Addis Ababa University
School of Graduate Studies

CONCURRENT ENGINEERING AND IMPLEMENTATION

A CASE STUDY IN ADDIS ENGINEERING CENTER

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February 2007

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A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the Degree of Masters of Science in Mechanical Engineering (Industrial Engineering stream)

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Acknowledgements

This thesis was possible due to the contributions of many people. I particularly want to thank Ass. Prof. Prabahakar Reddy. K, my advisor, for his guidance and support throughout this endeavor and for his encouragement to seek my current position at Addis Ababa University, and his decisions and advices which continues to be a challenging and rewarding experience.

Any research work of this kind could be successful only when it is supported by the good will and cooperation of many companies. Of these, I acknowledge the cooperation of Addis Engineering Center's Management for allowing me to work this thesis in the organization and providing relevant data and information. Particularly I appreciate the cooperation of Ato Suleyman Mohamed and Mr. Fitwi.

Next, I would like to pass my gratitude to Dr. Ing. Daniel Kitaw and Dr. Subhash Chandra for their continuous follow - up, advices and comments.

My gratitude also goes to W/ro Woyneshet Tasew, Ato Zelalem Zewdu and all his families for their support on transportation and printing so that this thesis work gets an end. Above all, I would like to thank God for helping me in all aspects and my Family for their patience from the beginning up to now.

Abbreviations

AEC	Addis Engineering Center
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CE	Concurrent Engineering
CEPRA	Concurrent engineering in practice
CIT	Computer and Information Technologies
CPI	Continuous Process Improvement
CS	Core Strategies
DAMEC	Dejen Aviation Maintenance and Engineering Complex
DE	Design for Environment
DFA	Design for Assembly
DFD	Design for Disassembly
DFM	Design for Manufacturing
DFR	Design for recycle
EC	Estimated cost
ERP	Enterprise Resource planning
GM	General Motors
IA	Influential areas
IPD	Integrated Product Development
LCC	Life Cycle Cost
NC	Numerical control
NPD	New Product Development
P-D-C-A	Plan- Do –Check- ACT
PDP	Product development processes
PDT	Product development team
QFD	Quality Function Deployment
REFA	Real Estate Finance Association
SMEs	Small Manufacturing Enterprises
TC	Targeted cost
TQM	Total Quality Management

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CHAPTER ONE
1. INTRODUCTION, BACK GROUND AND JUSTIFICATION

1.1 INTRODUCTION

Concurrent Engineering - which is sometimes called Simultaneous Engineering or Integrated Product Development (IPD) - was defined by the Institute for Defense Analysis (IDA) in its December 1988 report 'The Role of Concurrent Engineering in Weapons System Acquisition' as 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 conception through disposal, including quality, cost, schedule, and user requirements

Concurrent Engineering is not a quick fix for a company's problems and it's not just a way to improve engineering performance. It's a business strategy that addresses important company resources. The major objective this business strategy aims to achieve is improved product development performance. Concurrent Engineering is a long-term strategy, and it should be considered only by organizations willing to make up front investments and then wait several years for long-term benefits. It involves major organizational and cultural changes.

The problems with product development performance that Concurrent Engineering aims to overcome are those of the traditional serial product development process in which people from different departments work one after the other on successive phases of development. In traditional serial development, the product is first completely defined by the design engineering department, after which the manufacturing process is defined by the manufacturing engineering department, etc. Usually this is a slow, costly and low-quality approach, leading to a lot of engineering changes, production problems, product introduction delays, and a product that is less competitive than desired. Concurrent Engineering invariably reduces total product cost.

Concurrent Engineering brings together multidisciplinary teams, in which product developers from different functions work together and in parallel from the start of a project with the intention of getting things right as quickly as possible, and as early as possible. A cross-functional team might contain representatives of different functions such as systems engineering, mechanical engineering, electrical engineering, systems production, fabrication, quality, reliability and maintainability, testability, manufacturing, drafting and layout, and program management. Sometimes, only design engineers and manufacturing engineers are involved in Concurrent Engineering. In other cases, the cross-functional teams include representatives from purchasing, marketing, production, quality assurance, the field and other functional groups. Sometimes customers and suppliers are also included in the team.

In the Concurrent Engineering approach to development, input is obtained from as many functional areas as possible before the specifications are finalized. This results in the product development team clearly understanding what the product requires in terms of mission performance, environmental conditions during operation, budget, and scheduling. Multidisciplinary groups acting together early in the workflow can take informed and agreed decisions relating to product, process, cost and quality issues. They can make trade-offs between design features, part manufacturability, assembly requirements, material needs, reliability issues, serviceability requirements, and cost and time constraints.

Getting the design correct at the start of the development process will reduce downstream difficulties in the workflow. The need for expensive engineering changes later in the cycle will be reduced. Concurrent Engineering aims to reduce the number of redesigns, especially those resulting from post-design input from support groups. By involving these groups in the initial design, less iteration will be needed. The major iterations that do occur will occur before the design becomes final. The overall time taken to design and manufacture a new product can be substantially reduced if the two activities are carried out together rather than in series. The reductions in design cycle time that result from Concurrent engineering invariably reduce total product cost.

Concurrent Engineering provides benefits such as reduced product development time, reduced design rework, reduced product development cost and improved communications. Examples from companies using Concurrent Engineering techniques show significant increases in overall quality, 30-40% reduction in project times and costs, and 60-80% reductions in design changes after release.

The implementation of Concurrent Engineering addresses three main areas: people, process, and technology. It involves major organizational changes because it requires the integration of people, business methods, and technology and is dependent on cross-functional working and teamwork rather than the traditional hierarchical organization. One of the primary people issues is the formation of teams. Collaboration rather than individual effort is standard, and shared information is the key to success. Team members must commit to working cross-functionally, be collaborative, and constantly think and learn. The role of the leader is to supply the basic foundation and support for change, rather than to tell the other team members what to do. Training addressed at getting people to work together in teams' plays an important role in the successful implementation of concurrent engineering.

An example of the use of Concurrent Engineering can be found in General Electric's Aircraft Engines Division's approach for the development of the engine for the new F/A-18E/F. It used several collocated, multi-functional design and development teams to merge the design and manufacturing process. The teams achieved 20% to 60% reductions in design and procurement cycle times during the full-scale component tests which preceded full engine testing. Problems surfaced earlier and were dealt with more efficiently than they would have been with the traditional development process. Cycle times in the design and fabrication of some components have dropped from an estimated 22 weeks to 3 weeks. [4]

Another example concerns Boeing's Ballistic Systems Division where Concurrent Engineering was used in 1988 to develop a mobile launcher for the MX missile and was able to reduce design time by 40% and cost by 10% in building the prototype.

Polaroid Corp.'s Captive instant camera is also the result of a Concurrent Engineering approach, as a result of which Polaroid was able to make literally hundreds of working prototypes. Throughout the process, development was handled by cross-functional teams.

Concurrent Engineering (CE) is a manufacturing philosophy that has emerged in the last decade in response to growing pressures to reduce costs and lead times while improving product quality. For the purposes of this research, CE is defined as a systematic approach to parallel development of all product life-cycle activities, from initial conception through design, planning, production and disposal. It presupposes an enriched communication infrastructure which is unconstrained by geographical location and encourages right-first-time methods through cross-functional team working and consensus (Hanneghan. 1997).

In Concurrent Engineering projects, we find what has been termed 'the multiple perspective problem' (Easterbrook et al. 1994) with many actors, diverse domain knowledge and differing development strategies. (Smith 1988) supports this point stating that co-operation of multiple competing perspectives and the integration of complementary engineering expertise are requirements for systems that intend to support Concurrent Engineering. This research contends that viewpoint analysis can therefore be used to help design the complex environments necessary to support Concurrent Engineering.

1.2 PROBLEM STATEMENT

Ethiopia has few industries, which follows the usual way of developing and processing the new product. One of these industries is Addis Engineering Center, which was established in 1945 E.C at estimated cost of Birr. 2,000,000.00. Even though the main objective was to produce different ammunition of simple machine guns, at present the company is producing other products like metal work and woodwork (furniture), medals, badges, tools and spare parts.

In traditional engineering a relatively short time is spent defining the product. A relatively long time is spent designing the product and even surprisingly longer time is often spent redesigning the product. The key to shortening the overall design time is to better define the product and better document for the design process. Traditionally, the development of a product had been seen as a cycle of plan...do...check...act... (Adjust). Concurrent engineering is a process in which appropriate disciplines are committed to work interactively to conceive, approve, develop, and implement product programs that meet pre-determined objectives. It is a relatively recent term applied to the engineering design philosophy of cross-functional cooperation in order to create products which are better, cheaper, and more quickly brought to market. This new trend reunites technical and non-technical disciplines such as engineering, marketing and accounting. Always focusing on satisfying the customer, these organizations must work together in defining the product to be manufactured.

So, why do companies like Addis Engineering Center need Concurrent Engineering?

- ***Competitive advantages*: -** it is used for the clear-cut benefits and competitive advantage. Concurrent engineering can benefit companies of any size, large or small.
- ***Increased performance*: -** companies recognize that concurrent engineering is a key factor in improving the quality, development cycle, production cost, and delivery time of their products. Concurrent engineering can eliminate multiple design revisions, prototypes, and re-engineering efforts and create an environment for designing right the first time.
- ***Reduced design and development time*: -** companies that use concurrent engineering are able to transfer technology to their markets and customers more effectively, rapidly predictably. They will be able to respond to customers needs and desires to produce quality products that meet or exceeds the customer's

expectations. They will have also been able to introduce more products and bring quicker upgrades to their existing products through concurrent engineering.

Addis engineering center is following the traditional way of product development that is why it can't compete with other enterprises. In order to be competent to the global and domestic market it is important to focus on processes and continuous improvements by using new techniques and systems.

1.3 OBJECTIVE OF THE THESIS

Concurrent engineering is a business strategy which replaces the traditional product development processes with one in which tasks are done in parallel and there is an early consideration for every aspect of a product's development process. This strategy focuses on the optimization and distribution of a firm's resources in the design and development process to ensure effective and efficient product development process.

The general objective of the theses is to create awareness of concurrent engineering and implementation. In addition to that, to prepare concurrent engineering implementation guide that suite in production industries like Addis Engineering Center.

The specific goal of the thesis is implementing Concurrent Engineering to improve the interactive work of different disciplines affecting a product. The following are some of the benefits:

a) Minimize the product life cycle - Shorten the redesign procedure and manufacturing planning.
b) Minimize production cost - results from the minimization of the product life cycle.
c) Meeting delivery schedule and time to market - The Company can increase the prospect of delivering a quality product to the customer.

1.4 METHODOLOGY

The methods employed to achieve the objectives of the research are:

1. Survey of literatures and previous research works on similar topics.
2. Visit to companies and gather all the available data and Conduct interviews,
3. Consultation: experts in the related fields was conducted

4. And finally identify the major wastes and prepare the implementation guide for Concurrent Engineering concepts in Addis Engineering Center.

1.5 CONCURRENT ENGINEERING BACKGROUND

The traditional approach to product development is sequential in nature where upstream functional experts perform their tasks and deliver final product related information to downstream activities. This is done with no or minimal interaction and cooperation between the different functional groups. Minimal interaction increases the probability of design conflicts between the functional groups. Resolving such conflicts requires designers and engineers to iterate through trial designs until and agreement is reached. This iteration process results in an elongated product development time, increased development cost, and consequently loss of market share [13].

Numerous design improvement strategies and techniques have evolved to solve the problems inherent in a sequential design environment. Design for Manufacturing (DFM), Design for Assembly (DFA), Quality Function Deployment (QFD), Continuous Process Improvement (CPI), and Total Quality Management (TQM), to name a few. All of the above mentioned techniques offered a partial improvement to the development process; however, the industry felt the need for a more comprehensive approach that can tie all their concerns together. Finally, the extensive research in product development resulted in the creation of a conceptual framework that acts as an umbrella to all design improvement tools and techniques and was called Concurrent Engineering.

Smith [28] argues that CE can be visualized as a summary of best practice in product development, rather than the adoption of a radically new set of ideas. Formally, CE is defined as a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support [16]. Simply stated, CE is the incorporation of downstream factors and concerns in problem solving during the upstream phase. The basic factors underlying CE include complete visibility of design parameters, mutual consideration of all downstream decisions, overlapping problem solving, and partial/incomplete information transfer, collaboration to resolve conflicts, teamwork, and continuous improvement [11]. From an information perspective, CE is concerned with the availability and timing of information to all design participants. The ability to act on this information by the process participants is yet another important dimension of CE. Therefore, CE requires the maximization of design information at all stages of the design process and the ability to share and communicate useful information on timely basis.

In a survey by Lawson and Karandikar of what constitutes a CE program, in the manufacturing sector, teamwork was rated as the number one component. The second major component in the list was DFM practice. Quality tools such as QFD and SPC came in the third place, while a process improvement initiative was ranked fourth. Less than half of the respondents considered information technology deployment as part of their CE program. Finally, business re-engineering, benchmarking, and CAD/CAM integration came in last according to the survey.

In another study of US manufacturing companies, Hull et al. found that there are three core sets of CE practices that lead to the improvement of product development performance. These three core sets are:

1. Early Simultaneous Influence: refers to the level of participation and the extent of influence of manufacturing engineering in the product design process.
2. In-process Design Controls: refers to the extent to which firms have adopted standardized design practices, emphasized design documentation, and conduct systematic design reviews.
3. Computer and Information Technologies (CIT): this set refers to three different subsets: the use of electronic databases, extent to which CAD and CAM is coupled, and the level of programmable automation.

Smith [12], in a recent study, traced the roots of CE in early engineering literature and outlined its principles as follows:

1. Increased role of manufacturing process design in product design decisions - design-manufacturing integration.
2. Formation of cross-functional teams to accomplish the development process - integration of design with all other functions.

3. Consideration of customer preferences during the design process – design marketing integration.
4. Adoption of computer tools or mechanisms for accomplishing integration: QFD, DFM and DFA.
5. The use of lead time as a source of competitive advantage.

