AN EXAMINATION OF DESIGN PROCESSES ADOPTED BY A COMPANY INVOLVED IN DESIGN-BASED MANUFACTURING AND FORMING AN APPROACH TO AN OPTIMUM SYSTEM: A CASE STUDY IN TEBA-GÜNKOL

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ABSTRACT

Today, a company's competitive advantage is directly related to its capacity to develop new products and global competitive pressure has motivated many companies to change to a more rapid form of product development with an emphasis on team and cross functional working. Concurrent Engineering (CE), or Concurrent Design, is a widely recognized approach to improving product introduction which attracts increasing attention of companies throughout the world. In the context of today’s manufacturing industry, design is essentially a social and collaborative process, thereby imposing cross-functional integration on companies. CE can be defined as a development philosophy that could improve design and produce better process quality via both integration and coordination. The CE approach enables synchronization of structural design and manufacturing processes, thus reduces product development time, and decreases costs by eliminating many of the trial-error steps. This research focuses on CE by using a case-study approach carried out in a Turkish company which has been selected as a representative sample of the companies involved in design-based manufacturing in Turkey. In this thesis, the traditional methods used by the company are extensively analysed and a Concurrent Engineering system for the optimum design and manufacturing of new products is proposed. The objective of this study is to provide further insight into the organizational aspect for success in Concurrent Engineering practices in design-based manufacturing.

ÖZET

Şirketlerin yeni ürün geliştirme kapasitelerinin, günümüzün rekabete dayalı ekonomik yapısı içerisinde önemli bir rol oynamakta olduğunu ve bu yüzden de sürekli artan sayıda şirketin takım çalışmasına ağırlık veren hızlı ürün geliştirme yöntemlerini benimsediğini görüyoruz. Tasarımın çağımızda kazandığı toplumsal ve işbirliğine dayalı bir süreç olma kimliği, şirketlere bünyelerindeki farklı işlevlerin yan yana çalışmaları zorunluluğunu dayatmaktadır. Eşzamanlı Mühendislik, ya da diğer adıyla Eşzamanlı Tasarım, ürün tasarımı ve üretim süreçlerinin işbirliği içerisinde ve eş zamanlı olarak gerçekleştirilmesi yoluyla ürün geliştirme zamanını kısaltmakta, birçok deneme-yanılma uygulamasını devre dışı bırakmakta ve tüm bunların sonucu olarak da üretim maliyetlerinde büyük ölçüde azalmaya olanak sağlamaktadır. Eşzamanlı Mühendislik yöntemi, tasarımın ve ürün geliştirme süreçlerinin daha iyi olmasına hizmet eden bir ürün geliştirme felsefesi olarak da tanımlanabilir. Bu tez çalışması, Eşzamanlı Mühendislik yaklaşımı bağlamında, tasarım odaklı üretim yapan birçok Türk firmasını temsil etme özelliğine sahip olduğu düşünülerek seçilen bir şirkette yürütülen uygulamalı bir çalışmayı esas almaktadır. Bu çalışmada, araştırmanın konusu olan şirketin kullanmakta olduğu geleneksel ürün geliştirme yöntemleri incelenmekte ve onların yerine tasarım ve üretim süreçlerini iyileştirmek amacıyla Eşzamanlı Mühendislik yaklaşımını temel alan yeni bir sistem önerilmektedir. Bu tez çalışmasının, tasarım odaklı üretim yapan firmalarda başarılı bir Eşzamanlı Mühendislik uygulaması için yapılması gerekenlerin ne olduğunun daha iyi görülmesine yardımcı olacağı düşünülmektedir.

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LIST OF ABBREVIATIONS

CE	: Concurrent Engineering.
ETS	: Department of Electrical Design.
GAZ	: Department of Gas Design.
GRF	: Department of Graphical Design.
GUNKOL A.Ş.	: Günkol Solar Energy and Air Conditioning Industry Joint Stock Company
KAL	: Quality Assurance Department.
KAM	: Department of Mould Design and Production.
MAL	: Finance Department.
MET	: Method Process and Development Department.
MT	: Mechanical Design.
PRN	: Department of Prototypes.
SAT	: Purchasing Department.
SE	: Sequential Engineering.
TEMA	: Tema Foreign Trade Joint Stock Company.
ÜDM	: Centre of Product Documentation. A person who works at this department is called *ÜS*, that is, *a production chief*.
ÜPK	: Production Planning and Control Department.
ÜRT	: Department of Production.
ÜS	: A Production Chief: a person responsible for all the processes from the design stage until the product is available for the market. He/She prepares product trees and enables the communication between the Design Department and the others.
ÜTG	: Department of Product Design and Development. This department includes these units: MT, GAZ, GRF, ETS and ÜDM.
YAN	: Unit of Side Industrial Activities. It is included in SAT.

CHAPTER 1

INTRODUCTION

Companies are striving for excellence in every area of their operations and they are now much more aware of the fact that 'time to market' is the key issue in the manufacturing industry today. To keep their profitability and viability high in today's global markets, product developers, manufacturers and suppliers have to be able to satisfy the current demands that products should be well designed, of high quality and at low prices with a reduced development cycle. In order to be able to meet these strenuous demands, companies are forced to adopt the best methods of technology and management.

Concurrent Engineering (CE), or Concurrent Design, is a methodology which leads to improved quality, reduced costs and decreasing lead times and this approach is widely considered to be a key element which can help companies to compete in today's markets. CE is defined as the process of considering all aspects of the total product at every stage, which requires extensive interdisciplinary co-operation and integration of all the fields. CE has such a wide domain that it includes many elements such as management of change, the team approach, the design process and its management, marketing, purchasing, manufacturing, distribution and support. As the concept of Concurrent Engineering is getting more popular and there have been many reported successes of CE in practice, an increasingly large proportion of the design-based manufacturing industry feels the necessity for information, awareness and training in good Concurrent Engineering practice (Syan and Menon 1994 p. xv).

In order to have better understanding of CE, it is useful to consider it in the context of design and design methodologies. Looking at design methods from a historical perspective can help to see why the CE methodology emerged in 1990's. It is also essential to compare CE with the traditional product development practice known as 'Sequential Engineering Design Process', or shortly 'Sequential Engineering'. According to this common traditional methodology, design is carried out in isolation and marketing identifies the need for new products. Sequential Engineering is a process of new product development where each design stage starts only when the previous one is accomplished.

This dissertation is intended to shed light on the *design processes* in individual companies which are involved in *design-based manufacturing* and to identify the basic problems of those companies caused by the traditional methods of technology and management.

A great deal of this dissertation is based on a case study which is presented for deeper understanding of typical problems in design-based manufacturing environments in Turkey. The reason why *case study methodology* is used as the core of this study is that case studies are the preferred strategy when 'how' or 'why' questions are being posed, when the investigator has little control over events, or when the focus is on a contemporary phenomenon within some real-life context, which is relevant for this work (Yin 1984; quoted in WEB_1).

The case study conducted in TEBA-GÜNKOL, which is a Turkish company involved in design-based manufacturing, illustrates the current product development processes within the company and some problematic areas during the development processes. Moreover, this dissertation suggests modifications and alterations in the product development practice of the company putting forward a new approach to a better design process to replace the traditional method of operation adopted by the company. The suggested approach is formed according to the Concurrent Engineering methodology.

In order to select out a representative sample of companies, some standards were determined and a selection was made by these standards. The criteria for selecting TEBA-GÜNKOL can be put as follows:

- It has substantial experience in NPD (New Product Development);
- It is involved in design-based manufacturing;
- It develops relatively complex products;
- It operates in highly competitive markets;
- It uses traditional methods of management in its design processes.

The case study was based on interviews involving management people in the steering boards, engineering manager, project leaders and design, planning and purchase engineers.

CHAPTER 2

DESIGN METHODS AND CONCURRENT DESIGN

2.1. An Overview of Design and Creativity

The word *design* has many different meanings. To some, it means the aesthetic design of a product, such as *the external shape of a car or the colour, texture, and shape of the casing of a can opener* (Boothroyd et. al. 2002 p.5). Evans et al. (1990; quoted by Dym et al. 2005 p.103) define *design* as an *elusive creature* whereas Xu (2003 p.19) argues that it is generally known to be an iterative, "trial-and-error" process that is based on knowledge, experience, and intuition. According to Rzevski (1980), design is (1) an investigative process, (2) a creative process, (3) a rational process, and (4) a decision-making process.

Hileman (1998) lists some definitions of design suggested by some professionals in the 1960s:

-Finding the right physical components of a physical structure

-A goal-directed problem-solving activity

-Decision-making, in the face of uncertainty, with high penalties for error

-Simulating what we want to make (or do) before we make (or do) it as many times as may be necessary to feel confident in the final result

-Relating product with situation to give satisfaction

-The performing of a very complicated act of faith

-The optimum solution to the sum of the true needs of a particular set of circumstances

-The imaginative jump from present facts to future possibilities

-A creative activity - it involves bringing into being something new and useful that has not existed previously

Dumas (2003) defines the word "design" more simply compared with all the definitions above and states that it is the process of turning ideas into material things. According to Dumas, *the word design can be used with legitimacy in many activities, the design of a sales or financial plan, the design of a new organisation, or the design of* *a home construction project like building shelves*. Therefore, it would not be incorrect to say that many individuals have followed a design process in the course of their everyday activities. It is also possible to say that it is a natural human ability like the other innate capabilities such as communication and language.

In order to be able to look at today's more complex realities of design, one should be aware of the past of design and he/she should have the competence to see things from a historical perspective. Jones (1970; quoted by Hileman 1998) relates the history of design in four eras, namely, the era of "Craft Evolution", the era of "Design by Drawing", the era of "System Designing" and the era of "Technological Change".

According to Jones, during the "Craft Evolution" era, in the craftsman's head were a set of rules about the design of the tools of the day, which roughly described a useful artefact with "invisible lines", which limited the dimensions and shapes of the parts in relation to the whole tool.

Hileman (1998) explains the distinguishing features of the era of "Design by Drawing" and mentions the difference between this era and the era of "Craft Evolution":

> From the renaissance to the 1950s, design was generally done by individuals. A patron submitted a "brief" to a designer who produced a solution to the given problem by a method which is now dubbed the "black box" method. As the name suggests, the process of design itself was not visible to anyone but the designer, and sometimes he didn't really know how he discovered the solution himself. Nor could he always give you the rationale behind every choice made in the design. However, he could design something that was too big for a single craftsman to construct, like a ship or a cathedral, and in both these cases, he must have had some technical understanding of the forces involved.

During the era of "System Designing", according to Hileman (1998), as a result of the great collective efforts required by World War Two, the process of designing began to move out of the "black box" into *the realm of conscious group effort*.

The last era in Jones' list, namely, the era of "Technological Change", can be said to be different from the other eras in several ways. According to Jones, the most distinguishing characteristic of this era is known to be a "Strategy Switching". This era has witnessed multiple levels of intelligence working together, namely, "co-intelligence" and a more sophisticated approach to the psychology of designing commonly used by design teams. Hileman (1998) elaborates on the era of "Technological Change" explaining the way a design process moves:

> The designers keep a log of thoughts that occur spontaneously which appear irrelevant to the design in process. Each thought is recorded in detail. When this material becomes substantial, it is periodically reviewed in parallel with the design in progress. If the patterns of the spontaneous thoughts contradict the design, decide either to ignore the thoughts or construct a new design strategy that more closely fits the pattern of thoughts. Repeat until the thoughts converge on the selected design.

To be fully aware of today's realities of design, it is also essential to analyse the concept of "creativity". Design and creativity are often thought to be the same thing. Although they have something in common, they differ in certain ways. According to Dumas (2003), *the early stages of creativity are characterised by the existence of rather fuzzy implicit ideas, plenty of divergent thinking, a tolerance of ambiguity and the use of intuition.* On the other hand, in the early stages of design, ideas quite rapidly give way to the creation of a strong concept which is tested out for feasibility. The later stages of creativity see more precise ideas and a tendency for convergent thinking while the later stages of design move into considerable concern for capability in production, market and customer acceptance. Dumas (2003) points out that *the early stages of design incorporate both stages of creativity while the later stages of design incorporate only the later stages in creativity.*

Dym et al. (2005 p.104) highlight the importance of creativity but they also argue that *design is not invention as caricatured by the shouting of "Eureka" and the flashing of a light bulb.* They elaborate on this saying that the design process is a complex cognitive process. The complexity of the design process is basically caused by the fact that the designer has a number of considerations such as having a client (or customer) who, in turn, has in mind a set of users (or customers) for whose benefit the designed artefact is being developed;.

Today's definition of "a good designer" includes many other features besides creativity. Dym et al. (2005 p.104) detail the skills often associated with "good designers" and according to their list "a good designer" has the ability to:

- tolerate ambiguity that shows up in viewing design as inquiry or as an iterative loop of divergent -convergent thinking;
- maintain sight of the big picture by including systems thinking and systems design;
- handle uncertainty;
- make decisions;
- think as part of a team in a social process; and
- think and communicate in the several languages of design.

According to Adams (1986; quoted by Sobek 2005 p.1), *creativity* should not be viewed as a stand-alone activity and good ideas are not very useful if never implemented.

2.2. Design Methods

Design methodology mainly deals with the study of the principles, practices and procedures of design. The primary focus of design methodology is to develop a deep understanding of the design process and how this process can be modified. *It also investigates how the design process can be made more effective and transparent, and be managed to achieve sustainable design outcomes* (Green and Bonollo 2002 p.45).

According to Beitz (1994; quoted by Green and Bonollo 2002 p.45), *design methodology is used for knowledge about practical steps and rules for the development and design of technical systems, based on the findings of design science and of practical experience in various applications*. Green and Bonollo (2002 p.45) argue that the term "design methods" describes any procedures, techniques, aids or tools that contribute to the design process and they represent a number of distinct kinds of activities that the designer might use and combine towards the solution of design tasks.

Cavallucci and Lutz (2000 p.1) emphasize the importance of design methods and underline the fact that in the face of competition, the rapid emergence of new products, changing consumer fashions and globalisation, companies are forced to question the efficiency of their design methods for their survival.

Although a big number of design methods have emerged so far, only some of them have been widely welcomed by the industry. Examples of design methods known to be commonly used are:

- Design-by-drawing
- Computer Aided Design (CAD)
- Brainstorming
- Concurrent engineering
- Value analysis
- Quality Function Deployment
- Design for X

(Green and Bonollo 2002 p.46)

Cavallucci and Lutz (2000 p.1) analyze some certain methods of design and try to draw a parallel between them as can be seen in Figure 1.1. The methods they have studied are Value Analysis (VA), QFD, Axiomatic Design (AD), the Pahl & Beitz approach (PB), Concurrent Engineering (CE), Robust Design (RD), Design for Manufacturing (DFM) and the TRIZ method. Their study is based on 4 essential phases, namely, data collection and analysis (collect); creation (create); construction (construct); and growth (produce):

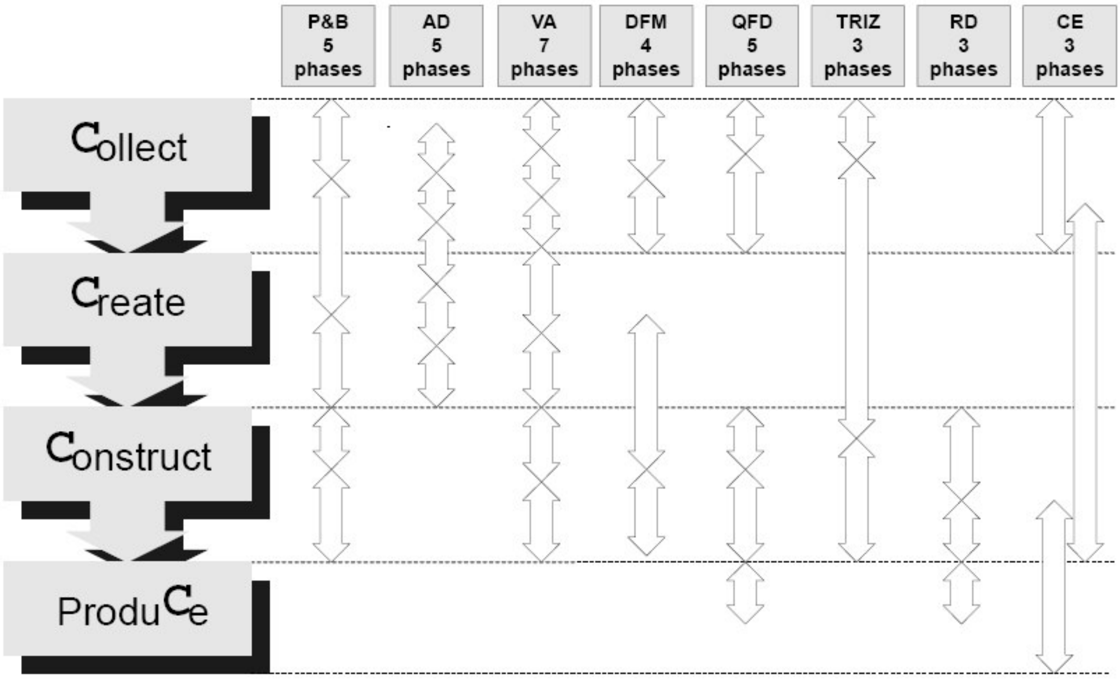

Figure 1.1. Drawing a parallel between design methods
(Source: Cavallucci and Lutz 2000, p.1)

2.2.1. A Brief History of Design Methods

According to Green and Bonollo (2002 p.46), design methodology dates back to 1960s, when new systematic design methods were first introduced. Green and Bonollo (2004 p.177) point out that those methods were applied in certain fields of design practice and these included engineering, industrial, architectural and urban design. They also account for the unwillingness of designers to adopt those methods at that time in that:

> During the same period, the techniques of creative engineering and brainstorming became more widespread and these provided some bases for idea generation. Some of the early methods did not work very well in practice; they were cumbersome to apply and required considerable input data and paperwork. For these reasons, designers did not embrace those methods and believed that they constrained the design process. (Green and Bonollo 2004 p.177)

Xu (2003 p.14) clarifies the purpose of design methods studies, which began in the late 1950s and argues that their objective is to recapture design decision-making activities so that designers can follow a defined procedure from the formulation of the program to its final solution effectively and efficiently. Thus, design activities would be *communicative, comparable, reversible, and repeatable*.

