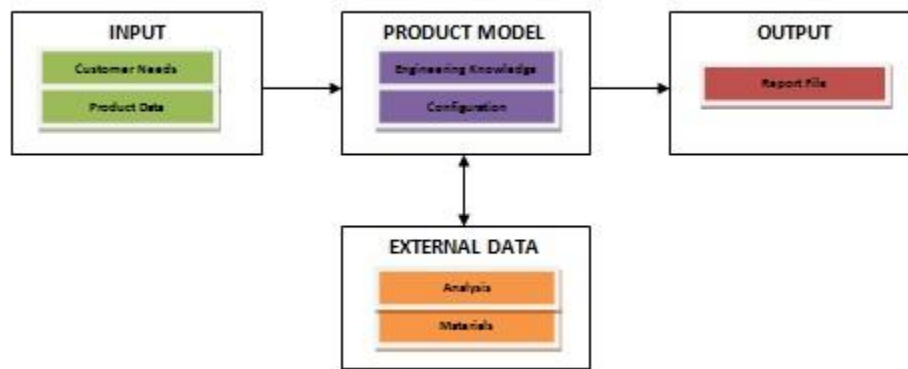


Figure I: Knowledge Based Engineering System

The core of this model is Product Model, where all knowledge related to production and process such as geometry, configuration and engineering knowledge is stored. As described before, the main driver in mass customization

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is customer needs, so Input to this model is product data and customers' need specifications which gives several kinds of output when the process of modeling start to work. There is another part as External Data that usually conclude tabled data such as catalogues, materials, analysis etc. The output as report file includes reports, drawings, costs, BOM and manufacturing plans. This methodology contains eight main steps.



**Figure II: Eight steps of methodology**

#### **4.1 Lifecycle of methodology**

Before a methodology could be developed to support the development and maintenance of this methodology in the field of knowledge based engineering applications, it is necessary to agree on the various stages in the lifecycle of a KBE application and which of those are to be supported. The lifecycle of a KBE system adopted for use within the Mass Customization project is shown in Figure III.

#### **4.2 Software tools to support the methodology**

The methodology will provide a systematic approach for the development of Knowledge Based Engineering applications. However, developing a Knowledge Based Engineering application is often a complex task, involving the management of many objects, rules, and constraints. Therefore, it is essential that a user-friendly, graphic-oriented, computer tool is provided to support this methodology.

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This tool will: Provide assistance in the use of the methodology, Verify model consistency, Facilitate iterations during the application development cycle, Improve software quality.

## **5. Validation of proposed methodology**

There are many kinds of industries area working in Mass Customization, but I select apparel, because there are more similarities in knowledge management process with other industries. Furthermore, implementation of Mass Customization process for this industry is much easier than other industries because of less complexity in the process of production. Information and knowledge are critical factors for apparel industry in order to move from Mass Production to Mass Customization. The purpose is to provide knowledge management process for the methodology in apparel business sector to deal fast as possible with changes in consumers' needs and habits.

### **5.1 Data Collection**

The data that collected for validating of the methodology, obtained from two different approaches. First, the data collects from analyzing online customization process and second, with some questionnaire by users and experts that have experience in this field. The purpose of collecting data and information from these sources is to provide knowledge into development the building blocks for Mass Customization Process for the Modeling step of introduced KBE methodology. The approach to collect data is a qualitative research method that enables researchers to receive information and capture knowledge about specific subject in which little is known. Five apparel retailers (Table I) selected for analysis and data collection which offering online customization opportunities in different sectors.

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Company	Production
Fine Cotton	A premium brand for bespoke shirts
Nur Berlin	T-Shirt for Men and Women
Custom Panties	Panties Producer
Blume	Apparel for Girls, Guys, Babies and Kids
Diejeans	Jeans producer for Men and Women

Table I: Selected Apparel retailers

## 5.2 Questionnaire Analysis

The questionnaire includes 14 questions that start with general questions about ways of shopping, habits of shopping and other general questions, then there are some questions that could support the knowledge about building blocks in terms of important factors in customizing a goods with paying attention to priorities and finally the questionnaire follows up with some score questions. The goal of this step is to find the precedence about online shopping from customer side and finding the customer role in design of production because of working with configurator. Motivation from customer side to work with configurator as co-design, online shopping preferences, purpose of shopping and customization preferences are four main objectives of doing this analysis.

## 5.3 Configurator Analysis

The data collection activity in this step related with analyzing of this process for some companies that implementing this ability for their customers. There are some general features, which are similar between these configurators. Products that provided by configurators and available for customers to select are Pants, Shirts, T-Shirts, Jackets, hats etc. Colors that allowed for customization usually includes some main colors such as white, black, red, blue, green. In terms of different personality changes, the possibilities facilitate to make changes about materials, body measurement, pocket numbers, style, size, location of design texts or pictures. Shopping time that allowed because of security problems for

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customers is about thirty minutes for each trying time. The price could change because of changes that happen for products in terms of colors, style text etc. Finally, total steps that requires for customizing a single item from enter to website until finish the shopping will take about nine main steps.

## **6. Conclusion**

The purpose of this study was to identify a systematic framework based on Knowledge-Based Engineering methodologies to tackle mass customization from engineering perspective by analyzing the secondary data from five selected company and questionnaire from user's side. This chapter will present the conclusion of findings from literature reviews, empirical study and questionnaire search. The proposed methodology in the first step is supporting the challenge of maximizing reusability by implementation of repeating process that happening to achieve the efficiency. Furthermore, repetitive activities cause an integrated product lifecycle, which includes entire product-development process from customer needs to product delivery. In addition, this methodology supporting the paradigm of product platform in step of "Formalize Product Family" by using the optimal building blocks.

From the other side this proposed methodology also going to support some existing shortcomings in current Knowledge-Based Engineering methodologies. As mentioned in chapter two, there are five main shortcomings about KBE and this proposed methodology will support at least two of them.

- Case-based, ad hoc development of KBE applications
- A lack of knowledge re-use

In step of validation, empirical work was chosen as the most appropriate method for identifying the current offering of MC program from variable types of apparel industry due to general condition limitation. However, by doing so, factor selected to test the performance of MC in a web base are mainly depends on



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author's personal decision which may not strongly support the accuracy of research findings.

The validation process only did for first step of proposed methodology” Knowledge Capture” and from the other side, result and implication of this study was from small sample size of sixty university student that were asked to response in an online customization question.

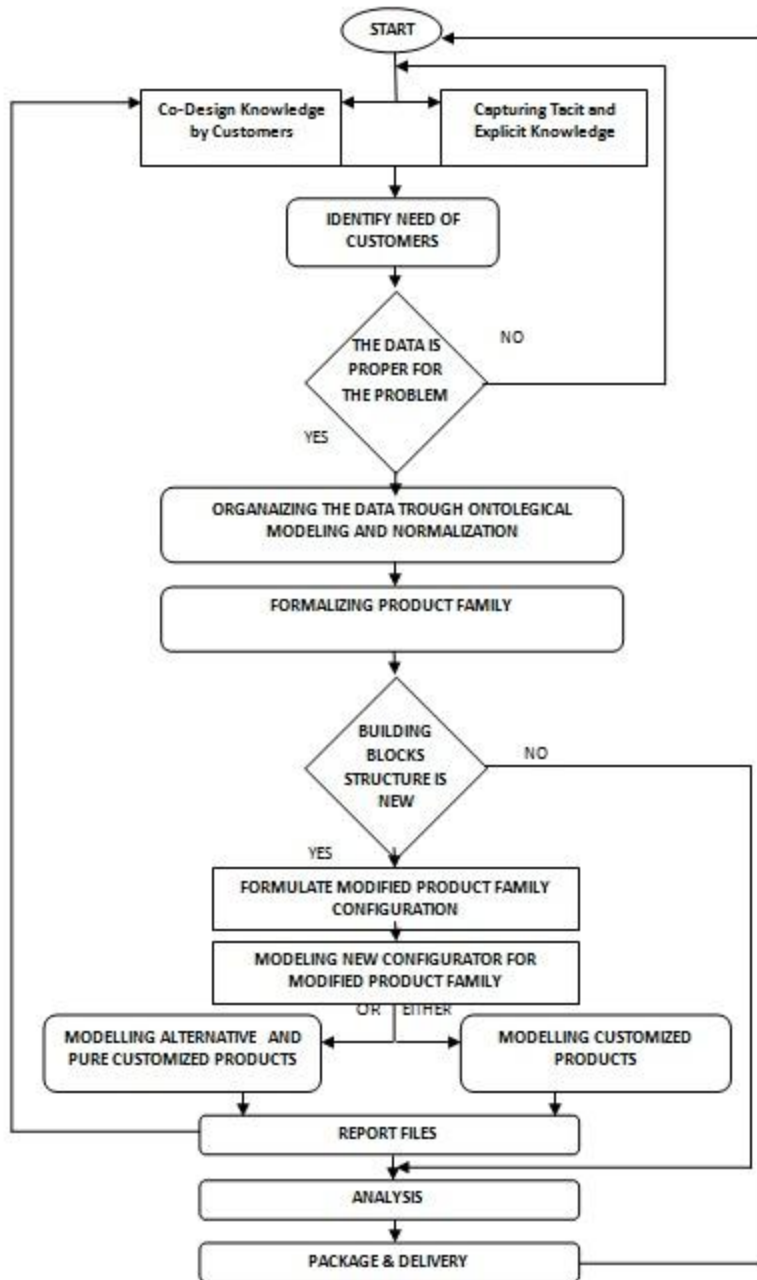


Figure III: Lifecycle of methodology

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## Chapter 1

# INTRODUCTION

## 1.1 Introduction

Knowledge Management has a long history and related to World war II in order to build the fighter planes .That time ,observes shown that building of second airplane took less time and less defects than the first one and this understanding about process of production was beginning to appear the concept of knowledge management. The point was that workers learned from the experience of past projects and this phenomenon was start for producer to analyze their production process and codify their observations to make a framework in order to produce in quicker time. Organizations understand that better managing the

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learning process will help them to operate in better way and managers understood that knowledge management is forcefully connect with the learning process.

Knowledge-Based Engineering (KBE) is relating to knowledge management, which has many levels itself. Some approaches to knowledge are abbreviation, as well they ought to be given the pragmatic focus of knowledge modeling. However, due to KBE dealing with aggregates that can be quite complicated both in structure and in behavior, some holistic notions (note link to Complex systems) might be proper. Knowledge-Based Engineering (KBE) is a combination of object-oriented programming, artificial intelligence, and computer aided design in order to capture product and process information to allow businesses to model engineering processes, and then use the model to automate all or part of the process. The emphasis is on providing information and knowledge of product and process from inside of organization and from outside such as databases and external company programs. The ultimate goal of the KBE system should be to capture the best design practices and engineering expertise in to corporate knowledge base (Stokes M, Ed, 2001).By the way the main objective of KBE is to reduce lead-time by capturing product and process knowledge.

On the other side, increasingly competitive and demanding markets are forcing companies to search for means to decrease time and costs for new product development, while satisfying customer requirements and maintaining design quality. Companies are increasingly moving towards mass customization: ‘the production of goods to meet individual customer’s needs with near mass production efficiency. This requires a specific methodology that is able to rapidly and collaboratively design and produce a large number of product variants, often based on modular design principles. Thus the methodology that is introduced by this thesis, going to support the subject of Mass Customization from knowledge management perspective and attempts to propose a systematic framework to implement and modify the process of Mass Customization, based on best practice with storing the past data as experiences, geometry and data that relate to a specific product family.

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## 1.2 Objectives of Study

The main objective of this model is to implement a KBE methodology in Mass Customization to develop configuration systems to modularize products to

- Reduce the lead time and cost of mass production by capturing the products and processes knowledge. This model is going to use the platform concept and tries to transfer the logic of no customizable products to the modular products that will support different individual needs. The model are using the recent development of IT technology that enables formalizing a configuration system. This system is a kind of solution space as a conceptual container for the matrix of product possibilities that made for each given Mass Customized products. The cost of production can decrease by elicitation and formalization of data, information and knowledge related with an application domain.
- Provide a consistency process of developing and maintaining KBE application. By using this formalized model, the analysis and model of product, design of production process and associated knowledge to these domains will facilitate. The combination of this methodology by software tools will make Knowledge Based Engineering developers more productive and consistent.

## 1.3 Methodology

The process of doing this thesis started with a literature study and then continued with case studies to validate the first step of methodology (Knowledge Management).

### **Literature Study**

Before I stated to work on the subject of KBE Methodologies, “Process improvement tools in Lean Manufacturing” was first subject of my literature

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review. Related to this subject, I started to work with a group from Management department to implement A3 sheet tool in INDESIT Company. During the meetings that I had with INDESIT's experts, I found "Knowledge Capturing", especially tacit knowledge more interesting subject. Therefore, due to my study background about "process improvement methodologies", I shifted my literature study to "Knowledge Management" and to Knowledge-Based engineering in detail. During my studies about KBE subject and with paying attention to the some specification about the fields such as automotive industry which KBE methodologies was implemented for them, I introduced a KBE methodology in Mass Customization.

### **Case Study**

In order to validate the first step of introduced KBE methodology, data, information and customer experiences are collected from two sources. The first, data collection from five companies related to apparel industry that prepare the ability of customization through configurator for their customers and second by preparing a questionnaire that include fourteen questions relating to shopping habits and customization specification. All data and information that received from these two approaches are useful sources of knowledge to implement in designing of building blocks through Mass Customization process.

## **1.4 Structure Planning**

This study will be generated step by step towards the objectives follow the structure showed below.

### **Chapter 2 – Literature Review**

This chapter introduces information about Knowledge Management and Mass Customization. The first part of chapter presents the definition of Knowledge Management and Knowledge-Based Engineering, key elements and their main drivers about them. This chapter also provides some information about famous

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knowledge-based engineering methodologies and the software that are using in these methodologies. Second part tells about concept of Mass Customization, the process of moving from mass production to mass customization, design for mass customization, product family structure and some benefits gained from Mass Customization implementation.

### **Chapter 3 – Methodology**

This chapter describes the introduced Knowledge-Based Engineering methodology for using in Mass Customization. This methodology includes eight steps and in this chapter, each step explained with details specification. In addition, the life cycle of the methodology and software that could use to support this methodology introduced.

### **Chapter4- Validation**

Due to the fact that introduced methodology has eight wide expanded steps its validation require lots of time which is further than the usual time for thesis, therefore validation process implemented only for first step, “Knowledge Management”. It includes introduction of knowledge sources for identifying, justifying and capturing of three kinds of explicit, tacit and customization knowledge. I hope the opportunity facilitate for me to validate other steps in future.

### **Chapter5- Conclusion, Limitations and recommendations**

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## Chapter 2

# Knowledge Management

## 2.1 Introduction

This chapter explains the importance of knowledge management methodologies to capture different types of knowledge in Product Development and then re-use them to reduce the errors that happening through manufacturing process. First part will introduce the concept of knowledge .Second part will explain the Knowledge Management .Third part is about Capturing Tacit

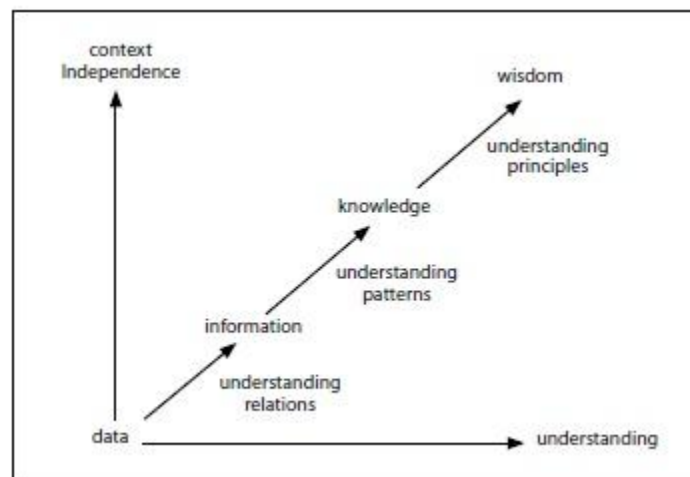


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Knowledge in New Product Development and the last part explaining the Knowledge Base Engineering .

## 2.2 Knowledge

Knowledge is relating with someone or something, which can includes facts, information, descriptions, or skills acquired through experience or education. It can refer to the theoretical or practical understanding of a subject. It can be implicit (as with practical skill or expertise) or explicit (as with the theoretical understanding of a subject). Russell Ackoff divided the classification of the human mind in to five categories: Data, Information, Knowledge, Understanding and Wisdom. He mentioned that the first four categories have connection to the past activities and deal with what has been or what is known But Wisdom dealing with the future because it include vision and design and because of this future estimation achieving Wisdom is not easy . You can find the process of data transition to wisdom in Figure 2.1.



**Figure2.1: Conceptual Progression from Data to Knowledge (Gene Bellinger , Durval Castro)**

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**Data:** The facts in the world and we can describe phenomena by data in the easiest way. Actually, it is raw and exists in any form, usable and not usable and by itself does not have any meaning. Thierauf (1999) gives another definition to data "unstructured facts and figures that have the least impact on the typical manager."

**Information:** The next step after data is information. In order to make information, we should categorize and connect data by together."Information is data with relevance and purpose (Bali et al 2009)". Usually we use information to answer the question that begin with who , what , where , when and how many .We can capture data in information and then move it in other way that other people can access it at different times .

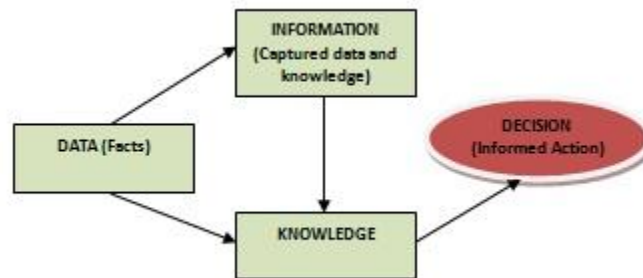
**Knowledge:** Knowledge is what we build in our brain about the happening of the world. Like a physical map, it helps us to know where things are and how can we use them. It also includes our beliefs, expectation and experiences .The brain connects all these factors by together to make network of ideas, memories, predictions, etc. Our brain continuously updates this map from the factors that receive through eyes, ears, nose, mouth and skins. It is the production of people's experiences, information and personal model of the world with closely link to imply Know-How and understanding. When we memorize information, actually we have collected knowledge in our mind and we are able to answer the questions related to the boundaries of that knowledge, but when we go beyond of these boundaries we need cognition and analyzing ability to answer them, so we enter to the next level that means Understanding (Gene Bellinger , Durval Castro).

Totally knowledge describes in two general meanings .Sometime we use the knowledge to mean that we have information about some fact and it means "Knowing That " and on the other side we know how to do and it mean "the ability to do something" . Furthermore, there is a dynamic concern about understanding of what knowledge is object or process. There are two management views. It is information technology, if knowledge more or less is the same

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phenomena like information but the negative point in this approach is that you select the easiest way and you are losing your budget.

On the other side, if you convinced that knowledge is a process, key to success in KM lies in people that you have in your organization (Anthony Mills). We can define knowledge as a capacity to act .Knowledge as process is dynamic, personal and distinctly different from data and information. With accepting that knowledge is human facility, the purpose of knowledge management concern about how organization can act best in this way and how system can leverage and motivate people to improve, innovate and share their capacity to act. By this approach, KM becomes a strategic issue for the whole organization.



**Figure 2.2: Relation between Data, Knowledge and decision**

**Wisdom :** It is a deep understanding of people , things , events and judgments and doing action with paying attention to them .Wisdom is the big difference between human and smart systems, because it needs many factors that computer does not have them so cannot process this phenomena .

An important issue is the distinction between knowledge and information. The difference is illustrated in Figure2.3. The bottom of the pyramid consists of data, i.e. information in its raw form; it could be statistics or even ones and zeroes. When the raw data is interpreted and organized, it moves up a notch and becomes information. However, it is when the information and its consequences are understood, that it becomes knowledge. When all knowledge in a field comes together, and an understanding of the big picture and the interplay between different knowledge fields emerges, wisdom is reached. Traditionally, the focus

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of product development has been on the two bottom lines, which is implied by the huge investments in PDM systems made by companies in the last decades. It can be argued that it's beneficial to try to reach the top two lines in the pyramid (Davenport & Prusak, 1998)



**Figure 2.3: The knowledge pyramid (Ackoff 1989)**

According to the study of (Koulopoulos & Dover), there are three important criteria's for knowledge in order to use as enterprise value. "Connectivity", that explains the knowledge is connected and it is multiple of experiences and perspectives. "Leveraging", knowledge is always relate to environmental conditions. "Applicability", If the environment is planned the information will be knowledge when is using for new situation. Information, which merely plugged into a previously unplanned model, is not knowledge (Koulopoulos & Dover, 1999).

## **2.3 Knowledge Management**

### **2.3.1 History of Knowledge Management**

Knowledge Management has a long history and related to World war II in order to build the fighter planes .That time ,observes shown that building of second airplane took less time and less defects than the first one and this

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understanding about process of production was beginning to appear the concept of knowledge management. The point was that workers learned from the experience of past projects and this phenomenon was start for producer to analyze their production process and codify their observations to make a framework in order to produce in quicker time. Organizations understand that better managing the learning process will help them to operate in better way and managers understood that knowledge management is forcefully connect with the learning process.

There are many theorists have contributed about evolution of knowledge management such as Peter Drucker, Paul Strassmann, and Peter Senge in the United States. Drucker and Strassmann have stressed the growing importance of information and explicit knowledge as organizational resources, and Senge has focused on the "learning organization," a cultural dimension of managing knowledge. Chris Argyris, Christopher Bartlett, and Dorothy Leonard-Barton of Harvard Business School have tried different functions of managing knowledge. In fact, Leonard-Barton's well-known case studies of Chaparral Steel, a company that has had an effective knowledge management strategy in place since the mid-1970s.

By the mid-1980s, the importance of knowledge as a competitive asset was apparent, even though classical economic theory ignores knowledge as an asset and most organizations still absence strategies and methods for managing it. With increasing the importance of organization's knowledge, the concern emerged about dealing by growing up by the amount of available knowledge in organization. The computer technology that cooperated so heavily to superabundance of information started to become part of the solution, in a variety of domains. Doug Engelbart's Augment, which introduced in 1978, was an early groupware application capable of interfacing with other applications and systems. Rob Ackson's and Don McCracken's Knowledge Management System (KMS), an open distributed hypermedia tool, is another notable example and one that predates the World Wide Web by a decade. By the 1980s the development of systems for managing knowledge that relied on work done in artificial

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intelligence and expert systems, gave such concepts as "knowledge acquisition," "knowledge engineering," "knowledge-base systems, and computer-based ontology. By 1990, a number of management consulting firms had begun in-house knowledge management programs, and several well-known U.S., European, and Japanese firms had instituted focused knowledge management programs. By the mid-1990s, by progressive events that happen for Internet, the International Knowledge Management Network (IKMN), begun in Europe in 1989, went online in 1994 and was soon joined by the U.S.-based Knowledge Management Forum and other KM-related groups and publications.

### **2.3.2 Definition of Knowledge Management**

In our daily life, we have contact with many kinds of data and information. This data and information is not knowledge until we analyze and change it in a way that has possibility to give value for us. It is the main reason why we need knowledge management. Knowledge Management is about identifying, capturing and representing of experiences and insights gained by individuals and spreading it in to others in the organization to manage process better. With setting up some professional practices by knowledge management, we can see improvement in the capabilities of the organization's human resources and enhance their ability to share what they know. Bellow there are some Definitions about Knowledge Management by famous theorists.

Harry Scarborough et al (1999, p.1) define KM as

"any process or practice of creating, acquiring, capturing, sharing and using knowledge, wherever it resides, to enhance learning and performance in organizations".

Hedlund (1994) suggests that

“KM addresses the generation, representation, storage, transfer, transformation, application, embedding, and protecting of organizational knowledge”.

Gregory Wenig defined

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“KM is consists of activities focused on the organization gaining knowledge from its own experience and from the experience of others, and on the judicious application of that knowledge to fulfill the mission of the organization”.

It is important to understand that knowledge management does not follow a set of formal methodologies. In the mid of 1980's, researchers from all over the world started to study about role of knowledge in businesses. The term of managing knowledge used in the context of artificial intelligence in the US. In Japan early 1980's research team by Nonaka concerned with innovation and how to increase the speed about process of innovation .They found that in US businesses often do not pay attention enough for developing invisible assets such as loyalty and trust in business, because they are not mentioned in balance sheet. Hansen, Nohria and Tierny introduced two different approaches to handle the knowledge that are Codification and Personalization. These approaches are very different, and represent two views of how knowledge can be transferred within an organization. Hansen, Nohria and Tierney's article is the result of a study of practices in consulting firms, chosen because they have knowledge intensive operations, and therefore pursue problems around knowledge handling to a larger extent than industrial companies (Hansen, Nohria, & Tierney, 1999).

### **The Codification Approach**

This approach focuses on providing reliable solutions by reusing codified knowledge. Making acquired experiences explicit are the main issues with in companies that following this approach. Hansen, Nohria and Tierney points out Accenture as an example of a consulting firm using this approach (Hansen, Nohria, & Tierney, 1999). The emphasis on codifying knowledge is to increase skills in documenting, reporting and storing those documents and reports, which in its turn leads to a strong need of an advanced IT-system that can support the storage and reuse of documents. The importance of feeding the system with new knowledge generated in projects is strongly prioritized among employees, along with a general view that the system consist of a lot of knowledge that should be taken advantage of in current projects. It's considered crucial that new employees

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learn how to use the system, and quickly can take advantage of all the experiences made earlier, it's also important that employees are encouraged in different ways to use the database while working.

The problem of a codification approach is that no knowledge can be made explicit in simple way, which results in a struggle to make it explicit anyway. The system focuses on enabling communication between people and documents, which could be argued is not optimal in transferring knowledge. Finally, the approach has a limiting aspect in that sense that it focuses on only exploiting existing knowledge, not on the constant development of individual and organizational competences.

### **The Personalization Approach**

If the codification approach is about communication person to person document, the personalization approach is about communication person-person. It focuses on providing creative solutions by channeling individual expertise. In this approach, it's crucial that people meet and socialize and interact in order to be able to transfer knowledge between one another. One company working like this mentioned by Hansen, Nohria and Tierney is McKinsey. If a person at McKinsey lacks knowledge in one field, he or she is simply coupled with people that have that knowledge (Hansen, Nohria, & Tierney, 1999). In that sense, this approach has some comparison with the old apprentices in craftsmanship. McKinsey hire people based on problem-solving abilities and then train them through consulting. One big advantage of a personalization approach for a consultant firm is the potential of knowledge created at a customer staying at that customer. The risk of a codification approach is that the consultants take their knowledge with them when they leave their customers. Since McKinsey, for example, interact closely with their customers, the transfer of knowledge is more likely to be successful. The personalization approach is more expensive because of the time required for all people involved in a project to interact, but for a customer, the chance of learning increases. The use of IT-systems is not that central in a personalization approach, although it is used to store documentation and works as a means to find



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people within the organization that has the wanted knowledge (Hansen, Nohria, & Tierney, 1999).