Another important CE dimension that is discussed extensively is the concept of overlapping. In overlapping, we determine what fraction of the predecessor task must be completed before the follower task can begin. For overlapping to be effective, upstream (predecessor) information availability and downstream (successor) information needs must be understood. In many design situations, the official release time of design information does not coincide with the time this information is really available. Finding this information is really available and whether it can be released right away to subsequent tasks is critical for overlapping]. The critical step in overlapping is identifying a point within the predecessor task duration where preliminary (i.e. partial) design information is sufficiently evolved to be utilized by the successor task.

Over the last decade the concept of manufacturing architectures has evolved to provide structure for the analysis and design of manufacturing enterprises. A common thread to these architectures is that they use graphical models to represent the various aspects of manufacturing such as processes or functions and the logic or sequence of information flow (documents, verbal or data) that link and control them. Such modeling methods are characterized by a formal syntax and structured diagramming techniques and are based on concepts from General Systems Theory and software development methods. In practice this means that models claim to describe a complex manufacturing system (consisting of people, machines, material, products, data, etc.) in easily understood, related elements using a series of diagrams. A model can then be used as a common understanding of a complex situation, for gaining insight, for system design or as the basis of quantitative analysis.

Analysis Reference Model for Concurrent Engineering should sufficiently address all the needs of Concurrent Engineering, forcing the designers of CE support environments to use multiple, separate, and sometimes contrasting models to achieve their goal. When using multiple models, there is the risk that information from a particular model might be missed or misinterpreted in a following model when that information is transcribed. The challenge then, is to produce a model that can address the needs specific to Concurrent Engineering and yet is flexible enough to be extended to other domains with relative ease.

The specific needs of CE are highlighted in the definition of Concurrent Engineering as stated Chapter 2 and include: enriched communication between team members, cross-functional team-working and distributed access to resources, such as product information and software applications, to multiple team members at multiple locations. The bounds of these functions stretch from initial concept of a product through to its disposal so any model designed to support CE must be applicable for all stages in the product life-cycle.

CHAPTER TWO

2 DEFINITIONS AND BASIC PRINCIPLES OF CONCURRENT ENGINEERING

2.1 DEFINITIONS OF CONCURRENT ENGINEERING

Several approaches concerning the reduction of time-to-market have been developed in the last years. Approaches related to the product development and its interdependencies with different departments of the entire company can be summarized under the expression ''Concurrent Engineering (CE) ''

The roots of CE can be drawn back to the innovation attempts of the US Department of Defense and the American defense industry since it was recognized that the development of weapon systems was to expensive, time consuming and not meeting the expectations of its purchasers.

An overview of variants of Concurrent Engineering is given in:-

- Simultaneous engineering
- Integrated Product Development
- Synchronous Product-Process Development
- Generalized Systems Engineering
- Transition to Production
- Enterprise Integration

To get a notion of how widespread the approach of Concurrent Engineering is, it is important to see the definitions which are listed in the following according to their time of appearance:

''**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 conception through disposal, including quality, cost, schedule, and user requirements.'' [5]

’’**Concurrent Engineering** is the process of forming and supporting multifunctional teams that set product and process parameters early in the design phase“ [Jagannathan, V., K.J. Kleetus, A.S. Matsumoto, and J.W. Lewis 91]

’’**Concurrent Engineering** is getting the right people together at the right time to identify and resolve design problems. Concurrent Engineering is designing for assembly, availability, cost, customer satisfaction, maintainability, manageability, manufacturability, operability, performance, quality, risk, safety, schedule, social acceptability, and all other attributes of the product.’’ [Dean, Unal 92]

’’**Concurrent Engineering** is a systematic approach to integrated 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, synchronized by comparatively brief exchanges to produce consensus“ [K.J. Kleetus 92]

While the first definition by Winner, Pennell, Bertrand, and Slusarezuk tries to achieve an all comprising definition of Concurrent Engineering, the definitions by Jagannathan, Kleetus, Matsumoto, Lewis and by Dean, Unal try to be more concrete. K.J. Kleetus made a second attempt of a definition in 1992. This attempt had the aim to extend and to refine the definition by Winner, Pennell, Bertrand, Slusarezuk, in the perspective to achieve a definition ’’...that is suggestive of the efforts needed to realize a high level of Concurrent Engineering in an organization...“without loosing the comprehensiveness of the approach.

To get a more extensive look on Concurrent Engineering some definitions of the variants mentioned will be listed in the following:

’’**Simultaneous Engineering** is a method for organizing work in a manner that from the outset of the product development process all affected departments work together in parallel and overlapping activities, to timely contribute with their specific knowledge. The work is accomplished in cross-functional teams lead by a project manager. The line-oriented organization is supported by a project-oriented organization with equal rights to overcome the organizational dissection of responsibilities during the product development process. Often, but not necessarily, Simultaneous Engineering is combined with the roomy concentration of the team members. If Simultaneous Engineering is done consequently it must include the early and complete integration of suppliers, especially system suppliers. Many projects afford the integration of the costumer in the same manner. “ [13].

’’**Simultaneous Engineering** is the integrated and time related parallel carrying out of the development of products and processes with the goal to reduce time-to-market and costs, while the quality of a product - in its most comprehensive sense - is improved.“, [Eversheim, Bochtler , Laufenberg 95, pg. 2].

’’**Simultaneous Engineering** is characterized by numerous tools, methods and implementation alternatives. Therefore it is necessary to introduce simple strategies to organize this diversity. These are parallelization, standardization and integration of the product development process. The aim is to optimize aspects related to time, costs and quality within the areas usually regarded by the management when confronted with Simultaneous Engineering. These areas are: the product, the organizational structure, process structure and the resources. ’’.

’’While practicing **Integrated Product Development** all involved departments and specialists work closely together in an immediate way. It is thereby intended to influence the goals of the product development process concerning time, costs and quality in a positive manner. To save time, the former sequential fulfilling of tasks is done in parallel, especially the development of products, processes and marketing mechanisms.’’, When analyzing the last three definitions it becomes obvious that all here mentioned approaches (Concurrent Engineering, Simultaneous Engineering and Integrated Product Development) are very similar. The only difference is that the definitions of Simultaneous Engineering and Integrated Product Development seem to be more concrete, than the ones of Concurrent Engineering. The analysis of the definitions of Concurrent Engineering and related approaches are mentioned in the following insight:

- Concurrent Engineering is an approach with many facts, which makes it difficult to define.
- The amount of different definitions along time shows the variety of perspectives the Concurrent Engineering approach offers.

- Nearly every definition focuses on other aspects of Concurrent Engineering, but in the end all definitions deal with the same problematic nature.

This insight bares the necessity of building a synthesis of all approaches related to Concurrent Engineering in order to achieve consistency among all definitions. It is not the goal of this study report yet to provide another definition, but for the sake of a consistent model and at least to provide core strategies on which the approach of Concurrent Engineering focuses. The level of abstraction on which these core strategies are based might seem very high, but this level of abstraction is necessary in order to respect all definitions of Concurrent Engineering which focus on different aspects of this approach but in the end deal with the same or at least similar topics.

By integrating all core essences, it is possible to identify what CE is about. This can be summarized in four major core strategies (CS):

- **Parallelization**: The goal of parallelization in the product development process is the reduction of lead-time. First of all, processes which have no dependencies to each other are executed at the same time. If there are dependencies, the dependent processes are initiated before the preceding processes are finished. In general the start of succeeding processes is possible since, shortly after initiating a preceding process; enough information is available. This advantage of fulfilling tasks in a very short time turns out to correlate with an increasing decision complexity and an increasing information transition between involved departments. Furthermore the amount of unsafe and incomplete information increases, too. This is due to the fact that parallel occurring processes which serve as input for other Processes might not be finished.
- **Standardization**: Standardization is defined as a durable description or set of rules which is independent of persons or events of different aspects of the product development process. Standardization concerns technical/structural aspects (e.g. modules, components etc.), process aspects (e.g. phases, sequences etc.) and organizational aspects (e.g. interfaces between projects or departments etc.)
- **Integration**: Regarding the product development process as a continuous value added chain shows that in general different departments of a company are affected by the development of a product. This distribution of the development tasks

across the different functional areas is automatically connected to an increase of interface related problems. The increase of these problems depends on the volume of the tasks. Integration by the means of inclusion and far-sightedness is the key to solve these problems. This means interdisciplinary work, process oriented thinking and acting, and fulfillment of one common goal instead of specific departmental goals, as well as entrepreneurship and fast decision making instead of resort egoism.

- **Optimization**: Optimization in the context of Concurrent Engineering is to be seen as a continuous improvement of all aspects concerning time, costs and quality in a way to meet costumer needs and requirements.

2.2 THE INFLUENTIAL AREAS OF THE PRODUCT DEVELOPMENT PROCESS

For the application of CE on the product development process of a company, it is useful to subdivide this process into areas, which can be influenced by a company. This is necessary since this process as a whole is very complex and possesses many variables. A subdivision would reduce this complexity and at least provide a more operational view on this process.

In literature many sources mention different areas to be the ones, which can be influenced in order to evoke changes in the product development process. As already done above, it is important to gather different sources in order to derive the ’’Influential Areas of the Product Development Process’’ (IA).

Beginning with the analysis, it is also possible to identify wherein the product development process the core strategies mentioned earlier are to be applied, or better, where they take effect on the product development process in order to achieve a optimal CE performance. The areas derived out are:

- Costumer
- Product
- Process
- Supplier
- Tools & Methods
- Team
- Marketing
- Project

A very interesting but abstract model, which can also be presented in this context, is the REFA (Real Estate Finance Association) Working system. The REFA System aims at increasing performance through process organization and work improvement and includes all necessary methods, key figures, data, standards and reference solutions as well as the know-how for correct application.

This model is based on the assumption that the structuring of work nearly exclusively deals with the structuring of socio-technical systems. Since engineering science and also great parts of social science accepted the concept of system theory, modern authors use the term ''working system" when dealing with the structuring of work.

Therefore, the purpose of working systems is defined as follows:

- Working systems serve the purpose of fulfilling working tasks; by this human beings and facilities act together with the input under environmental conditions.

According to REFA, working systems can be described by seven terms [figure1]. The *working task* defines the purpose of a working system. The *input* could be materials and human beings being changed according to the working task, as well as information, energy etc. The term *human being* speaks for itself. *Facilities* and human beings are the subjects which transform the input. The *working sequence* is the timely and physical sequence of the interactions between the human being and the facilities with the input. The *environmental influences* can be differentiated between physical, organizational and social influences. And finally the *output* is the transformed input according to the task.

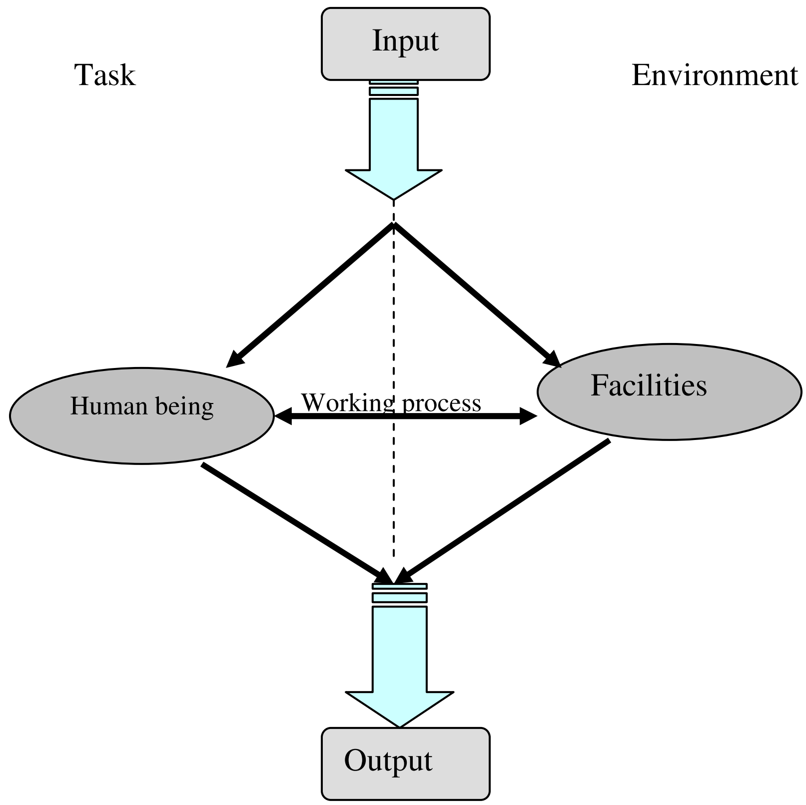


Figure 1 the working system of REFA.

The elements *working task*, *human being*, *facilities* and *environmental influences* are defined as being static, while the elements *input*, *working sequence* and *output* are defined as being dynamic. According to the definition above, a product development process can be compared with a socio-technical system, since it includes all elements described. Therefore, the seven terms of the REFA ''Working system'' model mentioned above could represent the IA of the product development process. However, the above described model is generic for all working systems. Therefore it is preferred to consider other sources directly related to the product development process for the assessment towards Concurrent Engineering. Ehrlenspiel names nine possible areas which have an impact on the product development process [Figure 2] and therefore see on CE activities of a company.