During the 1980s, as a result of some immense technological developments, Computer Aided Design became popular. Similarly at that time, Value Analysis, Design for Manufacture and Assembly and Quality Function Deployment became highly accepted.

In the 1990s, modern approaches to product development such as "Concurrent Engineering" emerged. Green and Bonollo (2002 p.46) explain the trend in the 1990s:

> In the 1990s, interest returned to design methods because of a trend towards integrated product development. The integration of various disciplines into the product development process required that the thinking, upon which the design was based, needed to become more transparent and amenable to internal communication within a company. Shortening the time required for product development became important together with a quality philosophy that sought to get-it-right-the-first-time. As a consequence, the design process had to become more sophisticated with greater certainty afforded by high-quality concepts, rather than relying on random inspiration. This required further use of design methods.

Despite all the popularity of the above-mentioned methods, they were used within certain limits in industry. Gill (1990) seeks for an answer to the question why industry did not embrace all those methods and he points out that one of the reasons for the limited use of methodologies was that formal design tools have not been taught widely at colleges and universities in the past. According to Green and Bonollo (2002 p.46) design methods are seen as something outside the design process, additional and optional. Designers come to learn of design tools through short-course training. They also state that *the problem arises that designers cannot readily include these tools in the design process because it is difficult to change established and proven techniques of design.* They detail their opinion saying that many of these tools and methods require significant input data and paperwork and as a result they are time consuming. Since most design is done under the pressure of deadlines, it is difficult to introduce new ways under these circumstances.

2.2.2. Applications of Design Methods in Certain Fields: Industrial Design and Engineering Design

The methods that were first introduced in the 1960s were applied in some fields of design practice and these included *engineering*, *industrial*, *architectural* and *urban design*.

Industrial design is an applied art whereby the *aesthetics* and *usability* of products may be improved (WEB_2, 2005). Therefore, the industrial designer has to consider a number of design aspects such as the overall shape of the object, the location of details with respect to one another and aspects concerning the use of the product ergonomics.

Dumas (2003) looks at industrial design from a historical perspective and argues that while the educational philosophy that underpins industrial design is in essence German and developed at the Bauhaus School in the early 1920's, the practice of industrial design grew in response to a commercial problem faced by US companies in the 30's.

As Sparke (1986) puts it clearly, industrial design has changed over time due to changes in the socio-economic framework:

> "…the difference between a seventeenth century pattern maker and a modern industrial designer is less one of their respective creative activities than of the economic, technological and social constraints within which the activity is performed"

The difference between the products of an artisan and an industrial designer mainly lies in the way the product is produced. It is important that in order to be an industrial design the product has to be produced in an industrial way, for example an artisan cannot be considered an industrial designer although she may challenge the same aspects of a product. (WEB_2, 2005)

Caplan (1982; quoted by Dumas 2003) accounts for the creative aspects of industrial design giving an interesting example about the motor of a power drill and states that the designer who is responsible for the casing around the motor is supposed to see to it that both form and material meet the requirement that the shape of the housing must be both functional and expressive of the character of the drilling operation.

Dumas (2003) explains the differences and common points between industrial design and engineering design relating her arguments to Caplan's example:

> It is important here, to consider what separates industrial design from engineering design. The passage above enables us to think of some of the differences and indicates that there is probably some overlap. Engineering designers would have conceived of the motor for the power drill, so we can already see that communication between the two might be advantageous. The extent of engineering design can be described as follows: The development of a product from its technical conception through detail design, and the design of the related manufacturing process and tooling. Industrial design can be understood as a part of engineering design, or as running parallel to engineering design. However, when industrial design activity is engaged in the more aesthetic or style concerns of a product it can be understood as running parallel with marketing and brand activity. There is not a right or wrong answer here, but this is an important issue because there is a lot of room for ambiguity and misunderstanding. Lack of clarity contributes to an ineffective use of industrial design. We cannot rely upon the specificity's of industrial design and engineering design to sort out their differences. One reason for this is because of the different basis of their education which creates rather different approaches or mind-sets. Engineering is primarily taught as a science, industrial design is primarily taught as an art.

Dym et al.(2005 p.104) explain in detail what the word "design" means in an engineering context and they point out that "engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints".

According to the booklet titled "Educating Engineers in Design" (WEB_3, 2006) published by The Royal Academy of Engineering, "engineering design is the process of converting an idea or market need into the detailed information from which a product or system can be made to satisfy all the requirements safely, economically and reliably".

Persson and Warell (2003) point out that focus on customer and market needs has initialized changes in product development work, which involve integration of industrial design and engineering design functions. They analyze the relational modes between industrial design and engineering design and state that integration of industrial design and engineering design has the purpose of uniting the two functions and to incorporate them into a more homogenous unit. According to Persson and Warell, product development work affects the activities in several departments, the direction of the work would diverge into each department's own goals, and fragmentation of tasks would reduce the efficiency, unless disciplines work in an integrated manner.

Dumas (2003) mentions the fact that there is a general move in all industry to flatter, less hierarchical structures and an emphasis on team and cross functional working, the potential to integrate industrial design in real and she further states that in order to achieve integration, design should not be understood as a particular activity undertaken by a particular individual or function. According to Dumas (2003), today's design must be understood as a sort of umbrella:

> Under the centre of the umbrella are the specialised design activities, the functions of industrial and engineering design and since these are more visible, they can be referred to as "seen design" Beside them, still under the umbrella, are the activities of those in marketing and production who are linking needs of manufacturing processes and the purchasing customers. Holding all this together is the general manager whose task it is to ensure appropriate levels of cooperation among the various specialised functions and the broad fit of product, process and context. All these activities, where managers take decisions on design in the stream of their other decision making can be referred to as "silent design".

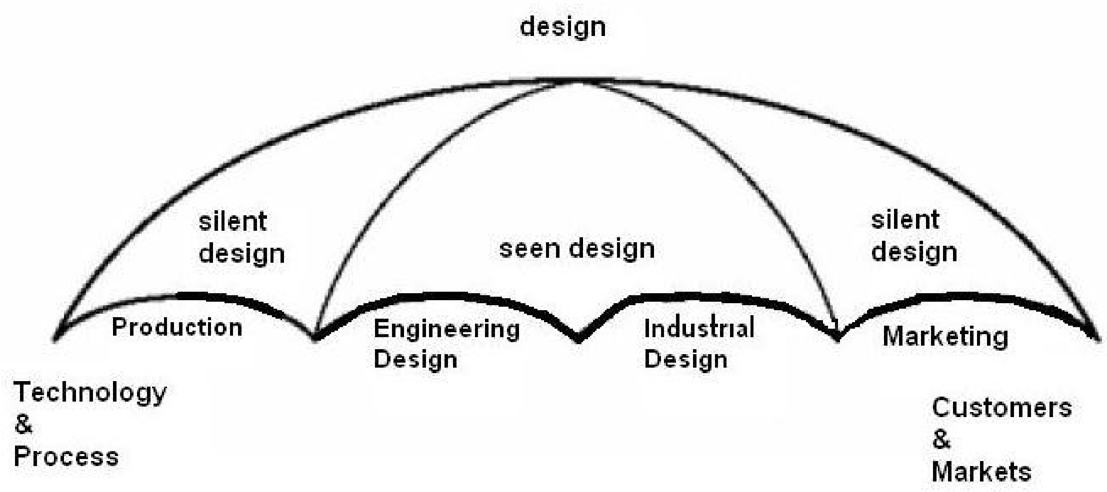

Figure 1.2. Design Umbrella (Dumas 2003)

As the concepts of "integration" and "cross functional working" gain popularity in industry, there appears a question to be answered: "Can engineers design, and can designers engineer?" Burns and Salustri (2005) seek for an accurate answer to this question and the following is the point they arrive at:

> Clearly, no profession can consider itself the centre of the product development universe, and change and design are hard to plan for when the source of the solution is inherently unpredictable. Both education and industry are tied to deadlines, and the challenges and risks may seem prohibitive. But the benefits could be enormous. There is no unique approach, and it is clear that the lines that have evolved between disciplines must be challenged. Everyone within the product development process can be creative. Not simply to be different, but to offer positive improvements. Designers must be encouraged to engineer, and more importantly engineers need to be encouraged to design…and we should all be prepared to share both our wisdom and our ignorance.

2.3. Stages in a Design Process

Sobek (2005 p.1) lists the views of various authors on typical design process stages and adds that while no two design process models are exactly alike, they all seem to explicitly include a problem definition/information gathering/need recognition phase, a concept design phase, and a detail design phase. He further states:

> Most also include a transition phase of some kind between concept and detail design. For example, Ulrich and Eppinger (2000) define concept, system-level, and detail design phases of product development; Dym and Little (2000) present concept, preliminary, and detailed design as key stages; Pahl and Beitz (2001) identify concept design, embodiment design, and detail design as distinct design phases. Interestingly, many tools and techniques exist for concept design (e.g., brainstorming techniques, attribute analysis, and selection matrices), and for detail design (e.g., CAD and CAE tools), but the transition from the vague and abstract to the detailed and concrete has received little attention.

Reidsema and Szczerbicki (1998 p.735) view the design process as consisting of a number of distinct decision-making phases and according to their definitions, *the transition phase* between concept and detail design is called “Analysis Phase”:

> 1. Requirements phase: Conversion of customer requirements into engineering specifications and accumulation of product, process, and organizational design constraints;
> 2. Conceptual phase: Generation of alternative models or solutions which may satisfy the initial specifications and constraints to varying degrees of confidence and desirability;
> 3. Analysis phase: Determination of the best model or solution using analytical techniques;
> 4. Detailed design phase: Drawings, manufacturing specifications, and costing.

The starting point for the design process is an idea or a market need, often stated in vague, and sometimes contradictory, terms. Before the subsequent design phases start, it is important to clarify the task by identifying the true requirements and constraints.

In the phase of Conceptual Design, concepts with the potential of fulfilling the requirements must be generated. The overall functional and physical relationships must be considered and combined with preliminary embodiment features. The result of this phase is a concept model (drawing).

In the phase of Embodiment Design, the foundations are laid for detail design through a structured development of the concept. In the case of a mechanical product, the result of this phase would be a detailed layout model (drawing) showing the preliminary shapes and arrangement of all the components, along with their materials (Ashby 2005).

Finally, in the stage of Detail Design, the precise shape, dimensions and tolerances of every component have to be specified, and the material selections confirmed. There is a close interrelationship between the shape of a component, its material and the proposed method of its manufacture. The result of this phase is a set of detailed manufacturing instructions.

Green and Bonollo (2002 p.47) list the phases of a design process categorizing them as to whether it is engineering design or industrial design. According to Green and Bonollo, in engineering design, there are four main stages, namely, *clarification of the task*, *conceptualising*, *embodiment and elaboration* and *detailing*. Industrial design consists of five phases and these are *clarification*, *concept generation*, *evaluation and refinement of design concepts*, *detailed design* and *communication of results*.

As can be seen in Table 1.1., the basic steps needed to design a product can be illustrated, including the tasks and responsibilities of the key functions for each phase.

Table 1.1. The basic steps needed to design a product (WEB_4, 2006)

PHASE 0: PLANNING	**PHASE 1: CONCEPT EVELOPMENT**	**PHASE 2: SYSTEM-LEVEL DESIGN**	**PHASE 3: DETAIL DESIGN**	**PHASE 4: TESTING AND REFINEMENT**	**PHASE 5: PRODUCTION RAMP-UP**
MARKETING					
• Articulate market opportunity. • Define market segments.	• Collect customer needs. • Identify lead users. • Identify competitive products.	• Develop plan for product options and extended product family. • Set target sales price point(s).	• Develop marketing plan.	• Develop promotion and launch materials. • Facilitate field testing.	• Place early production with key customers.
DESIGN					
• Consider product platform and Architecture. • Assess new technologies.	• Investigate feasibility of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Generate alternative product architectures. • Define major subsystems and interfaces. • Refine industrial design.	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentation.	• Reliability testing. • Life testing. • Performance testing. • Obtain regulatory approvals. • Implement design changes.	• Evaluate early production output.
MANUFACTURING					
• Identify production constraints. • Set supply chain strategy.	• Estimate Manufacturing cost. • Assess production feasibility.	• Identify suppliers for key components. • Perform make-buy analysis. • Define final assembly scheme. • Set target costs.	• Define piece-part production processes. • Design tooling. • Define quality assurance processes.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train work force. • Refine quality assurance process	• Begin operation of entire production system.

Some scholars compare the phases of a typical design process and argue that what distinguishes a safe and reliable product is often not its conceptual design but its detail design; many excellent concepts fail in the market through lack of attention to detail. Sobek (2005 p.1) holds a very similar point of view and argues for the importance of the implementation of ideas quoting from Adams (1986):

> "…over the years I've become increasingly frustrated with the belief that more ideas alone mean better results. If you're serious about encouraging creativity in yourself or others and if you want to deal with change effectively, then implementing ideas is at least as important as generating ideas…. Creativity requires that ideas be implemented, and it is in the pragmatic details of implementation that creativity often fails, relegating the ideas to occasional hindsight discussions at cocktail parties."
>
> Creativity is certainly a very important part of innovating clever solutions to problems encountered as part of the human endeavour, what we call engineering design. However, as James Adams points out in the introduction to his book on creative problem-solving, good ideas are not very useful if never implemented.

Sobek (2005 p.2) highlights the significance of "system-level design" saying that "it bridges the gap between the highly abstract, concept design and the concrete, detail design phase". He also points out that the most eminent factor lying behind the success story of Toyota is mainly the design method adopted by the company, namely, a kind of Concurrent Engineering which highly focuses on "system-level design activities". According to Sobek, *a focus on system design* and *working with sets simultaneously* are two important principles of Toyota's method.

2.4. A Design Method: Concurrent Engineering

Product design today cannot be regarded as a stand-alone process. It must be considered in the context of integration with other product development activities, such as manufacturing, costing, quality control, etc. If this integration is ignored, it is likely that the designer will design a product that is difficult to manufacture or assemble, requires high material or equipment cost, or contains some design faults that the production engineers have to correct or send back for redesigning before manufacturing can be done. For most products, producability has become a vital design criterion. If it cannot be manufactured or assembled efficiently, a product is not properly designed (Schuch 1989; quoted by Chen et al 2001). In addition to designing a product that fulfils manufacturability requirements, it is also advantageous to design a product that satisfies performance, customer needs and cost reduction criteria. To obtain an appropriate design that will satisfy performance or customers' requirements as well as manufacturers' constraints (e.g. reduce costs), a methodology that integrates design and manufacturing is desirable. The concept of *Concurrent Engineering* (CE), also referred to as *Concurrent Design*, is a relatively new approach to system and project design which has been growing steadily in recent years, particularly in the space and car industry. Essentially, the idea of *Concurrent Engineering* is to bring together experts from several related disciplines in a single facility where they can perform their regular tasks, using all of the same tools that they normally employ, while working together with other experts in a structured collaborative environment. In this environment, they can work together directly, in real time, to create and refine design concepts, analyze issues and trades-offs, and improve the communication of ideas and decisions (Gough et al. 2005 p.2).

Concurrent Engineering incorporates the downstream product development life-cycle considerations into the design phase (Yang and Xue 2003 p.3616). It is a new design technique introduced in recent years to reduce product development lead times and to improve the life-cycle performance of product. Different from the traditional, narrowly focused design practice, Concurrent Engineering simultaneously incorporates considerations from all product life-cycle aspects, including design, manufacturing, assembly, maintenance, disposal, etc., into the design phase to produce better overall product life-cycle quality. The approach also reduces the number of re-designs, thereby shortening the product development lead times and reducing costs (Xue and Dong 1998 p.70). Trygg (1993 p.404) argues that CE is the outcome of an intensified search for alternative organizational solutions driven by the struggle for lead time reductions, and the need for better market-oriented products. Colborn (1989 p.1), just like Trygg, describes the pressure brought by cost and quality:

> Under pressure to both cut costs and improve quality, a number of companies have embraced the concept of concurrent engineering, in which design, manufacturing, and test engineers participate as equal partners in all phases of a product's life cycle. The trend has not only affected product quality and development, but also redefined engineering roles and attitudes.

Concurrent Engineering (CE) or *Concurrent Design* is an approach to organize design activities into more parallel processes. In particular, at each design phase, manufacturing and assembly feasibilities are reviewed and predicted, as can be seen in Figure 1.3. It should be pointed out that although CE has the benefits of reduced product development lead time and increased product functional reliability it is essentially about the design process, not about the manufacturing process (Sinha 2004 p.28).