Furthermore, from other side of view there are six main drivers about Knowledge Management that play critical role in success of useful KM process:

1. **The Wealth from Knowledge:** A company's value depends on intangible assets, on their knowledge assets, intellectual capital and intellectual property. Economics and organizational Knowledge Capital will include the value of Information, Data or Knowledge in particular contexts, including considerations of intellectual property rights.
2. **Knowledge Interdependence:** Cross-boundary interdependence between organizations: between the stakeholders such as customers, suppliers, partners etc. What is often over-looked is the cross-boundary nature of managing knowledge, involving processes that are inter- and intra-departmental, inter- and intra-organizational, partial, international, transnational and intercultural.
3. **Technology:** Limits in information systems will drive Knowledge management.
4. **Human resources issues:** People capture their own knowledge, create value and maintain organizational memory and then they can leave.
5. **Organizational learning and the Learning Organization:** The pace of change nowadays requires continuous regeneration of an organizational knowledge base.
6. **Innovation:** Organizations must exercise their advantages through innovation, knowledge creation, knowledge sharing and application.

### 2.2.3 Tacit and Explicit Knowledge

The development of theory and practice sides in knowledge management field is being driven by two main different approaches to identify and managing knowledge in organizations that are "Tacit Knowledge" and "Explicit Knowledge". The distinction between explicit and tacit knowledge provides a field to understand the differences between computer-system and human-system about supporting of knowledge management process. The concept about separation of knowledge in two sections are mentioning to the point that

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knowledge has deep root in human process that lives within the private world of the individual and it is hard to change it into information processing and software automation.

### **The Explicit Knowledge**

Explicit knowledge is a type of knowledge that codified and conveyed to others through dialog, demonstration, or media such as books, drawings, and documents. This approach assumes that the useful knowledge of individuals in an organization can articulate. Explicit knowledge approach believes that organization can reach to this kind of knowledge through documents, drawings, standard operating procedures etc. Because of the nature of this knowledge, Information systems are usually play critical role in order to facilitate the dissemination of it over through organizations. Nonaka et al. (2000) and other authors such as Hall and Andriani (2002) describe explicit knowledge as what can be embodied in a code or a language and as a consequence it can be communicated, processed, transmitted and stored relatively easily.

In the 1990s, Motorola started to manage explicit knowledge by its engineers during each project and leveraged that knowledge in development of next future projects. Toyota also follows that approach about its assembly lines. These documents provide detailed descriptions that explained how each task should perform, how long it should take and what should be the sequences of activities. Other firms have taken this explicit knowledge management in product development processes, for example GE Funuc Automation, develops design methodologies that applied in design of new kinds of components.

### **The Tacit Knowledge**

This type of knowledge made up from practices, experiences wisdom and other intellectual property that are not recordable. This knowledge exists within our minds and is not possible to show as numbers or graphs. There are many other definitions of tacit knowledge but Polanyi (1969) is widely accepted as the founding father that identified the significance of the concept of tacit

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knowledge.”We know more than we can tell” is a sentence by Polanyi about tacit knowledge. The ability to recognize faces, ride a bicycle or swim, without the slightest idea to explain how these things are examples by Polanyi to explain better this kind of knowledge. Nonaka (1991, p. 98) explores the term further. He mentioned that tacit knowledge is highly personal and it is hard to formalize it. Thus, it is difficult to communicate with others, and details his description that there are two dimensions of tacit knowledge: the first is the technical dimension, which encompasses the ‘know-how’, the second is the cognitive dimension, which consists of beliefs, ideas and values which we often take for granted.

Because of the special characteristic of tacit knowledge, it is difficult to extract this knowledge from the heads of individuals, so one of the best ways to share this kind of knowledge through organizations is to transfer people as “knowledge carriers from one part to another part. Thus, knowledge managers in the first step recommend for companies to manage people in a proper way to use their knowledge in better method. As an example, Toyota launches an approach to extract and transfer this kind of knowledge within this organization. This company sends a core group of three hundred new employees from France for several months training and works on the assembly line in one of Toyota’s existing factories and after some months, they sent back to new factory site with new tacit knowledge that stored in their minds. Usually, most of the Knowledge used in the design and development of a new product is tacit. In order to leverage this kind of knowledge by organizations, they should establish knowledge management process. Supporting NPD phases with this kind of knowledge is critical to improve product innovation, reduce product development errors and generally aid quality development, manufacturing and after sale customer services.

Tiwana (2002) suggests that tacit knowledge is typically developing through a process of trial and error encountered in practice. He states that subjective insights, intuition, assumptions, beliefs, values, judgment and intelligence (Know – How) are examples of tacit knowledge. Social interactions are essential for

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knowledge transfer and the transfer of tacit knowledge is an essential component of learning complex tasks [Nonaka, 1996; Howells, 1996].

There is some controversy as to whether tacit knowledge can be converted into explicit knowledge (Cook and Brown, 1999). By definition, tacit knowledge cannot be clearly expressed, documented, or understood using direct questions. Therefore, it is difficult to study tacit knowledge empirically (Wong and Radcliffe, 2000). Traditional interview techniques are not suitable, as individuals cannot necessarily articulate their thoughts on complex or ambiguous topics [Ambrosini and Bowman, 2001]. People use metaphors and stories when explaining experiences which they are otherwise unable to express [Lakoff and Johnson, 1980; Srivastva and Barrett, 1988; Mascitelli, 2000]. Furthermore, metaphors and stories have been identified as supporting tacit knowledge generation within groups [Gherardi, 2000].

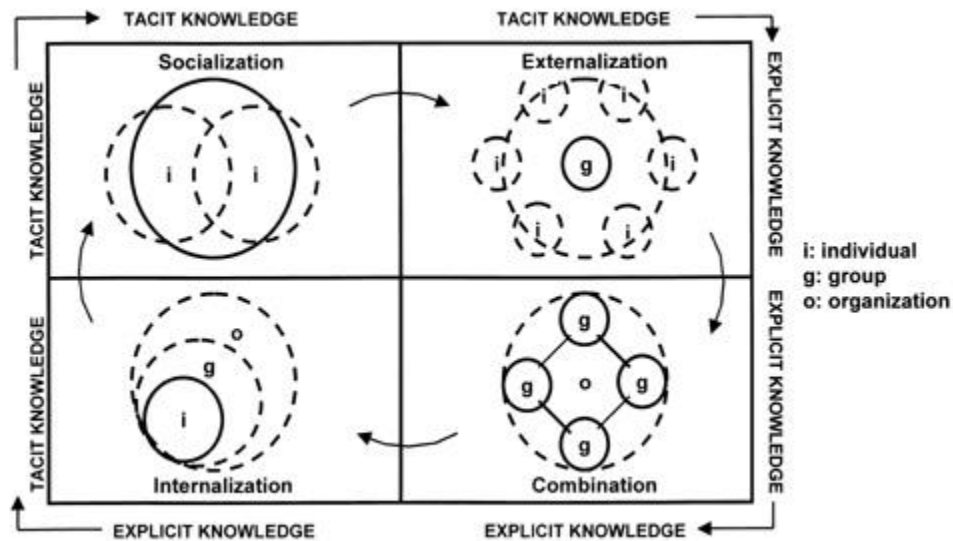
### **2.3.4 Nonaka's Theory of Knowledge**

In 1995, Ikujiro Nonaka and Hirotaka Takeuchi, in their book "The Knowledge Creating Company" explained How Japanese Companies Create the Dynamics of Innovation presented the following model of how tacit and explicit knowledge interact in the knowledge creation process.

Nonaka, same most of theorists in the field of knowledge management emphasizes on the difference between tacit knowledge and explicit knowledge. As we mentioned in previous sections, tacit knowledge is "codified and transmittable through systematic languages", explicit knowledge is "personal, context specific and difficult to formulate and communicate". Nonaka, in adjustment with the results from the interview with Claes Mellby and the book by Allen Ward, found out that the western world traditionally has been focusing on managing the explicit knowledge, which would be the background to knowledge management initiatives. In Japanese culture on the opposite, explicit knowledge is considered to be only a small part of the actual knowledge. The most useful

knowledge is the tacit, extracted through active generation and organization of experiences, and the part of it that can be expressed through numbers and letters are only the tip of the iceberg (Nonaka & Takeuchi, 1995), (Ward, 2007).

The interrelations between tacit and explicit knowledge that transferring the knowledge within an organization occurs in four different modes (Figure: 2.4). The four modes are described in detail below, a note here is that the examples mentioned by Nonaka are from 1995.



**Figure 2.4: Spiral of knowledge creation**

**Socialization** (From Tacit to Tacit): With sharing of experiences and Know-How with other learners, tacit knowledge will share in shape of tacit. Socialization is the transformation from tacit knowledge in one person to tacit knowledge in another person. It is about sharing experiences, mental models and skills.

**Externalization** (From Tacit to Explicit): Make formal models from tacit knowledge in order to convert them in form of explicit. The externalization process is about formulating the unspoken, and perhaps the greatest challenge of the four modes. According to Nonaka, the best way to do this is use of metaphors and analogies, to connect the new knowledge to existing mental models.

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**Combination** (From explicit to Explicit): Make a combination between the tacit knowledge that changed into explicit from the previous step with other explicit knowledge. This combination and learning process on it, may cause to create new knowledge. In the combination mode, explicit knowledge is combined into a knowledge system. Everyday individuals exchange and combine the explicit knowledge through documents, meetings, phone calls.

**Internalization** (From Explicit to Tacit): By internalization of the people's experiences, the explicit knowledge that created through online learning process, the possibility of converting those explicit to tacit will happen. This is learning by doing. It is about embracing explicit knowledge and making it one's own through practice. A prerequisite for this mode is that the explicit knowledge is formulated in documents, manuals or stories.

As you can see in Figure 2.5, Grant (2008) puts two levels of knowledge with other levels that are individual or organization. The interesting result by this combination is the acquisition of knowledge and the discussion level here is tacit knowledge that can be difficult to identify and understand and is therefore more valuable to a company than explicit knowledge that can be captured easily.



**Figure 2.5: Different types of knowledge. Modified from Grant (2008)**

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### 2.3.5 Goals of Knowledge Management

With paying attention to the mission of organization, there are some goals defined that all organizations can benefit from them by people learning, sharing, re-using, collaborating and innovating.

**Better and faster decision-making process:** With using of knowledge and information at the proper time when we need it, the power of decision will increase. Furthermore, the re-use of knowledge in repositories enables decisions to be base on actual experience, large sample sizes and practical lessons learnt.

**Making it easy to find relevant information and resources:** In a time that you need information and knowledge in order to respond customer, solve the problem, doing benchmarking, making plan strategy etc ,it could be helpful. If it is easy and fast to find what you need when you need it, you can perform all of these tasks efficiently.

**Reusing ideas, documents and experiences:** When you did a process in proper way, you can make it as experience in documented form in order to use it again if someone wants to repeat that process. Just as the recycling of materials is good for the environment, re-use is good for organizations because it minimizes rework, prevents problems, saves times and accelerates progress.

**Avoiding making the same mistakes twice:** As George Santayana said “Those who ignore history are doomed to repeat it”. If we do not learn from our mistakes, we will make them repeatedly. KM enables us to share lessons learnt, not only about successes, but also about failures .To facilitate this option, there should be trust inside of organization to talk about what we did wrong in the past to avoid repeat of that process.

**Communicate important information widely and quickly:** Knowledge Management helps to feed everyone that need information in organization to do jobs effectively.

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**Providing methods, tools, templates, techniques and examples:** Methods, tools, templates, techniques and examples are the building blocks supporting repeatable processes and procedures. Using these consistently streamlines work, improves quality and ensures compatibility across the organization.

**Showing customers how knowledge is useful for their benefits:** It is important to show your organization differ from others in today's competitive market. Demonstrating to potential and current customers that you have widespread expertise and have ways of bringing it to bear for their benefit can help convince them to start or continue doing business with you.

**Accelerate the delivery to customer:** Knowledge sharing, innovation and re use of data in proper way will increase the delivery of product and service to customer.

**Enabling the organization to leverage its size:** If an organization be able to use in a useful way all knowledge and experiences that employees creating, the revenue and benefits of organization will increase. This exploration in economical side will cause to leverage the size of company in each sector that market has demand for it.

### 2.3.6 Technologies that supporting Knowledge Management

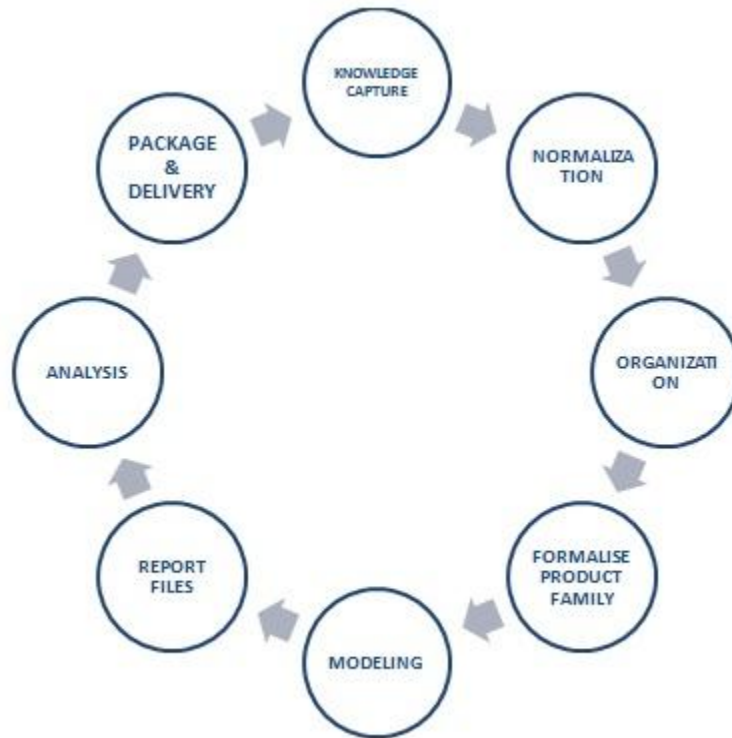
Alavi and Leinder mentioned to technologies that used to support knowledge management roughly correlated to four main stages of knowledge management:

First, knowledge is acquired or captured using intranets, extranets, groupware, web conferencing, and document management systems. Second, an organizational memory is formed by refining, organizing, and storing knowledge using structured repositories such as data warehouses. Third, knowledge is distributed through education, training programs, automated knowledge based systems, expert networks and the last one, knowledge is applied or for further learning and



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innovation through mining of the organizational memory and the application of expert systems such as decision support systems.



**Figure 2.6: Main technologies that support knowledge management systems**

## 2.4 Importance of Knowledge and Learning in NPD

Top managers recognize that new product development is a core competence (Harmsen et al, 2000) and the “product innovation literature has progressively highlighted the importance of knowledge management as the main source of long-term competitive advantage” (Corso et al, 2001, p348). New product development generates vast amounts of knowledge, not only about the product and about technology, but also knowledge about the processes used by the NPD team (Cohen and Levinthal, 1989). To constantly improve NPD, organizations depend on the ability to learn from previous projects (Gupta and Wilemon, 1996; Nonaka and Takeuchi, 1995; Wheelwright and Clark, 1992). If organizational learning

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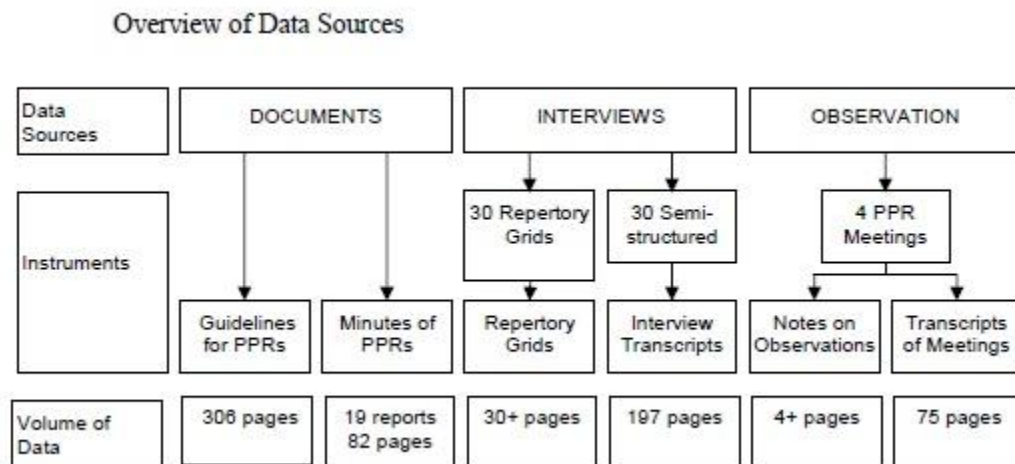
occurs, it leads to a change in the way in which subsequent problems are investigated (Michael and Palandjian, 2004), it helps to avoid the repetition of mistakes [Tidd et al, 2001], and supports knowledge retention [Jensen and Sandstad, 1998]. Can say that learning occurred when an organization uses knowledge to solve or prevent problems and this can lead to competitive advantage (Ambrosini and Bowman, 2001).

Sustained improvements in R&D depend on the capacity of an organization to learn [Gupta and Wilemon, 1996; Takeuchi and Nonaka, 1986; Wheelwright and Clark, 1992). Organizational learning changes the way in which a company solves problems (Michael and Palandjian, 2004), and helps to avoid the repetition of mistakes (Jensen and Sandstad, 1998). Consequently, learning has been identified as fundamental to R&D (Drejer and Riis, 1999; Prahalad and Hamel, 1990) but companies find it difficult to learn from new product introductions (Michael and Palandjian, 2004). During the 1990s, scholars of organizational and Bartezzaghi, Corso, and Vergani (1997) found it can be promoted by transferring people between projects, or by utilizing databases. Project-to-project learning is worthy of research, but before it can be adequately investigated a clearer understanding of the other two types of learning is necessary. By the way, there are various mechanisms to capture the lesson learnt by NPD team:

Checklists (Riek,2001), close interactions between members of team (Mascitelli ,2000), experts who are willing to share their knowledge (Mehra and Dhawan 2003), produce databases from lesson learnt (Bartezzaghi 1997), Micro Histories (Schindler and Epper 2003), Learning Histories (Kotnour and Vergopia 2005), Post Project reviews (Busby 1999), Knowledge officers responsible for inter project learning (Schindler and Epper ,2003) and Metaphors storytelling (Cook and brown 1999, Nonaka 1994) are the most important ways to capture the knowledge in an organizations.

From all these mechanisms, PPRs has been identified as highly effective by a number of authors over the past decade (e.g. Bowen et al, 1994; Thomke and Fujimoto, 2000; von Zedtwitz, 2003; Kotnour and Vergopia, 2005). PPR runs as a

meeting shortly after the product launched , where core team members objectively discuss how the project was conducted and what could have been improves .Keith Goffin(2008 UK ) mention that engineers and NPD project leaders perceived PPR to be a useful mechanism for promoting individual and team learning . Figure shows the overview of data sources that are using in PPR.



**Figure2.7: Overview of Data sources [Keith Goffin and Ursula Koners]**

### **Documentary Evidence**

- The term “Tacit Knowledge “was not found in any of the guidelines. MedCareCo’s guidelines stated a PPR should be characterized by the “Joy Of Having Finished the task “and stresses the importance of good atmosphere. No factors that might influence tacit knowledge generation, only some metaphors and stories were identified.

### **Interview Evidence**

- The transcripts provided evidence on how knowledge is generated in discussions. The importance of the right atmosphere and the role of the moderato have impacts on the results and the influence of management. PPRs were perceived to facilitate the generation of knowledge, because discussion exposes point, which individuals may not have previously recognized. On the other hand, the value of discussion is important, because the difficulty is to try and capture knowledge during discussion in the minutes of the meeting .Furthermore, Good Atmosphere is very

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important to extract knowledge from people's mind. The interviewers provide evidence on how the presence of a senior manager at a PPR can either support or disrupt open discussion, also. Interviewers gave the impression that a more effective discussion is possible if the moderator is not a member of the project team.

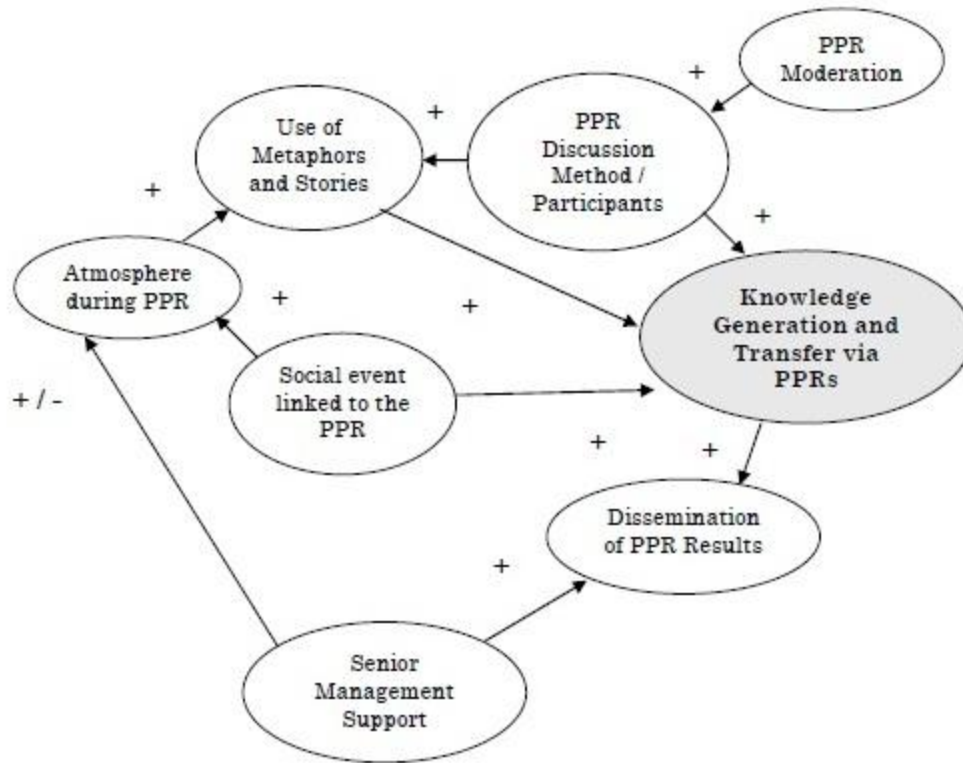
### **Evidence from Observations**

- Different approaches to moderation were observed. The project leader at Engineering Co focused on what went well about the problems that occurred. The external moderator took a number of perspectives and used various diagrams to stimulate discussion. NPD project teams have shared experiences and language that enables the transfer of tacit knowledge. The use of particular metaphors and stories also appeared to be closely linked to the working culture of the NPD team.

### **Data Comparison**

- There are two drawbacks to relying on documentation: Firstly, many interviewees recognized the limitations of written documents for disseminating lessons learnt and, secondly, the stories and metaphors, which were observed to be a lively and important part of PPR discussions, appear not to be documented. Therefore, the associated learning appears not to be captured and disseminated.

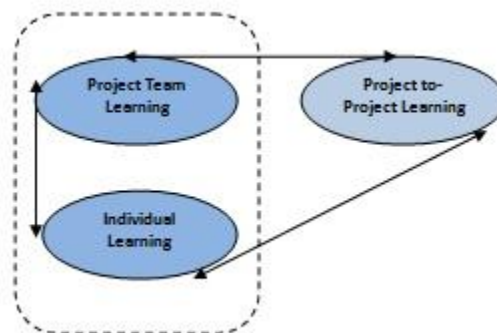
There is a tentative conceptual model of the factors that appear to influence knowledge generation and transfer through PPRs that introduced by Keith Goffin and Ursula Koners. Figure 2.8 shows that three factors: Social interaction, the use of metaphors and stories, and the method for discussion are all likely to directly lead to the generation and transfer of tacit knowledge. Use of metaphors and stories, depend on atmosphere and by the type of discussion guided by the moderator. Both the amount of knowledge generated in the PPR and the role of management are important in determining how the learning is disseminated. In addition, the role of management can have a positive or negative impact on the atmosphere in PPRs.



**Figure2.8: Model of Knowledge generation by PPRs [Keith Goffin and Ursula Koners]**

The culture of the organization in which a PPR takes place will be a key contextual factor to consider as this impacts the atmosphere in discussions, is dependent on senior management, and the role allocated to the moderator and A “blame-free” environment appears essential. Proposition 1: Even PPRs that produce tacit significant knowledge do not necessarily lead to organizational learning, unless companies specifically focus on disseminating tacit knowledge (and utilize mechanisms other than written reports). To really understand the way inter-project learning occurs, it will be necessary to understand a company culture. Therefore, ethnographic research would appear to be a promising approach to the study of knowledge and learning in NPD. From our exploratory study, an exciting area to research can be expressed as. Proposition 2: Organizations with a “blame-free” culture are more likely to generate and disseminate tacit knowledge in their PPRs than more formal, hierarchical companies.

Thomke and Fujimoto (2000) recognized the importance of tacit knowledge in solving the inevitable problems that occur in NPD. Also, “below the surface of conscious thought lies a vast sea of tacit knowledge” (Mascitelli, 2000, p. 182) that can provide ideas for breakthrough innovations. Up until now, however, the concept of tacit knowledge has not been applied to studies of NPD (Saban, Lamosa, Lackman, and Peace, 2000). The underlying processes for knowledge creation and dissemination in NPD are not well understood (Reger and von Wichert, 1997). It appears that learning can take place at the individual, project team, and project-to-project levels, or through a combination of this Figure 2.9. The importance of project-to-project learning has been recognized (Lynn, 1997), on his own experience to produce checklists of the key points to consider, such as managing technical and commercial risks and managing NPD personnel. The final phases of projects have been identified as presenting the best opportunities for individual learning and for transferring the lessons to future projects. (Björkegren, 1999). Individual learning can lead to knowledge transfer within the project team but care needs to be taken to capture individuals’ learning before they are transferred to new projects (Michael and Palandjian, 2004).



**Figure 2.9: Relation between Project team, Individual [Keith Goffin and Ursula Koners]**

The interviewees all had substantial experience and the eight key lessons learnt are indicated Budget, Learning, Organizational complexity, Problem solving, Product specifications, Project objectives, Resources and Time. Nonaka published extensively on explicit and tacit knowledge and his ideas relate back to Polanyi’s

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famous quote, “we can know more than we can tell” (Polanyi, 1962,p4). Although it is possible to distinguish between explicit and tacit knowledge in theory, they are hard to differentiate in practice (Lam 2000; Brown and Duguid, 1991). Nonaka concluded that knowledge always has a tacit component that is generated and shared through interaction. “In project work... a great deal of the know-how required is tied to knowledge that is not written in documents but realized through the expertise and understanding of the project personnel” (Koskinenet al, 2003).

## **2.5 Knowledge Based Engineering**

Increasingly competitive and demanding markets are forcing companies to decrease time and costs for new product development, while satisfying customer requirements and maintaining design quality, motivating companies to moving towards mass customization. The goal in Mass Customization is the production of goods to meet individual customer’s needs with near mass production efficiency (M.M.Tseng , J.Jiao,1996). This approach requires the capability to rapidly and collaboratively design and produce a large number of product variants, often based on modular design principles. In the design domain, one of the technologies that support rapid, modular design is Knowledge-Based Engineering (N. Wognum, A. Trappey, 2008).

### **2.5.1 Definition of Knowledge Base Engineering**

Knowledge-Based Engineering (KBE) is a combination of object-oriented programming, artificial intelligence, and computer aided design (Figure 2.10) in order to capture product and process information to allow businesses to model engineering processes, and then use the model to automate all or part of the process. The emphasis is on providing information and knowledge of product and process. KBE also provides information from outside of organizations such as databases and external company programs. The ultimate goal of the KBE system should be to capture the best design practices and engineering expertise in to



corporate knowledge base (Stokes M, Ed, 2001). By the way the main objective of KBE is to reduce lead-time by capturing product and process knowledge.