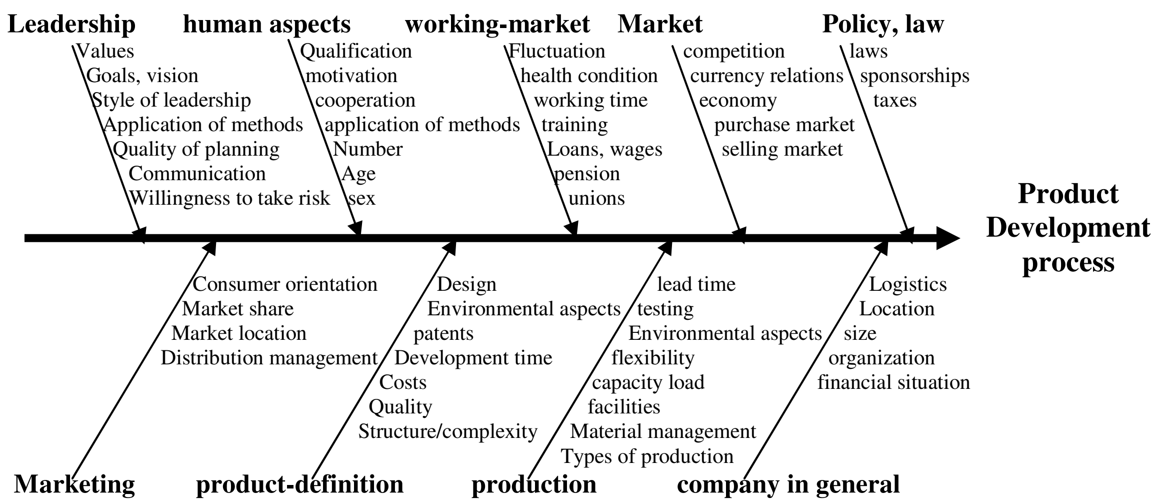


Figure 2 Fish bone diagram for Influential areas of product development process

The areas *Working-market*, *Market* and *Policy/Law* are considered as being external aspects while the other aspects are considered to be internal aspects. The difference between both aspects is the capability of influencing them. While external aspects are only to be influenced marginally, the influence on internal aspects is much stronger. According to Ehrlenspiel, the external aspects may not be considered independently from the internal aspects since both may have strong influences on each other (i.e. the competitive and economic situation on the market may have influence on motivation and co-operation).

Assuming that external aspects are regarded in a company's goals, allows the reduction of the influences mentioned by Ehrlenspiel to the six areas:

- Leadership.
- Human aspects.
- Marketing.
- Product definition.
- Production.
- Company in general.

Furthermore, in [CEPRA] different approaches of tools and methods where analyzed with respect to their usability for the assessment of a company regarding CE activities.

A closer look at the aspects analyzed by different assessment tools cover the same areas as the ones described by Ehrlenspiel (mentioned earlier above).

In [2] the areas mentioned to be the influential areas of the product development process are:

- Organization.
- Processes.
- Human resources.
- Physical resources.
- Product.

When taking a closer look at all areas of influence mentioned, it is possible to summarize specific areas under more abstract terms, thus reducing the amount of areas. This has been done in the following. Therefore, the derived areas in which a company can take influence on the product development process, and which will be regarded in this study report are documented and explained below:

- **Strategy**: This area relates to visions, values and goals of a company, how a company deals with its own employees with respect to. E.g. decision making and how a company wants to deal with suppliers. Furthermore planning and scheduling activities are of strategically importance as well.
- **Organization**: This area relates to aspects concerning the formal organization of the company, of projects and teams, as well as on aspects of communication since in principle the formal structure pre-defines the information flow.
- **Human resources**: This area relates to aspects concerning qualification and motivation thus regarding the abilities, skills and the readiness of human capacities.
- **Physical resources**: This area relates to aspects concerning technical and logistical resources which serve as support to enhance the product development process. This area comprises e.g. technology, rooms etc.
- **Product**: This area focuses on the product design itself. It addresses to the complexity and the structure of a product as well as on the product data.

It is to remark that the area ´Processes` mentioned by [2] does not explicitly appear in the listing above. This is due to the fact that each of the influential areas consists of numerous processes itself, thus making the creation of an individual influential area which deals with processes unnecessary.

The influential areas as defined above need to be broken down into more practicable sub areas since the influential areas are to tough to locate a specific improvement potential during an assessment. These sub-areas can also be derived from all approaches presented above by first summarizing them and then allocating them to each defined influential area. The result is illustrated in Figure below.

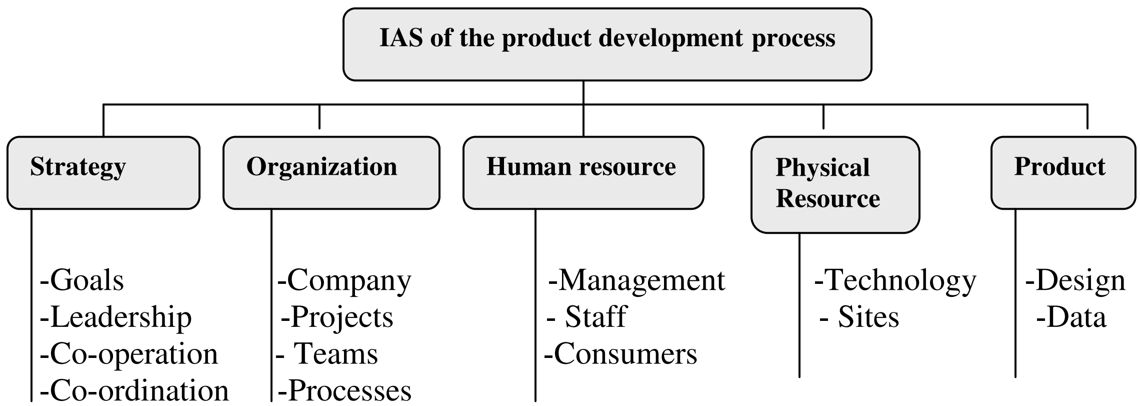


Figure 3 Influential areas of the product development processes

An advantage resulting from the separation of the Core Strategies of CE from the influential Areas of the product development process, thus building matrices, is the possibility of considering all relevant aspects of either dimension. This fact allows generating a comprehensive questionnaire for an assessment towards Concurrent Engineering to be performed.

Motivation

In the most general sense, a process is simply an ordered sequence of events. In human-designed systems, the events that constitute a process are designed and ordered to achieve some desired outcome. A business process, in particular, is an ordered sequence of events involving people, materials, energy, and equipment that is designed to achieve a defined business outcome. The importance of business processes is self-evident. They not only define what the business does, but more importantly, they determine how well the business does what it does.

Several motivating factors led to the development of IDEF3 (information integration for concurrent engineering). Some of the more prominent motivations are described in the following sections.

Enhance the Productivity of Business Systems Analysis

One major motivation behind IDEF3 development was the need to speed up the process of business systems modeling. Business systems analysis often begins by acquiring an accurate description of the problem situation. Domain experts express recurring situations in terms of an ordered sequence of events or activities. Moreover, domain experts generally describe the specific ways in which activities and the objects that participate in them are related. There is a need for both a *method* to facilitate the capture of the dynamics of business activities and process descriptions, and for a *representation medium* to store and manipulate this captured knowledge. IDEF3 fulfills these requirements with a structured approach to communicate such process information described by domain experts.

Facilitate Design Data Life-Cycle Management

Earlier studies to identify method needs revealed the lack of methods to capture descriptions of design-data life cycles To describe the engineering design data life cycle, it is necessary to describe: (1) design information artifacts (i.e., drawings,
CAD models, etc.), (2) state transitions through which these artifacts proceed, and (3) the decision logic or processes that determine the state transitions. IDEF3 provides mechanisms to describe this data life cycle information.

Support the Project Management Process

Project management techniques are used to monitor and control projects in various application domains. Several software tools support these project management techniques. However, many of these techniques are not expressively powerful enough to capture many of the complexities that occur in project management situations. IDEF3 provides mechanisms to capture the constraints (including resource and temporal relationships) between the activities of a project. The IDEF3 also represents detailed information about the objects that participate in, are produced by, or are used by the project activities. Furthermore, the activation of IDEF3 diagrams, which can be supported by an automated tool, will provide the means to monitor and control project activities in real-time.

Facilitate the System Requirements Definition Process

Another motivation for the development of IDEF3 was the need to provide the concepts, syntax, and procedures for building *system requirements descriptions.* These descriptions must be adequately detailed to determine whether a delivered system is acceptable.

2.3 BASIC PRINCIPLES OF CONCURRENT ENGINEERING

Timing is an important consideration in CE. A lot rides on timing of decision making and problem discovery. Approximately eighty percent of product's life-cycle development cost is driven by decisions made in the first twenty percent of the program effort

Concurrent Engineering is founded on eight fundamental principles:

- **Early Problem-discovery:** Problems discovered early in the design process (particularly during the first 20% of the cycle-time) are easier to solve than those discovered later.

- **Early Decision-making:** The "window of opportunity" to affect a design is much wider during an early design stage than at a later stage-when some of the decisions are frozen and when the design is matured. Teams often have the natural tendency of making quick and novel decisions, which is good, except those decisions should be lasting as well.

- **Work Structuring:** Human minds practically cannot work on multiple tasks simultaneously, parallel computers do. What a human mind is good at is systematically structuring the work, or more importantly structuring the work-environment so that each task can be performed independently of each other either by a human being, a machine or by a computer.

- **Teamwork Affinity:** Teams of people working in separate groups are likely to create designs, which may be optimal in their individual domains but will seldom remain optimal in a domain, which is a union-sum of those individual domains. Also, teams will have a better affinity if they trust each other. Trusting members, if they agree to accept responsibility for a task, do prefer to work together rather than working in isolation.

- **Knowledge Leveraging:** The domain of product design is often very large. It may be impossible to create a general purpose "automated" or knowledge-based system, which will use appropriate tools and knowledge-driven rules (mostly computerized) to guide decision making. Inter-linking decision support tools with spurts of "human knowledge-base" will continue to be the most valuable tool for solving complex problems.

- **Common-understanding:** Teams will work better if they know what other members are doing. This includes operational understanding of all relevant interplay; e.g., what constraints a team-member would encounter when certain parameters will be changed.

- **Ownership:** Teams will work enthusiastically to make a good product if they are empowered to make decisions in shaping the design and are given "ownership" of what they produce.

- **Constancy-of-purpose:** Most departments have a natural tendency to make their departments look good to others-create false profits, even though it may be detrimental to the overall corporate goals. The whole corporation will do even better if everyone works towards a common set of consistent goals irrespective of departments, they have allegiance to. This requires a change in thinking beyond the goals of one individual department or teams to the company's goals. The obligation of any supporting unit is not to sub-optimize its own goals (such as unit's profit potential or sales) without a clear and direct relationship to the company's overall goals. It must contribute its best towards the system goals.

CHAPTER THREE

3. INTEGRATED PRODUCT DEVELOPMENT AND ITS CHARACTERSTICS

3.1 INTEGRATED PRODUCT DEVELOPMENT (IPD)

CE is structured around multi-functional teams that bring specialized knowledge necessary for the program. The multi-disciplinary setup called product development team (PDT) is composed of several distinct technical sub-units specializing in a variety of disciplines:

- Product Planners (T_{pp})
- Product concept engineers (T_{ce})
- Engineering and analysts (T_{ea})
- Product designers (T_{pd})
- Prototype engineers (T_{pe})
- Production engineering planners (T_{ep})
- Management & control (T_{mc})
- Computer integrated manufacturing (CIM) and Assemblers (T_{ma})
- Delivery& support (T_{ds}) teams:

PDTs = Ú [T_{pp}, T_{ce}, T_{ea}, T_{pd}, T_{pe}, T_{ep}, T_{mc}, T_{ma}, and T_{ds}].

Where, Ù indicates union-of and T stands for "Talents." In the above, nine concurrent teams are intentionally chosen to show the actual correspondence with each of the nine concurrent tracks. Each track is responsible for developing and integrating its own aspect to the product's life-cycle as the program requires. However, there could be as many tracks/tasks and teams as needs arise. For example, experts from the volume production area must be involved in prototype production to identify as early as possible opportunities to improve process reliability. By using this multi-functional team approach to merge design and manufacturing, general electric(GE) Aircraft engine division reduced design and fabrication lead time for some GE engine components from 22 to 3 weeks.

3.2 PRODUCT DEVELOPMENT PROCESSES

The goal of this section is to define product development, put it in context, and describe typical characteristics of the product development process.

3.2.1 Product development context

Basically product development concerns the definition and creation of new products. It is one of the most basic characteristics of human beings; they make a wide range of tools and other artifacts to suit their own purposes. In traditional craft-based societies designing is not really separated from making; that is to say, there is usually no prior activity of drawing or modeling before the activity of making the artifact (Cross, 1994).

In modern, industrial societies the activities of designing and making artifacts are often separated. One of the reasons for this is that products have become more complex and hence more employees from several disciplines are needed to design and make the artifact or product. The separation of the activity of designing from the activity of making has also been stimulated by the Scientific Management principles, *i.e.* division of labor, from Frederick Taylor.

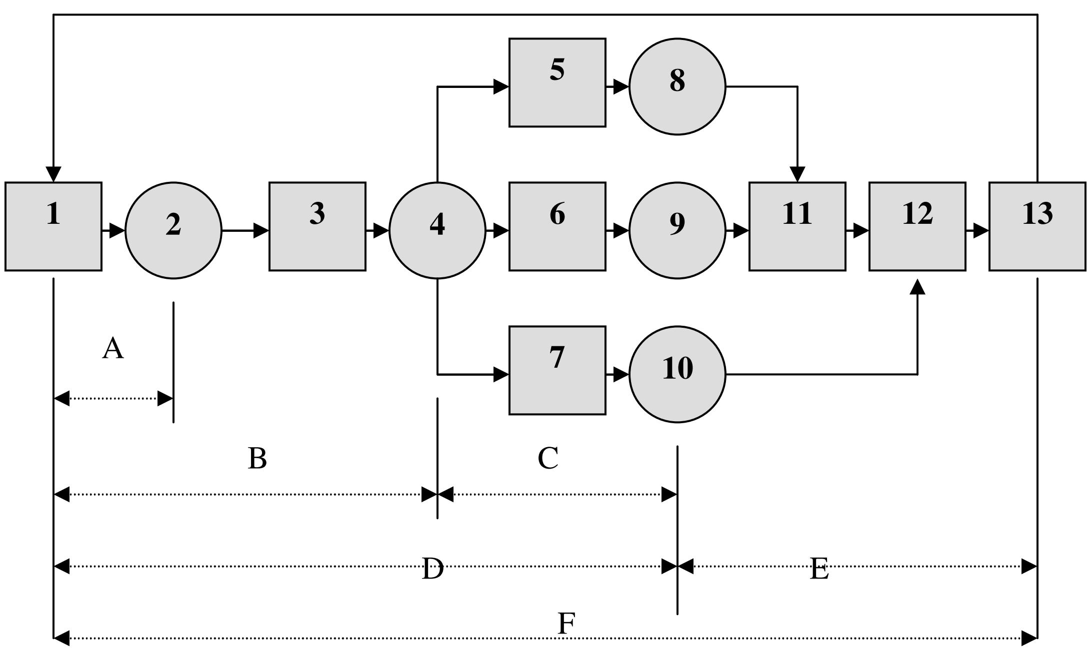


Figure 4 Product developments in context

Key:

1. Formulating goals, and strategies	8. Production plan	A. Policy formation
2. Product policy	9. Product design	B. Product planning
3. Generating and selecting Ideas	10. Marketing plan	C. Strict development
4. New business Ideas	11. Production	D. Product development
5. Production development	12. Distribution and sales	E. Realization
6. Product designing	13. Use	F. Innovation
7. Marketing planning		

Product development is one of the processes of a company. Several authors such as Andreasen and Hein (1987), Hales (1991) and Roozenburg and Eekels (1991) provide models that put the product development process in context. De Graaf (1996) refers to these types of models as management models. The management models of different authors are quite similar. The model of Roozenburg and Eekels is selected to discuss product development in more detail because of its focus on processes (Figure 4).
Roozenburg and Eekels use the name Innovation for the collection of all processes of a company. The Innovation process starts with what they call Product Planning (the first two processes). It involves defining the strategy and goals of a company and defining which markets they want to serve. Generating ideas and selecting ideas follows the definition of strategy and markets. The ideas concern new products and services or complete ranges of products and services. Wheelwright and Clark (1993) use a funnel to describe the generation and selection of ideas. Reinertsen (1997) calls it the Fuzzy Front End. With the term fuzzy he refers to the fact that during product planning it is often unclear what the market or customer needs are and how these needs can be translated into unambiguous product specifications.