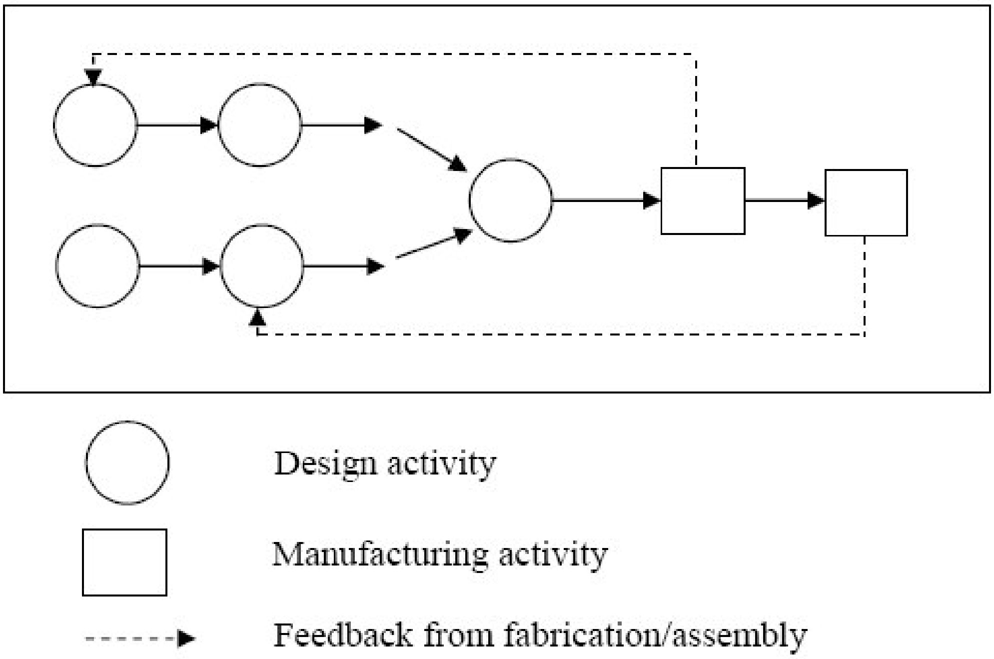

Figure 1.3. Concurrent Engineering Process
(Source: Sinha 2004 p.28)

According to Shai and Reich (2004 p.93), the reason why Concurrent Engineering is so widely welcomed is the fact that design is a social and collaborative process and collaborative design is inevitable. Shai and Reich (2004 p.93) define Concurrent Engineering arguing that it is seen as a collection of techniques and development philosophy that could improve design. They further mention the fact that Concurrent Engineering helps to consolidate the different perspectives that are active in a design project.

Whyte et al. (2005 p.18) highlight the importance of concurrent approach to new product development:

> …if design is about a process over time requiring different perspectives it makes sense to organise it in a much more integrated fashion. Instead of sequentially involving people, there is a case for bringing the whole set of perspectives together at the outset and building a shared and clear concept around which everyone can contribute. **Concurrent working** involves the shared working of all these different sets of people together, at the same time, and it can play an important role in the organisation and management of the design process. Early involvement of this kind can demonstrably reduce the incidence of problems at a later stage (for example in designing for easy manufacturing) and it can also help head off what can otherwise be tricky problems which occur at interfaces and at handover between phases.

Concurrent Design is also known as ‘Simultaneous Engineering’, ‘Concurrent Engineering’, ‘Life-cycle Engineering’, ‘Integrated Product Development and Team Design’ and as Swink et al.(1996 p.41) explain, CE concepts have evolved from an original emphasis on "design for manufacture" to more comprehensive life-cycle considerations. Early approaches forced designers to consider how parts were to be fabricated. This emphasis was then expanded to include assembly considerations and relationships between pairs or groups of parts, which in turn forced the integration of many diverse, complex issues in design decisions.

The Concept of CE is not new. Japanese industry has practiced CE, without using its name, for some time. This is clearly illustrated by the studies done in the automotive industry, comparing the time to market of Japanese and European manufacturers. For 12 projects studied, typical Japanese companies could develop and introduce a new car to market in 43 months against 63 months for the 11 projects studied in Europe (Hartley, n.d.; quoted by Syan 1994 p.7).

As Yazdani and Holmes (1999 p.30) put it, Concurrent Engineering requires a greater involvement of downstream activities to bring in all specific expertise to the design stage. Figure 1.4. illustrates how CE works in practice and how the process required for concurrent definition is characterized by the overlapping of design and the planning of the process development.

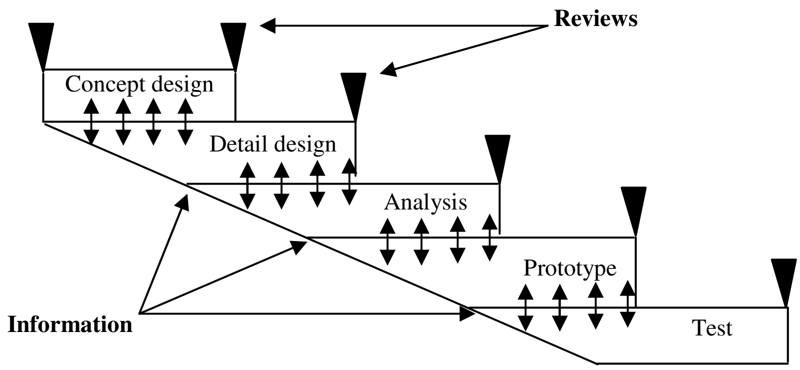

Figure 1.4. The concurrent definition model (Yazdani and Holmes 1999 p.30)

It is usually more understandable to everyone to define the concept of Concurrent Engineering by drawing a comparison between CE and the traditional methodology, namely, Sequential Engineering. According to Brooks and Backhouse (1996; adopted by CAMR 2001 p.6), the difference can be best illustrated as follows:

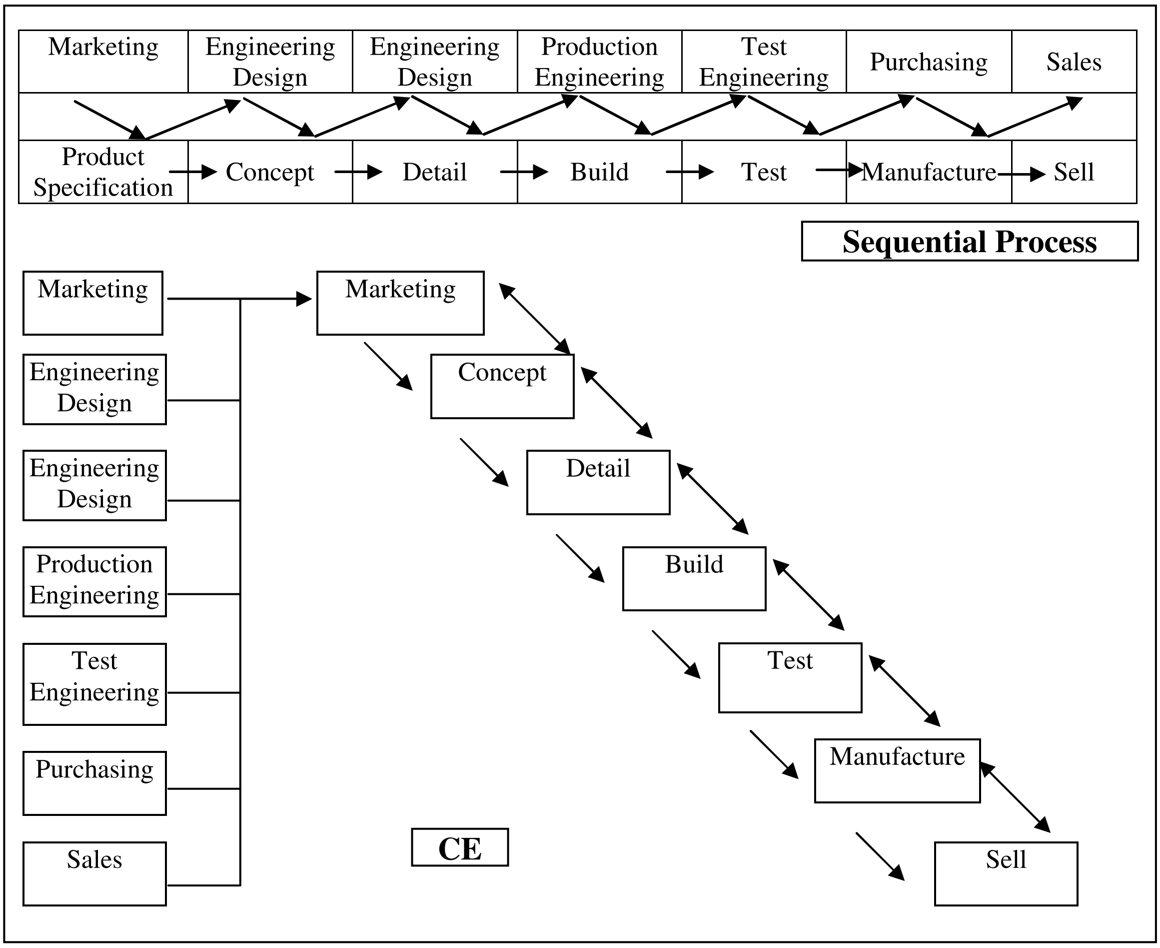

Figure 1.5. Sequential process and concurrent development of new products (Brooks and Backhouse 1996; adopted by CAMR 2001 p.6)

As Hall et al. (quoted by Balamuralikrishna et al. 2000 p.2) state, Concurrent Engineering has now become a common phrase heard on factory floors and mentioned in the literature but the term was first used in a report of The Institute of Defense Analysis (IDA) in the USA in the late 1980's. The Institute, which brought the term concurrent engineering to the forefront in 1986 in its report R-388, defined it in 1988 and the definition given below is now widely accepted.

> Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, schedule, and user requirements. (Trygg 1993 p.404)

This root definition of CE focuses on expanding the traditional role of product developers to include attention to the process of manufacturing and supporting the product in the field. This expanded role is further explained by using the term life-cycle of the product as the area of responsibility of the product developer (Componation et al. 1999 p.169).

Although the term "concurrent engineering" was only coined in the late 1980's, it has now become institutionalized as a concept with a dedicated journal, many conferences, numerous books and other publications, an industry award in the United States, and a number of dedicated research centers around the world (Badham et al. 2000 p.237).

Since the first definition of CE appeared in the report of IDA, Concurrent Engineering has been described by many different people and organizations and many other definitions have been published since this one (Skalak 2002 p.4). One of the later definitions suggested by Knight and Jackson and Walklet (1989; quoted by Componation et al. 1999 p.169) introduced the concept of using a team approach in product development. Cleetus (1992; quoted by Skalak 2002 p.4) proposed a definition of CE that combined both the concept of a life-cycle focus that includes product and process components, and the proposal that teams are the way to achieve this integrated effect. Here CE was defined as:

> …a systematic approach to integrated and concurrent development of a product and its related processes, that emphasizes response to customer expectations and embodies team values of cooperation, trust, and sharing in such a manner that decision making proceeds with large intervals of parallel working by all life-cycle perspectives early in the process, synchronized by comparatively brief exchanges to produce consensus.

This definition combines the original concept of integration and teams and adds increased attention to customer expectations. Prior to this point, definitions of CE implied the focus was on the customer expectations, but did not always clearly state these expectations as the driver of the product development process (Componation et al. 1999 p.169).

Turino's (1992 p.1) definition of Concurrent Engineering puts the main difference between this methodology and the traditional one:

> Today's shorter product life cycles and increased pressure for shorter time to market make it imperative to replace the "redo it until it's right" philosophy with the "do it right the first time" philosophy--concurrent engineering. Using concurrent engineering, you can determine design tradeoffs for the overall success of the product (and the business) given the specific customer requirements, business capabilities, and competitive environment from the onset.

Besides conventional definitions of CE there are also witty comments on the concept of CE. McGrath (quoted by Swink et al. 1996 p.230) gives a very conventional definition of CE stating that "Concurrent Engineering means developing the product and all its associated processes, that is, manufacturing, service, and distribution, at the same time". One of the wittiest comments was made by Hiroto Kagani (quoted in Markowitz 1991 p.1), senior quality assurance manager for Canon. He says, "If pure water flows from the upper stream, then there is no need to purify it father downstream". According to Don Carter (quoted in Markowitz 1991 p.1), corporate technical director at Mentor Graphics, "Concurrent engineering is a journey, not a destination.".

Badham et al. (2000 p.238) state that there are two ideas central to the CE philosophy and these are 'integration' and 'concurrence' (or simultaneity). According to Badham et al., the former involves both *functional integration*, which means improving cross-functional communication, cooperation and coordination and *design integration*, that is, considering all elements of the product life cycle, and the associated design considerations, during the earliest design phases. Swink (1996 p.42) agrees with Badham et al. on the point that there are two key initiatives at the heart of the CE process and one of them is *cross-functional integration* but Swink's description of the second feature differs from that of Bedham et al. According to Swink, *design for excellence* is the second key characteristic of the CE approach and "successful CE programs provide the infrastructure necessary to produce that excellence".

The important role that 'integration' plays in Concurrent Engineering is strongly argued for by Hauptman and Hirji (1999 p.180). They account for their opinions giving a very interesting example from one of Shakespeare's well-known plays:

> This could be effectively illustrated by the romantic Shakespearian classic Romeo and Juliet: when reviewing the `Project of Juliet's Death' we find hardly any differentiation in terms of language, culture, cognitive styles and goals among Friar John and the tragic heroes. Nevertheless, disaster strikes because the coordinating information about the ruse, which helps Juliet avoid marrying Prince Paris does not reach Romeo in time to prevent his suicide. Review of additional Shakespearian plays suggests that many tragic and humorous occurrences could have been prevented with a mobile telephone or basic email. This means that to accomplish positive organisational outcomes, the organisation needs both integration and coordination.

Maddux et al. (1994 p.2) highlight the importance of the team approach in Concurrent Engineering stating that the multi-disciplinary teams are at the very heart of

CE because, when properly constructed, they contain the intelligence base for a successful program. De Wilde (1993 p.13) puts it similarly and says:

> …central to the methodology is a multi-disciplinary team in which all the different specialists who work on the same product development project tackle it simultaneously, at all time having access to the same information. Instead of one department throwing the design 'over the fence' to the next department, once it has made its contribution to the project, representatives from all departments sit down together to develop the product. The team will typically get input from the following key-players in the development process: design engineers, manufacturing engineers, marketing people, purchasing people, accounting people, the workforce, principal suppliers of manufacturing equipment and components, and customers.

Although teamwork is of vital importance in CE, it is a severe task to be tackled carefully. One of the greatest challenges in managing the simultaneous operation of inter-related tasks is to figure out ways that get people to work together as a team (Balamuralikrishna 2000 p.3).

According to Componation (1999 p.172), the primary components were technology to support Concurrent Engineering, use of teams to support Concurrent Engineering, and a focus on the process used in Concurrent Engineering. Like Componation (1999 p.172), De Wilde (1993 p.14) also accounts for the important role of computers in CE saying that computers facilitate the communication and data interchange between the team members.

Duffy and Salvendy (1997 p.368) argue that among the main factors contributing to successful implementation and performance in concurrent engineering are the human and organizational factors and they outline these factors:

> • Human variables that contribute to predicting successful concurrent engineering efforts include: Quality of communication, Knowledge of manufacturing for problem solving, and Problem-solving effectiveness.
> • Organization variables that contribute the most to predicting successful concurrent engineering efforts include: Number of team members, Proximity, Reward Structure, Manager perception of value communication, Number of employees, and Technology push.
> • Technology variables that contribute to predicting successful concurrent engineering efforts include: Consideration for Design for manufacture and Design for assembly, and Technical training. Other aspects of technology should be acknowledged as important for success in concurrent engineering, such as: the existence of standard component libraries and or process modelling tools. System response time may also be an important technology issue. However, "Amount of Time" that the organization has been using concurrent engineering was not detected to be an important indicator in effectiveness of the individual team.

According to Rosario et al. (2004 p.3), systematic studies within the automobile and technology industries have substantiated that for a successful implementation of CE various critical factors or characteristics must be present. These critical factors are:

1. Strong Management Commitment
2. Interdisciplinary and multi-talented teams
3. Comprehensive training to all team members
4. Adequate resources and tools
5. Early and continuous involvement of Customers and Suppliers.

Swink (1996b p.47), just like Rosario et al., emphasizes the importance of *strong management commitment* and states that “to increase the probability of success, managers must: (1) elevate the project, (2) externalize the agenda, (3) eliminate barriers to integration, and (4) elaborate concurrent engineering processes”.

Markowitz (1991 p.1) also attaches a lot of importance to the commitment of top management and puts is this way:

> Critical to the success of broad-based, organization-wide concurrent engineering is the commitment of top management. While you may achieve some success in applying narrowly defined concurrent engineering to your projects, the greatest benefits require enterprisewide dedication. The IDA (Institute for Defense Analysis, USA) report suggests the greatest benefits result from improvements to systems, such as formal or informaly company policies related to purchasing decisions, interdepartment communications, emphasis on short-term returns, technical training, personnel evaluation, and team spirit. "Managers must be coaches," says Ken Reindel, director of engineering for Keithley Instruments.

Skalak (2002 p.5) lists the following attributes to characterize a typical CE design process:

- Customer focus and involvement,
- Early and continual involvement of suppliers in the design process,
- Cross-functional, self-directed, empowered teams,
- Incremental sharing and use of information,
- Life-cycle focus,
- Systematic and integrated approach,
- Concurrent (parallel) design teams,
- Use of modern tools such as CAE, CAD, CAM, finite element analysis, etc., and continuous improvement of all processes.