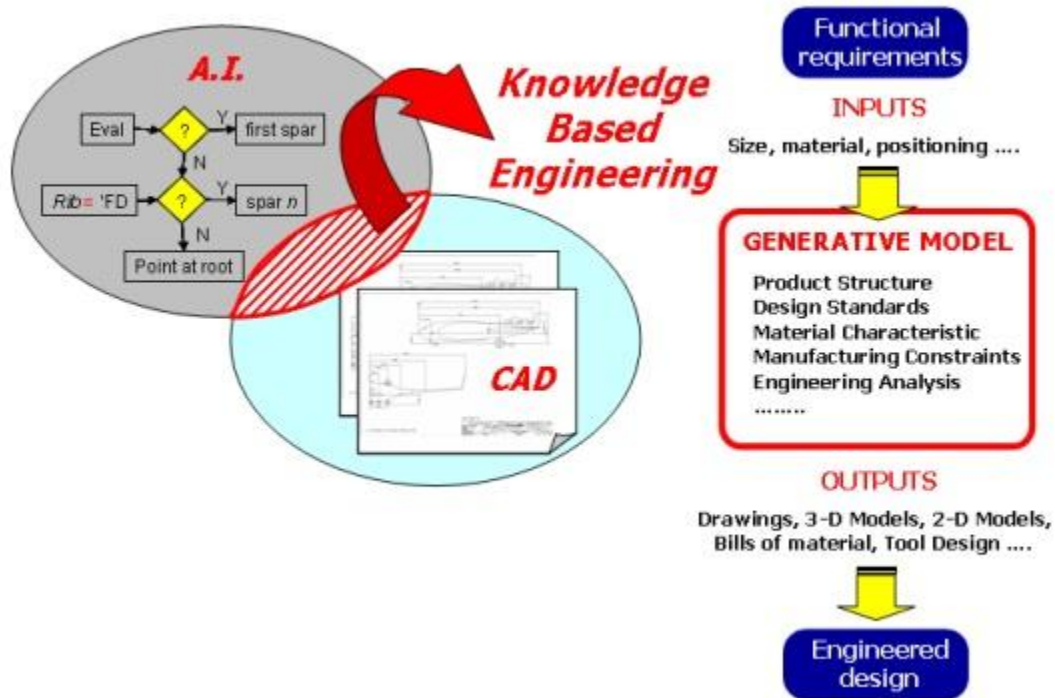


Figure 2.10: Knowledge Based Engineering (Van Tooren, 5 March 2003)

Engineering design is a multi-disciplined environment and a highly integrated process. It requires the integration and utilization of information, supplied from many sources both internal and external and in different formats. The success of a traditional design projects is determined in two stages, by the effective relationship of information related to a productive solution and then the capturing of the outcome solutions. Designers can introduce many different projects, but the main constrain is for manufacturing engineers, limiting their ability to improve the process. Design decisions are made continuously during the product development cycle. Early decision can determine almost 80% of the product costs at a step where knowledge about the product, customer and process involved is low or misty. By the way, figure 2.11 is illustrating the improvement process that happening because of KBE implementation.



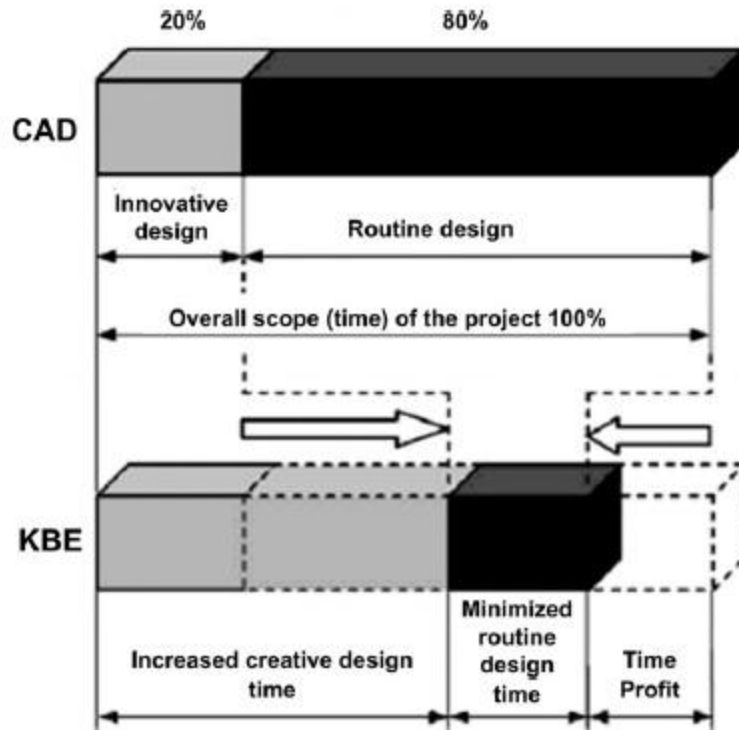


Figure 2.11: Achievable design time allocation by KBE adoption [W. Skarka, 2007]

Current engineering allows the engineering team to utilize the various inputs, knowledge and technology to speedup product development by integrating downstream concerns as early as possible in the design process. For CE is need to integrate with other departments with paying attention to the changing of information .In order to create a integrated design environment Computer Aided Design (CAD) systems are using. But there are limitations about these tools in their inference ability and this is the duty of knowledgeable team member to interpret and assess the impact of any change to the product model .Design analysis tools need a system to analysis new materials and constructions .This range of different options requires a faster method for analyzing (Marcus Sandberg , 2003). In the late 70's first solid modeling system (CAD / CAM /CAE) were employed and in the beginning of 90's, the big step was the integration of production process parameters. KBE system have the same

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importance for companies in 2010 that CAD/CAM had in 90's (Andreasen M.M & Springer Verlag , 1987).

KBE provides designers with tools to virtually access their ideas, model the multidisciplinary aspects of products, manipulate geometry and annexed knowledge and support the investigation of multiple what-if on their design (Van Tooren, 5 March 2003). To develop KBE system, we need first acquire, represent and finding the reason of developing and then communicate the intent of the design process. We should understand the problem in conceptual level, then decomposed it into understandable working objects, then developed further through iterative process until we reach to satisfaction level for outcome. The core of the system is the product model where product and process knowledge is stored. A product can often be divided into several parts which contains the details [Boart Patrik , Jonasson Pierre .2002].

- **Product model** there is knowledge about how a certain product should be developed in terms of rules.
- **External Database** holds information about standard parts and material properties needed in the product development .This data should not be confuse with the knowledge of the KBE system that lies in the product model.
- **Input** is a place for customer specification that continuously fed with new product data.
- **Outputs** are reports, drawings, manufacturing plants, costs, and COM and CAD models.

The KBE systems are built utilizing an object-oriented approach. The implementation is often done with IF – RULES [Chapman C.B, 1999]. Application of KBE-System is the field of product development is to automatically generate product concept from input specifications .The output were from the beginning often only the geometry of the product concept. Concept Generation (A draft of the product showing its main features.), Concept

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Evacuation (To take step further on KBE has been used to make a preliminary evaluation of the solid mechanics properties by using the finite element method. Usually the interactive work between design and analysis is often slow and costly, so a developed KBE system, which makes this work faster, is developed.) And manufacturing Aspects (A knowledge base environment for choice of rapid manufacturing process is presented in KBE.) are three main area of Application (Philips R.E 1997).

### **2.5.2 Methodologies for developing KBE Systems**

The power of computer hardware and software have important rule in the implementation of KBE methodologies and high performance IT systems need more budget. There are two different types of companies that KBE methodology implementing for them, small or medium size and big.

The lack of staff with experience of KBE systems and IT system in general are problem for small companies to develop KBE system. The volume of work in small organizations is not proper to justify their employment and consequently the development of a new system may necessitate the corporation of an external organization. In time of bad situations for companies, they try to keep up their staff and it is a problem for them to lost the experience of that staffs and the danger will happen, if critical knowledge was in hand of selected people. Therefore, it is vital for company to capture that knowledge for future in order to develop KBE system. Small companies has small KBE application, so because of that the relation and lines between people will be small .This is an advantage in some cases and disadvantage on some others. The limit of people in small companies in some cases make problem of concern about corrective of knowledge. When there is only one person to use the data, it will possible to increase errors. Furthermore, Small companies have budget limitation, because of this they will not be in a position to invest in R&D in lean time to engage in speculative projects.

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The existing methodologies mostly are about KBS system that is for large companies instead of small organization that needs KBE. The most widely known methodology for KBS is KADS. It supports project management, organizational analysis, knowledge acquisition, conceptual modeling, user interaction, system integration and design. KADS is large and difficult to learn in order to use in small organizations and small projects.

- Because of characterize about KBE application, the quality of knowledge that extracted in early stages has important effect in the development of application. Thus, there is a danger of trying to inflict an artificial structure on processes, which are natively unstructured. In order to perform a complex procedure, we need a methodology to set of instructions and guidelines .This methodology say in details the individual sub-tasks and the way that how they should be carry the work in what order and how the work should be documented. Using of methodology is not necessary and we can develop a KBE application without any methodology, but because of quality, reusability and maintainability of the delivered system. By the way, a methodology contains details of the activities that need to be performed during system development, a systematic instructions for each task, techniques to use trough the tasks such as interviewing and modeling techniques, Documentation methods, general advice and guidelines.

There are many benefits to be gained from using a methodology:

- Developers can benefit from the knowledge of experts in the specific fields.
- Developers who are new to the field will not omit essential tasks.
- Standardized procedures mean that the work of an individual can follow easily by others.
- It may possible to recruit staff already trained in a required methodology.
- Applications, or parts of applications, can be more easily adapted and reused.
- Ease of maintenance. The time and effort devoted to the maintenance of most applications is greater than that needed for the original development.

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- Project management greatly simplified, as recognized stages and activities can be identified, and if necessary allocated to development team members.

### 2.5.3 The MOKA Methodology

A number of KBE methodologies are available to support the development of KBE applications and systems. By far the most famous of these is the Methodology and software tools Oriented to Knowledge-Based Engineering Applications, or MOKA (Methodology and software tools Oriented to Knowledge based engineering Applications) methodology. This methodology, consisting of six KBE Life-cycle steps (Identify, Justify, Capture, Formalize, Activate and Delivery) and accompanying informal and formal models, is designed to take a project from beginning towards industrialization and actual use (Oldham, Kneebone, Callot, Murton, & Brimble 1999; Stokes, 2001). The informal model comprise of so-called ICARE forms: Illustrations, Constraints, Activities, Rules and Entities. The formal model uses MML (Moka Modelling Language, an adaptation of UML) to classify and structure the ICARE informal model elements, which are translated into formal Product and Process models. When the problem knowledge has been converted into a structured representation, the next step is to formalize this knowledge in order to represent knowledge in a form that is acceptable to knowledge and software engineers and suitable for subsequent development of the KBE application. . When contrasting the MOKA methodology and other KBE methodologies (Kingston, 2005; Lovett, Ingram, & Bancroft, 2000; Schreiber, Akkermans, Anjewierden, et al., 1999) to Colledani et al.'s list of requirements (Colledani et al., 2008), a number of major shortcomings of current KBE methodologies can be identified. The main elements of the MOKA methodology are illustrated in Fig 2.12. The important point about MOKA is that, focus lies with the 'Capture' and 'Formalize' steps of the KBE life cycle.

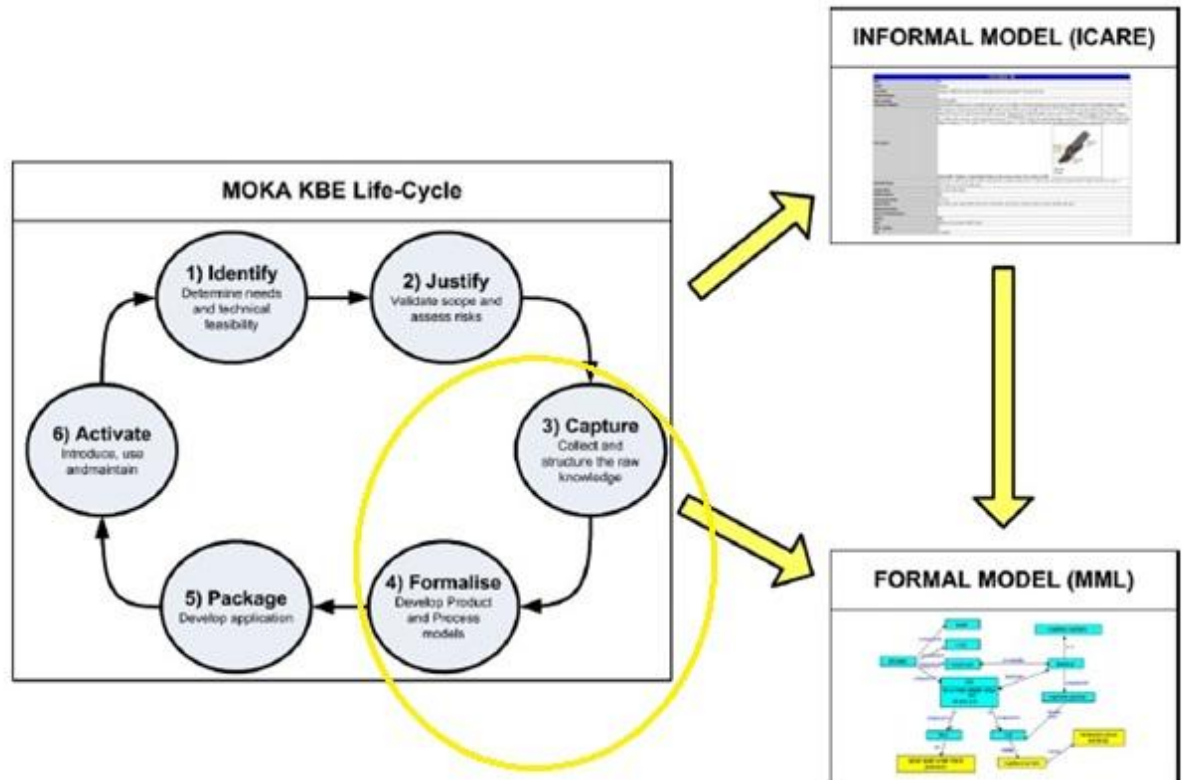


Figure 2.12: MOKA methodology elements [M.Stokes ,2001]

- **Some Problems about MOKA methodology:**

In the MOKA methodology the focus is supporting knowledge for engineers to do capturing and formalizing the necessary knowledge for KBE application rather than preparing the knowledge for end user. In addition, it is very important for both the development and the actual use of the KBE application because for example the end user is typically the domain expert who holds the knowledge. In addition, the end user should derive a clear benefit from using the KBE application with paying attention to minimizing any extra workload to improve acceptance and maintenance of the application. Miss the knowledge representation mechanism and support tools is another negative factor about MOKA. This was done purposefully, as MOKA is intended as a neutral methodology. However, this choice has implications with respect to the

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accessibility of knowledge in developed KBE applications. Furthermore, MOKA does not give much attention to the use of the KBE applications in the design process itself and does not thoroughly consider maintenance and re-use of knowledge and the last lack about MOKA is product orientation approach rather than process orientation.

Another available KBE methodology similar to MOKA is KOMPRESSA. Knowledge- Oriented Methodology for the Planning and Rapid Engineering of Small-Scale Applications. This methodology aims to support KBE implementation at Small to Medium Enterprises (SMEs) and shares many steps and rules with MOKA. It distinguishes itself from MOKA by an increased emphasis on risk analysis and management, the increased use of activity diagrams to guide organizational and individual participants, and the assumption of little to no IT expertise on part of its users (P.J. Lovett, A. Ingram, C.N. Bancroft, 2000).

#### **2.5.4 Design Engineering Engine (DEE) methodology**

The DEE includes of three major elements (Figure 2.13). The first is concerned with the design process, which includes multidisciplinary optimization. After starting the design process by listing the requirements and making initial calculations, the parameters of value related to product model are generated. This initiator supports the parameter values to the second major element of the DEE, the Multi-Model Generator (MMG). The MMG is a modeling framework that uses the product model parameter values from the initiator by compounding with formalized domain knowledge to generate product models. As the result, the MMG contains the fully formalized KBE applications that would result from implementing the MOKA KBE Life-cycle. The MMG generates the Report Files. These fed to the third major element, detailed analysis modules (DDE). These modules receive the output from the MMG and calculate the design implications on a virtual per-discipline basis. Finally, the loop closed by analyzing the Data

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files in a Converge & Evaluator, which checks for mathematical validity and requirements compliance in a multidisciplinary procedure. (Van der Laan et al. 2006).

In effect, the current DEE repetition of the Converge & Evaluator is a fully completed multidisciplinary design optimizer. To summarize, the DEE addresses KBE application in the form of the Multi-Model Generator, but extends beyond conventional KBE approaches such as MOKA by including detailed discipline analysis and subsequent multidisciplinary optimization into its routine. However, the negative point about DEE is that DEE does not conclude a methodological and formalized approach towards knowledge capture, knowledge formalization and knowledge delivery into business processes (Van der Laan et al. 2006).



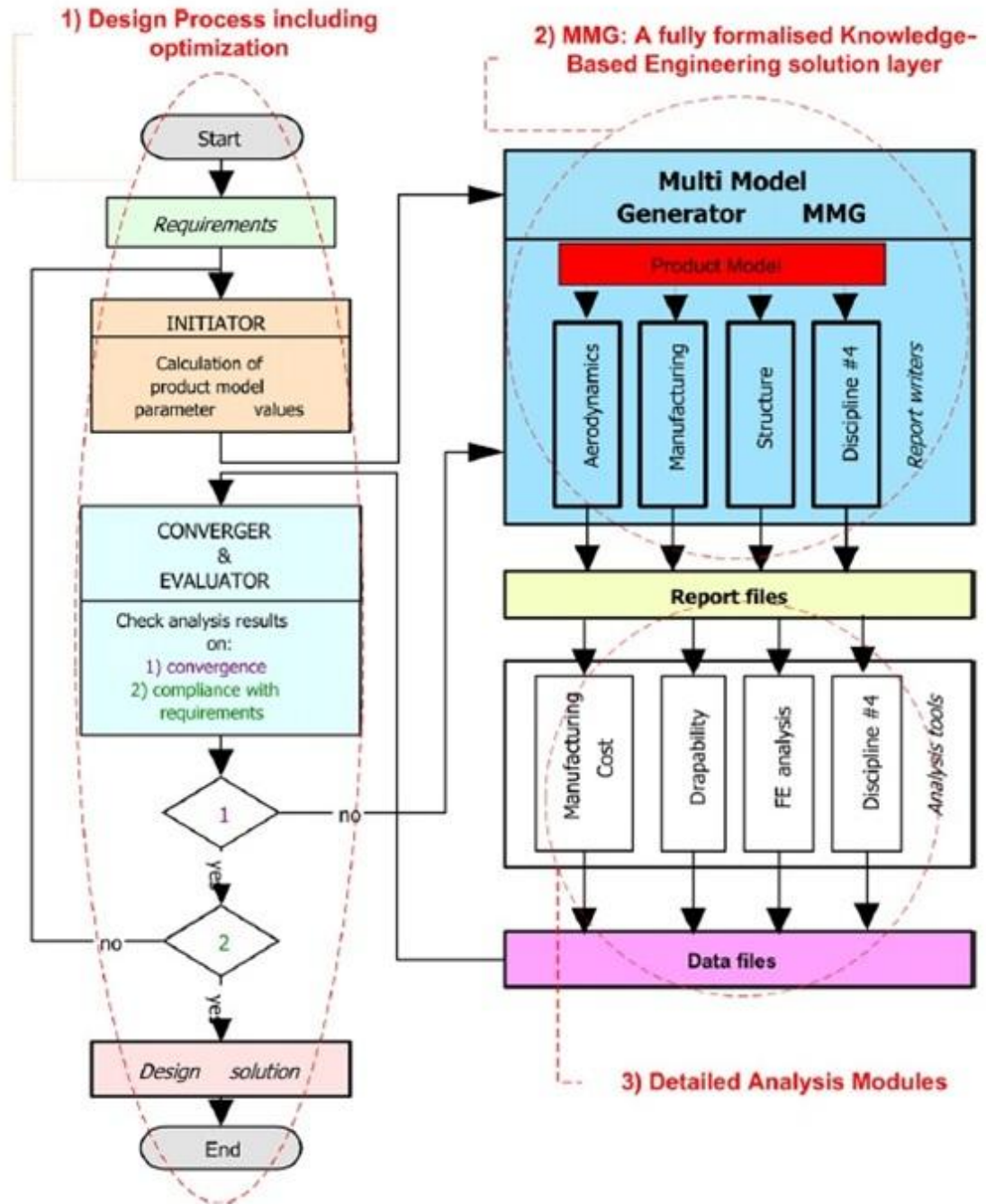


Figure 2.13: Design Engineering Engine DDE methodology (Van der Laan et al. 2006)

### 2.5.5KNOMAD Methodology

The KNOMAD (Knowledge Nurture for Optimal Multidisciplinary Analysis and Design) methodology has been developed to address the previously identified

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shortcomings of existing KBE methodologies and extends the scope of existing multidisciplinary KBE enabled optimization frameworks such as the DEE. The methodology requires specific implementation steps to be taken that may be repeated as part of the knowledge life cycle and in this context KNOMAD nurtures the whole Knowledge Management across that life cycle, as well as at any particular stage (Richard Curran , Wim J.C. Verhagen ). This methodology consists of following steps.

**1- Knowledge capture:** This first step concludes the identification of the scope, objectives and assumptions of the case that the methodology want to implement and with paying attention to these factors the required sources to capture knowledge will identified. Subsequently, knowledge is captured from explicit sources and tacit sources. Various knowledge elicitation techniques can be used to capture knowledge.

**2- Normalisation:** In this phase, the hard quality controlling and normalization will implement for the knowledge that captured in the previous step. By this way, the high quality knowledge will prepare to modeling and analyzing. First, the set of raw knowledge is checked against applicable quality criteria to see whether it is fit for inclusion (again, see the detailed KNOMAD substantiation further on for more detail). Secondly, the captured knowledge is subjected to normalization, during which the knowledge is standardized for use in subsequent methodology steps.

**3- Organisation:** The organization of knowledge is an essential step towards knowledge utilization in modeling and analysis. The purpose of doing this step is to prepare a structural framework of knowledge for stakeholders to reach by them in every time in proper way to do modeling. Ontology methodology is useful and recommended way. Ontology is a ‘explicit formal specifications of a conceptualization’ (Gruber, 1993). In simpler terms, this indicates ‘a way of thinking about a domain that is typically understudied and expressed as a set of concepts, their definitions and their inter-relationships’ [Uschold, 1996]. Structure of ontology allows for formalization of knowledge through use of intensive

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definitions and axioms. The ontology forms the object-oriented knowledge structure.

**4- Modeling:** The next step is the modeling of products and processes. Here, KNOMAD uses the Multi-Model Generator (MMG) approach that introduced in the DEE. As mentioned before in MMG, the MMG is a modeling framework that uses product model parameter to combine with formalized domain knowledge in order to generate product models. This process can repeat also in modeling of process. Within the MMG definition, it is immediately evident that the ontology constructed in the previous step can be used to provide the product or process model parameters and any supporting formalized domain knowledge.

**5- Analysis:** For instance, a manufacturing analysis module can calculate some important factors such as manufacturing costs, manufacturability estimates and manufacturing logistics. The Analysis step in KNOMAD can also conclude single or multi optimization with paying attention to the design objectives. As such, the KNOMAD Analysis step takes the DEE Converger & Evaluator within its fold. KNOMAD includes a full methodological approach towards multi-disciplinary analysis and optimization with attention to the combination that occur in modeling step.

**6- Delivery:** This step starts with a check of the solution versus the requirements specified at the beginning of the design process. If this check is well done, the detailed analysis results delivered and resource indication can be evaluated. Furthermore, a well set up ontological representation of the problem in organization level will have included resource implications, either as a class in its own right with relationships to the products, processes, tooling classes and other sections. This property has then ‘accompanied’ the instantiated objects during modeling and analysis in the subsequent KNOMAD phases, which will result in resource implications for each object.

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### 2.5.6 Knowledge Based Engineering Software in market

Knowledge Based Software is more than just a computer application and it is a methodology for capturing, applying, distributing, and accumulating firm's expertise. These methodologies start by capturing knowledge in the form of rules that a person applies every day to enable them to make informed decisions. It then applies these rules to reoccurring problems with a speed and consistency that only a computer can achieve, assisting the software operator in discovering the optimal solution. The software, allows for easy dispensation of the captured knowledge. Experts in each domain contribute their wisdom by preparing rules in order to use in application. It is like having the experts from each domain beside your side to use in each time that you need them (Liberatinginsight site).

There are some advantages by using KBE software in the market. For example, Liberating Insight LLC indicates that they specialize in the Knowledge Based Software methodology. Whether applying the technique to component design or assisting the sales force with real time product configuration feedback, they realize improvements in productivity, quality, consistency, employee and customer satisfaction, and time to market. Our past successes include:

- Reduction in the design cycle length from 6 hours to 2
- 15% efficiency increase in product performance
- Generation time of sales quote from 2 days to 20 minutes
- Expanded certification test cases from 150 to over 5000 without increasing cycle time

#### **GENWORKS Software**

Genworks provides “General-purpose Declarative Language” (GenDL), a Generative Application Development system for creating web-centric Knowledge Based Engineering and Business applications. Based on both ANSI and de-facto standards, GenDL is generative on many levels, generating detailed code while customers’ write high-level definitions, then generating solutions to their problems according to those definitions. Genworks GenDL makes for different

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configurations depending on needs and resources, starting from a free open-source distribution through to fully supported packages with proprietary licensing and built with high-end commercial components. Genworks is the first-level vendor for GenDL that provide customized services and end-user applications, depending on precise requirements. It can use particularly in complex systems, including three-dimensional geometric models. Examples with geometry are auto or airplane wiring or hose systems, sheet metal surfaces, baggage delivery carousels, storage tanks and boilers, airplane fuselage or other components, plus many others. Examples without geometry would be such things as a Trucking company's national delivery scheduling, a company's multi-national Patent tracking system, an individual's computer Diary system (Genworks Site).

### **GENUS Software**

Genus Design Language (GDL) allows to divide and overbear difficult design problems in stages with a model and language that dividing the problem in sub-problems and making the solution of each simpler. Genus Designer is different because the designer automates both the design exploration and generation. Designer creates and evaluates design alternatives, eliminates invalid designs, presents the set of possible designs and their trade-offs, generates the CAD model and makes drawings and reports for the designs you choose (Genussoftware site).

The power of Genus Designer's GDL is simplifying process to solve the real problem. Design automation enables product customization for each customer:

- Manufacture to orders received, not to inventory
- Give the customer what he wants, not a loose fit to a stock item
- Forge a customer relationship, build a barrier to distant competitors
- Lower resource use by customizing, avoiding compromises and overdesign
- Quote rapidly and accurately, don't estimate a product not yet designed

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Genus Designer provides a means of describing variations within a family of design and the rules for choosing between them. What is important is that you can do this without programming. Diagrams and spreadsheets like formulas, the lingua franca of engineers, capture the configuration rules. Linking to and orienting geometric elements is equally easy using Genus Designer's innovative "asset builders" to capture them "by example". Just enter your inputs to create a beautifully rendered Solid Works model of a unique design.