Strict Development follows product Planning, there are two important processes in this phase that are conducted concurrently. It involves Technical Development (Production Development and Product Designing) and Commercial Development (Marketing Planning). Technical Development concerns the definition of form, fit, and function of the product as well as the definition of the required tooling and equipment to make the product. The process translates the selected idea from the Product Planning phase into a blueprint of the product. The Commercial Development process takes care of the business economic goals of the company. It determines how the company can make profit by developing and selling products and how the company can survive in the long run. The final process is the Realization process. It concerns the production of the product, distribution and sales of the product, and the actual usage of the product by the customer. Although it is not shown in the figure it also includes maintaining the product.

3.2.2 Definition of Product Development

In literature several definitions can be found, which define the product development process in more detail. De Graaf (1996) reviewed definitions from Hales (1991), Finkelstein (1993), the English Department of Scientific and Industrial Research (1964), and Wallace (1993) to come to a working definition for product development in his thesis:

"Product Development is a sequence of design processes that converts generally specified market needs or ideas into detailed information for satisfactory manufacturability products, through the application of scientific, technical and creative principles, acknowledging the requirements set by succeeding life cycle processes."

This definition limits product development to idea finding and Strict Development according to the model of Roozenbrug and Eekels. It defines that product development does not include the manufacturing processes. The primary goal of a product development process is to provide all the required product-definition information, but also to ensure that the information is fit-for-use.

Although product development does not include manufacturing the definition mentions that it should acknowledge the requirements set by succeeding life cycle-processes such as manufacturing and service. Therefore, the result of product development is an intelligent trade-off between the various other design goals, for instance manufacturing cost, ease of use, and environmental aspects. Several techniques have been developed to support this way of thinking and is generally referred to as Design for X techniques (Tichem, 1997). Product Data Management technology is hardly used during the earlier phases. During these phases other methods and tools are required. To define Strict

Development the definition by *Life Cycle Processes* or the *Product Life Cycle* involves all the phases from conception through design, engineering, manufacturing, use and maintenance to disposal.

De Graaf is slightly adapted to exclude the Idea Finding phase, resulting in the following definition:
"A sequence of design and engineering processes that converts general product specifications into a detailed product definition for satisfactory manufacturability products, through the application of scientific, technical and creative principles, acknowledging the requirements set by succeeding life cycle-processes."
This definition indicates that idea finding is not included. The activities, to be performed in the strict development phase, are design and engineering. Design determines the rough outline of the product while engineering determines the detailed product definition. The outcome of Strict Development has been defined here as *product definition* instead of the more general term *information*. The product definition involves all the information that is required to describe the product as well as the equipment and tooling that is required to make these products. In the remainder of this thesis the term Product Development will be used instead of Strict Development because most readers are more familiar with the term product development.

3.2.3 Typical characteristics of Product Development Processes

Product development processes (PDP) have typical characteristics. Only those characteristics that are relevant for this research are discussed in this section, it involves:

Uncertainty
At the start of a product development project there can be a lot of uncertainty about the future. "At a fundamental level the development process creates the future, and that future is often several years away. Consider, for example, the case of a new automobile. The very best companies in the world in 1990 could develop a new car in three to three and a half years. At the outset of a new car development program, therefore, designers,

engineers, and marketers must conceive of a product that will attract customers three years in the future. But that product must also survive in the marketplace for at least another four to five years beyond that. Thus, the challenge is to design and develop a product whose basic architecture will continue to be effective in the marketplace seven to eight years after it has been conceived."

Therefore, at the start of a project assumptions are made about the customer requirements, about the demand for the new car etc. Uncertainty comes to the surface when there are changes or unforeseen events. Examples of changes or unforeseen events are changing customer requirements, lower demand or new technology or materials that become available.

When changes or events occur a company has to revise its assumptions and has to determine the new course of action.

This can lead to iterations in the product development process. For instance, if new materials and technology become available during the project then a company has to make the decision whether to apply this new material or technology or not. If they decide to apply it they have to re-do part of their product development process what delays the introduction of the product to the market.

Iterations

In the previous paragraph it was already identified that uncertainty can lead to iterations in the product development process. Clausing (1994) identified two types of iteration that are directly related to the design work itself, *creative* iteration and *dysfunctional* iteration.

Creative iteration is the result of the fact that it is impossible to conceive an idea, consider it from all perspectives instantaneously, and draw the final design. Several iterations are required to consider an idea from several perspectives, which can lead to several alternatives. During the iterations the idea slowly evolves to the final design, *i.e.* select one of the alternatives.

Dysfunctional iteration involves amongst others the stream of changes caused by problems regarding the manufacturability and maintainability of the product or by additional customer requirements. Consequently designers and engineers have to revise their work and that takes time. The later a problem is detected in the project, the longer the iteration and hence the delay. Hence in contrast to creative iterations, dysfunctional iterations do not add value but incur unnecessary cost.

A badly designed product development process can be recognized by looking at the number of iterations over time. The number of changes increases during the development process and reaches its highest point during production. In production all errors made during design are found. Then the number of changes drops because the product needs to be shipped to the market/customer. After that the number of changes increases again because during use of the product new errors are found that were not discovered during design and production. All the changes lead to expensive iterations and hence delay the project.

Product Complexity

Over the last decades the complexity of products increased, amongst others because of the application of electrical and software components. The increased product complexity also affects the number of people that are required to develop a product. Take for instance an aero-plane; Sabbagh (1995) described a Boeing 777 as '*several million of parts flying in close formation*'. Because of the amount of parts it took thousands of employees to develop a Boeing 777.

An example from Korbijn (1999) also illustrates product complexity. He compared a copier from the mid nineties with a copier from the mid eighties (see Table below). Both copiers are able to copy 45 black/white A4 pages per minute. However, the engineers have added much more functionality to the copier from the mid nineties. The following table shows a comparison of the number of components in both copiers as a measure for the complexity. Because of the increase in parts also the number of employees increased substantially, from 500 to 1250.

Table 1- Complexity of a copier

	Mid 80's	Mid 90's
Number of different mechanical parts	3,300	4200
Number of electro-mechanical parts	19	77
Number of sensors	15	52
Number of components on the main control board	443	614
Number of programmable components	1	7
Source code in Mb's	4.5	12.5

The complexity increases more than exponentially as the number of parts increases because the number of possible interfaces between the parts also increases exponentially. Therefore good interface definition is an important activity in product development because it can reduce the number of interfaces (Reinertsen, 1997). But not only has the number of parts determined the complexity of a product. Also the shape of a product or the number of constraints can increase the complexity of a product. Note: In electronics there is a trend towards more functions on a single component (Very Large Scale Integration, VLSI). Hence the number of components decreases, but the product complexity increases because the number of functions increases. Hence in electronics the number of functions is a better measure.

CHAPTER FOUR

4. COMPONENTS OF CONCURRENT ENGINEERING

4.1. WHY CONCURRENT ENGINEERING?

The recent advances in telecommunication and transportation, global alliances among enterprises, and changing customer needs characterize a rapidly emerging global market economy. Products entering this market are designed and manufactured across geographical boundaries and distributed and marketed world-wide. In addition to a world-wide competition, companies are also faced with shrinking *time-to-market* for new products. This is the elapsed time between product conceptions to its actual availability on store shelves. During this period, the product goes through several stages that collectively define the product life cycle (LC).

A crucial stage in the product life cycle is the design stage. Any mistake in the design stage can be very costly in terms of engineering changes and its impact on manufacturing, delays in product release to the market with potential loss of the market, and product recalls in the case of a released product with significant financial losses and goodwill. Hence, there should be special emphasis on the design of the product, to ensure that the product can reach the market flawlessly and in the fastest time possible. G*etting it right the first time*, which is all the more vital in a global market, can be implemented only with a good design.

A company's competitive advantage in the global market depends on its ability to produce high quality products at a low price in the quickest time. It should also be able to continuously innovation both the product and the processes that produce the product in order to respond quickly to the market changes and reduce the risk of failure. The concurrent engineering (CE), is a good tool in achieving these objectives. In the perspective of the above statements, concurrent engineering can be defined as follows:

Concurrent Engineering is the earliest possible simultaneous work of experts from various functions in an enterprise, concerned with producing a specific product, in order to achieve high quality, functionality and manufacturability in the shortest time, for a minimum cost. Concurrent Engineering is primarily an expression for the desire to increase the competitiveness by decreasing the product lead time, while improving its quality and cost.

The main premise of this relatively new engineering method is the integration of the product design, development and manufacturing processes. Concurrent Engineering relies on well founded methods, efficient tools, and a dedicated implementation team for its success. The concurrent engineering way of work requires various engineering activities in the product design, development, and production processes to be integrated and performed in a parallel rather than in a sequential manner [8].

4.2 CE TEAM: DOMAIN EXPERTS

The domain experts come from different functions (departments) in an organization. Each expert contributes individually as well as collaboratively to complete the product design. Product features are negotiated among the experts during the course of the design. All of the domain experts have a specific role in designing the product. For example, a domain expert from the Chemical Engineering function will be useful in choosing the material for a part that will give the best results under certain processes. That is due to the fact that this expert has knowledge of the properties of the material. An Electrical Engineer on the other hand, will be the best person to contact in building a design for a circuit board for a television set. Presented below, are the functions of the domain experts from various departments involved in the design process:

-Manufacturing

This department is responsible for manufacturing the part. The manufacturing expert determines whether the design of the product is well suited for manufacturing. If the design is difficult to manufacture, the expert will suggest an alternative design while maintaining the functioning and the quality of the product. If the initial design cannot be manufactured on the equipment available, the expert of this department will suggest a change, so that the product can be manufactured with the same equipment. The expert will also consider avenues for manufacturing of the part easier and faster, a process referred to as Design for Manufacturability (DFM).

It is very crucial for the manufacturing function to be involved in the design stage. Typically, in the traditional approach, the opinion of the manufacturing department can be heard only in the manufacturing stage. Unfortunately, that is too late for making any changes. If redesigning is required, then it is even worse. The production of the part would stop, and the product will have to go back to the design stage. This will result in losing two valuable characteristics of the product. One is a shorter *time to market*, and the other is a higher price of the product, due to the increased manufacturing cost.

Design For Manufacture and Assembly DFMA is a set of programs, techniques, tools and methods for improving the fabrication of parts or simplifying the assembly of product, by analyzing values tolerances, movements, complexity and environment for automatic, manual or flexible (robotics) assembly. DFM means the design for ease of manufacture of the collection of parts that will form the product after assembly and design for assembly means the design of the product for ease of assembly.

As we know design is an activity that starts with sketches of parts and assemblies and progress to CAD workstation where assembly drawings are produced. These drawings are then passed to manufacturing and assembling engineers whose job is to optimize the process used to produce the final product.

Frequently, it is at this stage that manufacturing and assembly problems are encountered and request are made for design changes. Some times these changes are large in number and result in considerable delays in the final product release and consequently product life cycle cost increases. Therefore, not only it is important to take manufacture and assembly into account during product design but also, these considerations must occur as early as possible in the design cycle.

Thus, DFMA reduces both the cost and the time to bring the product to market. Another reason why careful consideration of manufacture and assembly should be considered early in the design cycle is because it is now widely accepted that the 70% of final product costs are determined during design.

DFMA provides a systematic procedure for analyzing a proposed design from the point of view of assembly and manufacture. This procedure results in simpler and more reliable products which are less expensive to assemble and manufacture. DFM tool encourage dialogue between designers and manufacturing engineers and any other individuals who play a part in determining final product costs during early stages of design.

-Industrial Engineering

This function focuses mainly on the process design. However, since the process design and the product design are not independent of each other, the IE department will also be involved in the product design. The IE expert will tend to design a product to streamline its flow through the entire process from design to manufacturing and beyond. The IE expert can also bring logistics considerations of storing, transporting, and distributing into the design of a product.

-Marketing

The task of the marketing department is to ensure that the designed product will sell. In other words, the product should have to be competitive in the market in terms of its functionality, quality, and price. Marketing determines whether the characteristics of the product meet the expectations of the customer (QFD). Marketing may use forecasting tools and a variety of information ranging from historical sales, demographics, and technology trends to predict the features of the product that are likely to be successful in the market.

-Quality

The quality department attempts to design quality into the product so that inspection can either be minimized or if possible completely eliminated. They also design statistical process control procedures that will ensure that quality is maintained during the manufacturing of the product. Quality function influences product design features to ensure manufacturability of high quality products.

-Service/Maintenance

This department will take care of the service and maintenance of the product. Some products require maintenance. If the conditions for maintenance of the product are not good, then the expert from the service department will react with suggestion for redesigning the product. Sometimes, new and different equipment will be required for maintenance of the product. This department will be informed whether any new equipment acquired for manufacturing the product will need any special maintenance. If it is so, the service department may suggest alternative product designs to keep the cost of training and maintenance down.