In order to achieve success, is it always necessary for a company to have all the CE characteristics listed above? Roy Wheeler of Hewlett Packard answers this question by giving *the best prescription for success*: “What tools does an engineer need to get started in CE? Pencil, paper, some intelligence and a willingness to work with peers in other functional areas to get the job done." (Watson 1991; quoted by Syan and Menon 1994 p.5).

2.4.1. A Brief History of Concurrent Engineering

For the past three decades, all design-based manufacturing companies in the Western world have been under the pressures of similar challenges. According to De Wilde (1993 p.4) and Syan (1994 p.3), these are:

- Increasing competition and more demanding customers;
- The advance of technology and its influences on the manufacturing process;
- Increasingly demanding legislation and the sensitivity to environmental issues;
- Demands for improved quality, low prices and shorter time to market;
- The highly volatile world economy and its effects on both suppliers and competition.
- Demographic changes such as the increase in the average age of the population.

The pressure of growing international competition together with the other factors listed above forced western companies to respond to the Japanese invasion in the global market. However, they were slow to see what was behind the success story of the Japanese and this caused them to follow some wrong strategies such as trying to offset their weakness by using computer-based technology, which eventually proved to be useless. Syan (1994 p.3) explains the reason for this failure saying:

> This expensive technology was largely ineffective, because the new tools were used with existing structures, practices and attitudes. Products continued to arrive in the market place at unsatisfactory quality levels, and often too late to achieve sales and profit objectives.

The 1980s and early 1990s witnessed a dramatic evolution in new product development (NPD) processes as global competition has led to shorter product life cycles and necessitated higher quality, more producible products (Swink et al. 1996a p.230). Many companies which wanted to remain viable in 1980's and 1990's had to be able to develop their products fast enough to keep up with changing markets by reducing their time to market. Turino (1992; quoted by Badham et al. 2000 p.237) describes the situation in the 1980's:

> In an increasingly globalized and competitive environment, manufacturers are under considerable pressure to improve their new product introduction performance. In particular, they have to strive to keep development and introduction costs down, improve market targeting and customer focus, and (most importantly to many commentators) reduce the lead time-to-market. In the late 1980s, concurrent engineering (CE) emerged as the solution to the problem of achieving more rapid and effective product innovation processes.

It is now recognized by the majority of the western companies that to compete successfully they have to strive for excellence and among the significant means to achieve excellence are better quality and shorter product development times. The Concurrent Engineering approach is commonly acknowledged to be the best strategy to achieve these goals.

2.4.1.1. The Sequential Engineering Process

To be technically aware of the current product development trends in the design-based manufacturing, it is essential to have information of the traditional process of new product development which is commonly known as Sequential Engineering. In the Sequential Engineering Process, each stage of product development follows completion of the previous stage, that is, each design stage starts only when the previous one is completed. Skalak's (2002 p.2) description of the Sequential Engineering Design Process is as follows:

> In a sequential engineering process, sales and marketing define the parameters of the new product, including the sales, price, and requirements, which are based on customer needs. Then, they present a product definition document to the design engineers. Using this information, the engineers then define the product specifications, design the new product, and pass detail design drawings to manufacturing. If the requirements ask for a prototype, and the product is not too far behind schedule, then manufacturing will build a prototype. The results are then reviewed by the design engineers. Problems that are identified in the prototype and any difficulties that manufacturing finds in producing the product as designed are discussed. The design engineers then make changes to the product to accommodate manufacturing and any problems found in the prototype. Finally, production will occur after all problems are solved or minimized to an acceptable level. In this model, the groups rarely interact beyond the hand-off of the design from one stage to the next. Most of the design changes occur in the redesign phase of the sequential engineering process, causing additional costs and time delays. Since the next development phase can only begin after the preceding one is completed, the product launch date is delayed with each change.

As can be seen in Skalak's description, the most significant drawbacks of the Sequential Engineering Process are 'additional costs' and 'time delays' since the subsequent stages will be delayed until the current stage has been accomplished in this method of operation.

According to Syan and Menon (1994 p.5), there are many weaknesses of the Sequential Engineering Process which lead to an excessive amount of modifications resulting in delay and additional costs, a lack of confidence in the estimated costs of projects and expensive changes to tooling and other equipment. Figure 1.6. not only shows a sequential process of new product development but also accounts for the arguments about the cause of time delays in Sequential Engineering:

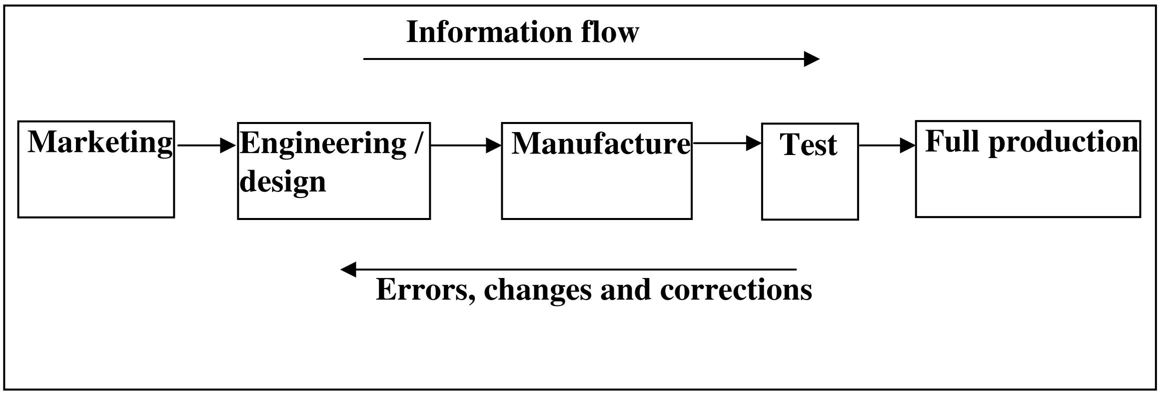

Figure 1.6. The Sequential Engineering Process (Syan and Menon 1994 p.5)

Figure 1.6. clearly indicates that the product designs developed during "over-the-fence" engineering are usually inefficient to manufacture and as Trygg (1993 p.404) put it, they usually need to be reworked once those responsible for quality, manufacturing, maintenance, and purchasing, and so on have a look at them. In today's business world, corporations must be able to react to the changing market needs rapidly, effectively, and responsively. Decisions must be made quickly and they must be done right the first time out. Corporations can no longer waits time repeating tasks, thereby prolonging the time it takes to bring new products to market (WEB_7, 2005).

Figure 1.7. shows that design and engineering do not work in cooperation with each other. Instead, they carry out their tasks alone. The figure also indicates that each stage begins after the previous one is finished:

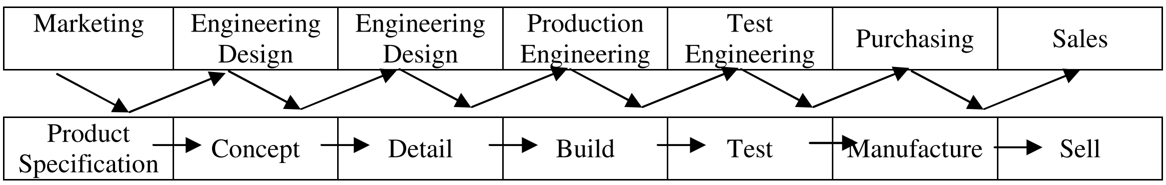

Figure 1.7. Sequential development of new products (Brookes and Backhouse 1996; adopted by CAMR 2001 p.6)

As Figure 1.7. illustrates clearly, the Sequential Engineering Design Process encourages a system where design is carried out in isolation and some departments only see the design in an almost complete state. Anderson (1993 p.1), severely criticizes this approach saying:

> Traditional product design encourages a sort of "hands-off" policy between designers and manufacturing engineers. Design engineers frequently work in off-site design centers or in secured areas on-site. Also, designers tend to view themselves as elite; they can experience culture shock when placed elbow-to-elbow with manufacturing engineers in plant environments. That's when the people barriers may build up - especially when the manufacturing engineers are ex-designers who "didn't hack it," and when people without college degrees have been promoted from the shop floor to become engineers. In such cases, product designers may feel they've lost status and power when asked to work with manufacturing. Manufacturing engineers may feel they've got a chance to "even the score" with the ivory-tower techies who threw elegant designs at them and said, "Build them," but offered no assistance. External suppliers enter the picture when the actual manufacturing of a product is done outside the plant. In such cases, it may be advisable to include suppliers in the early stages of a product's design so that they can provide both design services and production knowledge.

The Sequential Engineering Process is also known by many other names, including 'Sequential Engineering', 'Over-the-wall Engineering', 'Serial Engineering' and 'Time-phased Engineering'. Markowitz (1991 p.1) accounts for the term 'over-the-wall' and expresses his criticism of Sequential Engineering as follows:

> Companies organized along functional lines typically employ greater degrees of sequential engineering. This unidirectional approach to product development is limited by the ability of each group to finish its portion of the design. As each functional group finishes its task, it hands the project to the next group in the sequence. This approach is often called "over-the-wall" engineering. The greatest disadvantage of sequential development is that information only flows in one direction. Although downstream development disciplines, such as manufacturing, test, and service, might contribute useful information to the design team, no formal mechanism for that data flow exists. Worse, independent schedule pressures on each of the functional teams act to inhibit any spontaneous bidirectional information flows. Schedule pressures may also cause you to compromise vague project goals-such as the unquantified ability to test, manufacture, and service the product.

2.5. Benefits of Concurrent Engineering

The primary goal of Concurrent Engineering is to reduce time-to-market while improving quality (Anderson 1993 p.1). According to Syan (1994 p.9), among the other objectives of Concurrent Engineering are:

- greater competitiveness;
- greater control of design and manufacturing costs;
- improved profitability;
- close integration between departments;
- enhanced reputation of the company and its products;
- promotion of team spirit.

The most obvious benefit of CE is the reduction of the product development cycle time (De Wilde 1993 p.15). Figure 1.8. shows a representation of typical time savings of using CE in comparison with Sequential Engineering (SE):

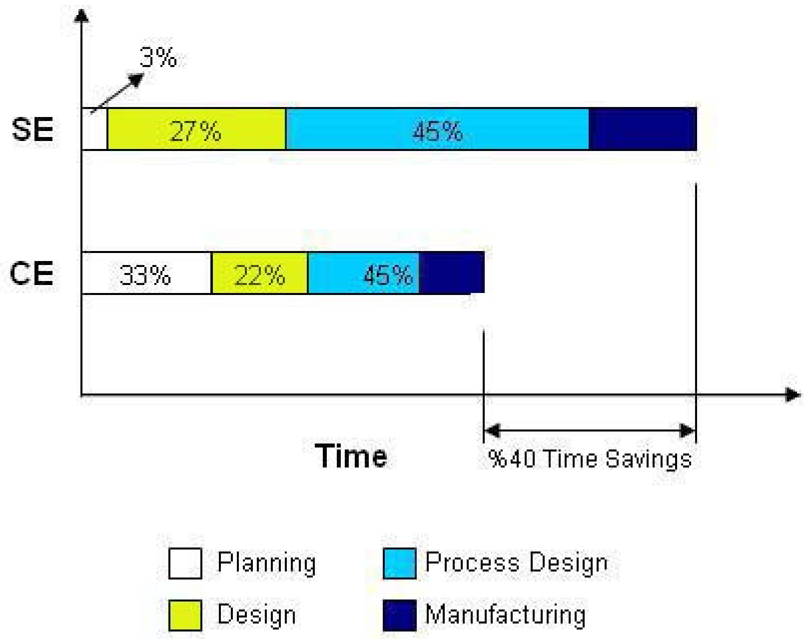

Figure 1.8. Comparison of SE with CE, showing time savings with CE use. (US Air Force R&M 2000 Process Study Report 1987).

The exceptional performance achieved by world-class companies has been the best evidence of the effectiveness of Concurrent Engineering. Company results that have been published are very positive in terms of overall benefits. Turino (1992; quoted by Syan 1994 p.12) reports that Boeing's Ballistic System Division achieved the following improvements after the CE implementation in the company:

- 16% to 46% in cost reduction in manufacturing.
- Engineering changes reduced from 15-20 to 1-2 drafts per drawing.
- Design analyses for the '-ilities' (e.g. design for manufacturability, etc.) cut from two weeks to less than one hour.
- Materials shortage reduced from 12% to 1%.
- Inspection costs cut by a factor of 3.

Graf (quoted by Badham et al. 2000 p.237) gives the following statistical data to show the benefits achieved after moving from the sequential to the concurrent approach:

Table 1.2. Benefits Obtained from Concurrent Engineering (Graf, 26; quoted by Badham et al. 2000 p.237)

Benefits and Metrics	Results
Decreased lead time	
Development time	30-70%
Time to market	20-90%
Improved quality	
Engineering changes	65-90% fewer
Scrap and rework	up to 75% less
Overall quality	200-600% higher
Reduced cost	
Productivity	20-110% higher
Return on assets	20-120% higher
Manufacturing costs	up to 40% lower

When examples in the US and Europe are analysed, it is clearly seen that especially the three major manufacturing areas, automotive, electronic and aerospace industries have implemented the Concurrent Engineering approach. Rosario et al. (2004 p.2) state that "the philosophy of Concurrent Engineering (CE) has shown great success in private industry, specifically in the automotive and technology industries."

Table 1.3. shows some 'success-cases' in the US and Europe and the remarkable impact of CE on the development lead time in these companies:

Table 1.3. Typical "Success-Cases" with Respect to a Short Time-to-Market (Source: Trygg 1993 p.405)

		Development lead time (months)		
Company	Product	Old	New	Reduction (%)
ABB [13]	Switching system	48	10	79
AT&T [9]	Phone	24	12	50
British Aerospace [17]	Airplane	36	18	50
Digital Equipment [14]	Personal computer	30	12	60
General Motors [25]	Engine	84	48	43
Goldstar [20]	Telephone system	18	9	50
Honeywell [1]	Thermostat	48	12	75
Hewlett-Packard [1]	Printer	54	22	59
IBM [23]	Personal computer	48	12	75
John Deere [35]	Construction equipment	NA	NA	60
Motorola [27]	Mobile-phone	36	7	81
Navistar [9]	Truck	60	30	50
Warner Electric [22]	Clutch-brake	36	9	75
Xerox [1]	Copier	60	24	60

2.6. The Impact of Concurrent Engineering on Product Quality

The benefits of Concurrent Engineering and its impacts on product quality have been discussed in both academia and industry, and it seems apparent that Concurrent Engineering helps to improve design and produce a better overall product life-cycle quality.

According to Reidsema and Szczerbicki (1998 p.730), effectively applying a CE design strategy to the design process should produce a significant benefit to the overall product development process by reducing the duration of the design project, reducing development costs, and improving product and process quality. Reidsema and Szczerbicki (1998 p.733) also argue that "the potential benefits of CE design are in the reduction of late changes necessitating re-design activity as well as an increase in product quality".

Ranky (1994 p.14) discusses the advantages of adopting the Concurrent Engineering Methodology and points out that it increases productivity and creates products that are high quality, reliable, less expensive and a reflection of the customer's requirements.

2.6.1. Concurrent Engineering at TOYOTA

As Figure 1.9. indicates clearly, Japanese organisations are able to produce products more efficiently but with higher quality than its western counterparts (WEB_5, 2006). This dominance, especially in the car industry has "set the terms of debate over how to produce automobiles efficiently and with high quality" (Kochan, Lansbury, & MacDuffie 1997 p.3). According to Barker (1994 p.87) Toyota's production system is "so robust that output quality is in the zero defect category".

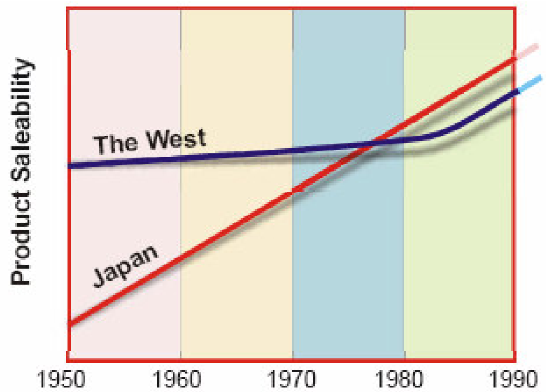

Figure 1.9. Competition in quality
(Source: Juran 1992 p.19; quoted in WEB_5)

The most recent explanation for the Japan's manufacturing competitive position has been in terms of flexibility and efficiency, and it is commonly known as 'Toyota Production System' (WEB_5, 2006).

Toyota Motor Corporation is one of the world's leading auto manufacturers. As Sobek and Ward (1996 p.1) put it, "Toyota consistently receives high, often best-in-class, quality ratings in Consumer Reports and JD Powers studies, continues to make cost reductions sufficient to maintain competitiveness, and maintains a high degree of model variety"; see Figure 2.0. It is a fact that Toyota is the industry leader in product development lead time while using many fewer engineers than its US competitors.