### **CSM Software**

CSM Software [P] Ltd. Supplies different types of softwares for various industries like Automotive, Aerospace and Heavy Engineering. The Knowledge Based Engineering Software under the brand name `Pacelab Suite` focuses on supporting the primary engineering requirements for aircraft preliminary design. (Suppliers.Jimtrade site)

### **SIGGRAPH CAE software**

SIGGRAPH CAE is a unique Computer Aided Engineering tool developed on an Object Oriented Technology (OOT) for application in the field of Electrical Engineering and Process Automation. In this object-oriented approach, it is possible to synchronize data models in the entire machine and plant technical Engineering chain right up to maintenance. The Electrical & Process Automation Framework for engineering and maintenance supports this approach. Building blocks of different engineering activities demands for continuous Computer supported work (Gongchang site). In the Table 2.1 there are other commercial tools that currently address the configuration and custom software space.

Tool	Company	Solution	Market Segment
3DVIA Virtools[5-7]	Dassault Systems	Custom software can be developed	Mid-Range
SolidWorks[5-7]	Dassault Systems	Custom software can be developed	Mid-Range
CATIA[5-7]	Dassault Systems	Custom software can be developed	High End
Autodesk inventor[8-9]	Autodesk	Custom software can be developed	Mid-Range
AutoCAD[8-9]	Autodesk	Custom software can be developed	Mid-Range
Autodesk Intent[9]	Autodesk	Rule-based solution for ETO space	Mid-Range
Unigraphics[11]	Siemens PLM	Custom software can be developed	High End
KnowledgeFusion[11]	Siemens PLM	Rule-based solution	High End
ConfigureOne[4]	ConfigureOne	Web-based configurator	Mid-Range
Vizualise[2]	Vizualise	Company that makes custom configuration	Mid-Range
Fluid Configure[3]	Fluid	Product customization solution	Retail Market

**Table2.1: KBE configurator Technology Landscape [Infosys]**

### 2.5.7 Area of KBE application

KBE is widely used in designing and developing both systems and subsystems in many different areas such as aerospace, automotive and heavy engineering industries, which result in around 30% productivity improvements, cost saving and quality improvements. CPG [Consumer packaged goods (CPG) are consumable goods such as food and beverages, footwear and apparel, tobacco, and cleaning products. In general, CPGs are things that get used up and have to be replaced frequently, in contrast to items that people usually keep for a long time, such as cars and furniture.] Industries and retail are the areas which KBE not known but is limited. KBE helps in realizing substantial tangible and intangible benefits. The product development effort can be reduced by 20-30% in the first iteration and 40-50% in the subsequent iteration by making the ordinary activities automotive and increase the bandwidth available for creative activities.

#### Sales Configurator

Conventional method of sales configuration largely involves creation of fast designers using manual process or through CAD software. For each configuration, may be it will takes days or weeks to prepare a new CAD model, so KBE can help



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in capturing the underlying rules of a product and in developing a kind of sales configurators. These applications accept functional requirements as input and generate a lightweight digital product that is representative of the final product. They can be used in presales environment to generate a quick model or buy a customer to design a product and place on order. They usually emphasizes on visually appealing that can help accelerate the design process. The improvement about lead time and reduction of cost up to 90% are the result of using this application. (Narayanan Chidambaran , Ravi Kumar)

### **Product Configurator**

Conventional method of product configuration involves capturing functional requirements and creating detailed design manually or through CAD software, which contains manufacturing information. Generating these complex designs often takes weeks, month or years. Since a lot of manual changes is required, this process is prone to human error. When functional requirements or the options variants of the product change, there is a need to change the entire design and created it again. KBE can help in developing product configurators that accept complex functional requirements and generate detailed digital prototypes such as 3D models, 2D drawings, manufacturing information, documentation and reports .These configurators are similar to sales configurators, but produce complete and more detailed output for design and manufacturing. They can efficiently manage the option and variants of a product in the design and manufacturing stages, human errors, cost of design, manufacturing and time to market. For example configurator can take a functional data and specification from a user and create s complex shelving solution of thousands of components within a few minutes thereby achieving substantial improvement in these areas.

### **Knowledge Configurator**

In some businesses, it requires to capture complex knowledge. Conventional methods of handling these involve a lot of manual intervention and keeping route of intermediate output of each stage in the workflow and in deciding the next



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knowledge path. KBE can help in developing knowledge configurators that capture information in a structured way, capture complex knowledge path and display resulting information to the user at every stage ( configurators site). Furthermore, this KBE can help in developing advanced productivity improvement solutions that can integrate with CAD software.

### **Enterprise Configurator**

Current enterprise-wide systems are often various and some of the subsystems are even manual. This solution creates inefficiencies and human errors in the quote-to-production workflow. KBE can help in developing complex enterprise-level solutions that interface with multiple enterprise-wide systems. They can facilitate quote-to-production order systems that enable sales and engineering process automation.

### **Reverse Engineering**

Many of the designs that are using today, is the result of previous design activities and there are many similarities between them. Many of new designs created by designer are replicating an existing physical part through visual inspection and measurements. Traditional methods involves of sketching or using a coordinate involve sketching or using a coordinate measuring machine to capture the design from the physical model and then generating a digital model, which can be used for design modification or presenting new one. KBE can offer an efficient and accurate reverse engineering process that involves creating point cloud data from an existing model using a 3D scanners and creating surfaces and solids out of the data. Also, It is possible to create CAD models that has the ability to be edited and capture feature data.

### **Product Solutions – Concept to Manufacturing**

There are not many unified solutions for handling data and workflow from concept to manufacturing. Because of this lack, these functions are largely handled by different systems that some of them involving manual intervention.

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KBE can offer unified solutions that include conceptualization, design, manufacturing and order management. In this process, parts can be standardized and a library of parameterized created. Knowledge items that are general to the design can be separated from those that are specific to a design. An example of a user workflow here could be that a customer logs in to web site-specific functional parameters and creates a digital prototype on the spot. This prototype can be evaluated against various factors such as strength, weight, cost etc and the customer can modify the functional parameters to generate better optimal design that satisfies their acceptance criteria. When an acceptable and proper design is generated the customer can place an order online [Infosys – White paper].

### **Interior Design Configuration**

Most of interior design is done individually with rules that are scattered in the system and several stages of the process are manual. KBE applications can help interior design companies define the functional requirements and generate different options for interior space configuration that could include free space furniture layout.

### **2.5.8 Current Shortcomings of KBE**

There are five major deficiencies about KBE that have been identified from previous studies

#### **1- Case-based, ad hoc development of KBE applications**

Development of KBE applications is still very much case based and happens on an ad hoc basis (P. Sainter, K. Oldham, A. Larkin,). Meanwhile a problem recognized, developers prepare a KBE solution based on a process, instead of using a framework or methodology to develop KBE applications. It is clear by the widespread non-adherence to KBE design methodologies. As a random from the 37 papers describing case studies, 81% of them did not specifically adhere to a special methodology. The resulting case-based nature of KBE development is an

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important problem that it can lead to knowledge loss because of poor modeling of the application and insufficiency in the used development language. In addition, it can cause knowledge misuse if the wrong kinds of applications are developed. The knowledge that captured by this way is in danger of being under-utilized, cause to an inability to share and re-use it at computer and human levels, and finally, maintenance costs will be higher due to non-standard development (P. Sainter, K. Oldham, A. Larkin,).

## **2- A tendency toward development of ‘black-box’ applications**

Another finding of the review is that current KBE development has a tendency towards ‘black-box’ applications and many applications at best represent captured knowledge as context-less data and formulas. There is no explication about formulas and the actual meaning and context of the captured knowledge. The difference between knowledge sources and knowledge engineers could be the matter here. Research efforts have however indicated the importance and validity of code annotation as a bridge between data and formulas with the underlying knowledge (P. Bermell-Garcia,). In practice, going back from application code to the formal and informal models in order to validate, update and reuse the underlying knowledge is what KBE development allows users and developers.

## **3- A lack of knowledge re-use**

From the previous review of literatures findings, there is problem about re-use of KBE application in same or other fields. Case-based black-box KBE applications do not particularly invite knowledge re-use. Aside from that, higher-level knowledge such as project constraint reasoning, problem resolution methods, solution generation strategies, design intent and supply chain knowledge (D. Baxter, J. Gao, K. Case, J. Harding, B. Young, S. Cochrane, S. Dani,) is often not captured, let alone re-used. Difficulty of sharing knowledge across applications and platforms make re-using knowledge as a big deal. As Bermell-Garcia notes, ‘using current data exchange standards, it is only possible to transfer an instance of the design (one state of the design), and not the knowledge

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embodied to generate it. STEP is such a data exchanging standard, let exchange of geometry information, however knowledge needed for making it cannot be indicated in this way so in order to having knowledge through platforms and apps it is required to have some new standards and modulus.

#### **4- A failure to include a quantitative assessment of KBE costs and benefits**

Another finding in this area is about the fact that most KBE research is unsuccessful to indicate the KBE's advantages and expenses quantitative; the resulting time or advantages related to the adoption of KBE do not explained in 25 out of 37 case studies (67%). An excellent example of how to perform and illustrate such a quantitative description of a KBE development effort is given in Embery et al. See Figure. 2.14. This figure compares two different product development cycles. First with traditional, where each design cycle leads to one generated design, versus the KBE design cycle where a KBE development must first be developed and is subsequently used in the design process. As you can see in figure, that the KBE development time was equal to the time required for six traditional development cycles. The KBE development effort recoups this time quickly by having a much faster design repetition cycle than traditional design. Corallo et al have performed more systematic quantification effort and used Activity Based Performance Measurement (ABPM) for cost-benefit assessment of KBE in new product development. Unfortunately, this quantification effort has been performed on a single case study, so validity, reliability and generalizability of the ABPM approach for KBE quantification are not known.

#### **5- A lack of a (quantitative) framework to identify and justify KBE development**

A final KBE aspect that has not received much attention in literature is the assessment of KBE development opportunities. The MOKA handbook (M. Stokes) presents some qualitative criteria for identification and justification of KBE opportunities and one paper by Emberey et al. uses these and more criteria to assess whether a design task is suitable for KBE application development.

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However, despite these initiatives, no specific framework or method is available to specify whether a design task, product or process is appropriate to develop a KBE application.

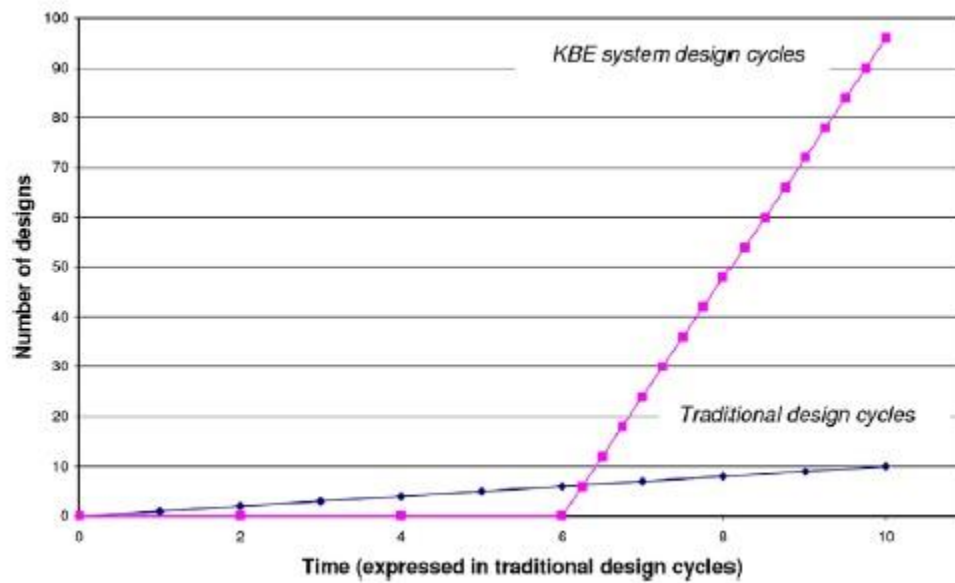


Figure2.14 KBE system development time versus traditional design time [Corallo]

# Mass Customization

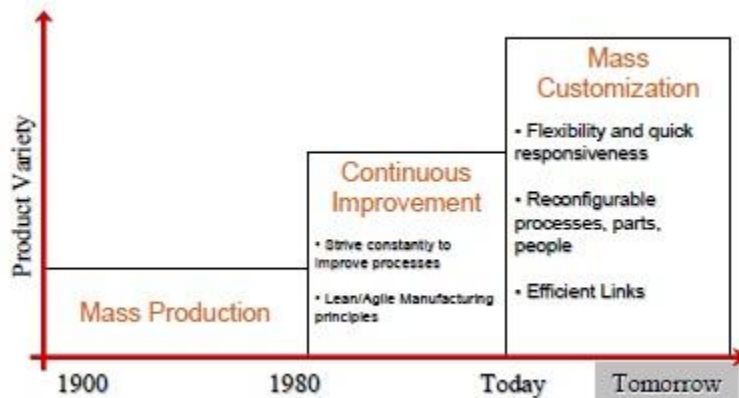
## 3.1 Introduction

Nowadays, customer's demand specifications are about high quality, low price and customized products and these factors increase the competition between companies. About twenty years ago, this competition was in prices, but today the main competitions are about product variety and speed to market. By this increasing competition in the global market, the manufacturing industries have the challenge of increasing the customer value. Much work is done to reduce costs and increase quality, but the definition of quality is not only conforming to specification. Quality means increase of flexibility to provide quick response to customer with new product catering to a specific spectrum of customer needs. Consequently, the trend of production is going to increasing product variety.

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Hence, Mass Customization intrinsically makes high-value-added products and services possible through premium profits derived from customized products.

Just as mass production was crucial to manufacturing in the 20th century, mass customization (MC) will be the key to economic growth in the 21st century. MC is the ability to design and manufacture customized products appropriate to meet a customer's needs at mass production costs and speed (Figure 3.1). While organizations continue to outsource for economical reasons, managing the interfaces between suppliers has become expensive and inefficient. By dispersing engineering and production geographically, manufacturers have increased the number of places their knowledge interfaces and multi-tier supply chains can breakdown. This amasses hidden costs, increases lead times, and reduces control. This is especially true for customized products that have tight deadlines.



**Figure 3.1: From Mass Production to Mass Customization**

The survival and growth of all companies will be significant reduction in inventory costs and lower obsolescence. Companies such as Dell and Lutron have clearly proven that customers prefer this type of sales model. This model requires manufacturers to be market-driven and customer-responsive, which means offering more product variation and allowing customization. However, adopting this model will have serious challenges for traditional manufacturing. It dramatically complicates the manufacturing system design if the same design

procedures that have been developed for standard products are used. In the MC model, value is created by people, designing of product, combining the supplier competencies, establishing supplier networks, and ensuring customer satisfaction.

Beside many challenges about MC, keeping cost low as possible, achieving high quality for high quantity products and satisfaction of customers on time are some more important issues about this subject. Furthermore, modularization of products and processes, ability of using knowledge-based software to configure products and flexible automation for manufacturing process are hint points to enable MC. There are increasing trends of companies that are adopting mass customization strategies at different levels in their product development cycles (Figure 3.2).

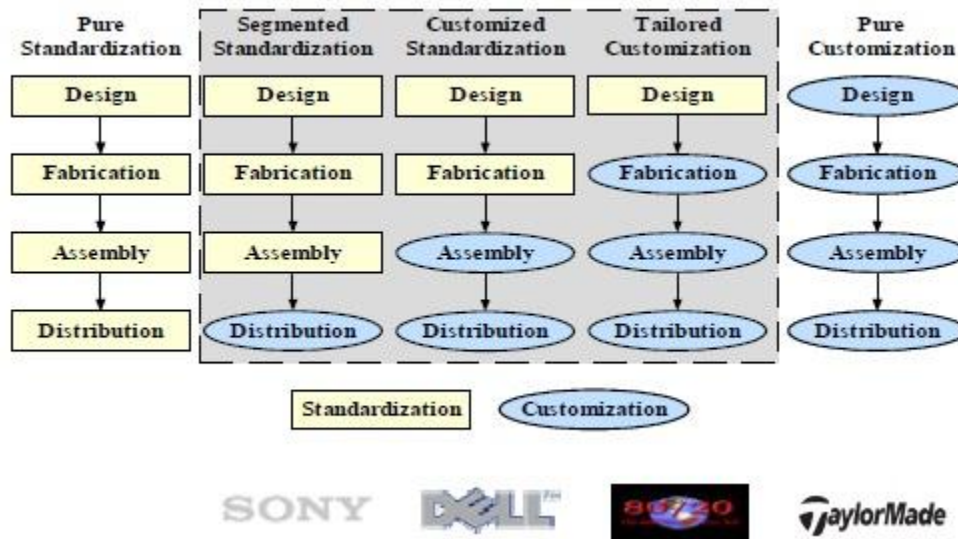


Figure 3.2: Level of customization [ Lampel 96]

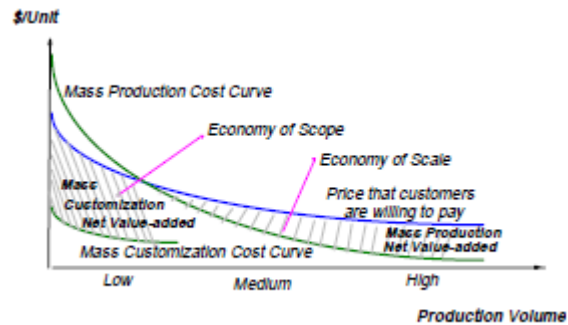
Currently Mass Customization are mainly implementing in Auto industry and PC industry. The position of win-win both for companies and customers is important but many companies are trying to achieve mass customization such as Dell, Nike, Levi,s etc.



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## 3.2 Mass Customization

Mass Customization has attracted increasing attention on satisfying customers demand for individual products. Before 1980s, firms were facing the choice of mass production or being innovative and tradeoffs between low cost and customization (Pine and Victor, 1993). Nowadays changing the environment, made the old competitive strategies invention and mass production no longer work well with market requirements. Since 1990s, strategies of continuous improvement and MC have shown that companies can overcome the tradeoffs (Boynton 1993). The prevalent philosophy is to replace old products continually with new versions, either an improved product or a new variation of the product. Differentiation in product variety, customization, has assumed ever-increasing importance as a marketing instrument. On the contrary, alongside pursuing flexibility and quick response, manufacturers have to pursue a 'dynamic stability' (Boynton and Victor, 1991). Mass customization aims to meet different customer needs while maintaining near mass production efficiency through economy of scope (Pine, 1993). Figure 3.3 (Tseng and Jiao, 1996) illustrates how mass production has an advantage in high volume production where the actual volume can defray the cost of huge investments in equipment, tooling, engineering, and training. However, satisfying each individual customer needs often can be translated into higher value, whereas lower production volume cannot justify the large investments. Because mass customization allows companies to garner the scale economy through utilizing repetitions, it is capable of reducing costs and lead-time. Hence, mass customization can achieve a higher margin and is more advantageous. With the increasing flexibility built into modern manufacturing systems and programmability in computing and communication technologies, companies with low to medium production volumes can gain an edge over competitors by implementing mass customization.



**Figure 3.3: the economic implication of Mass Customization (Jianxin Jiao)**

A review of literature about mass customization suggests several major streams. One area where mass customization has dominated as an important topic in recent years related to strategic management. In this context, much research has focused on conflicting mass production with mass customization approaches to competitive strategy (e.g., Pine, 1993; Kotler, 1989). Some research work done towards mass customization by highlighting organizational mechanisms that develop knowledge (e.g., Kotha, 1995). Meyer et al. (1993) anchor mass customization to the viewpoint of technology management and point out the correlation of a firm's product strategy to its underlying core capabilities. Hart (1995) defines and discusses mass customization in the basis of the service industry and some researches relate mass customization to marketing (e.g., Kotler, 1989).

Maccarthy (2003) described three aspect of the term "Mass" in MC. It implies the mass production economic, manufacturing and logistics. Regarding on the mode of production, this term implies the scale on which customization is delivered. Meaning that Mass reflect the extent of allowable or possible customization in operation, another respects of Mass concern with market that the availing of customization potential on offer to number of customers.

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From an implementation viewpoint, a large number of researches emphasize the importance of information technology as a tool for mass customization (e.g., Moad, 1995). Quite a lot of literature sets the standpoint on manufacturing management (e.g., Beaty, 1996) and advanced automation technologies (e.g., Moad, 1995). Lee and Bilington (1994) defend research on mass customization from management for supply chain perspective. Similarly, Hart (1996) tackles the logistic subjects related to mass customization. Moreover, mass customization research overlaps and intertwines with many other topics encompassing customer driven engineering and manufacturing (e.g., Muntslag, 1994), lean production, flexibility, agile manufacturing, and one-of-a-kind production (e.g., IFIP, 1992).

Fujita and Ishii (1997) tackle the basic issues about product variety design, including design specification analysis, system structure synthesis, configuration, and model instantiation. Simpson et al. (1996a; 1996b) tried to design robust product families that are readily adaptable to the changing design requirements. They adopt statistical model building techniques and goal programming to formulate formal algorithms for designing product families. Stadzisz and Henrioud (1995) bunch products based on geometric similarities to obtain product families in order to decrease product variability within a product family to minimize the required flexibility of the associated assembly system.

### **3.3 Shifting from Mass Production to Mass Customization**

In the 1960s, Mass Production began to breakdown for many companies in many industries and finally until 1980s it was fully into management consciousness (Pine 1993). Firm started to face choice of continues process mass production or being innovative. Continues improvement and MC have shown that companies can overcome the tradeoffs through two broad categories of product process matrix that are product change and process change. The right pass from

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mass customization requires firms to transform its capabilities and processes fundamentally, so to successfully obtain the competitive advantages in the marketplace firms need to capitalize on the different competitive strategies (Boynton 1993). There are four different organizational designs together with the four approaches to customization in organization.

### **3.3.1 Four types of organizational design**

#### **Mass Production**

In Mass Production, firms are going to maximize profit by producing standardized products, developing standard procedures, centralizing decision making and operating reutilized daily work (Boynton 1993). Maximum efficiency during Mass Production is obtained by dedicating the firm's human and capital assets to production of standardized goods or service contribute to the maximized efficiency. The reduction in unit costs is therefore resulted in the higher profitability and greater competitive advantages. In a MP organization which is often largely, hierarchically and vertically integrated, the allocation of all work is based on specialization of function of all work is based on specialization of functional capabilities and dedicated to the execution of standardized and product defined tasks (Boynton 1993).

#### **Invention Design**

Unlike the large scale and stability of a MP organization, the invention design want to creating small volumes of new products with constantly innovational processes on producing and developing (Boynton 1993). The invention organizations are organized for changes rather than seeking stability. For such innovative firms, the size is generally small for ensuring the focus on product variety and process innovation because the product specifications and work processes are unpredictable and constantly shifting. Yet they are often the

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separate research and development units within MP organizations (Boynton 1993).

### **Continuous Improvement Design**

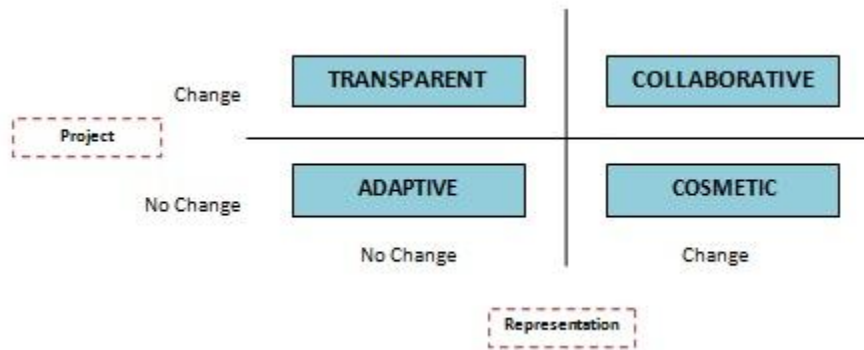
Organizations allow the design of product to be in low cost, high quality and standard (Pine and Victor 1993). The vision of what needs to be realized to satisfy customer needs in future with stable marketplace provides every individual in the company with motivation and direction of continue improvement during times. The key characteristic of continuous improvement design is the team based structure which permits that organization to make complex, value added transformation of its business processes (Adler 1991). The process innovation is pursued in the continuous improvement organizations while cost competitive remained with the mass producer through integration of specialized work of functional units and managing the rapid and effective refocusing of these functional units (Leonard Barton 1990).

### **Achieving Mass Customization**

Customer driven manufacturing was gaining increasing popularity in global market, but the concept of mass market as Kotler mentioned is over and market segmentation has now progressed to the stage of mass customization. Firms cannot produce longer standard products or services for obtaining competitive advantage in homogenous market. As a result, the heart of these changes is the increasingly customer demands in personalized products (Porter 1996).

#### **3.3.2 Faces of Mass Customization**

Before moving from mass production to mass customization, companies should realize that they examine enough on what kind of customization their customers would value before implementing the new strategy. Gilmore and Pine identified four distinct approaches to customization (Figure 3.4).



**Figure 3.4: Four Approaches for Customization**

### **Collaborative Customization**

It is one of that most often associated with mass customization. It is for businesses whose customers do not have a clear attitude toward what they want and frustrated when forced to make a decision from a plethora of options. In industries like apparel, customers have to make one-time decisions on tradeoffs such as length for width or complexity for functionality. Obviously, operators that using this approach focus particularly in the demand chain rather than supply chain as they not only delivery the products to customers but also customized the delivery.

### **Adaptive Customization**

This approach is for companies whose businesses offer customers standard products but with variable affects that can be altered according to personal interest. In adaptive customization, providers do not know what individual customer wants and by increasing the modularity of goods or services, they can increase the customization levels (Riihimaa 2004). Firms with such approach have already designed multiple permutations into a standard but customizable product that enables the independent value to each customer.

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## **Cosmic Customization**

This strategy is appropriate applied by companies whose major customers are satisfied by the standard products and only require the differentiations on the form of products. It means that cosmetic customizer focus their effort at the end of value chain and customers define the changes of the products or services in the end of value chain and customers define the changes of products or services in the end of the manufacturing process. Indeed, a product or service is used at the same way but the only different is how customers want it presented. As the cosmetic customization mainly emphasis on effects at the end of the value chain, companies is encouraged to do only a little extra value instillation for achieving personalization. It is important to notice that cosmetic customization approach is easy to perform but not everyone can pursue it efficiently.

## **Transparent Customization**

This approach is for companies whose customers' needs are easily to identify or predicate and especially when customers do not want to be bothered with direct interactions (Gilmore and Pine 2000). Unlike the collaborative customization, transparent customizers observe customers' needs without taking customers' time to describe their particular requirements but with plenty knowledge of customers' behaviors to move progressively closer to individual preference and then customization their offers inconspicuously (Codoni 2006). In this case customization is based on the standard products or services and companies are required to access customers' needs accurately with luxury of time.

### **3.3.3 Main components of Mass Customization**

Mass Customization composed from many different parts. Some of them have root inside of company and some outside. With paying attention to the field of methodology that has root in knowledge management engineering, three main components are:

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## **Co-Design and Customer Involvement**

Cox and Alm believe, Mass Customization arises from free market's relentless drive to bring what we buy closer to what we want. The focus by this view is about customer expectation. The term co-design is a conveyor to deliver consumers' descriptions of a collaborative relationship either in person or through internet between an individual customer who is trained to manipulate CAD images. To this point, customers are served as a consultant during the process of designing a custom garment (Ulrich 2003).

## **Modularity**

Pine in 1993 mentioned that essentially there must be standardized elements, components or modules together with linkage system. He also argued that modularity is a key to achieving mass customization as it reduce the variety of components while offering a greater range of end products. MC calls for unique products that are produced with economic of scale. Cost effective is considered as an important manner. Modularity enables part of the product to be made as standard modules in volume and allows the final product distinctiveness to be achieved through combination of the modules (Duray 2002).