-Assembly

An assembly of a part is not the same as manufacturing a part. This process is the actual assembly of some manufactured parts. The assembly department contributes in the design, by using the design for assembly (DFA) analysis. The DFA analysis tends to either reduce the parts of the original design, or change the parts so that they can be more easily assembled. This will result in decreasing the total assembly cost, because the product will have fewer parts, and shorter assembly time.

-Packaging

The expert from this department will work in the CE team in order to design a product, which can be efficiently packed. The packaging expert may develop a product that can disassemble, so all of the parts would fit in the most suitable package, in the shortest possible packing time.

-Environmental

The expert from the environmental department plays very important role in today's industry. The expert will work in making the product environmentally safe (DFE). What this means is, that the product should not contain any hazardous material. Another aspect that this expert may focus on is that the product be made with a recyclable material. This department will also insist in making the production process environmentally safe. For example, recently, there is a tendency to eliminate the use of CFCs (chlorofluorocarbons) as coolant while manufacturing. Hence, the environmentalist will tend to use dry machining for manufacturing the product, rather than regular machining.***Design for Environment (DFE):*** From CE practice, it is known that approximately 75% of a product's total life cycle costs are determined in the design stage. To avoid environmental problems after the design phase, there is no apparent reason why environmental concerns could not also be addressed in the initial phase; overall cost associated with waste stream can thus be reduced.

Besides the reduction or elimination of product waste streams from manufacturing process, the designers must examine the environmental impact of the design when it is being produced or disposed to recoil. Design for recycle (DFR) can play a significant role in this effort. DFR is an infrastructure where the products can be accepted at the end of their useful life by efficiently breaking them down and then recycling the individual products for use in other processes. To enhance eventual breakdown and re-cycling, Design for Disassembly (DFD) principles must be used before the design is finalized. Time, techniques and costs to disassemble are just as important as those factors during assembly. Since time is money, it is obvious that DFE cannot be implemented without added cost. The obvious solution to this is to reduce waste in first place, but more important to ensure that any kind of waste (scrap, material rework, unused inventories etc.) is minimized in all operations and this is one of the principles of CE; all production operations should be optimized to prevent waste and thus reduce cost. Recycle ability of the product at the end of its life is a concern for DFE designer, he/she has the added problem of simultaneously designing for disassembly and assembly therefore reducing disassembly time and associated cost, saving cost and time for the entire product life cycle , benefiting both the consumer and the producer.

4.3 CONCURRENT ENGINEERING VS. TRADITIONAL APPROACH

A comparison of the concurrent engineering model and the traditional model of product realization is shown in Figure 6. As it can be seen, there are huge time savings when concurrent engineering is implemented in the design-to-manufacturing cycle of the product realization. Also the concurrent engineering method does not lead into problems of implementing the design in manufacturing such as costly engineering changes. This will result in reducing the overall product cost.

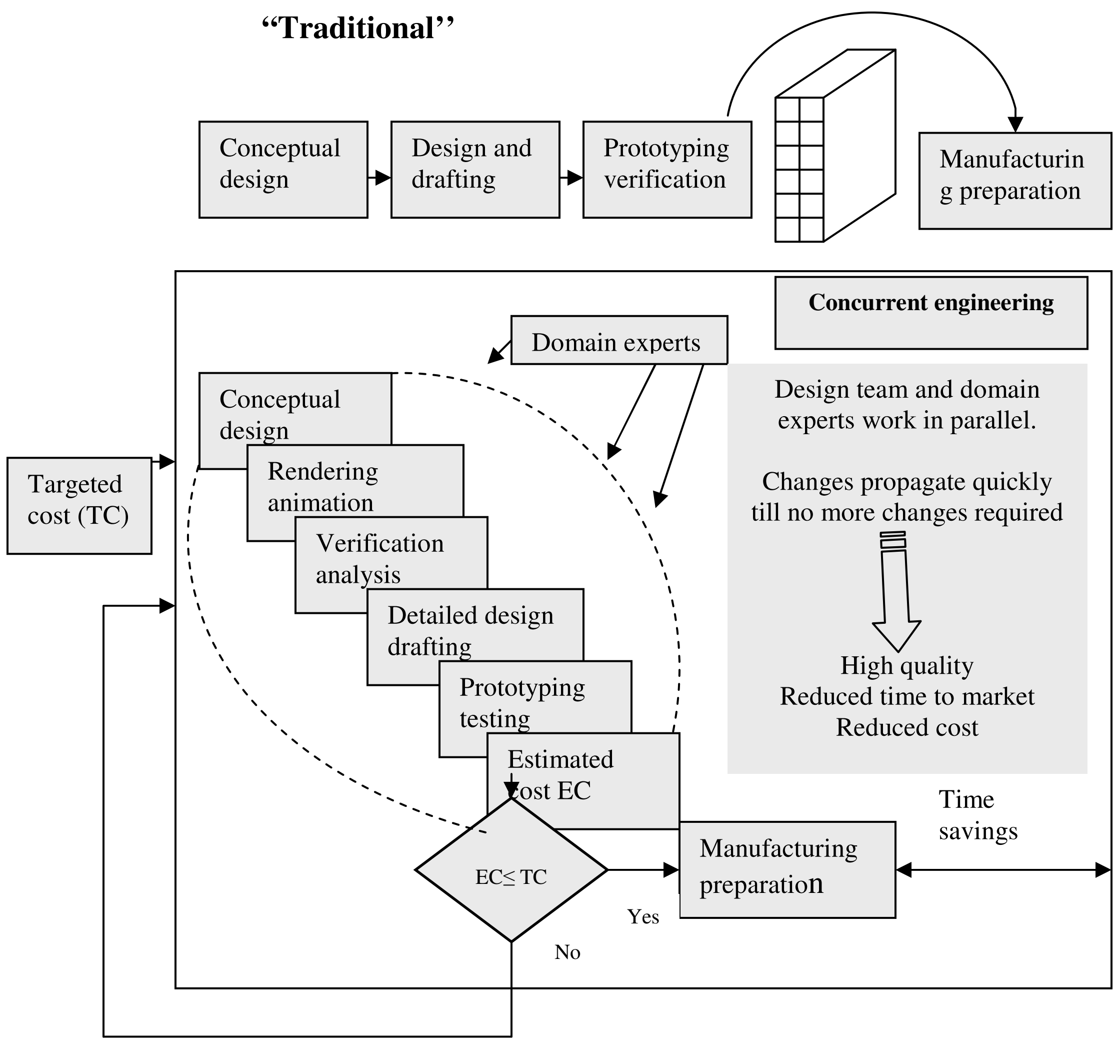


Figure 5 Concurrent engineering design stages

In the traditional model, once the design is made, all of the departments that are involved in the product realization are expected to follow it although they have very little input in the design of the product. A frequently asked question is, *how good the design can be without involvement of domain experts?* Very often, the design team in the traditional model does not have the knowledge and the skills to make a product that will be functional, of high quality and manufacturability.

After the design team completes its task, the production processes are designed based on the design of the product. Therefore, if the product is poorly designed, the ensuing processes will be poorly designed too. For example, if the manufacturing department has a part, that is difficult to manufacture due to the poor design, considerable time will be expended in order to manufacture the part. To accomplish this, sometimes, the manufacturing department introduces changes to the original design such as either updating the part tolerances or changing the number of parts in the design. At the same time, the changes in the product design may not be either communicated to others in the product realization process or too late to prevent decisions that are based on the original product design. At any rate the traditional model is vulnerable to a costly and error prone product realization.

Figure 6 shows that while the CE design method begins with a cost target for the product, the traditional method has no such benchmark. Following the design stage, the CE team compares the derived cost of the product design to the targeted cost. Only if the estimated cost is lower or equal to the targeted cost, the production of the product can begin. Such design discipline is essential to ensure that the price of the product is competitive in the market.

It is obvious that by following the CE model all the disadvantages of the traditional model can be avoided. The difference in the two approaches will be more evident upon study of the overall production cost in the product's life cycle.

4.3.1 THE TRADITIONAL PRODUCT REALIZATION MODEL

The traditional model of designing a product has been in use for decades. This method was useful especially when companies enjoyed significant market shares and the competition was either very limited or nonexistent. Today, however, the market is highly competitive and consequently the traditional method is deemed unattractive in favor of the CE method. The traditional product realization is shown in Figure 7

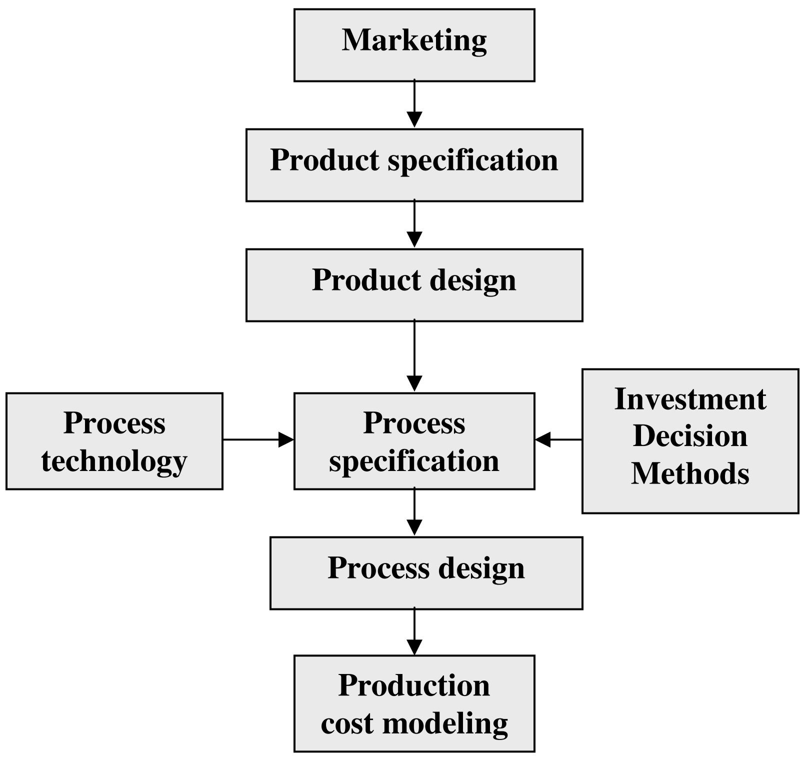


Figure 6 Product realization methods with traditional Engineering design

The first phase of the traditional method is the *marketing* phase. In this phase, the marketing department determines that there is a need for a new product, or improved version of an old product.

In the second phase, based upon the marketing research, the *product performance specifications* are determined. For example, if the product is an automobile, it is decided what will be the maximum speed of the car, will it have brakes, dual air-bags, power windows, etc.

The third phase of the traditional model is the *product design* stage. In this stage, the design engineers design a model based on the specifications given in the previous stage. Unfortunately, although they consider making the product easy to manufacture, assemble, and service, their limited knowledge will produce a product that is not that easy to manufacture, assemble, service, etc.

In the fourth phase, the *production system specifications* are determined over issues, such as, what kind of equipment will be used to manufacture the product, and how much will be invested in the production system. It is determined what processes are going to be performed on the product, and their sequence of operation. Since the specifications for the production systems are given, the specific design of the production system is made. Here, the plant layout is designed. It is determined how many machines will be used, and the product flow while being manufactured. For example, the layout of the machines will be in circular form, so the product will end up in the system at the same place where it began. At the end, the production cost is being determined. Based on that, it is agreed upon the product price. After this phase, the manufacturing of the product can start.

4.4 DESIGN ENGINEERING & ANALYSIS

Normative concurrent design engineering and analysis process and its supporting functions are shown in Figure 7.

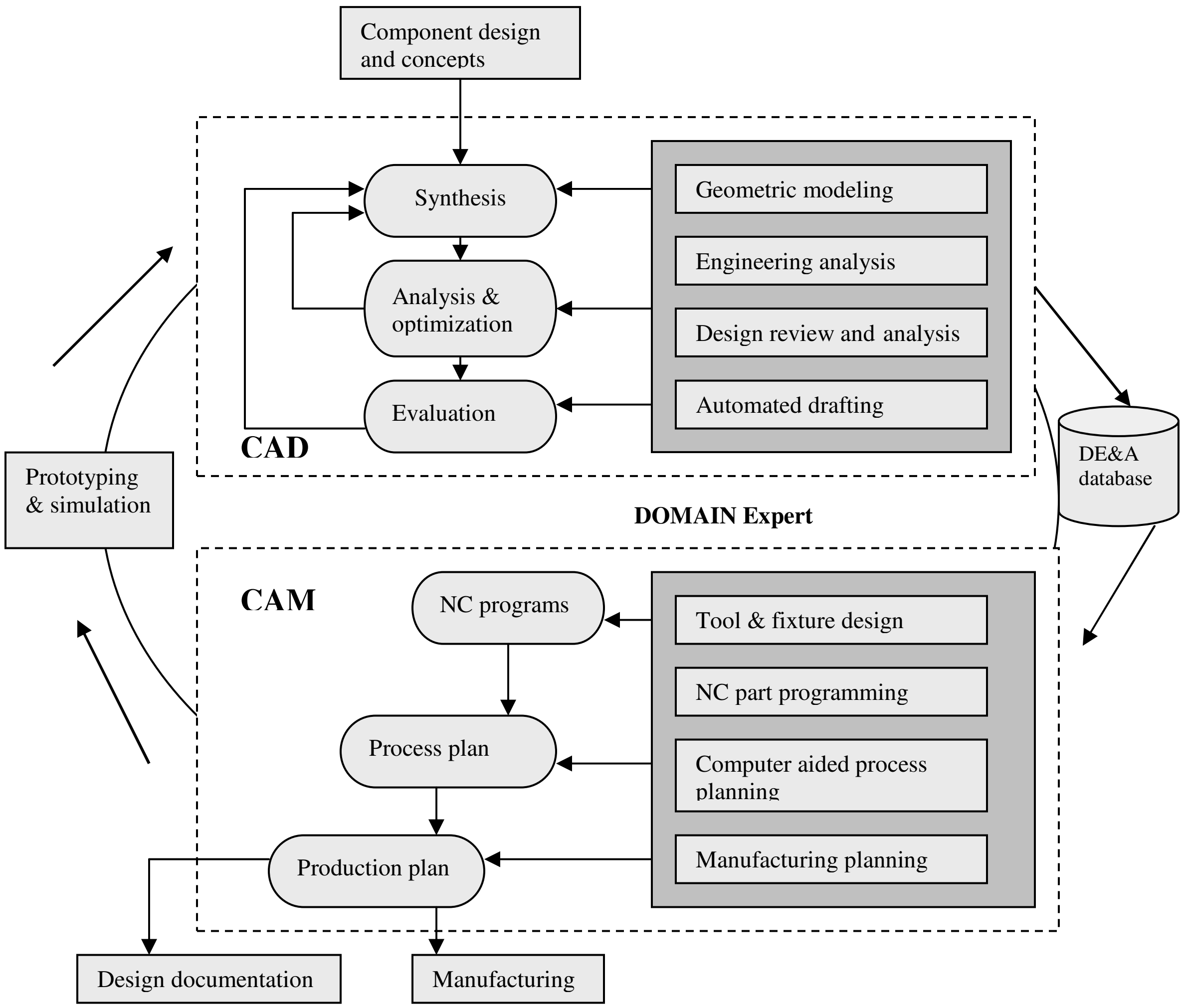


Figure 7 A Normative concurrent design engineering and analysis

The process begins either with the component design or some concept definition. These may include a number of competitive product attributes including the desired physical and functional characteristics, cost, quality, and operating performance.