Figure 2.0. Toyota Yaris: European Car of the Year 2000
(Source: WEB_6, 2006)

Toyota follows *a different paradigm of design* than US or other Japanese companies, what is called 'set-based concurrent engineering' (Ward et al 1995). Sobek and Ward (1996 p.1) elaborate on this paradigm of design:

> Design participants practice set-based concurrent engineering (SBCE) by reasoning, developing, and communicating about sets of solutions in parallel and relatively independently. As the design progresses, they gradually narrow their respective sets of solutions based on additional information from development, testing, the customer, and other participants' sets. As they narrow, they commit to staying within the set(s), barring extreme circumstances, so that others can rely on their communication. This paradigm results in development practices that at first glance appear inefficient and wasteful—for example, developing large numbers of alternative design prototypes—but are logical when viewed in context. Since the initial study we have continued interviewing Toyota managers and engineers. Further study verified that the practices we learned about were not aberrations. We also learned about other practices that contribute to design process efficiency and create a environment conducive to set-based design.

From the early concept stages, Toyota designers think about sets of design alternatives, rather than pursuing one alternative iteratively. As can be seen in Figure 2.1., they gradually narrow the sets by eliminating inferior alternatives until they come to a final solution.

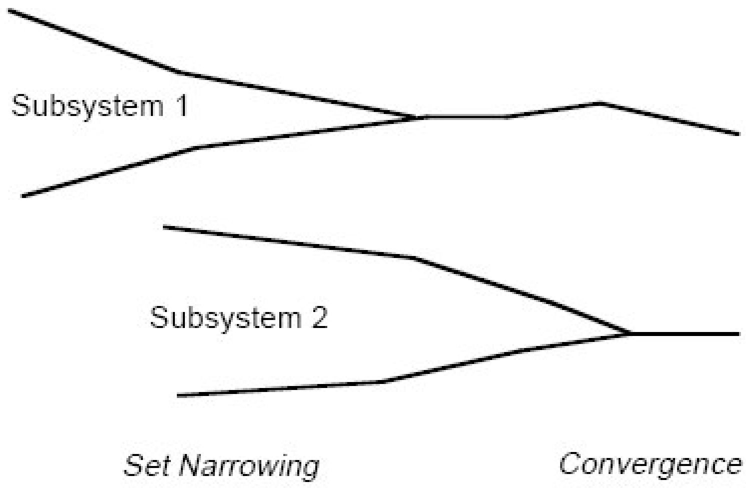

Figure 2.1. Set-Based Concurrent Engineering (Sobek and Ward 1996 p.1)

It is suggested that Toyota designers employ sets of design alternatives as a means of reducing the structural complexity and gaining a fuller understanding of the design problem. In addition, “multiple solutions help designers reduce design blindness or bias which comes from elaborating a single solution” (Papantonopoulos 2003). Design alternatives are generated by imposing a limited set of objectives or solution concepts or by professional expertise. Ward et al. (1995) report that Toyota designers make extensive use of "lessons learned" books to record lessons and define the space of manufacturable designs.

2.6.2. Concurrent Engineering at EUROPEAN SPACE AGENCY

The European Space Agency (ESA) performs some assessment studies as part of the definition of future space missions. Bandecchi et al. (2000 p.329) clarify the purpose of these studies by stating that they are to assess the feasibility of a new space mission from the technical, programmatic and economic points of view. They detail the routine procedures at the centre in that:

> This is normally achieved by producing a preliminary conceptual design of the mission and space system. The study results are used to support the mission selection process. If the mission is accepted the study report is used as an input to the industrial Phase-A design studies.

To evaluate the benefits of the Concurrent Engineering (CE) approach to these studies an experimental design facility was created in the ESA Research and Technology Centre (ESTEC) at the end of 1998 and used to perform the assessment of several missions. The main objectives of ESA can be summarized as:

1) create an experimental mission design environment (referred to as Concurrent Design Facility, or CDF) in which the conceptual design of space missions could be performed in a more effective way

2) apply the practice of CE to a number of test cases to identify the potential of such an approach in the various phases of space-mission development

3) gather the information needed to evaluate the resources required to create a permanent facility available to all programmes.

The key elements on which the CDF implementation has been based are a process, a multidisciplinary team, an integrated design model, a facility, and an infrastructure.

The team of specialists who had to accept to use a new method of working, co-operate and contribute to the team spirit, meets in the Concurrent Design Facility (CDF) to conduct design sessions. After about one year of successful activity and 10 studies performed in the initial experimental facility, a new and permanent facility has been built at ESTEC. As illustrated in Figure 2.2., the accommodation comprises a design room, plus a meeting room and project-support office space (Bandecchi et al. 2000 p.331).

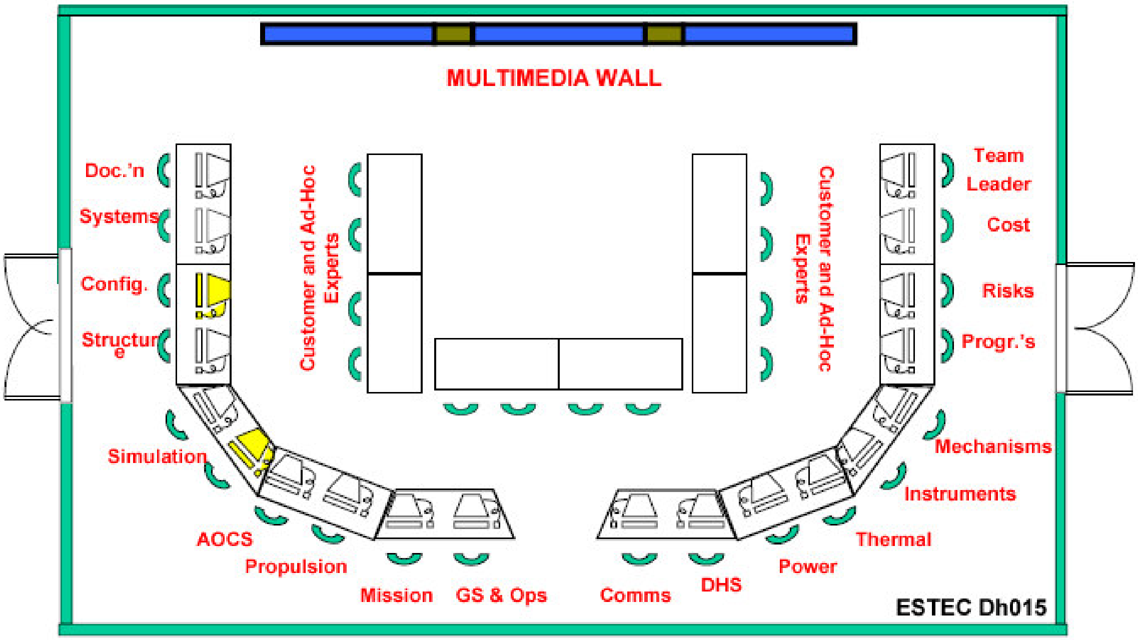

Figure 2.2. The meeting room at ESTEC
(Source: Bandecchi et al. 2000 p.331)

Since the start of the project a number of missions have been accomplished and these can be listed as follows (Bandecchi 2001):

- CESAR99
- Solar Orbiter
- Meteo Imager Sounder Satellite - MISS
- World Space Observatory - WSO/UV
- Mercury Surface Element - MeSE
- Eddington
- MASTER
- STORMS
- Hyper
- Ocean Earth Watch

According to Bandecchi et al.(2000 p.331), the result of the studies have been satisfactory and the assessment studies performed in the CDF have shown the benefits of centralising system engineering tools as part of an integrated facility. In fact they have also identified further opportunities where the concurrent engineering approach can be very beneficial by ensuring consistent engineering methods and standards and the efficient use of the manpower.

CHAPTER 3

A CASE STUDY IN TEBA-GUNKOL

3.1. Some Brief Information about the Company

Teba Group, a family-owned business group based in Izmir, is largely owned by Mr. Teoman Baygan, the founder, and his family members. Gunkol is a profitable white goods manufacturing company of the Teba Group. Gunkol has exported cooking ranges and ovens to over 80 countries since the 1980s and is Turkey's leading cooking appliances exporter with 85-90% of its revenues in hard currency. Gunkol is owned 44.2% by Mr. Baygan, 29% by Tema A.S., a distribution and marketing company of the Teba Group, 26.5% by Ente A.S., an air-conditioner manufacturing company of the Teba Group and 0.5% by other individuals. (WEB_8, 2005).

3.2. An Analysis of the Current Situation

3.2.1. Stages of Design and Manufacturing Processes

It is possible to mention five basic phases of the new product development process in the company:

1. Getting a demand for a design
2. Main design process
3. Receiving an order for a product
4. Evaluation process
5. Preparing a declaration form and starting production

3.2.1.1. Getting a Demand for a Design

As soon as TEMA gets a demand for a design, it passes it either to the ÜTG manager or directly to the relevant departments. If the latter way is preferred, then TEMA immediately contacts the relevant departments to have them carry out a feasibility study. If the target product works with electricity, it is MT which is asked to conduct an initial check on its feasibility. If it works with gas, GAZ is required to carry out the same task. If both gas and electricity are used to run the target product, then MT cooperates with GAZ to accomplish the required task. If the former way is chosen then the ÜTG manager passes this request to the relevant departments so that they can check whether the demand is feasible. The ÜTG manager, having analysed the opinions of the departments, lets TEMA know about the final decision. If the target product is likely to be designed and produced, TEMA is asked to give a written report about the standards required for the target product on the market, an estimated market share of the target product and the demand quantity. Considering that information, MT starts the main study of feasibility. During this study, an exchange of information is made between the relevant departments. Prototype and laboratory tests are also carried out.

Results of this study are forwarded to the ÜTG manager for approval. If it is agreed to start manufacturing, MT prepares a form of project details. Upon the approval, the main design process starts.

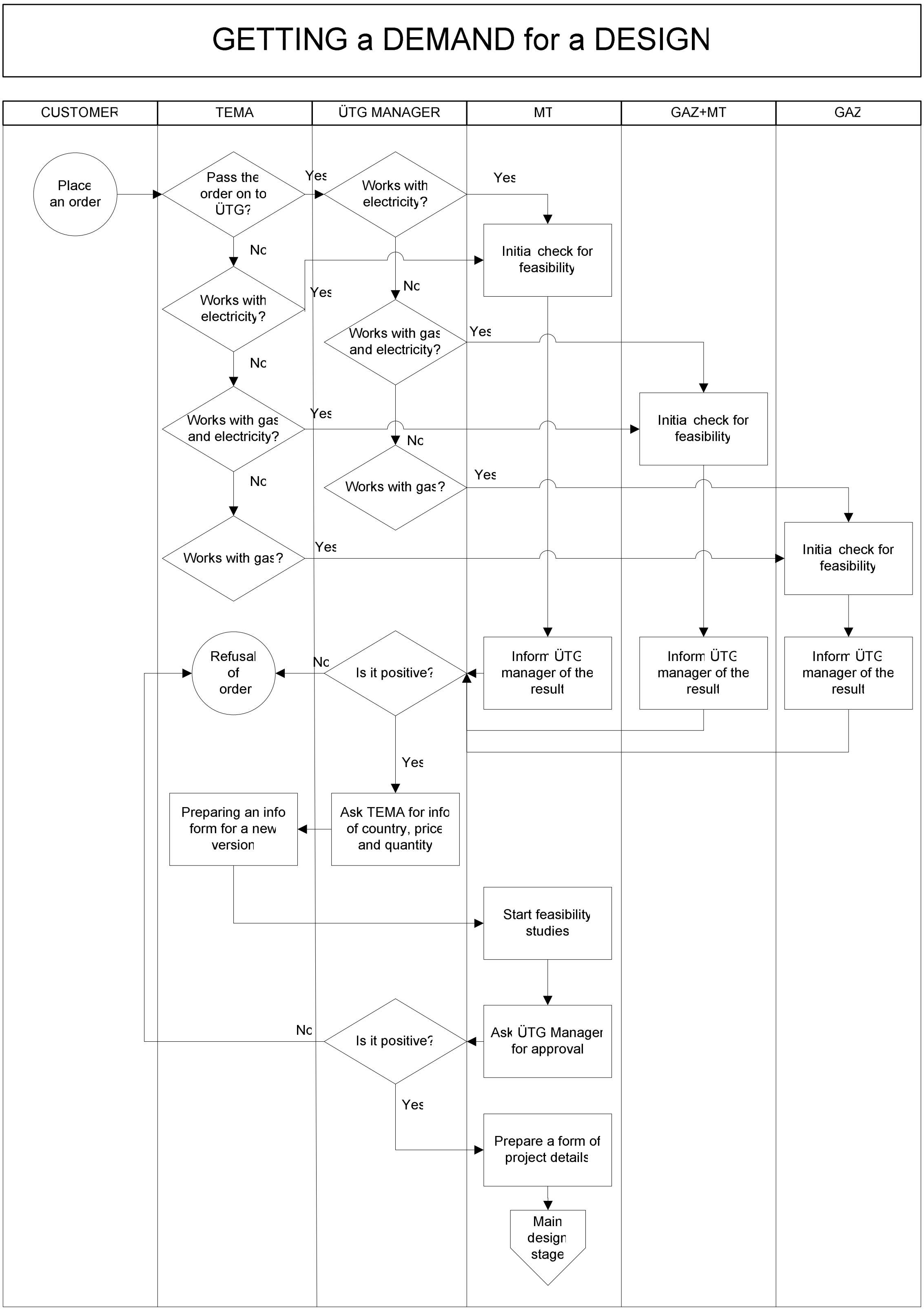

Figure 2.3. Getting a demand for a design

3.2.1.2. Main Design Process

At this stage, firstly, a project file is made available by MT to keep the documents to be prepared throughout the design process.

By using a similar product as a basis for production, a draft list of the product parts is made. New parts are added to the list and the parts to be modified are determined. Having made some preliminary sketches and technical drawings, they start producing prototypes of these parts. Prototypes of the target product which have been made up of new prototype parts are put to validation tests in ET and/or GAZ labs. Meanwhile, MT carries out some packaging tests. After that, they start a new stage where a request is made for samples of the parts which have passed the validation tests. This stage is divided into three sub-stages:

1. SAT (purchasing department) or design departments ask a supplier company for samples of materials needed,
2. MT asks MET for a new apparatus if needed,
3. Upon receiving the approval of the General Manager of the moulding department, a request for samples of the parts to be moulded is passed to KAM. If samples of the parts are to be brought from outside the company, the request is sent to SAT or YAN.

Parts which do not need to be officially approved are designed by MT and are produced by relevant departments and put to some quantity control and sample analysis tests. Either the parts themselves which are newly added or their technical drawings are sent to an organization for standardization to get an official approval. According to the sample approval procedure ÜDM gives code numbers to the approved parts considered to comply with standards and then they are introduced to the system and non-finalized product trees are formed.

Those parts which have just been introduced to the system are mounted to the target product and the target product with the new parts is sent to “Designing Validation Tests”. During this stage, only if it is thought that some problems may arise in manufacturing then a test-production is carried out which actually happens rather rarely.

All these activities that take place at the main design stage are so inter-related that they almost never follow each other in the same order.

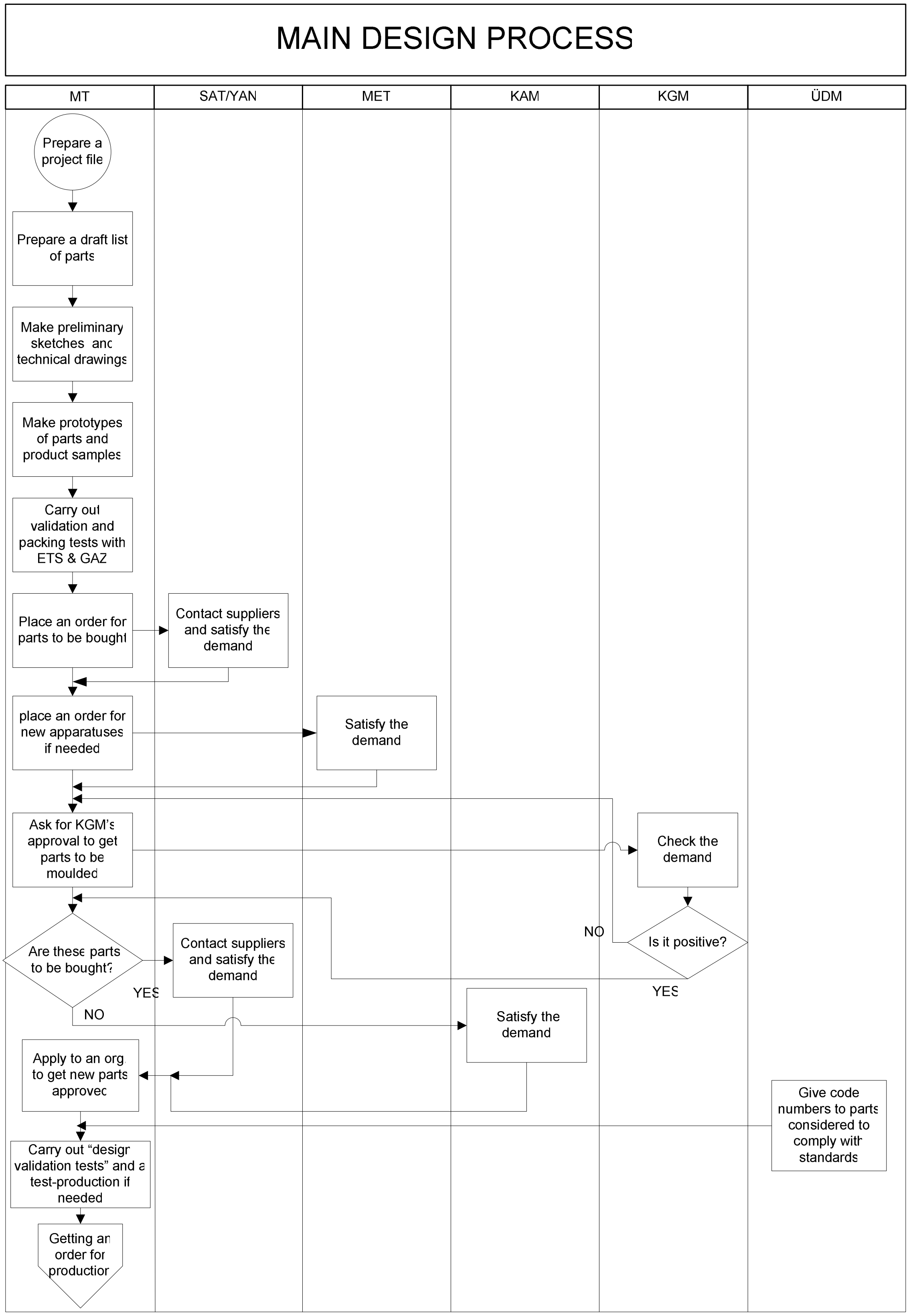

Figure 2.4. Main design process

3.2.1.3. Receiving an Order for a Product

After The Main Design Stage has been accomplished or when it is clear that there is nothing to prevent getting an order, then TEMA, having filled in a form of order + version requirement, sends it to a person in charge of products (ÜS) in ÜDM. By this way, the stage of placing an order officially starts. If there is any wrong or incomplete information in the form, (ÜS) corrects it cooperating with TEMA. To make it clear whether the production stage can meet the deadline mentioned in the form ÜS contacts GAZ, MT, ETS and GRF. ÜS gives the product a new code and sends the code to TEMA and ÜPK.