## **Fit Preference**

MC enables each manufacturer to produce goods or service that satisfies their customer's fit preferences which is very subjective and varies from person to person (Alexander 2005). Industries like clothing concerns about fit preference. MC naturally calls try to provide goods and services that are most close to customers' desires and requirements, therefore fit information is concerned increasingly important for MC program design.



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### 3.4 Technical Challenges about Mass Customization

The nature of mass customization occurs in the product and service providers' ability to realize and capture hidden market niches and subsequently develop technical capabilities to meet the different types of needs for target customers. Understanding the latent market niches requires the exploration of customer needs. To encapsulate the needs of target customer groups means to imitate existing or potential competitors in quality, cost and quick response. Keeping the manufacturing cost low necessitates economy of scale and development of appropriate production capabilities. Thus, the requirements of mass customization depend on three aspects: time-to-market (quick responsiveness), variety (customization) and economy of scale (volume production efficiency). In other words, successful mass customization depends on a balance of three elements: features, cost, and schedule. In order to achieve this balance, three major technical challenges identified as follows.

#### **Maximizing Reusability**

The activity should repeat a lot to achieve the efficiency, as well as efficiency in sale, marketing and logistic. This process will happen by maximizing commonality in design, which will cause reusability by tools, equipment and expertise in subsequent manufacturing. The result of mass customization from commercial viewpoint is diverse finished products that can enjoy by different customers. Thus, customization emphasizes about variation among products and important step in order to reach this goal will be the development of design repositories that are able to create different customized products. To reach this level needs to have continuous improvements of process, which seemingly contradict the pursuit of low cost and high efficiency of mass production. Maximizing reusability across internal modules, tools, knowledge, processes, components, and other parameters means that the advantages of low costs and mass production efficiency can be expected to maintain the integrity of the product portfolio and the continuity of the foundation. This is particularly true in

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savings resulting from leveraging downstream investments in the product life cycle, such as existing design capabilities and manufacturing facilities.

Although commonality and modularity are important design issues, these practices are usually emphasized for physical design or manufacturing convenience. To achieve mass customization, the synergy of commonality and modularity needs to be tackled starting from the functional domain characterized by customer needs or functional requirements, and needs to encompass both the physical and process domains of design (Suh 1990). In that way, the reusability of both design and process capabilities should achieve with respect to repetitions in customer needs.

### **Product Platform**

Product platform is a set of parts, subsystems, interfaces, and manufacturing processes that are sharing among a set of products (Meyer and Lehnerd 1997). A product family comprises a set of variables, features or components that remain constant in a product platform and from product to product. The design of platform-based product family recognized as an efficient and effective means to realize sufficient product variety to satisfy a range of customer demands in support for mass customization (Tseng and Jiao 1998). The platform based product development approach usually includes two main phases: 1) the establishment of the appropriate product platform; and 2) the customization of the platform into individual product variants to meet the specific market, business and engineering needs. In terms of mass customization, a product platform provides the technical basis for catering to customization, managing variety, and leveraging existing capabilities.

### **Integrated Product Life Cycle**

Mass customization starts from finding customers' individual needs and ends with a fulfillment process targeting each particular customer. The achievement of time-to-market through telescoping lead times depends on the integration of the entire product-development process, from customer needs to product delivery.

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Border expansion and concurrency becomes the key to the integration of the product development life cycle from an organizational perspective. To this end, the scope of the design process has to be extended to include sales and service. On the other hand, product realization should continuously satisfy various products life cycle matters, including functionality, cost, schedule, reliability, manufacturability, marketability, and serviceability. The main challenge for today's design methodologies is to support these multiple viewpoints to accommodate different modeling paradigms within a single, coherent, and integrated framework (Subrahmanian et al. 1991).

### **3.5 Design for Mass Customization**

With paying attention to the challenging factors that mentioned above and base on the belief that mass customization can be effectively approached from design, the effort is to include the role of customers in the development of product life cycle with making the connection between customer needs and capabilities of a company. The main stress of design for mass customization is to elevate the current practice of designing individual products to designing product families. Furthermore, it could be possible to expanding product design common standards, making it as a wider scope bridge between sale and marketing in one side and distribution and services in other side. Figure 3.5 show the conceptual amplification about DFMC in terms of design scope perspective and product differentiation perspective.

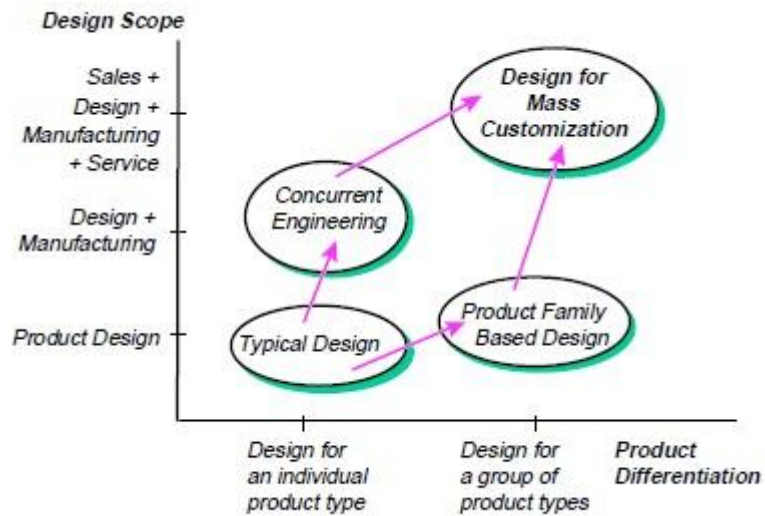


Figure 3.5: The virtue of DFMC (Jianxin Jiao, Mitchell M. Tseng, 1998)

In order to product differentiation customization we can characterize what is needed for customers and then perform these requirements by configuring and altering well-established building blocks hence we can named the product family architecture (PFA) and another as PFA-based product development life cycle (PFA-PDLC) as two fundamental concept underpinning DFMC. Figure 3.6 illustrates the framework of DFMC.

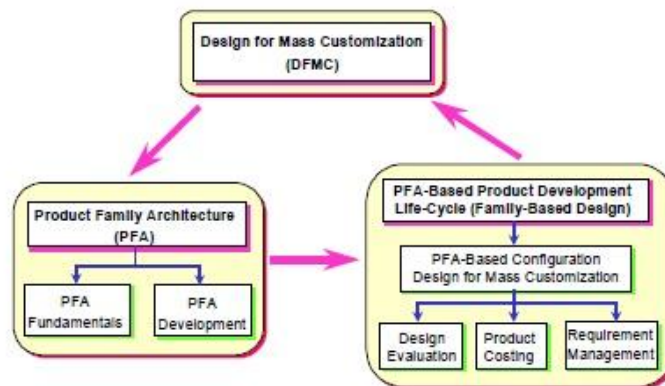


Figure 3.6: A framework of DFMC (Jianxin Jiao, Mitchell M. Tseng, 1998)

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### 3.5.1 Product Family

A product family is a set of products that derived from a common platform (Meyer and Lehnerd 1997).It includes a set of variables, features or components that remain constant in a product platform and from product to product. The design of platform-based product family has been recognized as an efficient and effective ways to realize sufficient product variety to satisfy a range of customer in mass customization (Tseng and Jiao 1998).Each individual product inside the family is called a product variant. While having specific functionality to meet a specific set of customer requirements, all product variants are similar in the sense that they share some common customer value, common structures, and common product technologies that form the platform of the family. A product family targets a specific market segment, while each product differentiation is developed to support a specific set of customer needs. On the other side, there are two main phases for development of product platform approach: 1) The establishment of the appropriate product platform; and 2) The customization of the platform into individual product variants to meet the specific market, business and engineering needs.

#### **Modularity and Commonality**

These two basic important issues related with product families that should be define in more clear way. The concepts of modules and modularity are central in constructing product architecture (Ulrich 1995).A module is a physical or conceptual grouping of components that share some specification and modularity tries to separate a system into independent parts or modules that can be treated as logical units (Newcomb et al. 1996). Thus, decomposition is a major concern in modularity analysis. In addition, to capture and represent product structures through the entire product-development process, modularity achieved from multiple views, including functionality, solution technologies, and physical structures. Correspondingly, there are three types of modularity involved in product realization: functional modularity, technical modularity, and physical modularity.

The most important part in characterizing the modularity is interaction between modules. These connections are between module (Intermodule) and within module (Inframodule), thus, three types of modularity with paying attention to the connection could be defined. As for functional modularity, the interaction is in related with functional feature (FFs) through different types of customer groups. The other is judging by coupling of design parameters (DPs) to satisfy the given FFs and finally in the process view, physical interrelation among components and assemblies (CAs) are mostly derived from manufacturability.

Issues	Modularity	Commonality
Focused Objects	Type (Class)	Instances (Members)
Characteristic of Measure	Interaction	Similarity
Analysis Method	Decomposition	Clustering
Product Differentiation	Product Structure	Product Variants
Integration/Relation	Class-Member Relationship	

**Figure 3.7: Comparison of Modularity and Commonality (Jianxin Jiao)**

## Product Variety

It is the diversity of products that a company providing for market. There are two types of variety, Functional and Technical. Functional variety means any differentiation in the attributes related to a product's functionality from which the customer could catch specific benefits. On the other hand, technical variety refers to diverse technologies, design methods, manufacturing processes, components and assemblies, and so on that are necessary to achieve specific functionality of a product required by the customer. Technical variety can be further categorized in product and process varieties. The technical variety of products is embodied in different components, modules, parameters, variations of structural relationships, and alternative configuration mechanisms, on the other hand process variety involves those changes related to process planning and production scheduling, such as various routings, fixtures, setups, and workstations. Figure 3.8 shows the concept of variety and its impact on variety performance.

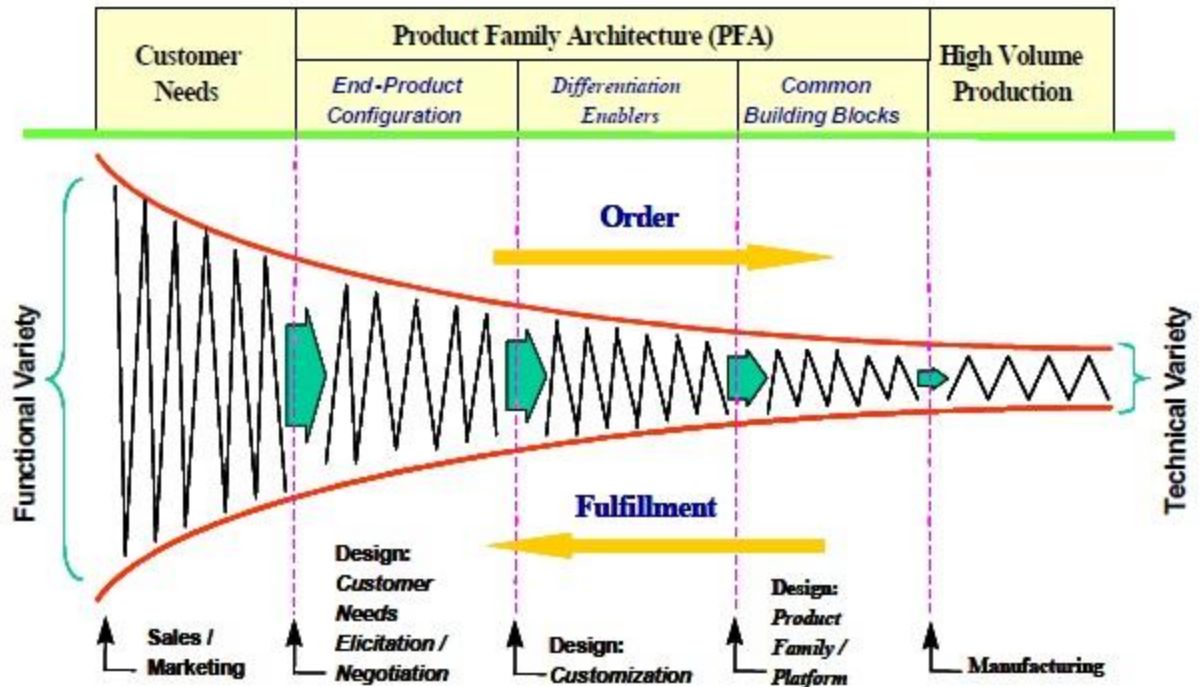


Figure 3.8: Variety of Mass Customization (MITCHELL M. TSENG, JIANXIN JIAO)

### 3.5.2 Product Family architecture for Mass Customization

There are three kinds of approaches widely used for representing architecture and modularity of product family: 1) product-modeling language (Erens et al. 1997), 2) graphic representation (Ishii et al. 1995; Agarwal and Cagan 1998), and 3) module or building block (BB) (Tseng and Jiao 1996; Gero 1990; Fujita and Ishii 1997; Rosen 1996). The product modeling language allows product families to be represented in three domains: functional, technological and physical. It support an effective ways for representing product variety, but offers little aid for design synthesis and analysis. In the graph structure, different types of nodes explain the individual components, subassemblies and fasteners, and the links denote dependencies between the nodes. However, it does not have ability to model product family constraints. Although the grammar approach is similar with the graph representation to improve its capability of representation, graph

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grammars are only able to implicitly capture product architecture information and product family information by production rules (Siddique and Rosen 1999, 2001). A model specifically tailored for representation of a product family architecture is the building block model, which is derived from the concept of using modules to provide varieties. Building blocks are organized in the hierarchical decomposition tree architecture (systems, modules, and attributes) from both functional and technical viewpoints (Kusiak and Huang 1996; Jiao et al. 2000). Under the hierarchical representation scheme, product variety can be implemented at different levels within the product architecture. However, module-based product architecture reasoning systems are currently being developed from different viewpoints (Rosen 1996).

With paying attention to above challenges, the attempt is to include customers in the product life cycle, especially in the design phase, through proactively connecting customer needs to the abilities of a company. The main emphasis is to boost the current practice of designing individual products to designing product families. To support product customization, a product family architecture (PFA) is needed to determine customer needs and subsequently to complete these needs by configuring and modifying well-established modules and components (termed as building blocks). In addition, a PFA performs as an integration platform for extending the traditional boundaries of product design to include a larger scope spanning from sales and marketing to distribution and services.

In this research, based on the chromosome model (Andreasen, 1992) and design domains (Suh, 1990), a functional behavioral structural-view (FBS-view) product model and associated design mappings are established and employed as the basis of representing a PFA (Figure 3.9) Functional view.



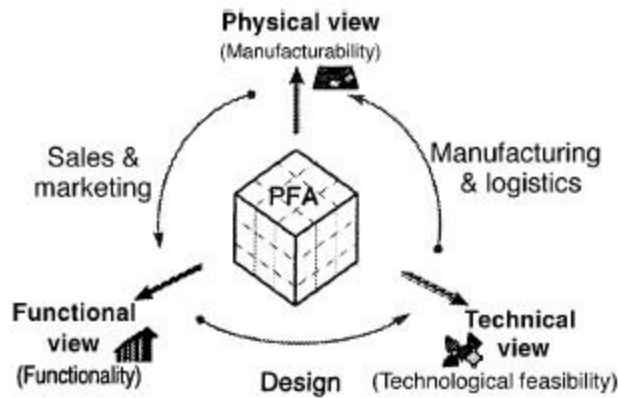


Figure 3.9: Structural implications and multiple views of a PFA (Andreasen 1992)

### Functional View

The functional modeling for a single product has been widely investigated, e.g., structural analysis and function structuring. The functional structure of a product consists of the functional elements (Ulrich, 1995), or the so-called functional features (FFs), and their interrelationships that involve decomposition and/or dependency (Pahl and Beitz, 1996). In the context of product families and mass customization, the functional structure of a PFA exhibits the product line of a firm that embodies the customer perceptions on its product offerings. The functional competence of a PFA is judged by the capability of its product line structure for customer recognition related to target market niches. A product line structure is referred to as the underlying patterns of customer requirements captured by the product portfolio. More specifically, the functional view of a PFA embodies a product line structure in terms of different customer groups, the FFs and their relative importance/priority for every customer group, and the classification of FF instances for customers within each customer group.

### Behavioral View

Corresponding to each customer group identified in the functional view, the behavioral view reveals the application of a technology (i.e., solution principle) to

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a product design and describes the product design by its modules and the modular structure. A modular structure is referred to as the combination of modules to configure modular products (Kohlhase and Birkhofer, 1996). It describes the subdivision of end products into smaller units and the interconnections (interrelationships) between modules (Pahl and Beitz, 1996), e.g., a circuitry topology in an electronic product design. In the behavioral view, modules and modular structures are defined in terms of technical parameters (TPs) corresponding to specific FFs instead of physical components and assemblies. The purpose is to highlight differentiation in product design resulting from different solution technologies applied to meet diverse customer needs. The variation resulting from manufacturing concerns is dealt with by the structural view of the PFA. Issues regarding the technical modeling of a technological solution include documenting TPs and the mappings from FFs to TPs, determining technical modules by minimizing design coupling, (Suh, 1990; Johannesson, 1997), and establishing modular structures for configuration design.

### **Structural View**

The structural view is similar to Eren et al.'s physical model (1997). This structural view represents product information by a description of the physical realization of a product design and is strongly related to the construction of the product. Existing process capabilities impose constraints on this realization to guarantee easy manufacturing and assembly operations without compromising the cost and lot-size constraints in order to keep the economy of scale. More specifically, the physical model consists of various types of components and assemblies (CAs) in order to realize technological solutions/product technologies generated in the behavioral view. Apart from mapping relationships of FF-TP-CA, an important concern associated with the structural view is the economic evaluation of granularity tradeoffs among various CAs options according to available process capabilities of a firm. This is approached by identifying suitable component clusters, or chunks as Pimmler and Eppinger (1994) called them, and

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assembly levels across all the products (families) incorporating volume and cost concerns.

### **3.6 Benefits of Mass Customization**

Mass Customization carries several advantages for manufactures and customers. Improvement on flexibility, maximum utilization and maximum availability of automated material handling system as well as strategies to ensure on time delivery has been considered as significant due to the trend of Mass Customization.

Compare with the situation previously, MC which featured in shorter product life cycle, smaller lot size and shorter delivery time has vastly increase and cause more frequent changes in the operating conditions across manufacturing and logistics facilities with velocities of reduction in inventory risk, elimination of waste and continual improvement in process can be achieved. According to Ahlstron and Westbrook in 1999, 40 manufactures in UK, which has previously participated in a workshop on Mass Customization, were involved in the survey on finding the positive or negative results associated with MC and the difficulties of implementing MC. The increased customer satisfaction and market share together with increasing customer knowledge were found as the main benefits from MC.

# THE METHODOLOGY

## 4.1 Introduction

The global competitions in industries force manufacturing companies to become more competitive by reducing the lead time and cost of their production. Through the host of new technologies, that supporting engineers to develop new production by the objects that mentioned, Knowledge Based Engineering represent potentially the most significant tool to date. It enables the creation of a fully engineering production and process design based on best practice with storing the past data as experiences, geometry and data that relate to a specific product family. This process is the result of providing support and appropriate automation of repetitive and routine design tasks with integrating huge sources of expertise in order to perform the multi disciplinary tasks.

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Furthermore, competition in industries, force producers in all sectors to change their view in terms of contacting with customer from a seller point of view to a buyer point of view. Both changes from companies view sides and the changes in customers need, result in a drastic increase in the number of product variants and costs of production. In order to stay in this competitive atmosphere, companies trying to make a modeled system for their production processes, so they introduce the platform concept. Because of introducing platform concepts, production concept changed from no customizable products to modular products that involve different types of customers.

On the other side by recent development of IT technologies, the possibility of using software based product configuration systems increased. These kinds of configuration systems are supporting the process of customized product development by using the modules based on the customer's requirements. Many companies develop their specific configuration systems, so the required rules for combining product modules usually implemented in the configuration systems. Consequently of his approach, any change related to the product or the system, requires changes in the configuration system's source code. Using of this source code system, leads to more dependency on software engineers that can be a large barrier for many companies to share their tacit knowledge with external .These problems propel toward development of an open framework that allow less dependency on software engineers and easier sharing know-how with external persons.

As the research of mass customization (MC), there is, increasing understanding of how MC can implement in the matter of data transfer and management, manufacturing capabilities, implementation of business systems and the development of product architectures. Mass customization aims to satisfy the customer by increasing the variety of production without a corresponding increase in cost and lead-time. It changes the meaning of mass production from economic of scale to the mass customization paradigm that emphasizes the economies of scope. In other words the quantity of production changing from high to medium

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or low production where production quantity cannot justify the investment, customers are willing to pay more money because of the special need satisfaction that happens for them. Mass customization force industries toward increasing manufacturing flexibility. Although the notion of pursuing a customization strategy has great appeal, the current condition of mass customization research seems to highlight only the end rather than the means, although without a coherent framework, Kotha and others consider that mass customization just a repackaging of many ideas with only limited synthesis

In this regards, I am going to introduce a model based on Knowledge based engineering (KBE) methodology that tackles mass customization from an engineering perspective and attempts to propose a systematic framework to realize mass customization.

## 4.2 Project Objective

The main objective of this model is to use the KBE methodologies in order to develop configuration systems to modularize products to:

- Reduce the lead time and cost of mass production by capturing the products and processes knowledge. This model is going to use the platform concept and tries to transfer the logic of no customizable products to the modular products that will support different individual needs. The model are using the recent development of IT technology that enables formalizing a configuration system. This system is a kind of solution space as a conceptual container for the matrix of product possibilities that made for each given Mass Customized products.

The cost of production can decrease by elicitation and formalization of data, information and knowledge related with an application domain.

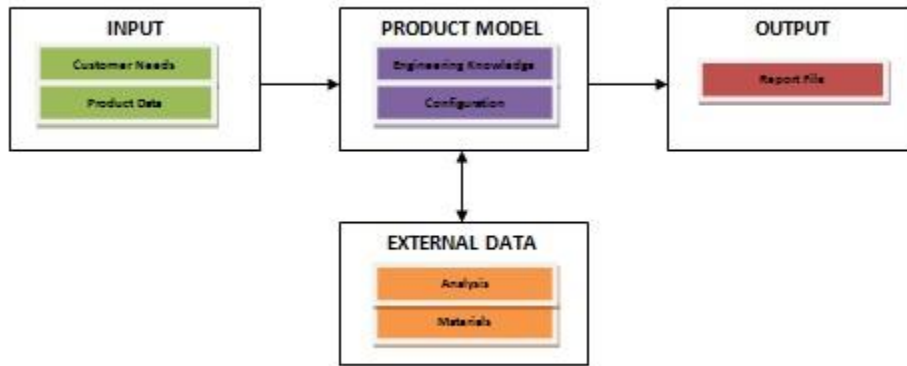
- Provide a consistency process of developing and maintaining KBE application. By using this formalized model, the analysis and model of product, design of production process and associated knowledge to these domains will facilitate. The

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combination of this methodology by software tools will make Knowledge Based Engineering developers more productive and consistent.

### 4.3 Architecture and process

This model devised to address the existing identified KBE methodologies such as MOKA (Methodology and tools oriented to knowledge based engineering application), KNOMAD (Knowledge nature for optimal multidisciplinary analysis and design). Existing KBE methodologies are optimization frameworks such as DEE but the point about this methodology is adding important factors that implementing critical role for mass customization. Formalizing product family by identifying optimal building blocks and modeling of configurator are strange point of this methodology with paying attention to customer needs.



**Figure 4.1: Knowledge Based Engineering System**

The core of this model is Product Model, where all knowledge related to production and process such as geometry, configuration and engineering knowledge is stored. As described before, the main driver in mass customization is customer needs, so Input to this model is product data and customers' need specifications which gives several kinds of output when the process of modeling

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start to work. There is another part as External Data that usually conclude tabled data such as catalogues, materials, analysis etc. The output as report file includes reports, drawings, costs, BOM and manufacturing plans.

## 4.4 Detailed Methodology Steps

This methodology contains eight main steps. Some steps include some sub systems that each one will explain one by one in the following sections:



Figure 4.2: Lifecycle of methodology

Here in Figure 4.3 you can see the eight levels of methodology with separated details related to each step. The methodology will start from the most important part ( Knowledge Capturing) and will finish with package and delivery of details for production and process of specific customized production.



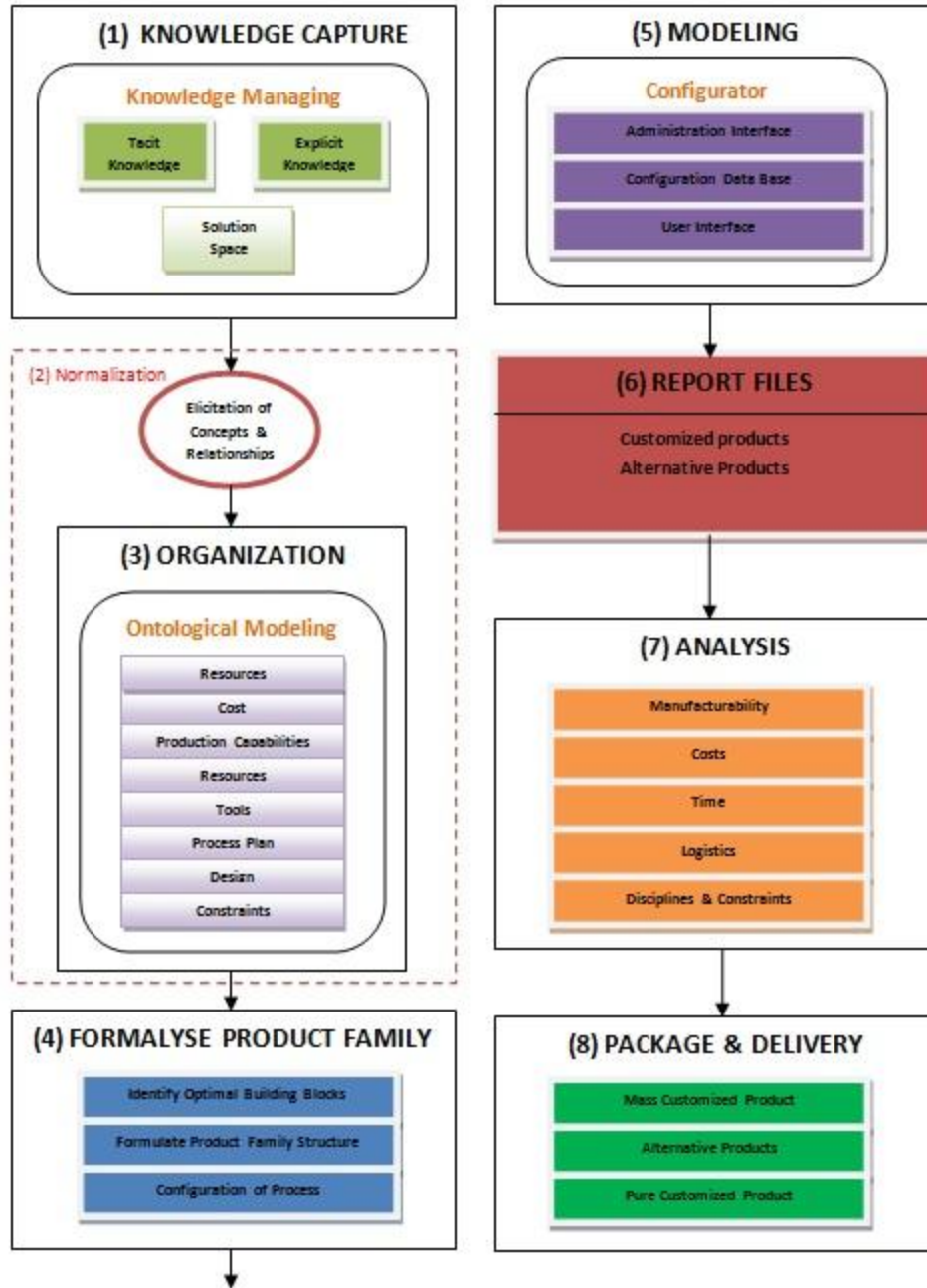


Figure 4.3: KBE methodology for Mass Customization

#### 4.4.1 Knowledge Capture

This first step includes the identification of the objectives, scope and assumptions about specific project. Based on these parameters, the required knowledge source will be identified. With paying attention to the point that finding the customer needs is a very important factor in Mass Customization, most of

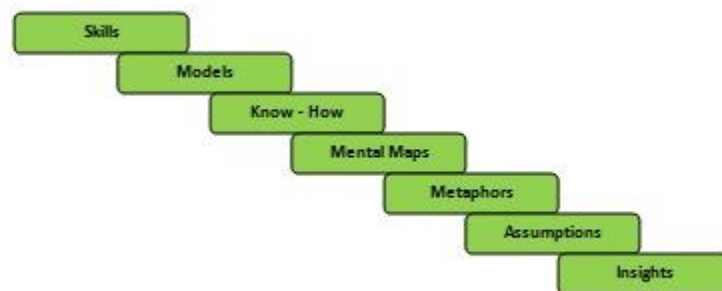
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activities about knowledge capturing will be about customization knowledge. In order to reach a final identification about scope, objectives and other assumptions that is supporting by all stakeholders, a combination of knowledge elicitation and systems engineering techniques could be more useful. Furthermore, using of some tools such as brainstorming and mind mapping can be useful to gain a fuller perspective on the involved aspects.