Synthesis and Analysis & Optimization are closely related and core of the Computer Aided Design (CAD) process. The component design or concept definition is first modeled and then subjected to analysis by the related CE team for improvement and redesign. The process is repeated until no domain expert imposes a conflict and the design is optimized within the constraints. Evaluation is concerned with measuring the design against the requirements expressed in the first step of the design process. The CAD functions to support the process steps described above include Geometric modeling, Engineering analysis, Design review and Evaluation and Computer Drafting. Following the CAD process, the design data is transferred to the Computer-Aided Manufacturing (CAM) process where the tool path is automatically generated and NC programs developed, the process plan for fabricating the design is specified, and a feasible production plan developed taking into account manufacturing constraints. The manufacturing activity is not part of the design engineering and analysis phase although constraints imposed by manufacturing are included in the design process (i.e. design for manufacturability). The CAM functions to support the aforementioned process steps include Tool & Fixture Design, NC Part Programming, Computer Aided Process Planning, and Manufacturing Planning.

The CAM output is evaluated through prototypes and simulations of the manufacturing process and production plans. The overall outcome of the design engineering and analysis process consists of the documentation of the design: drawings, material specification, assembly list, subassemblies, tools and fixtures required to manufacture the product and creation of a design engineering and analysis database. The facilities including hardware, software, and laboratory facilities for realizing the concurrent DE&A process is also described.

CHAPTER FIVE

5. CONCURRENT ENGINEERING COMPETITIVE ATTRIBUTES AND SUCCESS STORIES

5.1 THE COMPETITIVE PRODUCT ATTRIBUTES

Concurrent Engineering aims to develop the "best product" for the market. A number of attributes characterize such a product and some of them are reviewed here. These attributes in turn motivate the goals, objectives, and constraints of the CE model.

Attractiveness

The product has to be overall attractive to the customers who imply that it must have good design, functionally competitive, and also provide more value than the customer expects for the price charged.

High quality

Customers typically expect and look for high quality products. This in turn implies that the product is:

- *Reliable*

  The ability of a product to perform a required function under stated conditions for a stated period of time.
- *Available*

  Under certain conditions, the product should be able to provide quality performance, when called upon.
- *Maintainable*

  The customer is looking to buy a product that does not require a lot of time and money to maintain it.

Lower (Affordable) Price

The price that the market can bear is often difficult to estimate. At the same time an unaffordable but well engineered product does not sell well in the market. CE method strives to cut down on the lead time to bring the product to the market and does so in the most efficient manner to reduce the price of the product.

Safety

The safety issue is very important for the product. The product has to be functionally safe, child safe, environment safe (not to be hazardous), etc. The reliability and the availability of the product play a big role in this too.

Recyclable

There is a world wide trend in buying recyclable products. Therefore, the product will have to be recyclable in order to keep up with the competition. Also, it allows a firm to save money through reuse of the same product rather than purchase new raw material.

These product attributes are generally considered in the design stage. As much as possible, the CE team tries to achieve these goals.

5.2 PRODUCT LIFE CYCLE WITH CONCURRENT ENGINEERING

As it can be seen from Figure 7 (production realization phase) and Figure 8 (a normative concurrent design engineering and analysis), the design team and the domain experts work on issues such as manufacturability, assemble-ability, and testability of the product. This team work is crucial in ensuring that the product will be convenient to manufacture, assemble and test. However, in the CE model it is also important to decide on issues regarding human factors, reliability and maintenance of the product, and the overall feasibility of the cost estimate of the product.

Total quality management Figure 9 describes the compressed product and manufacturing process design cycle under concurrent engineering. This figure clearly identifies the phases and the associated sequence. The integration comes in the product design and modeling phase, and it ends with the prototype testing. However, prior to any prototype testing, the material for the product is selected and the manufacturing process and system design are completed. Based on the functionality, cost, quality, aesthetics, and other requirements, the design team makes the first draft. The first draft goes to the domain experts (concurrent engineering team domain experts' note) to be reviewed.

The next stage in the CE product life cycle, is the *Manufacturing system construction and installation*. In this stage, the preparations for the planned manufacturing process begin. The manufacturing system is being constructed, the equipment is being installed, and the raw material is being ordered.

The following stage in the system is the *Manufacturing/ Fabrication* stage. In this stage the production begins. The production system is working the way it was designed, the parts are on the production line, and they are on the way to be shipped to the marketplace.

The subsequent phase in the CE product life cycle is the *Customer (Service/ Maintenance)* phase. This is the stage when the product is already purchased by the customer. The customer takes the product to the service/maintenance department, where the product is evaluated due to the service and the maintenance required, as well as from the customer's opinion.

The following phase is the *Continuous improvement* phase. This is a phase where the inputs from the Service and the Maintenance department are considered, and alternatives for improving the process and the product are suggested. These alternatives will be used by the design team, in designing the new model of the product.

The last phase is the *Environment (Recycle/Waste)* phase. Here, the first product life cycle finishes with the product disposal in the environment. If possible, the product is recycled and reused. Currently, most of the products end up in the waste disposal.

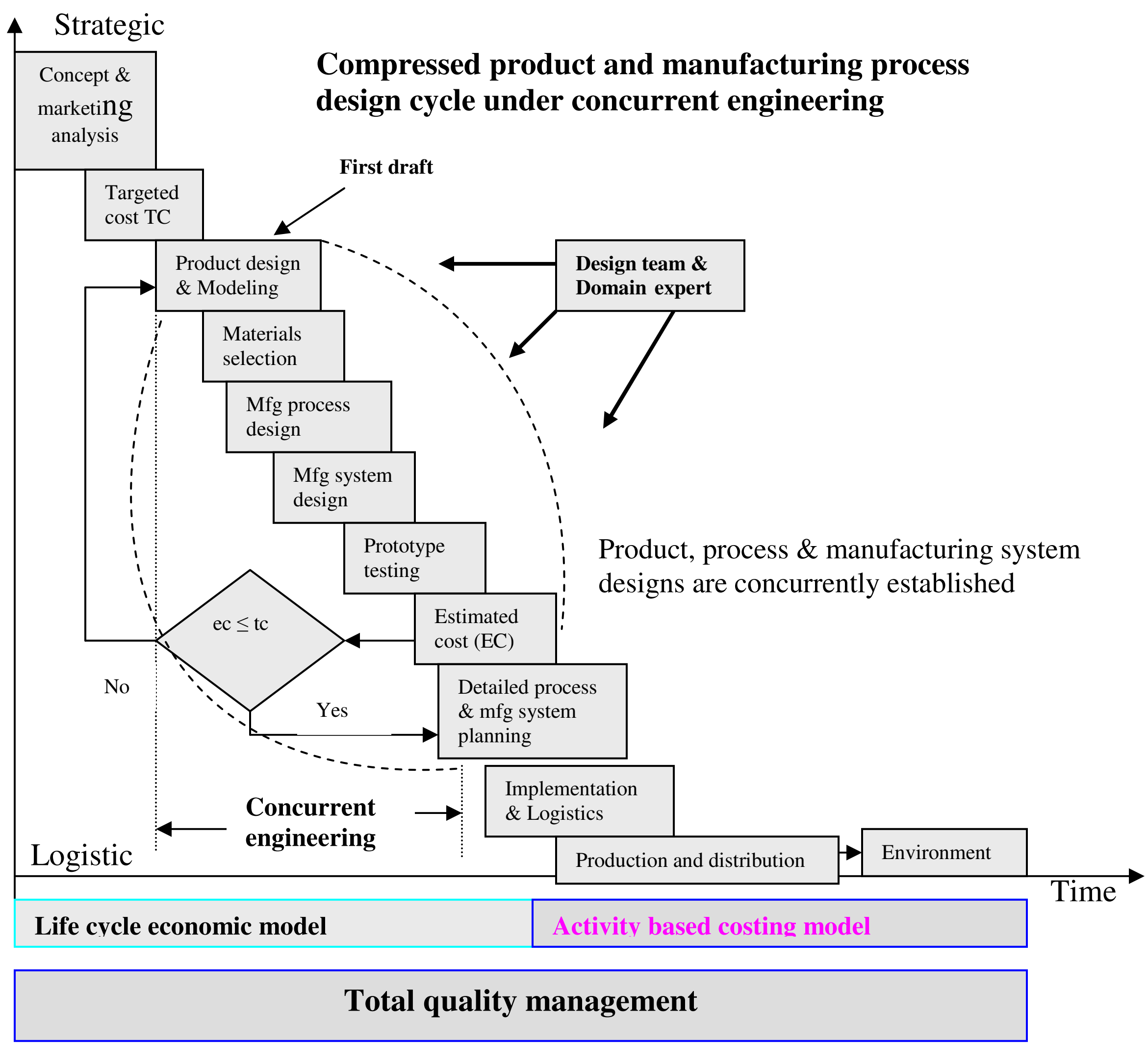


Figure 8 Compressed product developments under concurrent engineering

5.3 EXAMPLES OF CONCURRENT ENGINEERING PRODUCTS

Example 1: Aurora

Not your Father's Olds, Not Your Father's GM

General Motors has finally done it, but does it really "get" it? The new Oldsmobile Aurora is definitely not your father's Oldsmobile. With its tubular styling, leather seats, multi-valve engine, and quiet, solid ride, the Aurora is bound to give the Lexus-Infinity-

BMW-Mercedes luxury bunch a run for the money. Furthermore, it is priced several thousand dollars below the competition.

But before Olds managers finish their champagne, they should remind themselves of one simple fact: the success Olds has had in putting together a team from engineering, design, marketing, and manufacturing to work together from concept to launch is surprising only in the context of fief-ridden GM. This concurrent engineering is old hat to the Japanese. Chrysler has built its comeback on the concept.

It was the self-congratulations for listening to consumers. The Aurora team held focus groups all over the country to find out what people wanted in a luxury automobile before they designed the car. Smart, but again, this is remarkable only in the context of its being so rare inside GM. The auto company has had a long history of ignoring consumer input until the final stages of development, when it is often much too late to make a difference.

The Aurora is GM's first success in internalizing lessons learned from developing Saturn. Now it must race to spread the news throughout its other divisions. Time is running out. The $2,000 price advantage U.S. carmakers now have over their Japanese rivals won't last forever. The article is taken from Business Week (Mar 21, 1994.).

Example 2: Honda

Honda (Marshville, Ohio) is designing and cutting dies for its Ohio plant at Marshville using CE. They begin die making production at the same time they start body design. The die designer knows the approximate size of the new car and the approximate number of panel so they go ahead and order blocks of die steel. Then they begin to make rough cuts in the steel, so it's ready to move to final cutting as soon as the final panel designs are ready. Also die makers seem to be much better at scheduling production in the die cutting shop and the die cutter have special quick-change cutting tools, allowing one machine to handle many different types of cuts, so the dies that are being cut spend much less time in queues.

What the end result of this intense communication between panel designers and die makers plus accurate anticipation by die makers and clever scheduling of flexible cutting machines? It means that they can produce a complete set of production-ready dies for a new car in one year, exactly half the time needed in a typical die-making. Not surprisingly, this process require fewer tools, lower inventories (since the key element, the expensive die steel, is in the shop only half as long), and less human effort. This process of course involves considerable degree of anticipation. The die designer must understand the panel-design process.

Example 3: The American Automobile Industry

Recently it was a well-known fact that everybody could recognize that the Japanese cars were the one to buy, surpassing their American competition even in the US. It seems that the Japanese car industry focused their time and money in improving the quality and the design of the car. In the same time, it seems that the American automobile industries spent no time on these issues.

Just few years ago, that was the only truth about the American car industries, and not just that. The American cars would just not measure up. That certainly was not the fault of the American workers, since the American workers working for Toyota and Honda in the US, produced the same effective results as the Japanese workers.

Back in the good all the days of the American cars, three out of four automobiles in the world were made in USA. In these times, after the Second World War, the economy was growing, people had more money and the gasoline was extremely cheap. In those days making good numbers was what was appreciated, while often improving the processes of making cars was neglected. The things changed however with the increasing the price of the gasoline, and the introduction of the cars that would spend less gasoline than the American cars. It was the Toyota, and the Honda. Their advantage was not only the savings of the gasoline expenses, but also their price.

In the times when it was a success to make a car that would not fall apart after finishing a race, the Model T showed up as inexpensive and quality car. Ford's engineers afterwards created tools that would manufacture parts to exact dimensions. The mass production was ready to start. Later this growing company was divided into divisions. The divisions were broken down into specialized departments, like finance, engineering, purchasing and sales. The communications among these departments took place through top executives who made the key decisions. The emphasis was on control. These departments started functioning as a separate business, and their objective was to take care of their departments' interests, rather then the interests of the company. The new products were initiated by the senior management, and after consulting with sales and finance, the product would go to the design department. The completed design would then go to engineering. In this phase, the engineers conclude that if only they have been called earlier, they would change the design to improve the quality and the manufacturability of the part. Unfortunately, that is already too late because for any changes, the product would have to repeat the previous stages again. Due to the redesign expenses, as well as the inability of each of the previous departments to teamwork, the design would most likely not be changed and would sell with all the defects. Yet, until the seventies, there was no competition so these products were just fine.