TEMA, with the new product code, places an order with ÜPK. Meanwhile, ÜS starts forming the product tree and ÜPK starts planning for each part on the tree.

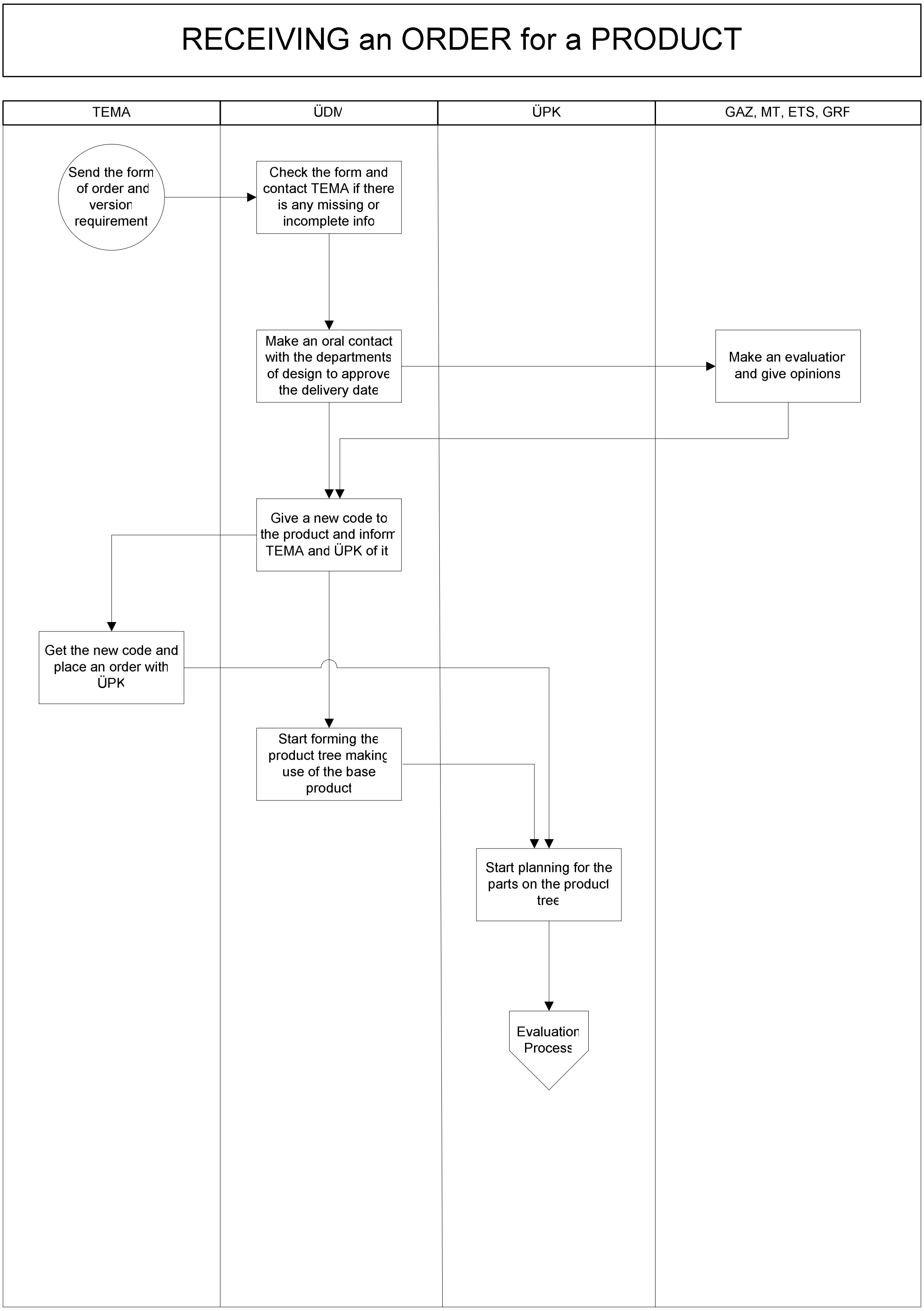

Figure 2.5. Receiving an order for a product

3.2.1.4. Evaluation Process

As can be seen in the appendix, the form of version requirement order and the form of version evaluation merge together in one single form. ÜS sends a product evaluation form to relevant departments to have them note down their detailed analyses made by taking into account the parts that are hardly available. During the evaluation stage:

*GAZ contacts MT to discuss some issues like technical drawings and the differences between the information about samples of the parts mentioned in the form and the estimated order. GAZ also contacts MT and KAM about parts to be moulded.

*MT fills in the evaluation form with all the necessary information about the current state of the new version, the date when it could be produced and the delivery date of the parts. MT prepares some extra documents if, considering the information in the form, it is thought that they are necessary.

*GRF, by contacting TEMA, finds out whether or not the information related to logos, packaging and imprinted documents has been changed by the customer. If needed, it sends some standard samples to the customer. Considering the information in the evaluation form, it revises some documents.

*ETS's task begins right at this point. Considering the evaluation form, ETS places an order with SAT and YAN for samples of new parts. As soon as the incoming samples get an approval, they are given their code numbers by ETS if they work with electricity. New parts are introduced to the other departments (SAT, ÜPK, KAL). ETS prepares a new list of materials, a tree of cables and an electrical scheme. Then it adds all of these to the form.

ETS and GRF start dealing with their tasks just after receiving the evaluation form. When they finish their evaluations, they send the form to the ÜS.

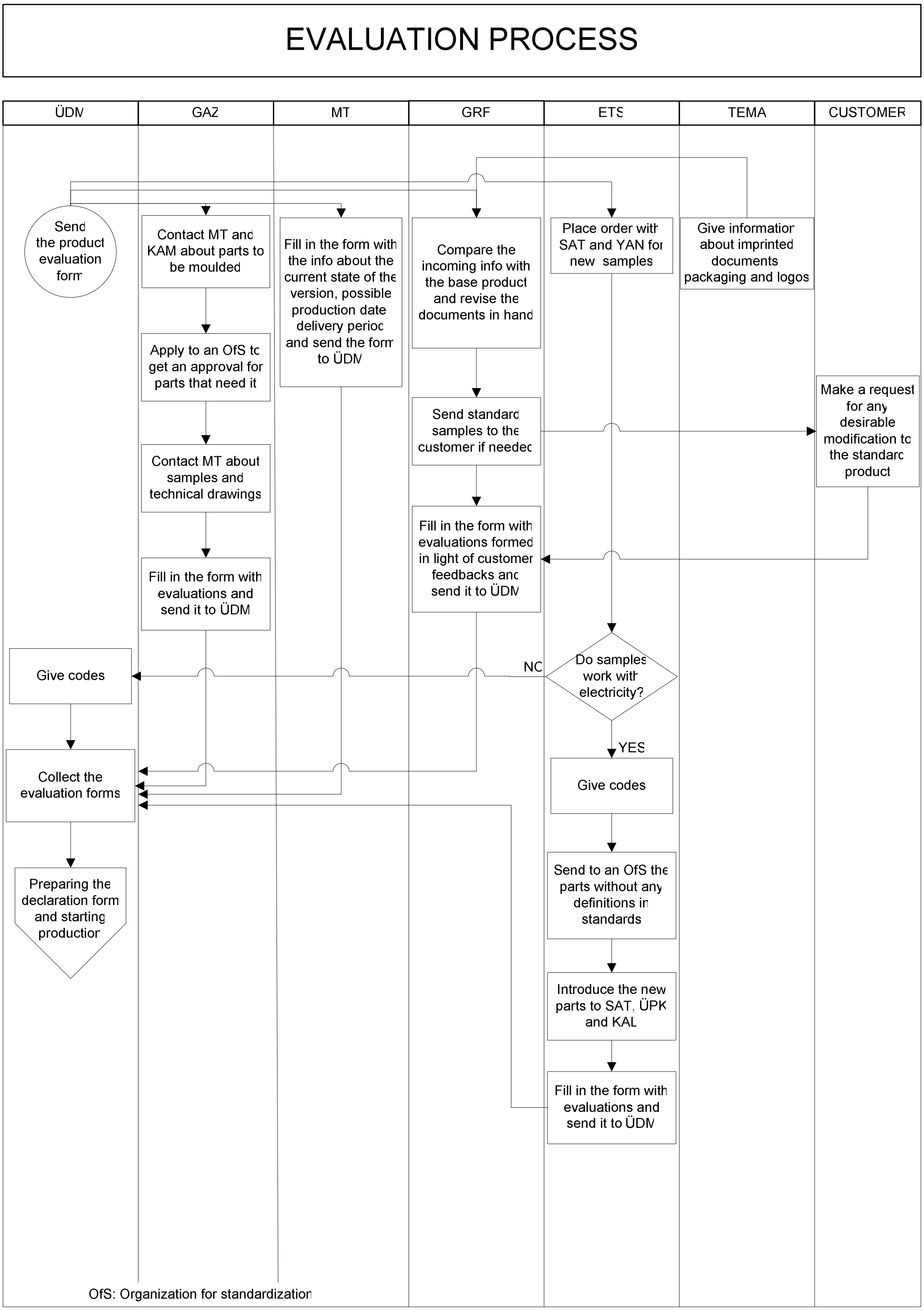

Figure 2.6. Evaluation process

3.2.1.5. Preparing a Declaration Form and Starting Production

Having checked all the evaluations and gathered together all notes and warnings in the same form, ÜS sends it to TEMA so that it can be double-checked there. The ÜS adds the information mentioned in the form sent back by TEMA to the product tree. The ÜS sends this form with attached evaluations to another ÜS as a declaration. The other ÜS is supposed to check the form and approve it if everything is appropriate with it.

The ÜS who has the authority to approve checks the current stage of product development and the product tree and adds his/her warnings onto the form. The approved declaration form is sent to MT, ETS, GAZ, GRF, TEMA, ÜPK, KAL and to the general manager. The ÜS follows the revisions of production planning and collects information about the product. If the information coming from the related departments says that there are some newly added parts, then ÜDM adds them to the product tree with their code numbers.

The declaration form is a stand-alone indication saying that there is nothing else to prevent starting production as to the aspect of design.

GRF starts carrying out its tasks right after the arrival of the declaration form. GRF prepares things like labels, packaging and user manuals. GRF checks if the product is scheduled to be manufactured and if it is so, then GRF starts working according to the schedule. It forms the product tree studying the base product. It gives code numbers to new parts and documents. Meanwhile, it tries to finish incomplete documents related to user guides, logos and packaging working in cooperation with TEMA. If there are some changes in the manual regarding the functions of the product, GRF asks for information from the related departments (TES, GAZ, MT). Then, it finalizes the serigraphy work and sends it to the atelier.

If the customer mentions another code number in the declaration form, then GAZ sends an identity declaration to the Organization for Standardization saying that those two code numbers represent the same product. It passes onto GRF all the information of the version coming from the Organization for Standardization.

MT, GAZ, ETS, GRF and the ÜS normally finalize the product tree and then they become ready to start production.

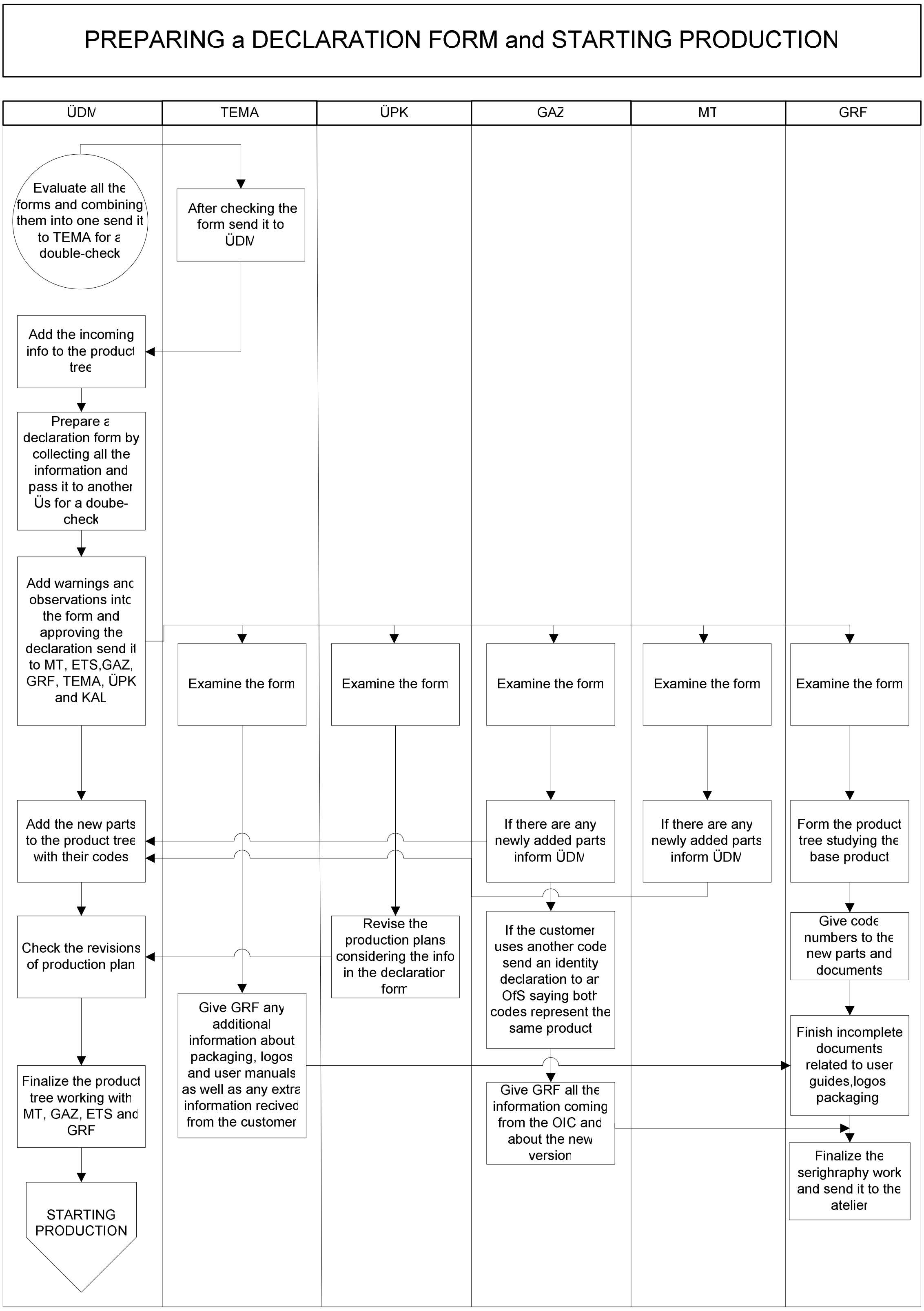

Figure 2.7. Preparing a declaration form and starting production

3.2.2. An Analysis of the Defects of the Current Situation

1. The task of making a study of the target market and customer expectations is carried out by TEMA. When it is planned to enter a new market or to start marketing a new product in the current market, TEMA asks the ÜTG manager and relevant departments if it is possible to do that. This process causes a waste of time as there is a great deal of unnecessary paper traffic between the ÜTG manager, other departments and TEMA.
2. As soon as there is a demand made orally, only MT and GAZ decide if it is possible to satisfy the demand and they do not consult ETS even if the product in demand is an electrical one.
3. While passing the written information about the product on to design departments TEMA has difficulty informing them of the technical features that the customer wants the product to have. This is usually because TEMA does not have enough technical knowledge and it causes either unnecessary studies of feasibility or some differences between the product in mind and the final product.

For instance, before starting the design of a cheaper version of an oven, namely TFU, TEMA announced that a standard oven must be the size of 50x50. At the end of a feasibility study, a design of the size 50x50 was considered impossible but TEMA insisted on what it had said before. After months, someone from MT accidentally found out that for cheaper versions of ovens abroad there is not a limitation imposed on their size standards.