Knowledge managing part includes three different types of knowledge. Tacit knowledge, explicit knowledge and the knowledge related to the collaboration of customer as co-design with company in the place of solution space.

### **Tacit Knowledge**

Most of the knowledge that are using in the design and development of a new product is tacit. To leverage this knowledge by organization, there should be knowledge management process to support new product development phases with improving the product innovation, reducing the error through product development process, quality improvement and after sale customer services. Tacit knowledge typically is developing by trial and error in practices. Intuitions, judgment, values, beliefs, assumptions and subjective insights are examples of tacit knowledge.

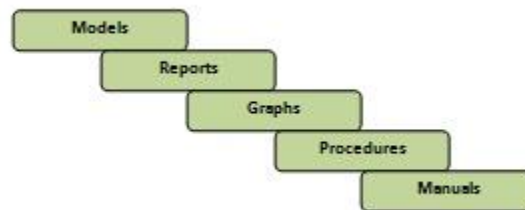


**Figure 4.4: Extraction of tacit knowledge**

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## Explicit Knowledge

This kind of knowledge approach assumes that the useful knowledge of individual or groups in an organization has the possibility to articulate and made explicit. Explicit knowledge can generally write down or otherwise documented, and shared. This "knows-what," or systematic knowledge can readily communicate and share through print, electronic methods and other formal means. Explicit knowledge is technical and requires a level of academic knowledge or understanding that gains through formal education, or structured study. Explicit knowledge is carefully codified, stored in a hierarchy of databases and is accessed with high quality, reliable, fast information retrieval systems.



**Figure 4.5: Ways to extract explicit knowledge**

## Solution Space

As a research of mass customization develops, we could mention that the main issues are about ability to implement manufacturing capability, data management and development of product architectures. Therefore, solution space defined as a conceptual place in order to collect the data related to product possibilities that are available for any mass customized or alternative products.

The knowledge related to customer needs and co-design experiences coming from customers' emotional connection with the product and purchasing process. Physio, Socio, Psycho and Ideo are four types of pleasure associated with

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products. Physio pleasure related to the body and it is the feedback from sensory organs such as touch, taste, smell etc. Socio pleasure is the result of connection with individual or groups that gives the feedback about owners view in society. Psycho pleasure is the emotional reaction result from cognitive interaction and finally Ideo pleasure is taste , moral values and personal aspirations that defines how people would like to be. The data related to product platform and modules, and rules related to production and processes are two more sections that support knowledge for solution space.

Actually, Solution space holds the knowledge that is using in mass customization process. In the previous KBE methodologies, the knowledge container includes only tacit and explicit knowledge, but in this methodology, the knowledge related to solution space added to Knowledge Capturing section with paying attention to market analysis and fining customer needs.



**Figure 4.6: Knowledge container related to Solution Space**

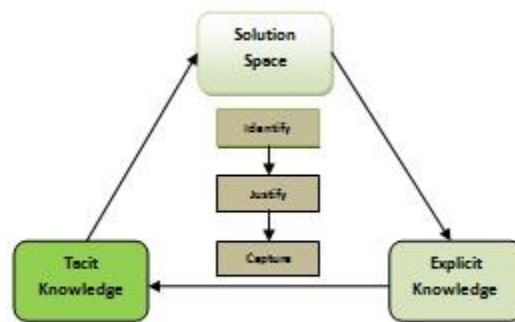
This knowledge capture section includes three main sub-subjects that also we have in MOKA methodology. Identify, Justify, and capture.

Before establish or maintain a Knowledge Based system, the knowledge required should identify. Suitable analysis tools and techniques, and representation methods, appropriate elicitation tools and techniques and possible knowledge sources are enablers to identify the proper knowledge. Thus, the identification step can create and activate the basis for a project plan.

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Justification process is to create a project plan to seek the management approval with paying attention to risk concerning, cultural and technical matters for project.

In the process of capturing, the various pieces of knowledge from solution space, explicit knowledge and tacit knowledge will collect and then will structure and represent it in an informal representation to check it for correctness and completeness with the knowledge sources. ICARE forms (Illustration, Constraints, Activity, Rules and Entity forms) could use to make an informal model.

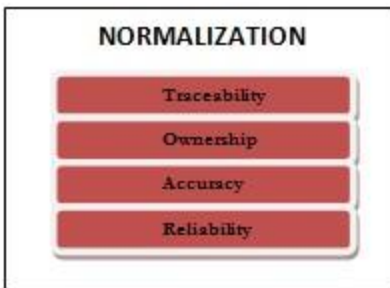


**Figure 4.7: The process of knowledge capturing**

At the end of this step the scope, objectives and assumptions are agreed upon by all stakeholders and based on this , the required knowledge sources are identified that can be explicit , tacit and solution space sources.

#### **4.4.2 Normalization**

In order to identify the proper building blocks to formulate perfect product family structure, achieving to high quality data and information is critical. To reach this, four activities are performing. To check the knowledge against applicable quality criteria such as:



**Figure 4.8: the process of Knowledge Normalization**

### **Traceability**

It should be possible for knowledge to be traceable to its sources. By doing this process the associated design trade-off will be possible and will give insight into the overall knowledge lifecycle and will benefit the design particularly in early stage phases. The faster learning and more insight in the overall design process are the result of this activity.

### **Ownership**

All knowledge that capturing by persons in company should tied on an owner because of taking the responsibility in case of accuracy and reliability. This will be a push for efficient knowledge management, especially for capturing tacit knowledge. In the next steps, if there is need for more explanation, knowledge owner is clear to support better the group.

### **Accuracy**

This step use to make sure about accuracy of captured knowledge for using in modeling and analyzing processes. There are some tolls in case of checking for accuracy and for instance, we can use the Friction Stir Welding (FSW) in terms of length, width and area of captured knowledge.

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## Reliability

The process of KBE methodologies is repetitive activity, so during stage design, parameters have a tendency to be guesstimates and in unchecked assumptions. Making sure about reliability of knowledge in early stages will be more useful and if parameters are subject to high variation, this uncertainty should be taken into account during subsequent steps.

### 4.4.3 Organization

It seems organization require in order to utilize the knowledge that are going to use in the modeling and analysis. A knowledge structure should provide to permit stakeholders to automatically access to necessary knowledge for use in modeling and analysis. To give a proper structure, ontology can be used. There are some ontological methodologies available to use in knowledge based engineering systems such as Uschold, Noy & McGuinness, Uschold & Gruninger and the METHONTOLOGY. Each methodology concludes some specific steps, but there are some common steps. Specification, Conceptualization, Formalization, Implementation and Maintenance are the steps that will repeat in all methodologies.



Figure 4.9: Ontological Modeling Sources

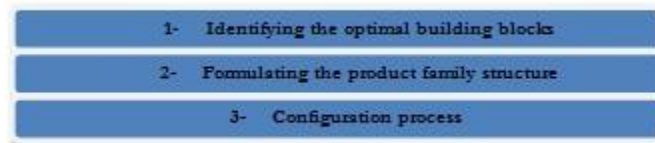
### 4.4.4 Formalizing Product Family

In order to support customized product, a product family platform is require to characterize the different needs of customer. Fulfillments of these needs are facilitating by configuring and modifying well-established building blocks.

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Therefore, there are two main concepts about design for mass customization, that are product family architecture and product family architecture based product development life cycle. Product family architecture, means the underlying architecture of firm's product platform that various product can derived from basic product designs in order to satisfy different types of customer needs. A good product family architecture provides a generic architecture to keep the variant forms of the same solution, but also modeling a class of products based on individual customer needs within a coherent framework.

PFA development in a good way depends to the appropriate formulation of building blocks with paying attention to functional, behavioral and structural perspective. Building block has two kinds of meaning, first a type of building blocks through modularity that means to decompose a system to modules and second for each module, various instances that shows certain similarity. There are three steps to formalize the product family.



**Figure 4.10: Steps to formulate PFA**

Before starting to find the optimal building blocks, there are some test evaluations: The information about current and future customs need should be evaluate. Then, find the repeatability in design and fulfillment. In third step, make sure about easiness of these building blocks for modeling of configurator and finally checking the appropriate level of aggregation.



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#### 4.4.5 Modeling Configurator

If your product line falls into Catalog Products, then a simple configurator is probably your best condition. Configurators will be useful when a product can be ordered directly from a catalog and require no changes. Configurators also can be used for the selection of pre-existing features or options. Basically, configurators are meant for any preexisting part or product that one doesn't need to change.

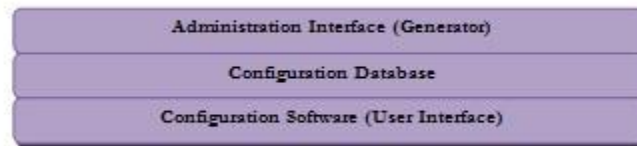
Configured Products require the ability to dynamically change the products that require a unique change to an existing product. Products Requiring Engineering Support are those that can involve standard parts, but which require complex engineering logic in order to make the correct product selection and Designed-to-Order products require complex geometries, calculations, data integration and the ability to play "what-if" scenarios as you iterate toward an optimum design. For example, with order-dependent, procedural code, if there are 100 lines of code and a change is made to line three, chances are that most if not all of the code following line three will need to be changed. However, with non-procedural code, it's more dependant to a "rules in a bag" concept where line three can be changed with no ramifications to any other line of code since they are not procedurally linked. Not only is programming time decreased, but also there should be a reduction in the number of system re-writes required over time.

Another attribute to KBE software is that it should work with your existing CAD system. Some of the KBE software has CAD language "glued" to it already, but if that CAD tool is not compatible with your pre-existing installed base, then applets/ APIs can be built to accommodate your needs. Finally, the tool should have the ability to be deployed over the Web and be object-oriented in design [<http://www.mtadditive.com>].

After formalizing the product family, there is need for modeling of products and processes. The process of modeling are doing by Multi-Model Generator (MMG) approach, which can be applicable directly in the further development of the production process. This configurator could be a tool to minimize risk by

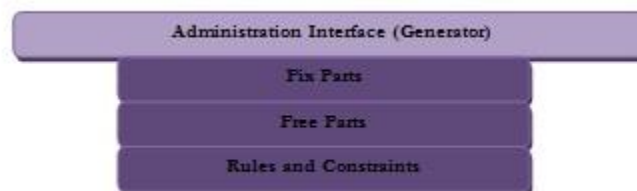
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accurate assessments of costs and profit about specific production before start of a project. The framework of this developed software consists of a generator or administration interface, the configuration database and the configuration software or user interface.



**Figure 4.11: The framework of developed software**

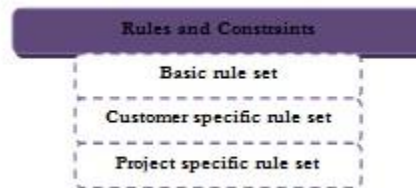
The generator concludes various editions for knowledge acquisition and representation and for designing the configuration software's interface. This generator provides three types of parts. Fix parts that are standard, outsourced parts that only using in unique way and the interaction with other objects is carried out by the help of some attributes. Rule based parts that are adjustable parts in predefined limits. Using of these components adapts to the demands of the customer by the entered parameters. These parts do not already exist in the demanded specification. Free parts do not depend to any specific product. In the configuration process they are considered as black box with predefined requirements and interface. These components integrate as placeholders in product structure.



**Figure 4.12: Components of Administrative Interface**

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The created configuration rules and constraints are the core of the configuration database that is using for the configuration of products. This configuration database composed of three level rule bases, where the levels are set up on each other. These three levels of the rule structure are basic rule set, the customer specific rule set and the project specific rule set. The basic rule set that provided with the software composes with two types of rules. Rules about general setup of the graphical user interface of the configurator and basic knowledge about the product design. In addition, the customer specific rule set that is the result of customer interaction with system includes the customized basic knowledge and product structure rules.



**Figure 4.13: Subset of rules and constraints**

These rule set are generating with IF-THEN rules , decision tables, external reference tables and simulation programs that automatically converted in the declarative programming language.

#### **4.4.6 Report File**

After the modeling step, now the result from configurator will published as reports. Here, there are two kinds of report files. First, the data related to customized products, which is the result of connection between customer and configurator and the second report is related to alternative models that introduced by configurator. These report files shows the specification of finalized product in terms of visual, technology, process of production and functions.

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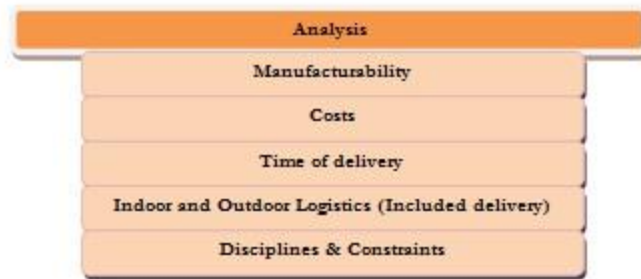
Alternative product could be the products in domain of Mass Customized production and pure customized. The Mass Customized productions have the ability to introduce into the market in same period or after time for demand of customers. Furthermore, there are pure customized products that give this opportunity for customer to find or select specific productions that are not in the category of MC products.



**Figure 4.14: Report File**

#### **4.4.7 Analysis**

Analogous to the DEE approach, the Analysis step in this methodology employs Report Files generated by the MMG that contain the set of product and process models in order to use in detailed analysis modules. As mentioned before, these modules calculate the design implications on a per-discipline basis. As with the MMG, the requirements for analysis depend on the viewpoints of the involved stakeholders. Manufacturability, Cost determination, Indoor and Outdoor logistics and disciplines and constraints about production processes are four main factor to analysis. Furthermore, the properties of the project (the scope, the objectives) and the product and process models themselves will steer analysis in certain directions. Analyses can be run for different objectives. Manufacturability estimation is a primary analysis effort. Also, manufacturability (technical feasibility) estimates can be arrived using commercially available Manufacturing Process Simulation (MPS) tools for analyses of drape ability, formability, and other process aspects. In addition, time analysis is a prime candidate for analysis. Frequently, time analysis and cost analysis go hand in hand.



**Figure 4.15: Analysis for report files**

#### **4.4.8 Package and delivery**

The delivery step of this methodology starts with a check of the solutions for MC, Alternative and Pure products versus the requirements specified at the beginning of the design process. If this study is accepted, the detailed analysis results can be delivered and resource implications can be evaluated. For example, process times and costs calculated that calculated in the Analysis step can be delivered directly, or subjected to subsequent analysis such as Discrete Event Simulation to further explore the resource implications of a design. For instance, if DES is used, the logistical implications of a design on production space and lay-out can be explored in detail. Furthermore, a well set up ontological representation of the problem (as discussed in Organization) will have included resource implications, either as a class in its own right with relationships to the products, processes, tooling classes and so on, or as a property of the existing classes.

### **4.5 Lifecycle of methodology**

Before a methodology can be developed to support the development and maintenance of this methodology in the field of knowledge based engineering

applications, it is necessary to agree on the various stages in the lifecycle of a KBE application and which of those are to be supported. The lifecycle of a KBE system adopted for use within the Mass Customization project is shown in Figure.

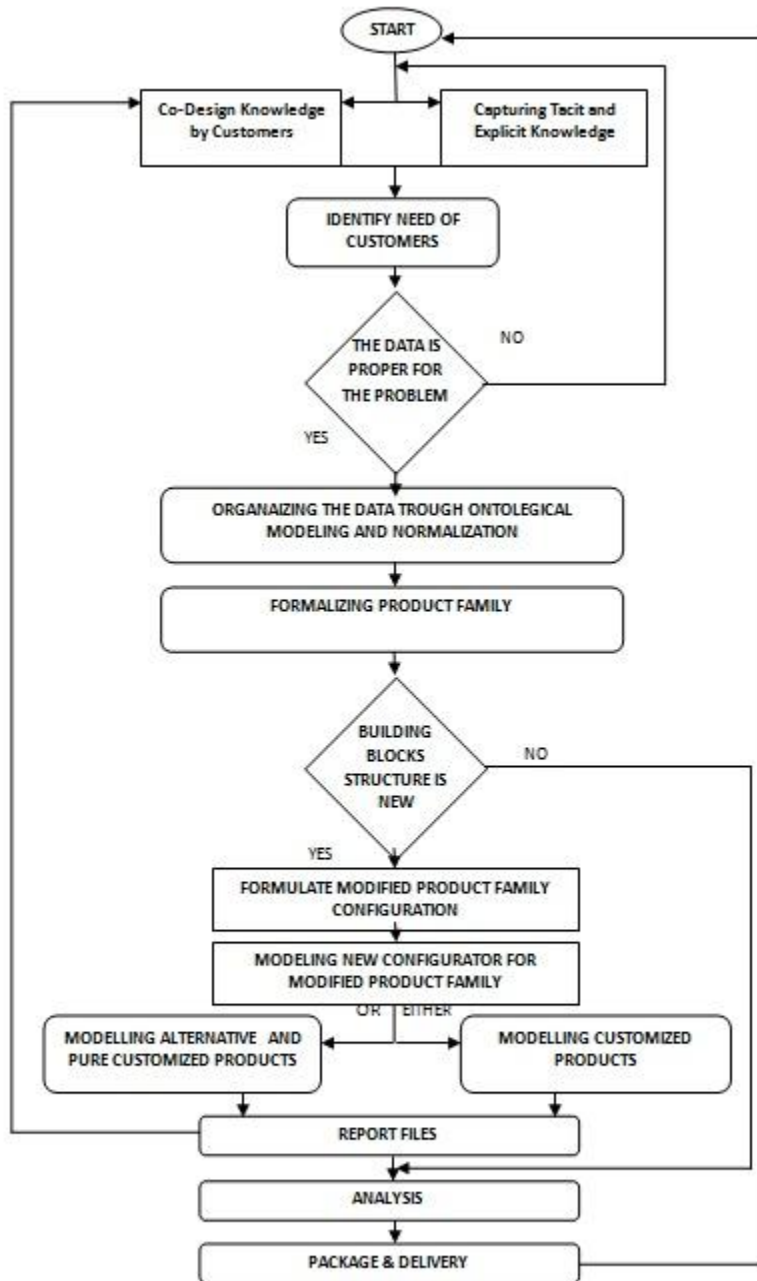


Figure 4.16: Lifecycle of methodology

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This life cycle is starting with knowledge management part. There are two fields for capturing knowledge, which will need during the implementation of methodology. Extract the tacit and explicit knowledge from the production and process, and the co-design knowledge related to the corporation of customer with production process and the knowledge about different parts of product family. The capturing section includes three sub steps of Identify, Justify and capture that we have in normal lifecycle of KBE methodologies. From the other side by the knowledge that captured by two levels, the specific need of customers or actually the customized products will identify. The point for the following step is that the knowledge that changed to information and data is enough for the process of modeling or not, If it will be enough we will go to next level as organizing and normalizing of data in order to shape the it in better way. Otherwise, we should come back again to the process of capturing of knowledge and prepare complementary knowledge. Next step will be the process of formalizing product family. As I mentioned in literature section there are three kinds of approaches widely used for representing architecture and modularity of product family: 1) product-modeling language (Erens et al. 1997), 2) graphic representation (Ishii et al. 1995; Agarwal and Cagan 1998), and 3) module or building block (BB) (Tseng and Jiao 1996; Gero 1990; Fujita and Ishii 1997; Rosen 1996). As I searched about these different approaches, I found that in most papers mentioned that product family architecture is proper model to establish components for Mass Customization approach. Building block model has root in the concept of using modules in terms of supporting varieties. Building blocks are organized in the hierarchical decomposition tree architecture (systems, modules, and attributes) from both functional and technical viewpoints.

Now there are two ways in section of making building block structure, if the structure of building block is same with previous one (NO), we will go to ANALYSIS section in order to study about the productions that suggesting by same structure. Otherwise, (YES) the modules will change, the building blocks

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also will change, and we have new modified structure for product family, or the product family in new structure that will represent new types of productions. Next step will be modeling of new configurator for modified product family. By modeling this configurator it will possible to introduce three types of production. One type that is customized productions by customer and two types of production as alternative and pure customization production by system. All data files as types of productions will publish trough report files. This report files will feed the knowledge management part to find the need of customers because of the interaction that customer had by configurator and also report file will send to next step to make analysis about all types of production. In analysis step, the confirmation process will happen for the productions that passed all factors that are important in manufacturability. Finally, packaging and delivering all information related to production and process for the items that passed from the analysis step.

## **4.6 Software tools to support the methodology**

The methodology will provide a systematic approach for the development of Knowledge Based Engineering applications. However, developing a Knowledge Based Engineering application is often a complex task, involving the management of many objects, rules, and constraints. Therefore, it is essential that a user-friendly, graphic-oriented, computer tool is provided to support this methodology.

This tool will: Provide assistance in the use of the methodology, Verify model consistency, Facilitate iterations during the application development cycle, Improve software quality.

Extensive programmers to develop methodologies for software development have been considered in recent years to be a success from a technical perspective but have failed to provide a delivery vehicle that:



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- Embraced and supported the methodology with effective paper-based or software tools.
  - Addressed the learning curve associated with implementing comprehensive software development methodologies.

Because of these reasons is that most of KBE methodologies have not delivered the tangible business benefits that were expected. These issues are in this methodology project by providing a software tool that will allow developers to utilize the methodology in the most efficient manner, and will help to decrease development time and support the whole software development life cycle. Such a tool is essential in order to capitalize and maintain the knowledge contained in Knowledge Based Engineering systems, especially in design, where knowledge constantly evolves. Retrieval of such knowledge will also be much more effective using common models generated by modeling tools.

## **4.7 Comparison with MOKA and DEE Methodologies**

As a mentioning about similarities between this methodology with other ones, can mention to first step that is knowledge capturing process. By comparing this methodology with MOKA methodology that is one of the famous models in KBE methodologies, we can find that three step of Identify, Justify and capture in MOKA methodology is included in the first step. Furthermore, there are some similarities in parts of organizations step and formalization step. In addition, in the last step of this model that we have delivery, could say that it is also similar with step of Use in MOKA. In terms of differences can mention to Normalization step that help to increase the quality of knowledge that is captured.

In comparing with DEE, the step of modeling is similar between these two methodologies. Also, Using of the step “Report File” is similar between DEE and this methodology. The main difference between this methodology and the DEE is that the former offers an explicit approach for knowledge capture, normalization

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and organization. Furthermore, KNOMAD offers a more extended concept of the Delivery phase, which is restricted to a solution versus requirements check in the DEE.

# Validation of Methodology

## 5.1 Introduction

The following case study provides a practical implementation of the introduced methodology in apparel industry. There are many kinds of industries working in Mass Customization, but I select apparel, because there are similarities in knowledge management process with other industries. Clothing industry is one of the most appropriate industries on implementing MC program because it is the possible strategy to enable the closet and fitted clothing offers based on customer's proposal requirements. Doing retail on a web base has become more popular in apparel industry because of the increasing trend of e-commerce. Furthermore, implementation of Mass Customization process for this industry is much easier than other industries because of less complexity in the process of production. Information and knowledge are critical factors for apparel industry in order to move from Mass Production to Mass Customization. The purpose is to

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provide knowledge management process for the methodology in apparel business sector to deal fast as possible with changes in consumers' needs and habits.

## 5.2 Apparel Industry

Apparel industry is a diverse and heterogeneous industry because it products such as clothes are virtually used by everybody including private households and business. In consideration of the importance of apparel industry, large number of small and medium size enterprises (SMEs) which dominate the sector have contributed great social and economic cohesion in particular regions.

In the past, this industry was based on two main season cycle, summer and winter. As consumers became more fashion, this industry responded to these needs by adding two more season as spring and autumn. Nowadays this collection increased to six or eight and in some cases such as Calvin Klein up to ten collections during a year. Thus a proper Knowledge-Based engineering system with the basis of CAD/CAM system will be able to support this vast moving and demanding in fashion world, in order to adjust itself with quick changes in customers' needs.

Traditional apparel industries' supply chain includes many cost and time-consuming processes. It takes place from raw materials and initial ideas and transform to end product. Generally, it consists of Identifying target market, designing, allocation jobs, sourcing fabrics, patterns, toile making, adjustment, process and operation planning, laying of fabric and cutting, finishing, putting labels, packaging and finally shipping. However, this process will decrease by implementing knowledge based engineering methodology that in base has the logic of mass customization. Once a customer has specific good in his/her mind, the design data fed the CAM process. This process will do by configurator system that is a co-design process by customer.

Actually as the steadily growing change in fashion cycle and high forecasting problems as well as the multi- channel distribution systems, MC is favored by more and more suppliers in clothing industry (Tseng & Piller , 2003). As one way to involve in MC process, some researchers have focused their studies on “Co-Design” approach and related to this subject Kamali & Loker(2002) have introduced an apparel MC model and suggested that from industry aspect, six points of customer involvement and MC options can be concluded in clothing customization Table5.1: .

Mass Customization Model for Apparel Industry	
Point of customer involvement	Apparel Mass Customization options
Patterns	Custom fit or design
Design	Size, Style, Fabric
Production Planning	Data forecast
Manufacture	Small-lot repeats
Deliverv	Point of sale data
Port Purchase	Customer adjustments

**Table 5.1: Customer involvement and MC in Apparel Industry (Kamali& Loker)**

As I mentioned about validation of proposed Knowledge-Based engineering Methodology, this method includes eight main steps and each step has wide subsets, thus validation of it needs more than a usual time for doing thesis. In this section I tried to work about step one that is knowledge management, specifically knowledge capturing.

### 5.3 Knowledge Capturing

The knowledge capturing process in apparel industry includes totally two kinds of knowledge, explicit and tacit. Tacit knowledge is the most important part in knowledge capturing for MC and catch from two sides: Technical Dimensions and Business Dimensions. The technical part includes Know-How and business relates to knowledge that show how can a company be success in business.

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In the apparel business, knowing the proper and exact target market and right time to suggest products to customer are important factors. This means, knowledge is critical factor in case of giving more power to support huge market demand and this knowledge can capture from the information comes from Customers, Contractors, retailers, Suppliers and manufactures through direct or internet contacts. However, all information collects form those sources could not change to knowledge and only some parts are applicable to customization and business process. Usually the sources of knowledge in apparel industry are two main categories. One category is relating to substructure information (E business, R&D, ID numbers and Bar codes, Technology and Industry news, standard management process and etc) other one is about structure information (Data related to trade, Export information, Import quotas and etc).