Since the car appearance, the Japanese tried to copy the American cars. The first Toyota was a copy of Chrysler and the Ford T Model. Since Japan did not have enough workers, the company offered lifetime employment, and therefore, these workers were ready to dedicate themselves to team work and implement Kaizen (constant improvement.) Another thing that the Japanese workers discovered first was JIT (just in time) system. They made factories with assembly lines which would be able to manufacture different types of products. With this ability, they managed to avoid unnecessary storage and delays. Those assembly lines would manufacture the products supposed to arrive at the following work station in the near future. The best of all is that the lines can work on one and then another product without even stopping. The effective team work takes the praise for this. In this team are the workers who are empowered to take decisions. Empowering workers is an asset that reduces the need of a lot of management. One of the major objectives of these teams is to simplify the things as much as they can be simplified. How do you get things done in the least amount of time using the fewest people and doing it for the least amount of money? That is all that is important. Concurrent Engineering, although invented in the United States, was used first in Japan. Its principles, producing a product for the lowest cost possible, at a minimum time to market, and of high quality, brought Japan to the title of the world largest automobile production nation.

In 1988 Chrysler did a study of Honda, as Toyota had done with Ford decades before. What Chrysler discovered is that the top management of the cooperation in fact did not design the cars, but it was the teams that did the complete design. In these teams there are specialists from various departments. They stay in the team from the beginning to the end of the project, and they often assume responsibilities outside their discipline. The Concurrent Engineering, as well as the TQM (assuring the quality of the product during the complete product's life cycle) principles gave the American Industries a chance to go back and fight for their share of the market. The fact however is that people in the US would oppose such an action where the managers would have to share the power, the middle managers would possibly disappear, and the workers would have another obligation added. The new reality for Chrysler is that the system must change, and they have to enforce empowerment. Chrysler also created teams of specialists and moved them together away from the headquarters of their discipline. When designing their model, the Chrysler specialist discovered they were making the rules as they were working. They also reduced the time to a minimum by breaking down the walls between the departments. The team also has the best new technology. CAD/CAM systems and stereo lithography machines help the designers to have a better vision of what they have designed.

Another major issue that Chrysler undertook is following the Japanese example in dealing with the suppliers. The suppliers and the customer have to have a mutual trust. The supplier has to know that he is part of the company, and if he helps the company, not just the company will gain, but also the supplier. The supplier is supposed to be strictly informed and all the time contacted about the details of the work. In other words, there should be constant communication between the supplier and the company. In the past, there was yet another wall between the company and the supplier.

Today, the American Cars are back. Once again they are popular. The car industries here managed to do so because they understood that in order to survive in the new global economy, you have to keep improving. Concurrent Engineering, TQM, and QFD (listening to your customers needs), are the major tools that help the American auto industry today to implement the KAIZEN theory of keep on improving.

CHAPTER SIX

6. CONCURRENT ENGINEERING CULTURE AND STAGES

6.1 CONCURRENT ENGINEERING CULTURE

Despite all the benefits that can be obtained by adopting the Concurrent Engineering, in practice it is not easy to switch from the traditional ways of realizing a product. Most companies, over the years, have been fostering a culture based on the traditional engineering method. Their employees have acquired work habits that belong to the traditional model, and they are quite comfortable with them. Most of these employees do not have much experience working in cross-functional teams making it more difficult to switch to the Concurrent Engineering method that relies on a cross-functional team. Therefore, before implementing Concurrent Engineering, it is necessary to work on changing the company culture. Some suggestions for adapting (improving) the company culture to the CE model are listed below.

- Clear Mission:
    - The purpose and the business mission of the project, as well as the project's objectives and goals must be clearly expressed to all in the CE team.
- Management Involvement:
    - The management should encourage cross-functional team work by assigning and empowering interdepartmental working groups.
    - The domain experts should be made aware of the values of teamwork, namely, that the sharing of ideas and goals beyond their immediate assignments and departmental loyalties. This will contribute strongly to the new product design and specifications, and will assure good warranty levels, easy serviceability, and testability of the product.
- Communication:
    - Improve the communication among participants by making best use of technology such as telecommunication and video conferencing devices.

   - Break the traditional barriers among working groups to facilitate interaction between the team participants.
- Training:
   - Training plays very important role in the CE team. As engineers move to a team, they have to have training for critical skills such as problem solving and conflict resolution.

6.2 STAGES OF CONCURRENT ENGINEERING AND THEIR PRIMARY CRITERIA

The following list identifies the phases of Concurrent Engineering and the goal for each. After each goal is a set of bullet items that indicate the primary criteria that must be met for that phase to have accomplished its purpose. Violation of any of these criteria will result in damage to the quality process, and subsequent inadequacies to the project.

1. **Project Identification**

   Goal: Ensure a single direction for corporate development to avoid shifting priorities, false project starts, and pre-empted project efforts. Provide a simple, clear process to start the project track.

   - Get executive commitment and goal consistent with business objectives and corporate vision for project.
   - Define a central point for approval, prioritization, and scheduling for all projects.

2. **Project Scope**

   Goal: Estimate the project's effort, time, and cost so executives can make an informed decision about the projects' worth.

   - Confirm the expectations of the Customers and get consensus with them and the executive and corporate goals.

- Support the project's success by avoiding unrealizable date or budget constraints or unallocated resources.

3. Requirement and Analysis

Goal: Build and validate a model of the business problem domain to ensure the correct problem is defined and customer needs are accurate before attempting a solution.

- Get requirements jointly with the user and write a specification that can be implemented, tested and explained.
- Provide traceability between the customers needs, system solution, and testing to enable change management.
- Justify project needs are best met by comparing purchase, build, or hybrid solutions (cost/benefit analysis of vendor proposals).

4. System Design

Goal: Provide a technical solution that meets the customer needs and enhances the corporate business position and value.

- Design and validate a technical solution at the high level.
- Define metrics to predict time of implementation and development effort, and to be used later for process improvement.
- Build a test plan from the requirements, not the design or code.

5. Development Planning

Goal: Define a work plan for implementing a technical solution, whether a purchased package, new development, maintenance change, or a hybrid.

- Collect work plans for testing, customer acceptance, development, and documentation, and ratify with all involved.
- Get written consensus on the project plan specification from all involved.
- Define a strong QA policy to ensure process compliance and product correctness.
- Establish configuration management for changes, defect resolution, and project control.

6. Construction

Goal: Install or construct the solution, using a mini-release, risk-driven and priority-driven approach, to run concurrently with testing and low-level design. Validate low-level design, collecting interface specifics (e.g., screen and report layouts) from customers.

- Perform regression testing to maintain quality and avoid later rework.
- Track personnel effort, time, and defect rate to monitor project and set a baseline for calibrating the project team and process efficiency.
- Separate developers from any testing except unit testing and their contribution to system testing.
- Define a procedure by which QA and the customers approve the release, and not the development team.

7. Installation and Assessment

Goal: Ensure a solid and methodical way of moving the product into the customers' environment as smoothly as possible.

- Emulate the production environment to test the final product for capacitance, stress, and performance. Examine growth potential and adjust accordingly.
- Access the project and process with the collected metrics to improve the process and calibrate the teams for future predictability.

6.3 SERVICE PRODUCTION SYSTEMS

A service is an economic activity that produces time, place, form, or psychological utility. The main features of a service, which distinguishes it from a product, are intangibility, heterogeneity, and inseparability of production and consumption [25]. These features emphasize the essential uniqueness of service management and dispel the common belief that manufacturing management principles can be applied to services without recognition of the uniqueness of the service delivery system.

Service design is the determination of design specifications for a new service that fulfills the needs and desires of a customer. These needs and desires, customer wants, are usually captured through customer surveys or questionnaires performed by the marketing function of an organization. Customer wants are then translated by management into performance specifications, which in turn will be translated by service designers into design specifications. These design specifications are fed to the delivery function of a service firm to implement during the delivery of the service. The process of service development and delivery, as described above, is depicted in proposed model.

6.3.1. Service Quality

Service quality can be defined as a measure of how well the service delivered matches the customer expectation of the service [19]. A service quality model is shown in figure 10. Service quality is labeled as gap 5, the discrepancy between the expected service and the perceived service. The model shows consumer's expectation of a service is influenced by communications with other consumers, personal needs, and past experiences. On the other hand, the consumer's perception of a service experience is influenced by four different types of gaps:

Gap 1: between consumer's expectations and management perception of those expectations.

Gap 2: between the management perceptions of customer expectations and service quality specifications.

Gap 3: between service quality specifications and the level of fulfillment of these specifications during service delivery.

Gap 4: Discrepancy between service delivery and external communications to the customer [2]

One of the major disadvantages of the above development process is that it is sequential process. Being sequential in nature the voice of the customer passes through too many transformation procedures and filters before being actually translated into an actual service. Thus, with every transformation point the gap between the customer and the delivery system grows bigger. Finally, resulting in a great discrepancy between the customers' expectation of a service and their perception of the service experience

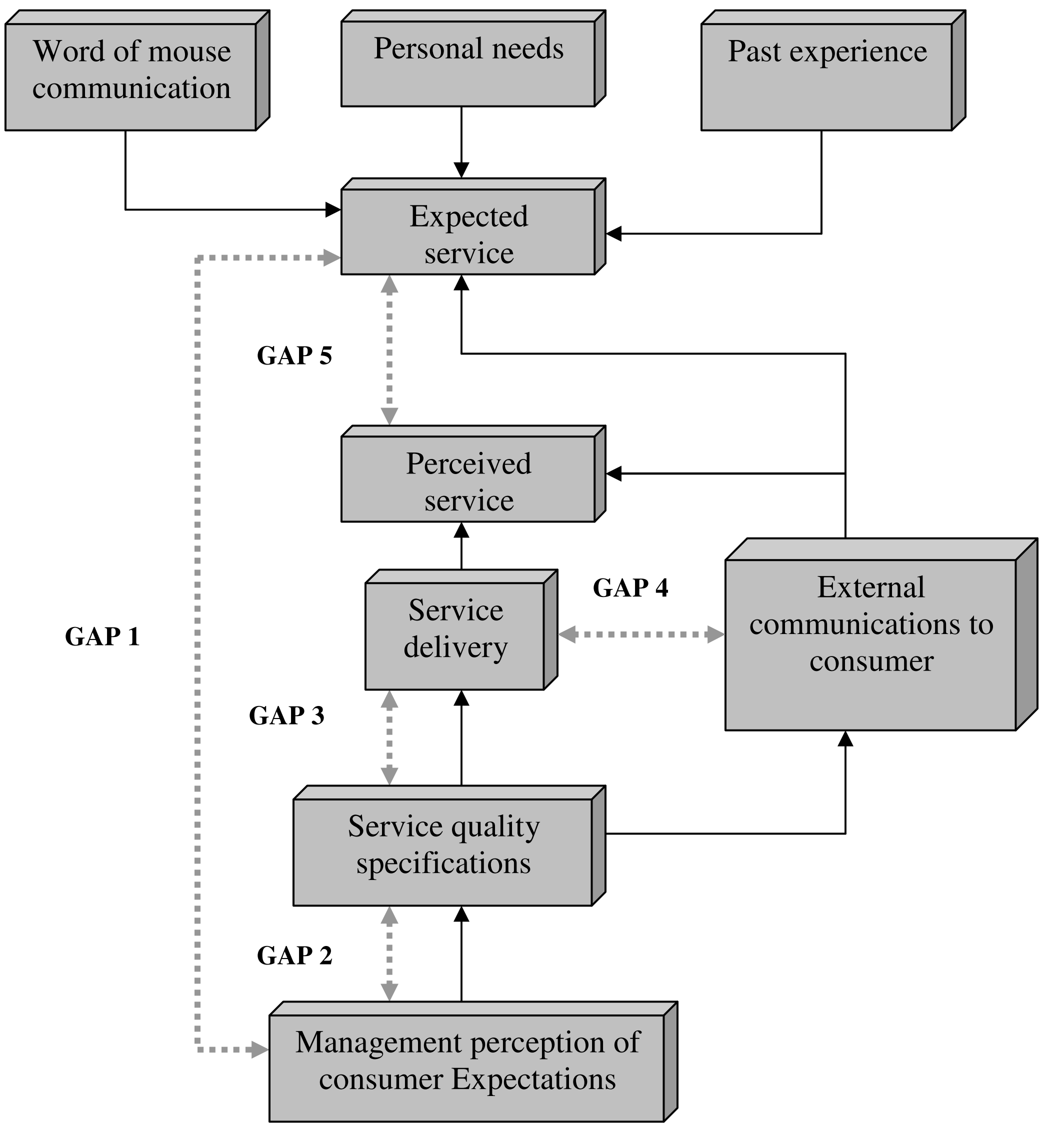


Figure 9 service Quality model

6.4 COMMUNICATION AND DATA MANAGEMENT

Nowadays there are many methods to communicate with each other, both traditional and telecommunication methods. Every method has its benefits and disadvantages but the main thing is to control the data and its distribution in a proper and easy way. In table 2 there are some benefits and disadvantages of some communication methods. It is necessary to agree on which method to use in a project. It is essential to control all the project data and therefore the project team must think about and synchronize the following.

- Data acquisition and data transfer between design teams and software
- Data compatibility and timing concurrent and real time use of software
- Data distribution: Public Vs classified information, access rights, data correctness and integrity.