4. Feasibility studies are carried out only by MT although they must be conducted by all the departments in cooperation with one another.
5. During the feasibility stage the cost of new parts is added to the overall product cost and an estimate of “a product target cost” is calculated and project costs are not taken into account. Considering market movements, a margin is added to the product target cost and then it is possible to calculate the product price. However, unlike the procedure suggested above, calculations are made so inattentively that some unexpected profits or losses are seen after sales.

6. Just because the project details form is solely formed by MT, there are always delays in following the schedule; so, in practice this form does not work thoroughly.

7. During the main design stage, those who work in the department of prototype making (PRN) usually do not have enough knowledge of both the target product and how urgent it is. That's why there are usually long delays and defects.

8. SAT, as it does not have enough information of the design process, can not supply samples of new parts on time and usually they are not of the desired quality. In order to get the new part on time, MT, ETS and GAZ establish a direct contact with the supplier company and meanwhile costs are disregarded.

9. When an apparatus is required by ÜTG, there arise some problems between the Method Process Department (MET) and the design departments:

- When ÜTG gives up its request for an apparatus, there is a loss of time and it usually causes unnecessary trouble.
- Some so-called "urgent apparatuses" are used months later.
- It is not definite when ÜTG will require an apparatus.
- When there is an engineering modification to the target product, MET is not given enough information of it and when the production stage begins, MET finds out that it is necessary to change some apparatuses as the product in mind has been modified but sometimes it may be too late for this change.
- Before an apparatus request is made, MET is not consulted about it. For this reason, even if it is impossible to make the apparatus, MET has the obligation to carry out this task.

10. As ÜSs are unaware of what type of a design study is being carried out they sometimes add wrong part to the product tree.

11. Sometimes, sample products cause trouble although their prototypes have been satisfactory. One of the causes of this problem is that technical drawings of the mould to be made are not controlled by MT and KAM together.

12. Design tasks may take longer than planned and they may exceed the deadlines in the project details form and that's why a written order for the product is likely to be received at any time during the design process, which also causes trouble.

13. As there may be incomplete or wrong information in the version requirement form given to GÜNKOL, a great many extra meetings are needed between TEMA and the departments at different stages of the process to complete the missing information.

14. ETS can be involved in design tasks only at the evaluation stage.

15. ÜPK makes a production plan with regard to the delivery date approved by ÜTG and announced by TEMA. However, ÜPK is sometimes not aware of possible delays in the designing of the product as its communication with ÜTG is rather poor.

16. ÜPK is not involved in the design tasks and consequently has difficulty adding new parts to the product tree.

17. GRF starts its work of design only after getting the declaration form. Once, for instance, at the last stage of the design process, GRF was asked to do serighraphy on some buttons; however, results were not satisfactory. The only reason of this was the fact that during the design of buttons the other departments did not work in cooperation with GRF.

3.3. A Suggestion for a New System

3.3.1. Suggested Changes to Design and Manufacturing Processes

In the previous section, we have dealt with a design process for a new version. In this section, the same process will be examined in the light of Concurrent Engineering and a suggestion for a new system will be made. There are four stages in the suggested system:

1. Receiving an order for a design,
2. Carrying out feasibility studies,
3. Main design process, and
4. Getting a product order and starting production.

In order to carry out all these tasks it is necessary to form some teams that are flexible enough to adapt to the needs of different stages. What should be prioritized during the working of these teams is a close contact and cooperation between team members and developing the ability of taking decisions unanimously is paramount. A design team must be given enough freedom, authority and budget to carry out all tasks effectively. To limit the scope of any decisions to be taken by the team it is the team leader's duty to clarify all the restrictions on project targets, budgets and design activities.

3.3.1.1. Receiving an Order for a Design

Having completed a market research, TEMA makes a written request for a new design from the ÜTG manager. The request conveys some information of the target market, an approximate selling price of the target product in that market and an estimated annual selling amount.

ÜTG manager examines the written request and calls on the core team to have a meeting.

Autonomy is a must for all the teams in the suggested system. Top management should take part in revising project studies but leave the authority for decision making to the teams.

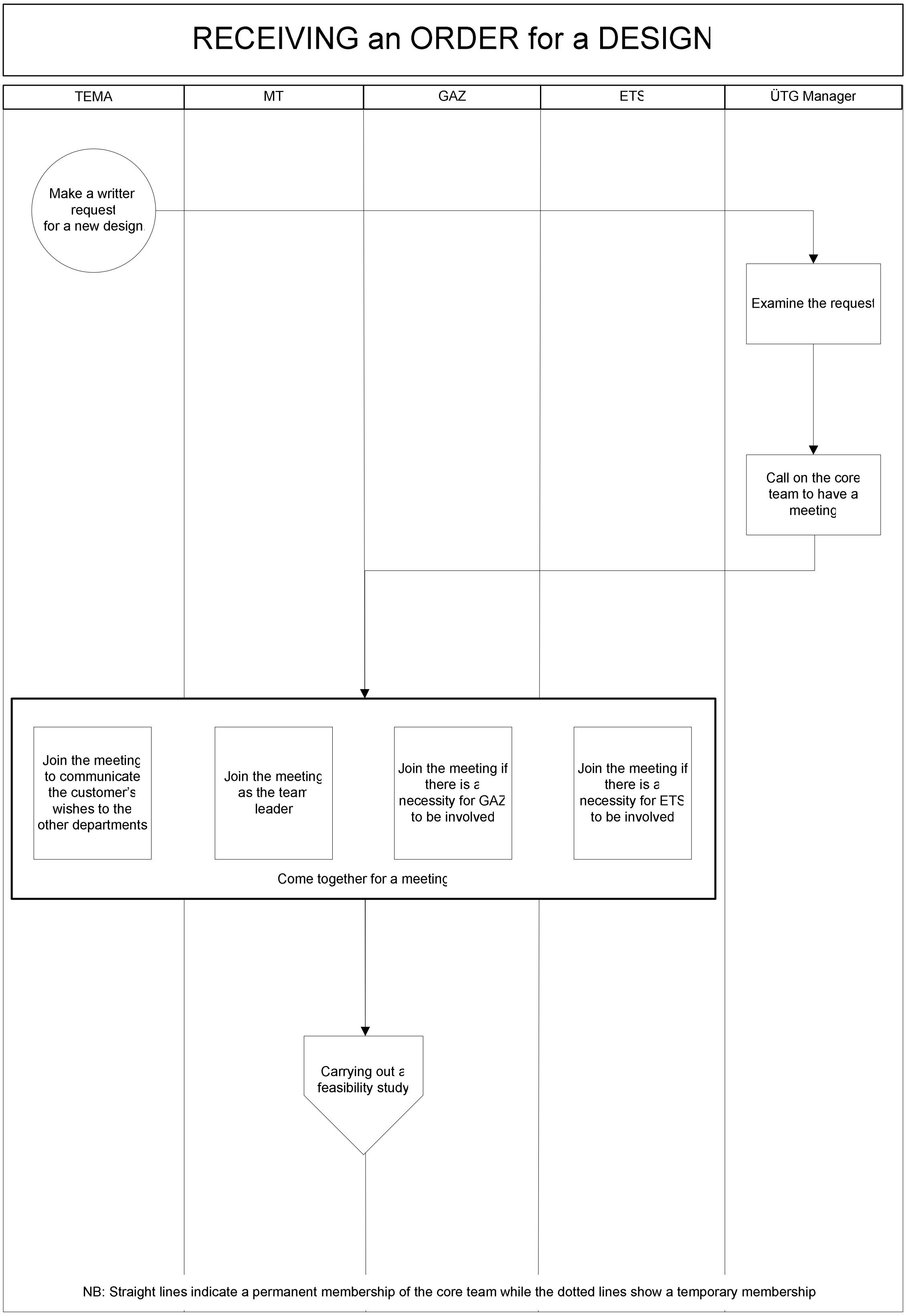

Figure 2.8. Receiving an order for a design

3.3.1.2. Carrying Out a Feasibility Study

This process starts with the meeting of the core team members. In the core team are MT, a TEMA representative and either GAZ or ETS or sometimes both depending upon the product type.

TEMA participates in the meetings to communicate the customer's wishes to the other departments. At this stage MT is supposed to be the team leader; yet, it does not mean that MT has authority over the others in terms of giving orders. Having full control on the subject and ability to motivate others are the qualities that a leader should have in the suggested system.

ÜTG manager asks the core team to write a feasibility report. To be able to write a satisfactory report TEMA has to clear up any misunderstanding over the customer's expectations and remind the others to comply with the national and international standards. During discussions TEMA is supposed to act on behalf of the customer. Meanwhile, the other members of the core team have to analyze the technical features of competing products on the market. They are to discuss the changes of production as to the target product's mechanical, electrical and gas design. They are supposed to determine an estimated completion period for production and clarify the actions necessary to be carried out for the new design.

The second phase in the feasibility process has the aim of determining a target cost for the target product and a total project cost. During this phase, MT is expected to contact KAM if a new mould is needed or contact MET if the production technology needs to be adapted or some modifications to the apparatuses are essential. MT has to analyze the parts of the base product and contact YAN and ÜPK to determine an estimated cost for the new parts and a cost for the side industrial activities. GAZ or/and ETS must determine an estimated cost for the parts relevant to their fields. When it comes to TEMA, if needed, they contact the customer in order to reduce the target cost.

At the end of the feasibility study, a feasibility report is submitted to the ÜTG manager. The core team compares the calculated cost and the market price considering annual sales. If the outcome of the comparison indicates that the target product is worth being manufactured, the main design process for the target product begins.

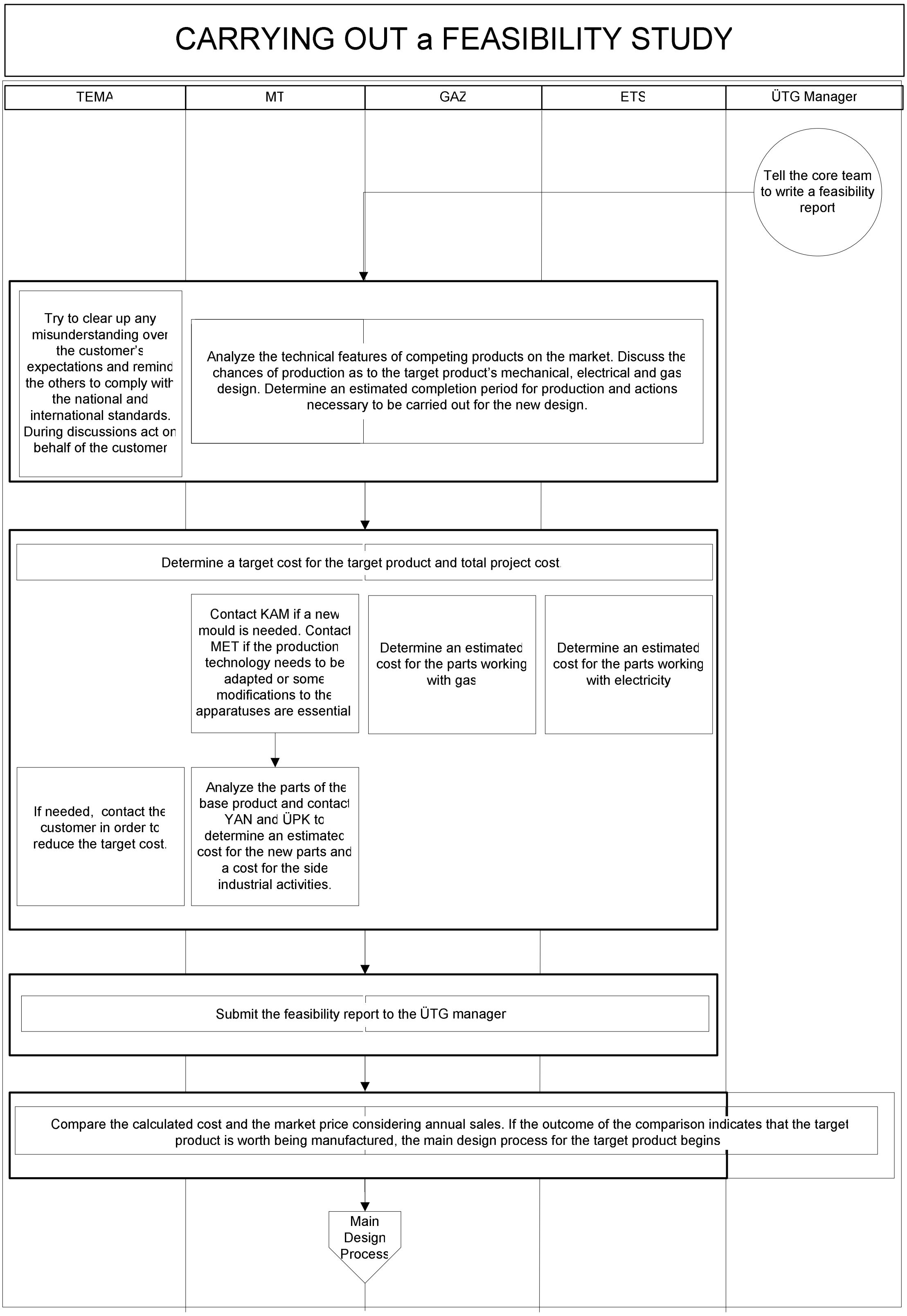

Figure 2.9. Carrying out a feasibility study

3.3.1.3. Main Design Process

MT informs the relevant departments about the outcome of the feasibility study and calls for a meeting to start the main design process. The team to carry out the design process is called "the main team" and among its members are TEMA, MT, ETS, GAZ, GRF, ÜS, PRN, KAM, KAL, MET, ÜPK, ÜRT, MAL, and SAT.

The main reason why all these departments join the team is to enable engineering, manufacturing and marketing departments to function together at different stages of the product design and to prevent contrasting points of view from arising between members. Moreover, through this system, time for passing on the necessary information to the other members is minimized. As a result of this, all the tasks can be initiated in a minimum period of time.

At the beginning of the meeting, MT informs the participants of previous studies in detail. Participants consider all the important factors such as cost, product's availability, technical support, customer's expectations and competing products in the market and they categorize all the activities to be conducted as to their interdependency. They also determine the project steps and form a project schedule indicating all the activities to carry out, time-scales, time-limits and the staff to be in charge. This information is published in a common database and updated continually.

In order to form a project schedule, firstly, tasks and people to carry out those tasks have to be determined and then to have these activities coordinated the questions below should be answered and considered:

1. Is there any interdependency between activities?
2. How can an activity supply information to have another activity start?
3. Are there enough specialists for each activity?
4. Is an activity in a critical condition?

As a result of these studies activities can be grouped into three categories:

1. Activities that are fully inter-dependent: One cannot be initiated before another has completed. These are called "sequential processes".

2. Activities that are partially inter-dependent: Information received after completing a part of an activity is enough to initiate another. These are called “activities in parallel”.

3. Independent activities: These activities can be started at the same time and they are called “concurrent activities”.

This schedule must be published in a common database and updated continually. The main team has to meet:

1. before starting a prototype,
2. after finishing a prototype,
3. before a trial run,
4. after a trial run,
5. at any critical time.

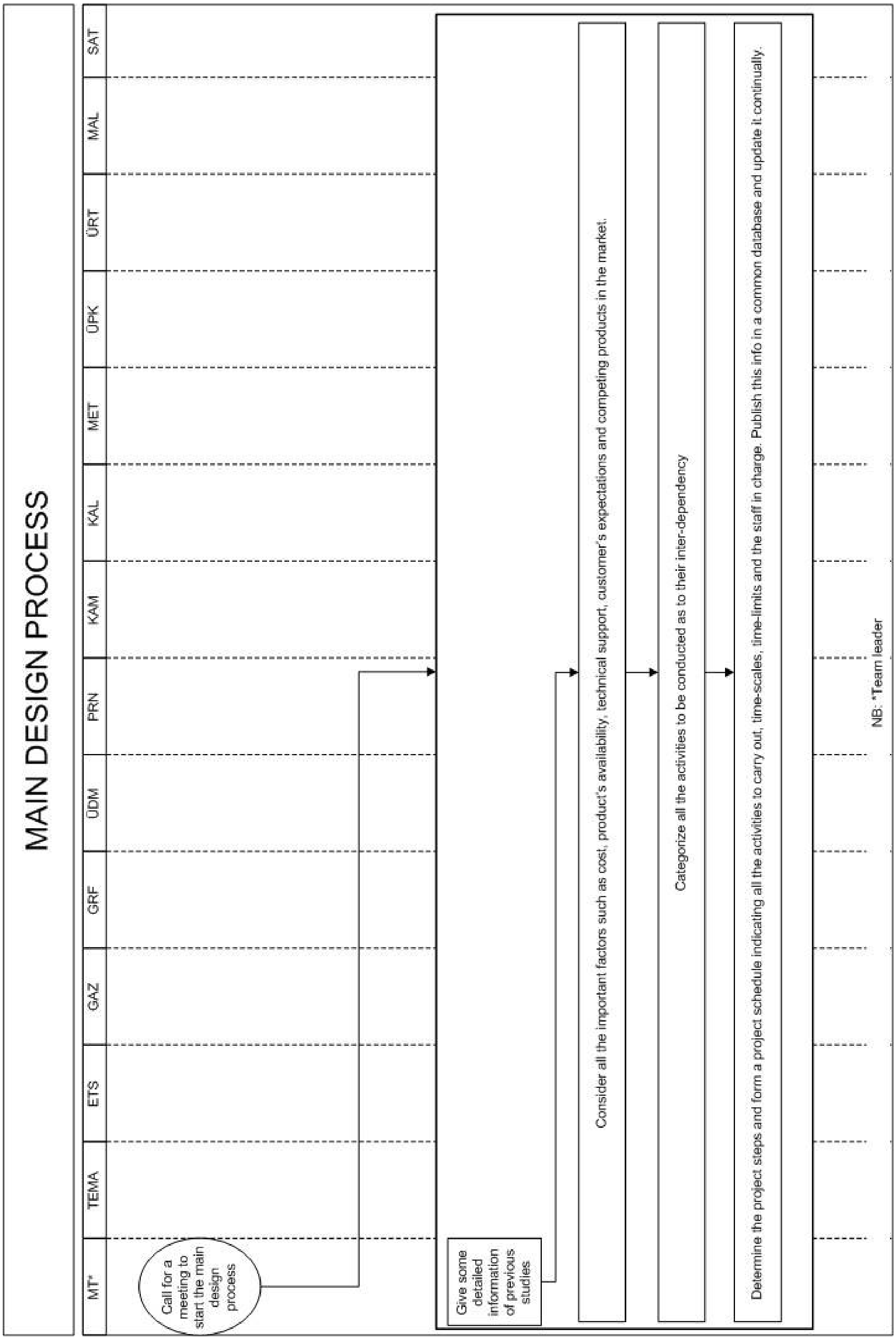

Figure 3.0. Main design process

3.3.1.4. Receiving a Product Order and Starting Production

TEMA passes on the form of order and requirement for a new version to ÜDM. At this stage, ÜDM takes over as team leader because the heaviest load of work falls on that department. Sending the requirement form to the relevant departments, ÜDM calls on the evaluation team to have a meeting. The evaluation team has these departments as its members: ÜDM, MT, ETS, GAZ, GRF, TEMA and ÜPK.