### **5.3.1 Explicit knowledge In Apparel Industry**

Same as other industries, in this industry also the knowledge is collection of leveraged information. As mentioned in knowledge management chapter, knowledge has three main characters of connectivity, leveraging and applicability that are vital to transform the information. Explicit knowledge includes most percent of knowledge in apparel industry and collects through internal (Table 5.2) and external (Table 5.3) sources. Internal sources are relating to the knowledge that identity inside of company through the experts, production process data and other factors that are relating to manufacturing. There are seven main sources of this knowledge:

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Explicit Knowledge
Internal Sources
Size Range
Diversity of Colors
Quality
Functionality
Weight
Fiber content
Style

**Table 5.2: Internal Sources of explicit knowledge**

External sources are relating to mostly customers and other stakeholders that are in direct and indirect connecting with company.

Explicit Knowledge
External Sources
Colors
Prices
Brand and Labels
Location of stores
Assortment
Logistics
Stock Status

**Table 5.3: External Sources of explicit knowledge**

This explicit knowledge that is important for communication between customer and company hands over through suppliers, manufactures, carriers and customers. Although the captured explicit knowledge is understood by supply chain members, but sometime it is need to explain and train more for people to obtain the useful knowledge from customer that does not know the apparel industries terminology.

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### **5.3.2 Tacit knowledge In Apparel Industry**

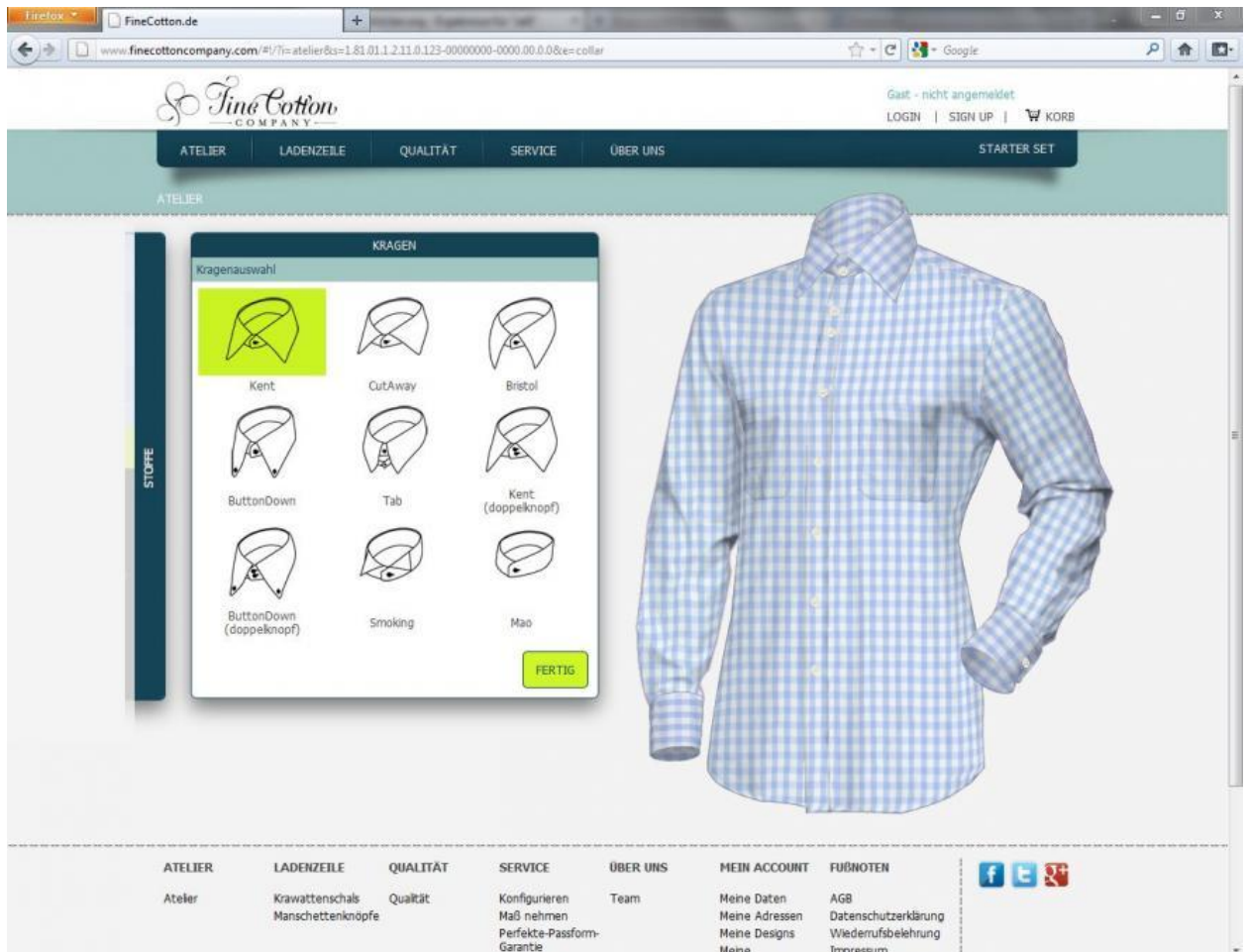
As explained in previous chapter about knowledge management, there are different ways to extract the tacit knowledge, but in the apparel industry metaphors is an efficient working process in order to explain vague concepts. Know-How and Technical are two main dimensions that introducing the tacit knowledge. In the apparel industry, tacit knowledge can extract through two sides of business dimension and technical dimension. Business dimensions that explain how can be succeed in business, includes the knowledge related to companies strategy, vision, mission and some principles. The most important section of tacit knowledge is related to customization, where the customer play important role in Mass Customization. Learning about customers' habits, their behavior in buying process and tastes is a critical activity that should do by company in order to do customization in proper way by extracting this knowledge. In traditional retail models, customers do not know the actual performance and other supportive information about products and the role of customer related to acceptance or rejection of the final products.

### **5.3.3 Knowledge of Co-Design activities**

With increasing the knowledge about customers, the process of customization will increase and the result is increase in revenue. This knowledge can extract through some resources and one of important sources is feedback on orders through shops or internet. The knowledge that extract from customer side is important because it make possible better and timelier design of new products and services, increase of customer commitment and loyalty, increasing collaboration for design of product process etc. These exchanging of knowledge is not just dealing about knowledge, but also is related to just in time inventory or supply chain management system. Many of companies believing that Mass Customization is a kind of business to consumer model (B2C). Internet is one of most important driver for B2C communication and through this connection, the relation between unique product and customer will happen. Study about what customers buy is the important part of customization about fashion market. Data



sources about colors, desired sizes, style and fabric are the important parts of data sources that support by stores and the configurator (Figure5.1) that customer reach to it through internet.



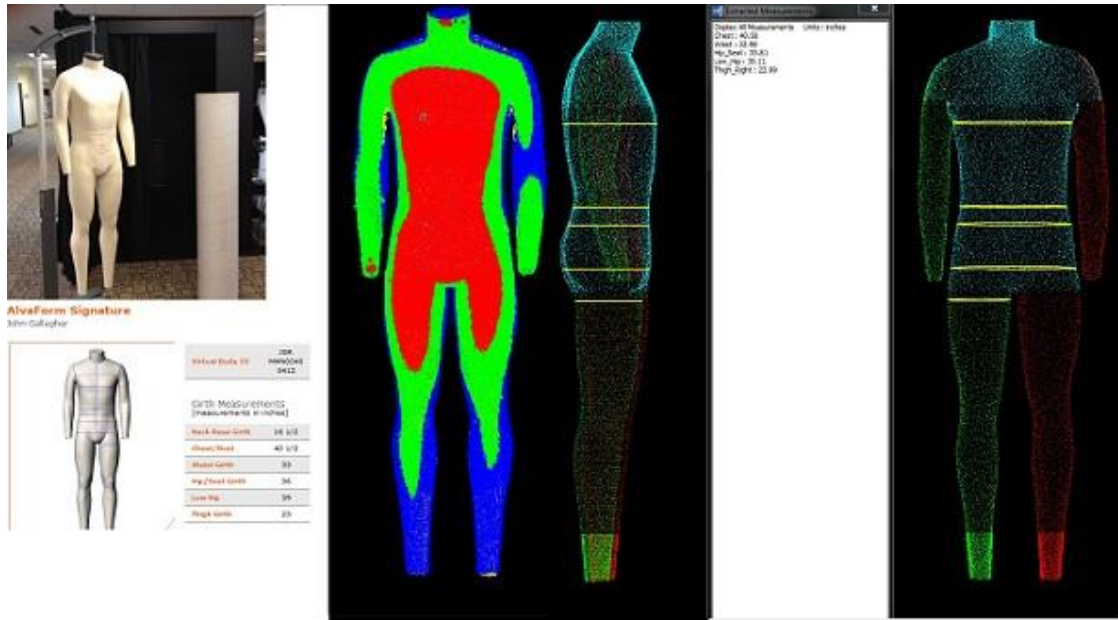
**Figure 5.1: Configurator for Fine Cotton Company GmbH Company**

Nowadays the information technology is supporting most industries for the process of capture knowledge. In terms of explicit knowledge, Codification and organization of explicit knowledge will be useful that extract by workflow tolls, Internet, search engines, document management systems, data mining, DSS etc. For capturing tacit knowledge, video conference, electronic workplace and email

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could be useful. In Apparel industry, Internet plays a crucial role to extract the explicit knowledge. These tools are very useful in the sections of business to business and consumer to business. Internet has important role of connection between consumers and firms. Furthermore, through the internet customers can access to explicit knowledge that company puts in the system of configurator and this system enables customers to find their own customized products.

The knowledge management part in the KBE methodology store human knowledge and experience. This KBE system enable the conversion of explicit knowledge to tacit one through the production process. In apparel industry for pattern design, the KBE system has a size table, an alternative table and style listing with the diversification of colors for each product. By this knowledge system can create a full set of pattern in all sizes that customer selected for outer fabric, linings and interlinings. This system has the ability to use the data with accuracy that customer can watch a human and stores with particular changes on the same type of pieces. In the solution space, actually data are collecting from the interaction of customer with company. In the process of customization, company offers products prototypes to the customer and then adapts or tailored them with paying attention to customers demand. This is a kind of collaboration approach between customers and company in order to help them to identify exact needs. Customers convey their preferences and these become the basis of the manufactured product. When a customer selects options by configurator, they become a co-producer and the data are collecting in solution space as customer's special specification about products. In apparel industry, there are two essential feeding processes to receive knowledge related to solution space from customers. Co-Design activity for a unique product and body scanning (Figure 5.2) for better fit.



**Figure 5.2: Technology of body scanning**

Use of body scanning is not general by all companies because of some disadvantages. First, it requires an investment in special equipments and expert persons to collect data from customer side. Second, usually all people do not like to be scanned by systems and finally in some specific products this scanning process is not adequate and requires manually measurements. In contrast to manual design, in case of using configurator with aid of CAD technology that applied in KBE methodology, customer assembles individual product from a company's offering by choosing style, fabric, colors, pattern and size. This process enables the client to do more customization independency trough a computerize system. The software tools that implementing in these methodologies usually made by each company or some companies use other company's software that are familiar in that industry sector. The software makes it possible to customize and design fashion product with less help from assistant side of the shops.

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## 5.4 Data Collection

The data that collected for validating of the methodology, obtained from two different approaches. First, the data collects from analyzing online customization process and second, with some questionnaire by users and experts that have experience in this field. The purpose of collecting data and information from these sources is to provide knowledge into development the building blocks for Mass Customization Process for the Modeling step of introduced KBE methodology. The approach to collect data is a qualitative research method that enables researchers to receive information and capture knowledge about specific subject in which little is known. Usually this kind of research includes the collection of a variety of case study, personal interviews, observations and visual texts. In this validation process, I selected personal experience and questionnaire and it is important to mentioning this point that in qualitative approach, it is better to select the companies with some clear differentiation to represent better the concept. Five apparel retailers (Table5.4) selected for analysis and data collection which offering online customization opportunities in different sectors.

Company	Production
Fine Cotton	A premium brand for bespoke shirts
Nur Berlin	T-Shirt for Men and Women
Custom Panties	Panties Producer
Blume	Apparel for Girls, Guys, Babies and Kids
Diejeans	Jeans producer for Men and Women

**Table5.4: Selected Apparel retailers**

## 5.5 Questionnaire Alanysis

In the section of data collecting related to online customization, questionnaire is prepared about online shopping process that is the interaction between customer and configurator. Questions prepared in a way to receive personal experience of purchasing customized apparel items. The results of these questions is a good

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source for capturing knowledge in order to prepare new building blocks or modify the previous building blocks that implemented through Mass Customized process of specific company. With paying attention to time constraints, the questionnaire responded only by sixty persons.

This questionnaire (Appendix 4 ) includes 14 questions that start with general questions about ways of shopping , habits of shopping and other general questions, then we have some questions that could support the knowledge about building blocks in terms of important factors in customizing a goods with paying attention to priorities and finally the questionnaire follows up with some score questions. The goal of this step is to find the precedence about online shopping from customer side and finding the customer role in design of production because of working with configurator. Motivation from customer side to work with configurator as co-design, online shopping preferences, purpose of shopping and customization preferences are four main objectives of doing this analysis.

### **5.5.1 Shopping Behaviors**

In this section, you can find the result of analysis about questions that shows the shopping manner by persons that answered the questions. The questions related to first part are about times of shopping, age of shopping, customization of cloths, online shopping habits and online customization.

About times of shopping (Figure5.3), 60% of answers are about once in month, 18% two or three times in a month, 15% two or three times in a week and only 2% daily. By analyzing this result, we can estimate that usually customers contacting with configurator once in a month and it shows that implementation of changes in production process could happen once in a month. Therefore, the building blocks will change with probability about 60% in a month.

#	Answer	Response	%
1	<a href="#">Never</a>	0	0%
2	<a href="#">Less than Once a Month</a>	18	30%
3	<a href="#">Once a Month</a>	18	30%
4	<a href="#">2-3 Times a Month</a>	11	18%
5	<a href="#">Once a Week</a>	3	5%
6	<a href="#">2-3 Times a Week</a>	9	15%
7	<a href="#">Daily</a>	1	2%
	Total	60	100%

**Figure5.3: How often do you shopping**

About customization of specific good (Figure 5.4), as generally not only through internet the result shoes the culture of customization is not so familiar between people yet. Only about 43% of respondents have the experience of this activity. With paying attention to changes in customers' needs and competition in market, trend of customization will increase in future and this increase will cause more improvements in co-design activities. Furthermore, from the 43% that customized their goods, only 22% implemented customization process through online configurator. Other results that could be mention in this section are risk of customization and time of customization. In terms of risk, 57% of respondents believe that customization throw configurator is a medium risk activity. In this part, 23% estimate this risk high and only 20% believe that risk is low. About the time, 73% of respondents answered that time for customization take less than one hour and this time seems to be logical. Related to this section 15% answered more than two hours and 13% about two hours.

#	Answer	Response	%
1	<a href="#">Yes</a>	26	43%
2	<a href="#">No</a>	34	57%
	Total	60	100%

**Figure5.4: Do you ever customize your cloths**

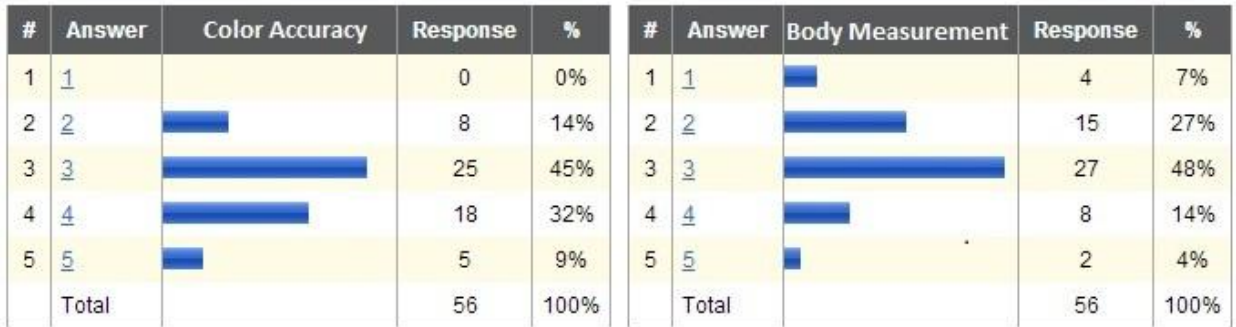
Second part of questionnaire is about the questions related to product features (Figure 5.5). Size range, diversity of colors, quality, functionality, weight, fiber content and style are seven important features that asked in a question and asked respondents to select top three of them. 81% selected size range as main constraint, in second rate 73% selected quality of goods and third was style with 58%. An interesting result in this question is the percent about diversity of color that seems is not main constraint for users.

#	Answer	Response	%
1	Size Range	48	81%
2	Diversity of colors	22	37%
3	Quality	43	73%
4	Functionality	18	31%
5	Weight	5	8%
6	Fiber content	9	15%
7	Style	34	58%

**Figure 5.5: What are top three important features about goods, in online shopping process**

Last part of questionnaire is related to the questions that have direct relation with the characteristics of building blocks. These questions are analyzing the accuracy between real goods with customized ones. Two main characteristic (Figure 5.6) about productions, which surveyed in this part are measurement and color. About the accuracy of body measurement, 48% of respondents believe that selected sizes 60% are fitting with their body. This result is a clear reason for high risk of customization and a good answer that why this process is not so familiar and comfortable between people yet. In addition, In terms of color accuracy the result is same with body measurement and 45% believe medium fitness between customized goods and real ones.



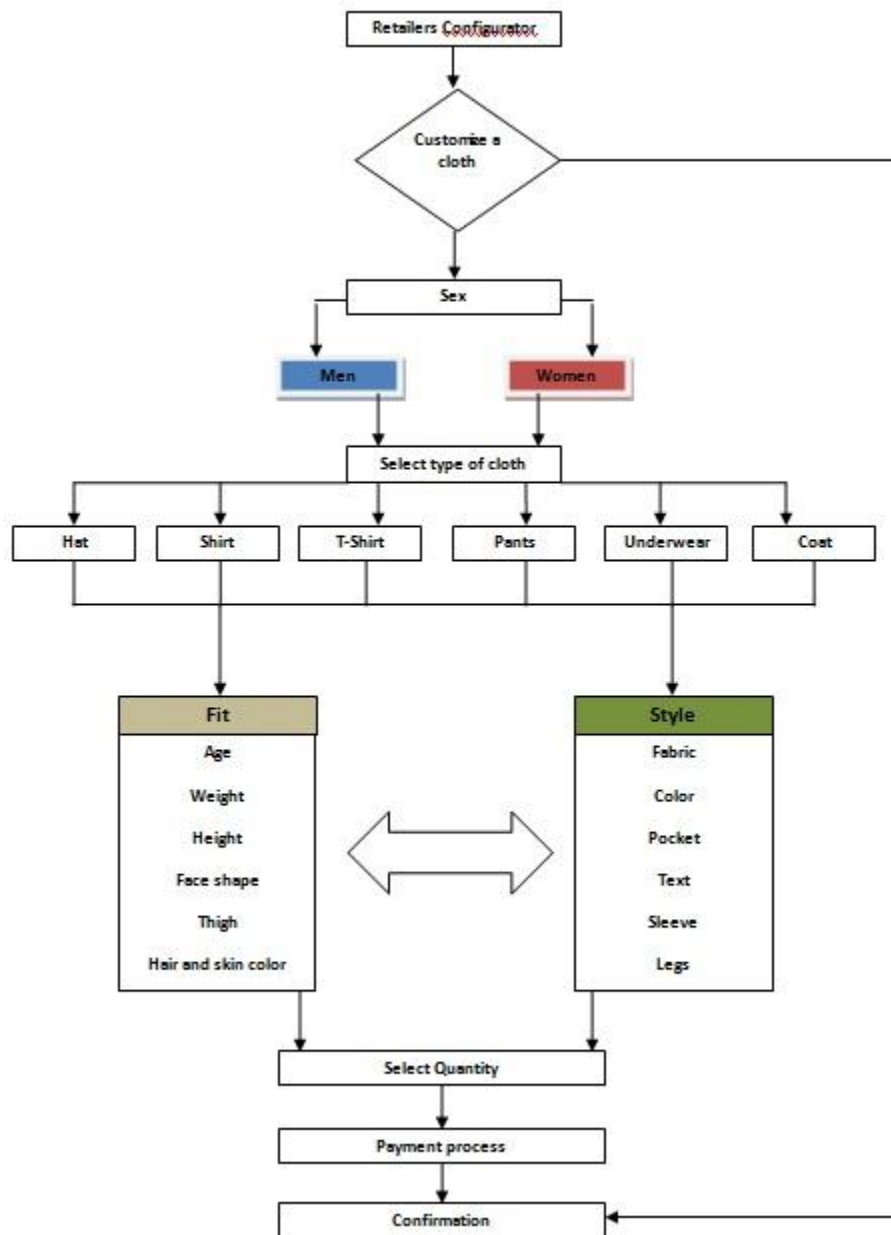


**Figure.5.6: Body measurement and Color adjustment accuracy**

## 5.6 Configurator Analysis

In apparel industry seems that usually each company has specific configurator (Appendix 1,2,3) in the process related to co-design activity. The data collection activity in this step comes from analyzing of this process for some companies that implementing this ability for their customers. There are some general features, which are similar between these configurators. Products that provided by configurator and available for customers to select are Pants, Shirts, T-Shirts, Jackets, hats etc. Colors that allowed for customization usually includes some main colors such as white, black, red, blue, green. In terms of different personality changes, the possibilities facilitate to make changes about materials, body measurement, pocket numbers, style, size, location of design texts or pictures. Shopping time that allowed because of security problems for customers is about thirty minutes for each trying time. The price could change because of changes that happen for products in terms of colors, style text etc. Finally, total steps that requires for customizing a single item from enter to website until finish the shopping will take about nine main steps. The customized process illustrated in Figure 5.7. This process offer proper customization choices on customers' individual measurement. In this process, customers insert their information about age, height, size etc in order to give in final step a 3D image once they implement any changes.





**Figure 5.7: Typical Configurator diagram in Apparel Industry**

Base on comparison between different types of configurators that applying by companies, I can indicate to results finding toward different types of customization through this co-design activity. In some configurators, retailers

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offer a limit type of cloths for customers to design by inserting their body measurements. Usually these companies are focusing more about customer specification and implementing the optional application only for some limited items that have high demand from customer side such as shirts or suites. On the other side, there are some companies that are offering customers the program on designing different patterns and texts, which will be display on the clothes. Products in these configurators are all semi- finished items and customer is able to buy cloths without implementing any changes of their design. By the way, the performances of these configurators are depending to companies' Mass Customization process so the more applicable configurator, the more flexibility on the process of production.

## 5.7 Captured Knowledge

This section extracted the knowledge from two approaches that mentioned above in order to analyze the difficulties about customization process through configurators. According to data that collected, first difficulty is about the time of customization. It is clear that more steps in configuration process, requires more time spending and the average time between configurators shows the time about one hour. This time seems to be logical, but this time is not usual between all configurators and in some cases, this time is more than one hour. Thus, the development of information technology as well as the software improvements drive product more complex that normally makes the customization process more difficult and complex. In other words, with increasing in the complexity of customization process, the time spending and decision-making will increase. Moreover, another difficulty that founded from analysis is accuracy. Most users believe that only in 50% of times they receive the customized good with high accuracy and near to real goods. With considering this concern, near to 90% of respondents agree with pay more money and spend more time in customization process by hope to receive cloths that would fit them. Because of these problems,

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56% of respondents believe that customization approach has not low risk. Another big problem about configurators is that emotional aspect of customization process is missing. Because of this problem, it is very important that structure and details of configurator should configure in a way that be able to reflect customers' emotional aspect more. This approach forces developer of configuraorsor to design it in more details. The findings from captured knowledge are a guidance to adjust building blocks. With attention to concerns and difficulties, in this section the most important findings are relating to products specification such as sizes, quality and style.

### **5.7.1 Sizing**

It refers to the assignment of a specific body type into categories that invert the body measurements of those in that size range. One of the important problems in apparel industry is the diversity of people sizes because of many different ethnic groups. Usually homogeneous populations are much easier to supply. For example in some countries such as Japan and Korea, only dozen sizes of people's apparel are typically needed. By comparison, people's clothing is developed and sold in categories for misses, juniors and petites with about eight to twelve sizes in each category. In addition to the issue of diversity, there are more issues such as the intermarriage and lifestyle changes, including eating habits and general fitness that producer should care about them. Product developers and buyers must be knowledgeable about the target population of the geographic area to which they market if they are to produce apparel that will fit their target customers.

Sizing problem is common to all categories of clothing, including men's, women's and children's. Because of the big diversity about sizing issues related to many different categories, in this study I only studied about women's body measurement characteristics to collect knowledge from this sector.

## Women's Apparel Sizing

In the past, sizing charts were developed to reflect groupings of young women and mature women. Numbers were assigned that reflected the age or girth of the women within these groupings. Early in the 20th century, firms that were producing garments for catalog sale needed to have some consistency in the measurements of their products so that consumers could purchase garments without trying them on. In women's body measurements the variations between the mature and general populations tended to occur only in the location and distribution of weight and shape. Preparing the body sizing chart is a difficult process and to appreciate the complexity of the voluntary sizing charts that were available, could mention for 39 girth, vertical, length, and width locations and measurements factors that helping to reach final size of a body (Figure 5.8).

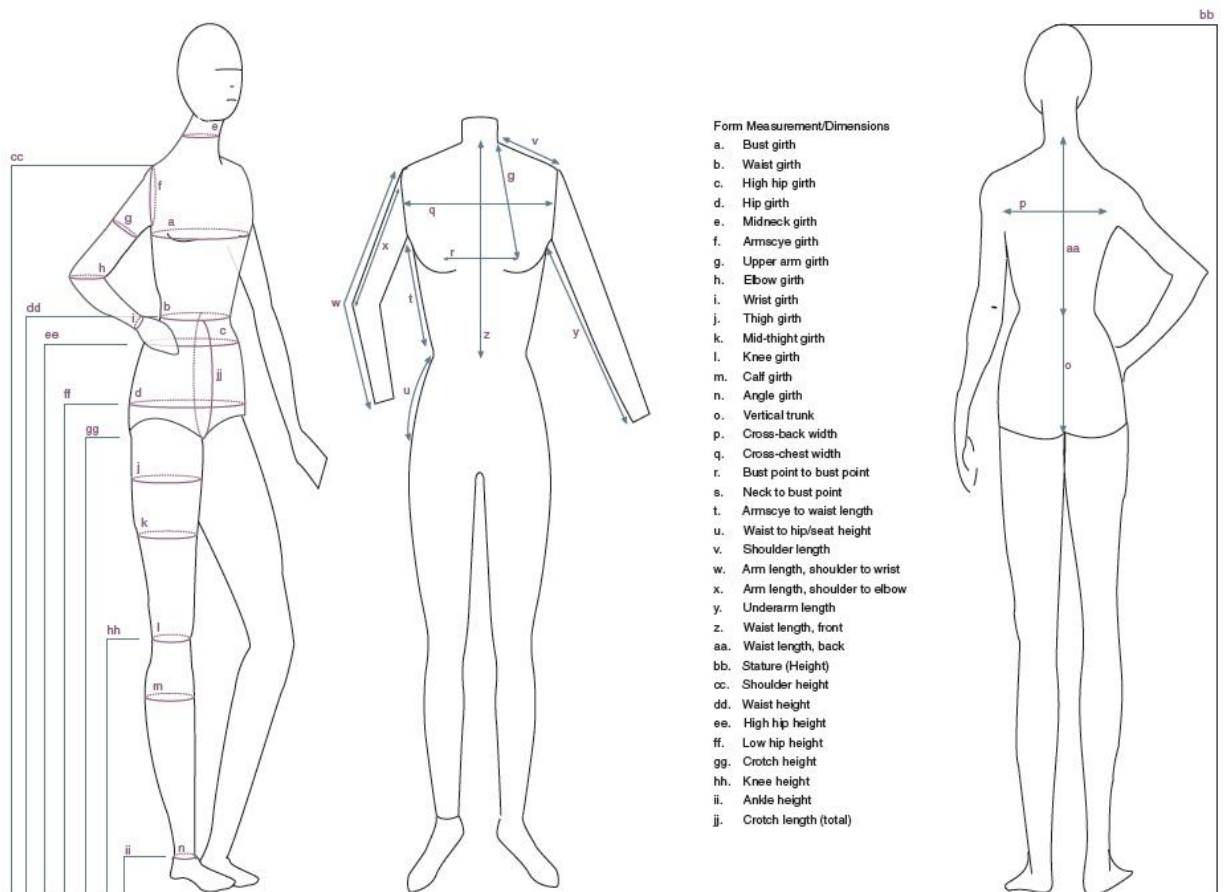
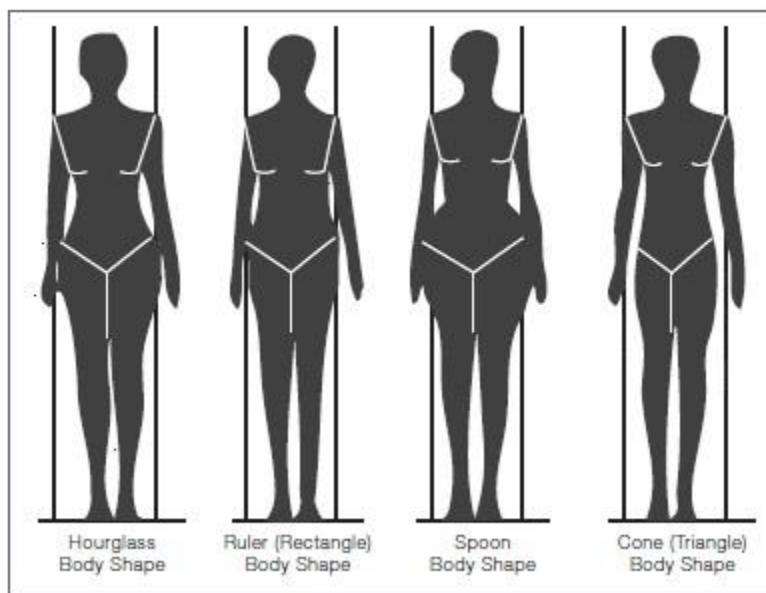


Figure 5.8: Body forms with list of measurement points

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Janice Wang claims that the “root cause of many ill-fitting garments is the industry misconception that the hourglass figure is the dominant body shape today” (Speer 2006). The data analysis of women’s measurements showed that the hourglass is the least dominant shape even though the industry had persistently based its grade rules on that shape. Cynthia L. Istook defined nine body shapes and honed in on four dominant types (Figure 5.9):

- Rectangle shape—bust and hips are basically the same circumference; the waist is less than 9 inches smaller than the bust. This shape represents 46.12 percent of the sample.
- Spoon shape—hips are larger than the bust by 2 inches or more; the waist is less than 9.25 inches smaller than the bust. This shape, sometimes called pear shape, represents 20.92 percent of the sample.
- Inverted triangle—bust is larger than the hips by 3.6 inches or more; the waist is less than 9 inches smaller than the bust. This shape represents 13.83 percent of the sample.
- Hourglass—bust and hips are basically same circumference; the waist is smaller than the bust by 9 inches or more. This shape made up 8.4 percent of the sample.



**Figure 5.9: Four most common female body shapes**

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By the data that collected about range sizes, product developers must choose a sample size as a starting point for sizing configurator. The sample size illustrates the body measurements from which the size range they plan to offer is developed. It is recommended that configurator developers use a midsize as the sample size within the range. This necessitates grading down to the smallest size and up to the largest size, and results in a more accurate grade than if the grading were done in only one direction.

# Conclusion

## 6.1 Introduction

The purpose of this study was to identify a systematic framework based on Knowledge-Based Engineering methodologies to tackle mass customization from engineering perspective by analyzing the secondary data from five selected company and questionnaire from user's side. This chapter will present the conclusion of findings from literature reviews, empirical study and questionnaire search.

The introduced methodology has preferable advantages over the existing methodologies such as MOKA and KNOMAD methodologies. This methodology includes approaches for multidisciplinary design for total process, knowledge

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capturing, formalizing building blocks, modeling of configurator and lifecycle nature. Furthermore, this methodology includes some subsets for each step with some affirmation.

## 6.2 Conclusion

Because of the nature about mass customization, it is important to realize and capture knowledge from hidden market niches and subsequently develop technical capabilities to meet the different types of needs for target customers. To encapsulate these needs it is essential to make a balance between features, cost and schedule. In order to achieve this balance we need a methodological approach to deal with maximizing reusability, product platform and integrated product lifecycle.

- **Maximizing Reusability:** The process of Mass Customization should repeat a lot to achieve the efficiency in high percent, so in the proposed methodology the process will repeat in a lifecycle mood and this opportunity will facilitate to find the optimal building blocks that play critical role in design for mass customization.
- **Product Platform:** Product platform includes variables, features and components of product family that remain constant. Proposed methodology includes step four “Formalize Product Family” that supporting this challenge in mass customization.
- **Integrated Product lifecycle:** Mass Customization process starts with finding the customers individual needs and ending with fulfillment process targeting each particular customer. The proposed methodology also includes this important challenge about MC through step five “Modeling”. In this step configurator modeled by information and knowledge that captured by step one. This step actually is co-design activity from customer side and the positive point is that role of customer through customization process highlighted by this way.

From the other side this proposed methodology also going to support some existing shortcomings in current Knowledge-Based Engineering methodologies.



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As mentioned in chapter two, there are five main shortcomings about KBE and this proposed methodology will support at least two of them.

- Case-based, ad hoc development of KBE applications: This proposed methodology is a framework to develop KBE application is MC and is further a KBE solution based on a process. There are many different industries that implementing MC and this proposed methodology has ability support these industries by modification and adjustment in some steps because of the specific industry.
- A lack of knowledge re-use: The most important step in this methodology is knowledge capturing. After the knowledge captured from internal and external sources, the knowledge will use to model product family structure. In the process of modeling, sometime the product family will not change and this is exactly the time for reuse of previous captured knowledge.

### **6.3 Limitation**

This proposed methodology is the first methodology that going to use as general framework in Mass Customization process, so it was conducted with some limitations. In step of validation, empirical work was chosen as the most appropriate method for identifying the current offering of MC program from variable types of apparel industry due to general condition limitation. However, by doing so, factor selected to test the performance of MC in a web base are mainly depends on author's personal decision which may not strongly support the accuracy of research findings.

The validation process only did for first step of proposed methodology” Knowledge Capture” and from the other side, result and implication of this study was from small sample size of sixty university student that were asked to response in an online customization question.

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## 6.4 Further Research

The next research steps could be:

- The validation process could be implemented for rest of the methodology to reach the final results.
- The development and modification of methodology could be implemented for other aspect of Mass Customization such as sale, cost, logistics etc.
- This proposed methodology only supported two shortcomings of KBE methodologies, but could be solve “Tendency toward development of ‘black-box’ applications” and “Failure to include a quantitative assessment of KBE costs and benefits”.

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**Appendix**

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# Appendix

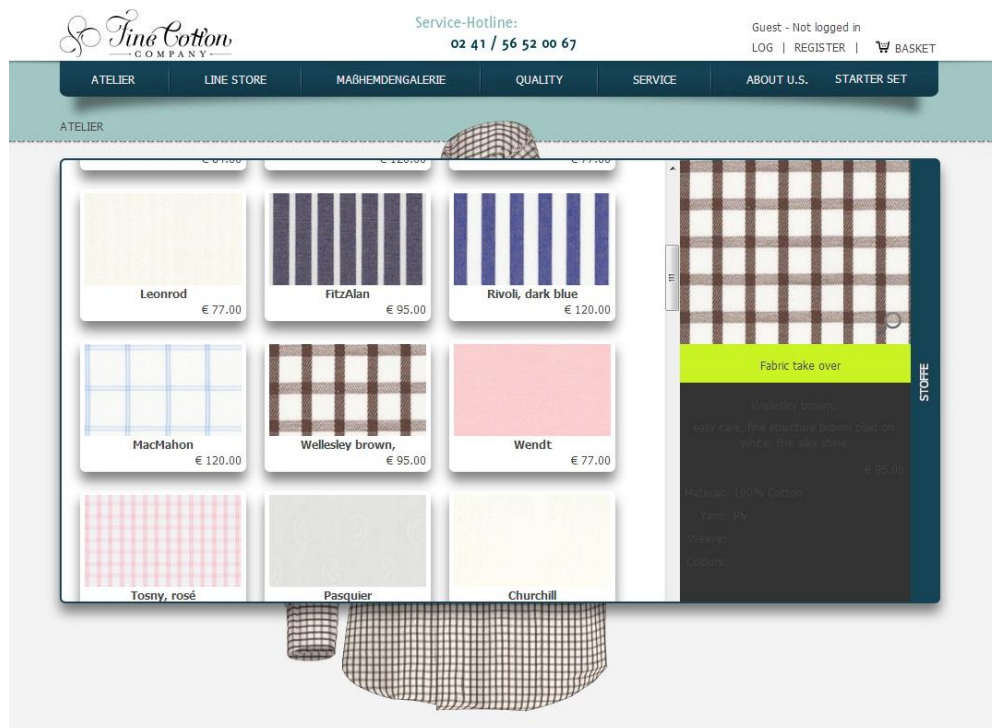
## Appendix 1

Fine Cotton Company is a premium brand for bespoke shirts. The label has been based since 2010 in Aachen. The founders and directors are Tobias Hahn and Philipp Maier.

<http://www.finecottoncompany.com/>

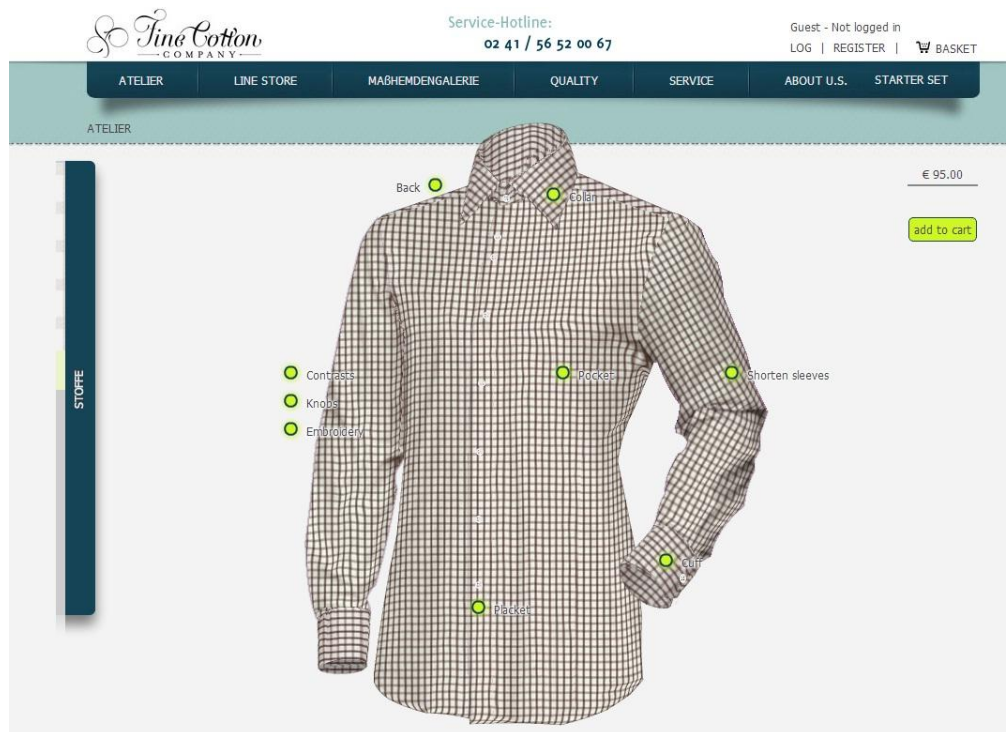
### Step 1: Choose fabric

First select the fabric for your shirt. We offer you a variety of colors, patterns and qualities to choose from. Put your favorite colors simply by using drag & move in your personal Stoffbox located at the bottom of the fabric selection. There you will be saved for future visits, and you can always fall back on your selection.



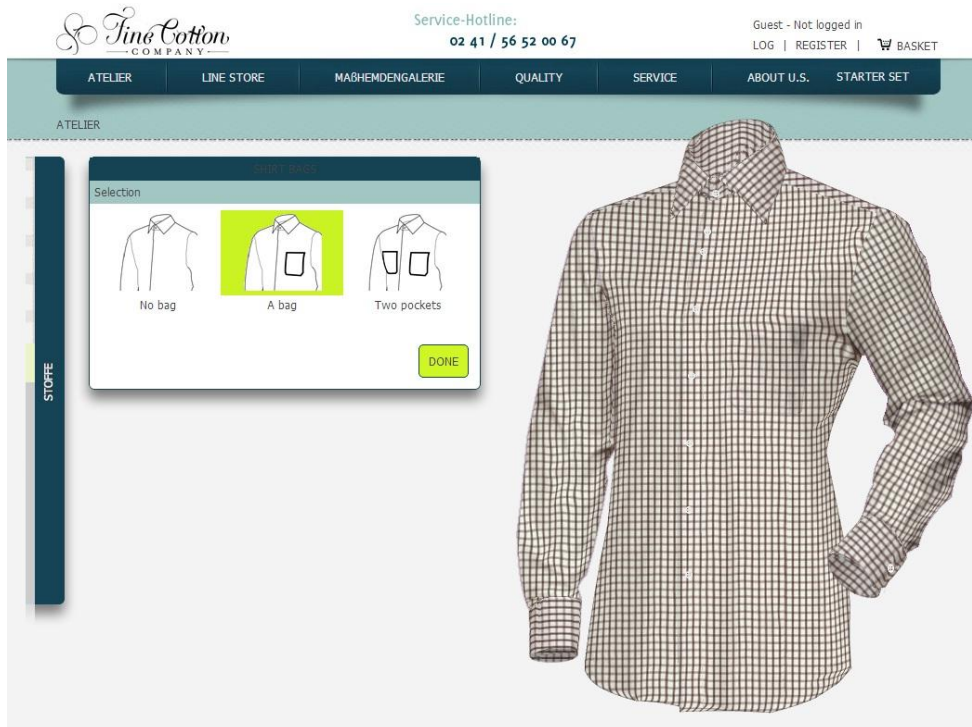
### Step 2: design tailored shirt

Next, you have the option to personalize the details of the shirt. You are the designer! Change, for example, collar, cuff and placket, work with different styles and shapes. Let your imagination run free and try out the various options in our studio. If you are not stuck in the game, you support our comment function. If you select too big, you can simply switch to the basic mode, where we present only the most commonly used options. You want more choice? Just go back to expert mode!



### Step 3: Quality Standards

In the last step before the order, you have the opportunity to have the shirt tailored to fit your body measurements. Our comprehensive guide shows you step by step how to put the individual dimensions. You have the written instructions and video formats. In addition, the dimensions of the corresponding equivalent of your standard size are predefined. They serve as a guide, you should be at a level not even be sure.



## Appendix 2

Back in 1963, Lands' End started with the simple premise: offer quality apparel and gear at honest, direct-merchant values. Lands' End™ soon became a brand people trusted for dependable quality, fair prices and cheerfully efficient service.

[http://ocs.landsend.com/cd/frontdoor?store\\_name=corpsales&store\\_type=1](http://ocs.landsend.com/cd/frontdoor?store_name=corpsales&store_type=1)

Step 1: Starting the personalization of own model with unit measurement

Step2: Create a name for the model

Step3: Choose the body shape from three choices

Step 4: Choose the bust size

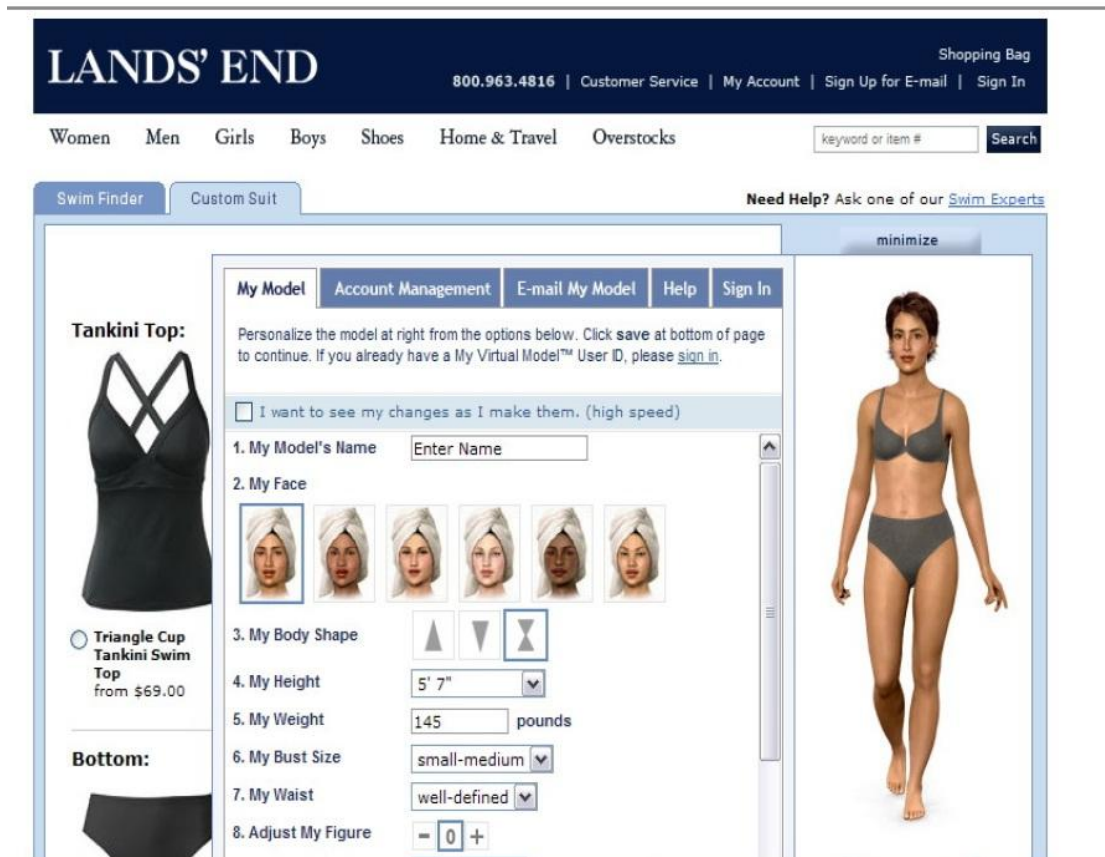
Step 5: Choose waist from undefined or well defines process

Step6: choose height from less to up

Step7: Entire the weight

Step 8: choose personal features from choices of younger or mature

Step 9: Choose eye, nose, lip, face, hairstyle and hair color.



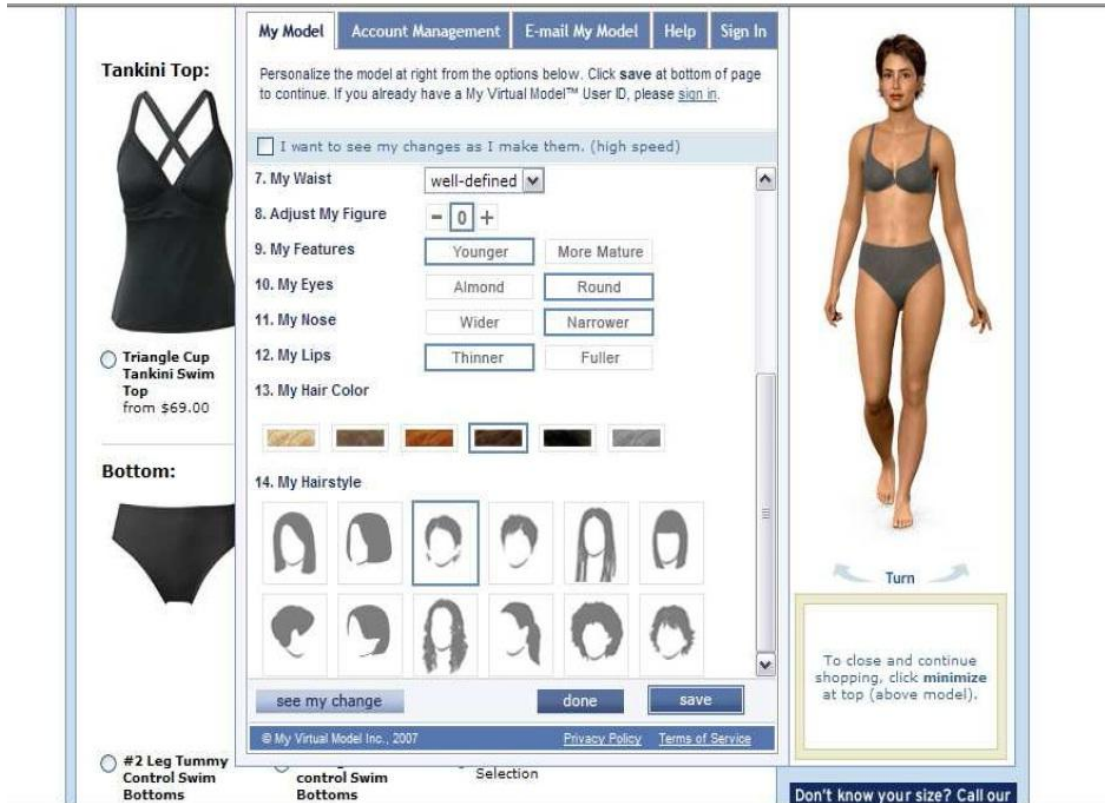
Step 10: save the model

Step 11: option of selecting from recommendation products by company

Step 12: Enter all personal fit information to select from list.

Step 13: select the quality

Step 14: process of confirmation and payment.



## Appendix 3

The jeans - by Ice Lion is your UK online fashion label with individual denim products that are individually handcrafted in complex operations for each client. The jeans - by IceLion allows you select products with exclusivity and individuality provide. The beginning of the jeans - by IceLion our concern was to find the perfect jeans.

<http://www.diejeans.de/>

Step1: Select Sex

Step 2: Selecting the color pattern





Step3: Select the appearance

Step 4: selecting the leg shape



Step 5: Selecting the seems

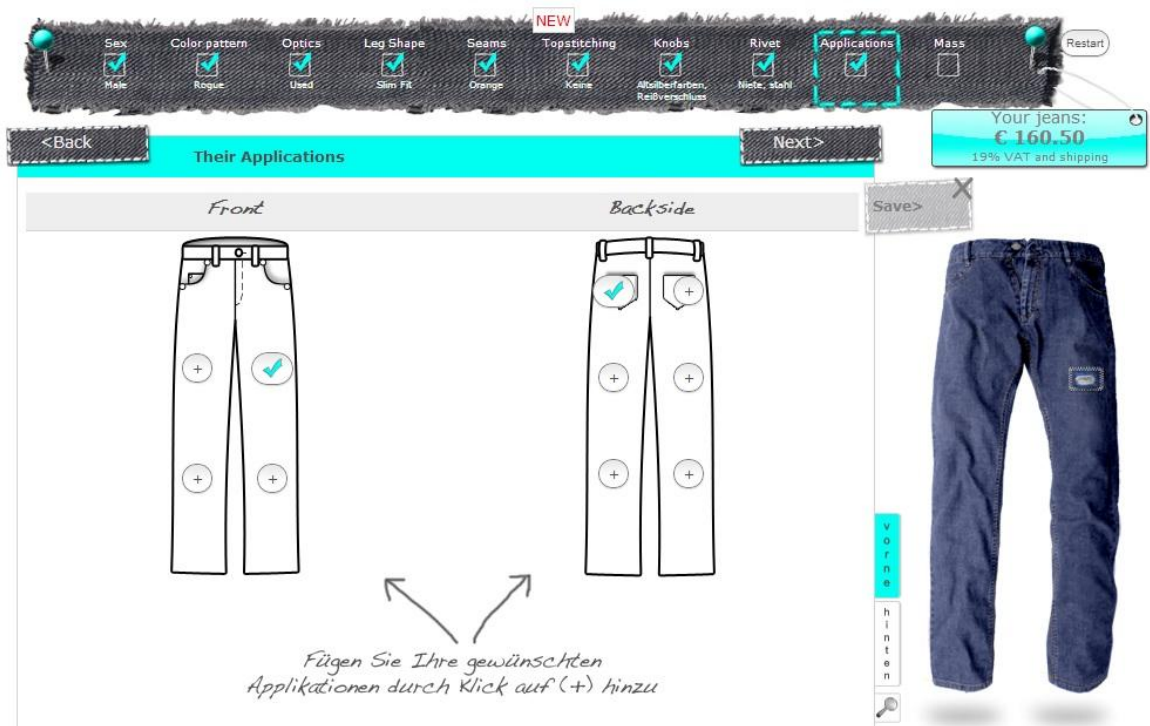
Step6: Selecting the hand-embroidered stitching

Step7: Selecting the knobs

Step8: Selecting the rivet

Step9: selecting the backside view

Step 10: finally the last one that is your measurements about jean.





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## Appendix 4

### Questionnaire

1. What is your age?

- a) <20                      b)21-30                      c)31-40                      d)  
>40

2. What is your gender?

- a) Male                      b)Female

3. How often do you shopping?

- a) Once a week              b)Once a month              c)Once a season              d)Once a  
year

4. Do you ever customize your cloth in a store?

- a) Yes                      b) No

5. Do you ever shop online?

- a) Yes                      b)No

5 Do you find online shopping useful?

- a) Yes                      b)No

6 Do you ever customize your cloth online?

- a) Yes                      b)No

7 How long does take your online shopping process?

- a) Less than one hour      b)Between two or three hours  
c) About one day      d) More than a day

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8 What do you think about the risk of online shopping.

- a) Vey high                      b) High                                      c) Low                                      d) Very low

9 What are the top three important factors about production in online shopping?

Size range

Diversity of Colors

Quality

Functionality

Weight

Fiber content

Style

- Please score for next questions:

10 The options that provide by online shopping processes are enough to support my needs.

- a )                                      b)2                                      c)3                                      d)4  
e)5

11 About Color, selected online colors exactly fit with real goods in stores.

- a )1                                      b)2                                      c)3                                      d)4  
e)5

12 About body measurement, selected sizes exactly fit to my body.

- a )1                                      b)2                                      c)3                                      d)4  
e)5

14 Delivery service rank in terms of price and time.

- a )1                                      b)2                                      c)3                                      d)4

[https://qtrial.qualtrics.com/SE/?SID=SV\\_71Evt7XSUHOzJzL](https://qtrial.qualtrics.com/SE/?SID=SV_71Evt7XSUHOzJzL)

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"Learning without thought is labor lost. Thought without learning is intellectual death."

Confucius