In the suggested system a product order is received only after getting over the most difficult problems and accomplishing the design process. That's why it is natural for the team members to come together only once except for extreme situations. As the design tasks are carried out by the main team and the evaluation team is a sub-group of the main team all the participants in the meeting will have enough information about the product.

Team members check the current state of the project and finish any incomplete tasks. They fix an "Earliest-as possible-Production Date" (EapPD).

The "EapPD" enters the system and it is the responsibility of ÜDM to update it whenever necessary. ÜPK uses the EapPD as a basis for some version products whose production dates have not been fixed yet and no production date is scheduled before the EapPD.

ÜS, ETS, GRF, GAZ and MT, altogether, finalize the product tree upon getting all the information related to the product tree. The evaluation team supervises first production to see if it is conducted in accordance with the determined principles.

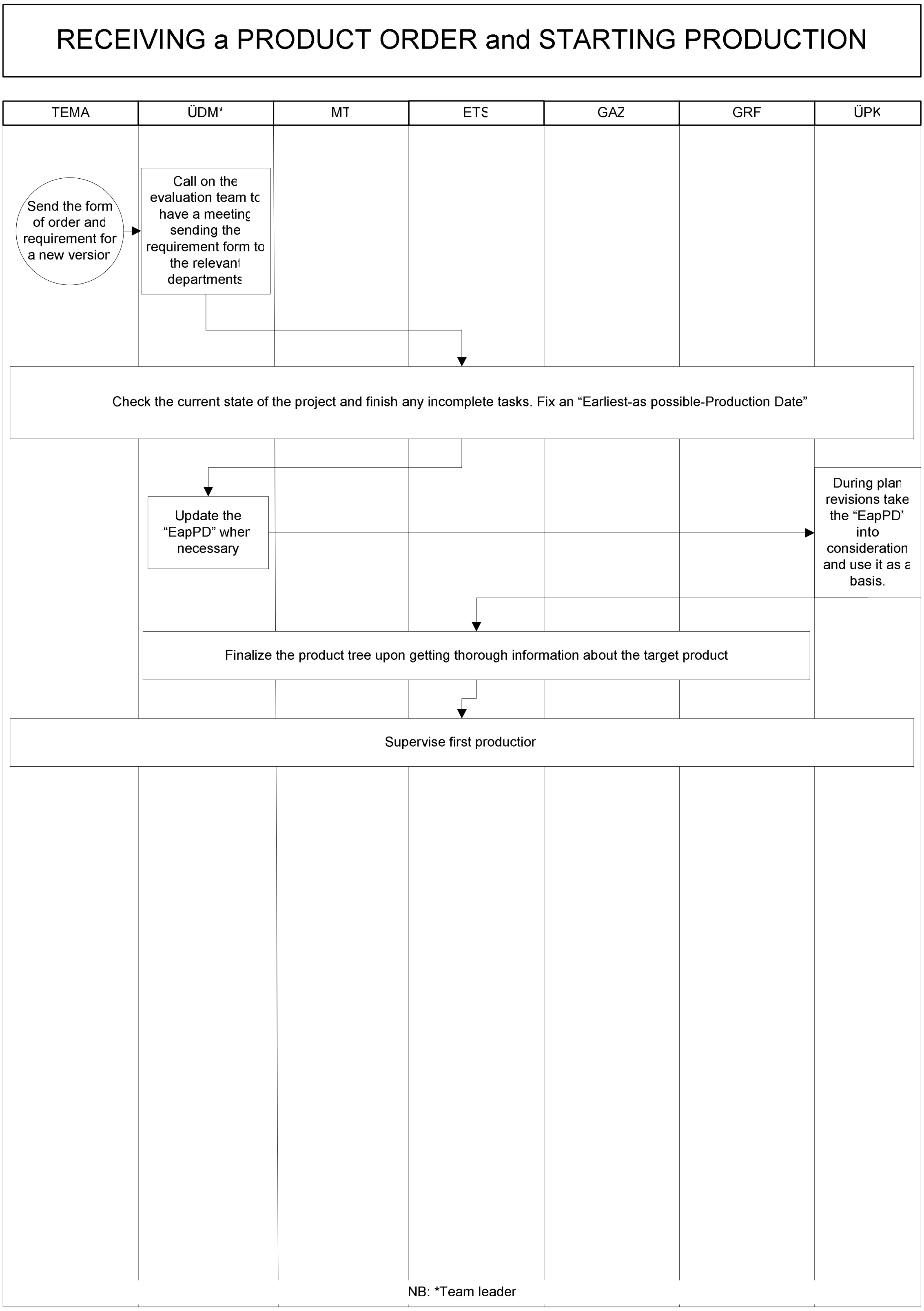

Figure 3.1. Receiving a product order and starting production

3.4. Observations about some Problematic Design-Related Activities and Suggested Techniques to Handle Them

During the case study carried out in TEBA-GÜNKOL, some problems related to the new product development (NPD) process of the company were observed. The following is a summary which indicates some specific problems observed in the company and suggested solutions based on the CE methodology together with the possible impacts of the suggested approach. While the problems are listed in the first column of the summary, in the second column some solutions are put forward. It is the third column where the expected effects of the suggested approach can be found.

Table 1.4. Some problems observed in the investigated company and suggestions

Some Problems Observed in Design and Manufacturing Processes in TEBA and a CE Approach Suggested to Effectively Handle These Problems

Current state of NPD	Suggested CE approach	Likely impacts
Due to the fact that TEMA is lacking in technical knowledge ÜTG is usually misled by TEMA and this causes a loss of time.	*The key ingredient in successful Concurrent Engineering is teamwork, and multifunctional teams are the most effective way known to cut through barriers to a good design. In these teams, representatives of many functions collaborate during the development project's life cycle, to ensure that it reflects customers' needs and desires, as well as the restrictions and possibilities of the manufacturing process (Trygg 1993:409)* What we suggest here is that TEMA should work together with engineering, manufacturing and purchasing departments from the outset to anticipate problems and bottlenecks and eliminate them at an early stage, in order to avoid delays in bringing the product to market and costly failures in service	TEMA will get so familiar with the technical aspects of products that it will be able to formally pass a fully correct request in a very short period of time
The marketing personnel in TEMA, who have been grouped as to the countries they work with, always consult ÜTG about any product concept as they hardly have any knowledge of new products and it causes a lot of emailing and telephone calls between TEMA and the design departments, which eventually results in a loss of time		From the very beginning of the design process, it will be possible to translate customers' wishes into the engineering jargon.
At the stage of receiving a demand from customers, a "version-request form" is handed to GÜNKOL and the form is usually full of incomplete or wrong information and to complete the missing information in the form it is necessary to have a number of extra meetings between TEMA and the other departments at the following stages.		TEMA will be able to better inform customers of the current state of products since it will have more technical knowledge and awareness of the design process.
During feasibility studies, MT does not always take all possible costs into account and for this reason the total cost at the last stage is usually figured differently.	*In efficient product development, early phases of the product development process play an important role. A feasibility study should be performed in order to define future product development needs and how they can be met. It should be a "convergent" process of a generation and reduction of concepts (Pugh 90; quoted by Ritzen, 1997).* We suggest that, in order to prevent any possible problem that may arise due to inaccurate feasibility studies, all the relevant departments should be involved in the process in the earliest phases and exchange information working in a team.	Feasibility studies will be more realistically conducted through teamwork. All costs will be recorded by contacting all the relevant departments.
It is the marketing department's duty to carry out market research and it tries to perform this task using its limited technical background and from time to time it causes design departments to lose time		During market research, MT, GAZ and ETS will share their technical knowledge with the other members of the core team while TEMA informs the team members about customers' characteristics and likes

(Cont.on next page)

Table 1.4. (Cont.)

Some Problems Observed in Design and Manufacturing Processes in TEBA and a CE Approach Suggested to Effectively Handle These Problems		
Current state of NPD	**Suggested CE approach**	**Likely impacts**
MT, alone, prepares a form of project details and this individually performed task usually causes a difference between the estimated project times and the actual ones. It is a fact that the departments which, one way or another, affect the way the design process proceeds are unaware of when they should get involved in the project and what they should really do. It is even possible that they might not have been informed about the initiation of a new design process in the company. ÜPK has difficulty making continual revisions to production and plans and, from time to time, before the design process has been accomplished the production stage can be started	*"Concurrent engineering is intended to cause the developers, from the outset, to consider all elements of the product life from conception through disposal including quality, cost* ***schedule*** *and user requirement." (Haque, 2004:191; quoted in WEB_9)* With regard to this problem we suggest that it should be paid enough attention to time management and "pacing" management i.e. the rhythms established along the product development process	Time allocated for information exchange will be minimized. A department will be able to get involved in the project on its own initiative as long as the involvement takes place according to plan. It will be possible to minimize the time allocated for the initiation of any task Through a shared database which is regularly updated, each relevant department will be able to access data about the project phases and their deadlines whenever necessary. ÜPK will be able to make a better pacing for production and ÜDM and GRF will get rid of the obligation to follow the revisions made by ÜPK.
One of the major problems observed in the company is 'departmentalization' which inhibits cross-functional communication and cooperation; and, the other is 'sequentialism' where each department completes its work before handing this 'over the wall' to another department. The purchasing department cannot supply samples for new products because it is not given timely information of new design development jobs and this causes design departments to contact suppliers on their own, which results in a kind of secondment from their primary duties	*Cross-functional teams are a tool that has been successful in the NPD processes (Norell, 1992; quoted in WEB_1).* *The two ideas that are central to the CE philosophy are "integration," to counter the disintegrating effects of compartmentalization, and "concurrence" (or simultaneity), to replace the relay race with the project equivalent of a team game like rugby (Takeuchi & Nonaka, 1986; quoted by Badham et al 2000).* What we suggest here is that all the departments should work simultaneously from the beginning to the end and team spirit should be encouraged.	There will be better teamwork and all departments will be sharing in responsibilities Departments will be prevented from adopting contradictory opinions and this will prevent a lot more problems than would otherwise have been the case The purchasing department will get the necessary information on time and start searching for suppliers at the beginning of the process, which will prevent some possible delays and time losses.

(Cont.on next page)

Table 1.4. (Cont.)

Some Problems Observed in Design and Manufacturing Processes in TEBA and a CE Approach Suggested to Effectively Handle These Problems

Current state of NPD	Suggested CE approach	Likely impacts
It is sometimes realized at the production stage that design requirements and production capabilities of the company do not coincide and then, they try to make some revisions to either design or current production facilities, which results in a great loss of time and money.	*Teams often get associated with meetings. Some teams form to solve problems or make decisions. For these teams, the team's work is done in meetings (Smith, 1998:443)* We suggest that teams should regularly have meetings. Critical issues should be discussed at those meetings by all the relevant departments.	At the production stage, it will be possible to make the necessary improvements to the product before the actual production starts and there will arise less problems during this stage
Unexpected defects in the parts to be molded have been observed due to the fact that MT and KAM have only few meetings about those parts		MT and KAM will have more meetings and eventually there will be less defective parts

CHAPTER 4

CONCLUSION

Product design today cannot be regarded as a process carried out in isolation from other processes. It is to be regarded in the context of integration with other product development activities, such as manufacturing, costing, quality control, etc.

Concurrent Engineering (CE), or Concurrent Design, is a design methodology which improves product and process quality and it involves the simultaneous execution of various phases of a new product development process via teamwork bringing up all the people who need to be involved in.

This thesis has been intended to cast light on the design processes in a company considered to be a representative sample of the companies involved in *design-based manufacturing* in Turkey. One of the main topics of this study has been to identify the basic problems caused by the traditional method of technology and management, namely Sequential Design Process; and it has also been intended to come out with an optimum approach to the problems observed in the investigated company.

The case study conducted in TEBA-GÜNKOL has indicated that the traditional method of design adopted by the company causes some problems in the new product development processes of the company. These problems can be categorized as follows:

1. *Integration* and *concurrence* are ignored in the company. Consequently, *departmentalization* and *sequentialism* are observed and these two major problems inhibit communication and coordination.

2. The company does not make use of cross-functional teams which are a tool essential for the success of the new product development process and it causes delays in bringing the product to market and costly failures with regard to design and product quality.

3. Teams do not have regular meetings and feasibility studies are not carried out accurately. This causes a loss of time as well as many miscalculations.

4. Time and pacing management is not paid enough attention and as a result of this, estimated project times differ from actual ones.

This thesis has suggested that Concurrent Engineering techniques should be used to improve design quality and produce better products in a shorter time in the investigated company and it is thought that CE will help to solve all the problems related to design processes in TEBA-GÜNKOL.

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APPENDIX A

A SAMPLE FORM OF ORDER

TOA/M/K,O VERSİYON/NUMUNE TALEP/DEĞERLENDİRME/DUYURU FORMU

TALEP EDEN TARAFINDAN DOLDURULACAKTIR

MÜŞTERİ BİLGİLERİ:

ÜRÜN GRUBU:	**TOA21**	*HAKİM RENK:*	**BEYAZ**
ÜLKE:	**AVUSTRALYA**	*CİHAZ GERİLİMİ:*	**240 V**
MÜŞTERİ:	**OMEGA**	*GAZ CİNSİ:*	**NG**
MARKA:	**OMEGA**	*UYGUNLUK BELGESİ:*	**SAA**

TEKNİK BİLGİLER:

DÜĞME TİPİ:	**DAMLA**	*HALOJEN KAFA:*	**-**
MUSLUK TİPİ:	**İTHAL**	*HIGHLIGHT KAFA:*	**-**
SÖNME EMNİYETİ:	**4 OCAKTA DA VAR**	*CERAN CAM:*	**-**
HIGH FLAME:	**YOK**	*BESLEME KABLOSU TİPİ:*	**AVUSTRALYA TİPİ FİŞLİ**
DÖNÜŞÜM SETİ:	**LPG**	*DİĞER:*	**YENİ ESTETİK BEK GRUBU**

SERİGRAFİ BİLGİLERİ:

PANO/LOGO:	**OMEGA**	*GARANTİ KARTI:*	**VAR**
KULLANMA KILAVUZU:	**İNGİLİZCE**	*BARKOD/YEİL NOK.:*	**VAR**

SEVK BİLGİLERİ:

İSTEK SEBEBİ:	**SİPARİŞ**	*SEVK ADEDİ:*	**120**
SEVK TARİHİ:	**14.07.1998**	*BEDELLİ/BEDELSİZ:*	**---**

DİĞER BİLGİLER:

TOA21AUSA01'İN AYNISI FAKAT 4 OCAKTA DA SÖNME EMNİYETLİ

ÜDM TARAFINDAN DOLDURULACAKTIR

FORM NO:	**TOA98-015V**	*ÜRÜN KODU:*	**TOA21AUS05**

BAZ ÜRÜN KODU:	**TOA21AUS01**

KAPASİTE BİLGİLERİ:

?????	***ELEKTRİK*** *ELEKTRİK MLZ. LİST.:* *KABLO KON.TAB.:* *ELEKTRİK ŞEMASI:* *DİĞER:*

DİĞER BİLGİLER:

GAZ LABORATUVARI TARAFINDAN OMEGA TEST KURULUŞUNA GÖNDERİLEN NUMUNENİN TEST SONUÇLARI BEKLENİYOR. OMEGA MÜŞTERİ ÜRÜN KODU NE OLACAK? KUL.KLA.'NA SÖNME EMNİYETLİ BİLGİSİNİN GİRMESİ GEREKİYOR. ROZETLİ TİPE BU YENİ ÜRÜN İLE GEÇMİYOR MU?

Lütfen değerlendirmelerinizi en geç 3 gün içinde bildiriniz.