Data management interfaces should be simple and easy to use. Nowadays intranet and extranet pages are effective way to distribute data to all partners. Most companies have traditionally many design and management software but concurrent engineering requires effective integration of the software.[19]

	Benefit	disadvantages
E-Mail	+ It is possible to reply whenever you have the time + privet	- Difficult to know if the recipient has read the message - It is possible to send the email to a wrong address
Discussion group	+ many people can attend +It is possible to trace a large discussion	-Some people do not read the message. - some people are afraid to write their opinions in a public group
Phone	+ accessibility is good with cell phone + easy and fast	-It is necessary to write down decisions separately - possibility to misunderstand
Fax	+official + It is easy to write and draw many things easily	- show, especially with large amount of data
www-page	+ a good place to store data + easy to manage and find a large amount of data	-some people do not read www-pages -regular maintenance is necessary
Personal meeting	+ effective communication + It is possible to make acquaintance + It is possible to learn to know a person	-Traveling -It is necessary to write a memo separately

Table 2 *Possible benefits and disadvantages of communication methods*

Software integration

During product development process there are various software used in a company. To gain all the benefits of concurrent engineering the design data must be integrated. Examples of software that are used in simulation based design (both design and management) are:

- Computer aided design (CAD)
- Computer aided Manufacturing (CAM)
- Production system Simulation
- Enterprise Resource planning (ERP)
- Product Data Management

- Email
- Project management software and Etc.

All of this software generates a lot of data that must be controlled. The same data can be used in various soft wares and by many people. Software integration helps to manage data transfer and use. Naturally it must be considered if the software integration is necessary, sometimes separate software will work fine if the project and data management interfaces are in order. Some software is almost impossible to integrate, so every case has to be thought separately.

In the future many software companies will produce integrated software including options for many design phases. The result of the trend is divaricated, when using totally integrated software data management and distribution are easy. On the other hand, the total cost for all necessary options can be too high or the software does not work properly with other vendors' products. In any case it must be remembered that the software integration is the last phase when implementing concurrent engineering. Organizational changes and personnel training must be in order before taking use the new data management systems.

In the table below there are some benefits and problems of integrated software, beforehand it is almost impossible to know if the software works properly, so testing various software in advance is recommended.

Benefits	**problems**
+ data transfer is fast, easy and reliable + communication and understanding between partners is better + co-operation is easier, because it is possible to concentrate on relevant issues + it is possible to use the same data in various applications	- Integrating separate software can cause compatibility problems. - The system can be in separate pieces, so the data management is often imperfect. - System/software must be adapted to the company. Just technological quality is not enough. - Software integration is often slow and expensive, also maintaining cost can be high

Table 3 Possible benefits and problems of integrated software

Traditionally concurrent engineering has been used in manufacturing industry, but its idea can also be used in other organizations. Previously mentioned organizational and software requirements does not differ much from industry to a research organization.

CHAPTER SEVEN

7. CASE STUDIES, PROBLEM IDENTIFICATION AND IMPLEMENTATION GUIDE

7.1 VISION, MISSION AND ORGANIZATIONAL STRUCTURE

The ***Vision*** of the Addis Engineering Center Company:

- To be competitive modern and quality tools and spare parts supplier, and research center to defense industries.

The ***Mission*** of the Company:

- To supply with competitive price and quality products of tools and spare parts for the arms produced, maintained and modified by various defense industries in order to strengthen and ensure the readiness of the national defense force.
- To work with different industries under the Ministry of National Defense in order to satisfy the needs of the Ministry cope up the dynamic change of technology and the influence of the global market.
- To be a source of income for defense Minister by producing products.

The ***Objectives*** of the Company:

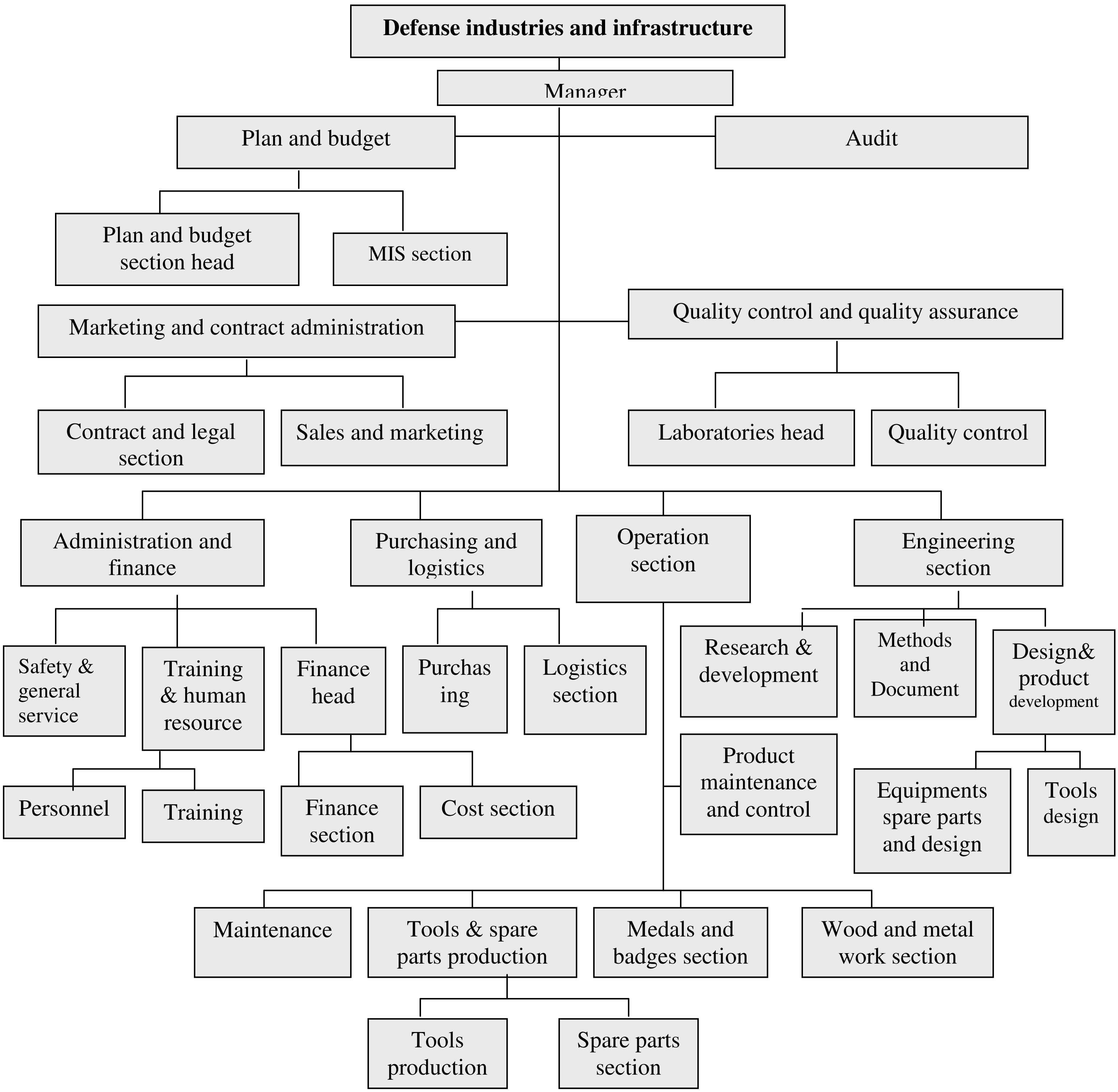
- To produce competitive price and quality products based up on the requisition of Minster of Defense and Defense Industries.
- To produce products which are competitive in price and quality for the local market to satisfy the demand of customers
- To Design and produce tools, dies, jigs, fixtures, and so on
- To produce different types of spare parts
- To perform different engraving and pressing works (like medals, badges, etc)
- To conduct research on machine tool design and engineering materials
- To produce wood works and metal works furniture.

The ***Values*** of the company:

- To have well known Company's name and to keep Company's reputation
- Customer is partner and Customer satisfaction

- ❖ Company with no ground for corruption
- ❖ Avoiding environmental pollution

Organization structure of Addis Engineering Center



7.2 DATA COLLECTION AND INTERPRETATIONS

1994-1998 EC sales plan				
Year	**Type**	**Plan**	**Performed**	**Percentage**
1994	Wood and metal	3,000,000	3,165,871	106
	Medals and badges	1,500,000	1,371,500	91
	Tools and spare parts	500,000	222,339	44
Total		**5,000,000**	**4,759,710**	**95**
1995	Wood and metal	3,450,000	5,495,400	159
	Medals and badges	1,725,000	1,402,462	81
	Tools and spare parts	575,000	709,790	123
Total		**5,750,000**	**7,607,652**	**132**
1996	Wood and metal	17995000	12211098	68
	Medals and badges	2245800	4236720	189
	Tools and spare parts	2000000	491484	25
Total		**22240800**	**16939302**	**76**
1997	Wood and metal	11851000	11797790	100
	Medals and badges	5271000	8643129	164
	Tools and spare parts	3000000	1247982	42
Total		**20,122000**	**21688901**	**108**
1998	Wood and metal	10000000	9547710	95
	Medals and badges	5210000	6526706	125
	Tools and spare parts	5000000	748908	15
Total		**20210000**	**16823324**	**83**

Addis engineering center’s actual plan and performance 1994-1998 EC

Work flow in Addis Engineering Center

S/N	RESPONSIBLE SECTION	EXPLANATION
1	customer	The customer may come with different tools and spare parts. He/she may bring sample, drawing or idea
2	Sales/marketing	This section records the requirements and needs of the customer and provide to the chief planner
3	Chief planner	He/she analyze the question of the customer and ask the process planner and control to be cost.
4	Process planner and controller head	He/ she will see and lead to the process planner
5	Process planner	If the questions do not have drawing, he/she will make the drawing to be made. If so, he will prepare the bill of material, labor and the required machines and then provide to PPC (process planner and control) head.
6	PPC head	He will compare and contrast bill of material and labor with the ordered job then send to finance.
7	Finance	Finance will calculate and give the cost estimation based on BOM and labor and finally provide to the manager.
8	Manager	He will see the cost and order to continue the job.
9	Finance	After receiving from the manager, it will give to sales/marketing
10	Sales/marketing	Prepare Performa and provide it with the delivery time.
11	customer	Based on the cost, delivery time, the customer may or may not agree. If agreed the job will be done through the order of sales section.
12	Casher	He/she receives half or full payment and gives receipts to the customers.
13	customer	The customer will provide the receipt to the sales/marketing
14	sales/marketing	Inform the chief planner to be done the customer's job
15	Chief planner	By filling production requisition form, he/she will transfer the job to PPC head.
16	PPC head	He will put sign (lead) to the process planner.
17	Process planner	He will make ready drawings and technological procedures.
18	PPC head	He thoroughly sees technological procedures and drawings and returns it to the process planner.
19	Process planner	He records the job and passes to the workshop planner.
20	Work shop planner	Technological procedures and drawings are recorded on work process record and passed to tools and spare parts head
21	Tools and spare parts head	After he/she checked the full information and documents, he will send it to the supervisor under him.
22	Forman	He will record the job on the follow up record and ask his boss store requisition for the raw material.

23	Tools and spare parts head	He /she will see the raw material requisition and sign on it
24	Logistics head	He/she allows the requisition.
25	Raw material head	Based on the requisition, size and amount of the raw material, he will give the requested Material to the Forman by signing on store issue voucher.
26	Forman	Assign the appropriate machinist looking the technological procedure and drawing by filling the work order form
27	Lathe machinist	After finishing his job based on the technological procedure, drawing and material, he will send it to QC and get signed on work order. Finally give the work order to the Forman.
28	QC	After checking the job based on the technological procedure and drawing, he/she will allow to pass to the next stage
29	Soft operation Forman	He will receive the job from QC, record it on work controlling manual. In addition, pass to the next operation.
30	Milling machinist	After finishing the milling operation like the lathe machinist, he/she will return the form to the Forman.
31	QC	The same procedure to that of no. 28
32	Hard operation foreman	The same procedure to that of no.29 but this leads to the heat treatment.
33	Heat treatment	According to technological procedure and specifications, he will heat treat and inform the Forman that he passed the work to QC.
34	QC	He/she will check the performance of the heat treatment section and allow passing to the next stage.
35	Hard operation Forman	Similar procedure to that of no. 29
36	GRR(grinding round, cylindrical)	After finishing the grinding operation based on the technological procedure, drawing and get signed by QC he will pass the work order to the Forman
37	QC	This is similar procedure to that of lathe, milling, and heat treatment
38	Forman	After the job is finished its operations, he will record on finished goods voucher. After that, he will get stamp from QC and send the copies to the PPC, sales, stock control, cost and budget.
39	Finished goods store	The finished goods from tools and spare parts are recorded on finished goods and receiving note and received by this section.
40	Sales	Using issue voucher, he/she will take the finished goods and delivered to the customer.
41	Customer	The customer will take the job if it is according to his requirement.

Improved work flow as compared to the previous

Previous work flow			Improved work flow		
No.	Work flow	Time spent	No.	Work flow	Time spent
	customer	Beginning		customer	Beginning
1	Sales/Marketing	½ hr	1	Sales/Marketing	½ hr
2	Chief planner	1hr	2	Process planner	3½ hr
3	PPC head	½ hr	3	PMPC	½ hr
4	Process planner	2 days	4 5	Cost workers Cost section head	1½ hr 1 hr
5	PPC head	3hrs	6	Finance head	½ hr
6	Finance	2hrs	7	Sales/Marketing	1/2hr
7	Manager	2hrs	8	Customer Manager	½ hr
8	Finance	1hr	9	Casher/Receiver	½ hr
9	Sales/Marketing	1hr	10	Sales/Marketing	½ hr
10	Customer Sales/Marketing	1hr	11	PMPC	½ hr
11	Casher	½ hr	12	Process planner	2 days
12	Customer	½ hr	13	PMPC	1 hr
13	Sales/Marketing	1 hr	14	Process controller	½ hr

14	Chief planner	½ hr	15	Tools & spare parts section	½ hr
15	PPC head	½ hr	16	Tools & spare Head	2 hr
16	Process planner	7 days	17	Logistics	½ hr
17	PPC head	4 hrs	18	Store/raw material	2 days
18	Process planner	3 hrs	19	Tools & spare Head	½ hr
19	Work Shop Planner	2hrs	20	Lathe Machinist	4 hrs
20	Tools & spare parts head	1 hr	21	Quality Control	½ hr
21	Forman	1 day	22	Milling Machinist	3 days
22	Tools & spare parts	2 hrs	23	Quality Control	½ hr
23	Logistics	1 hr	24	Heat Treatment Foreman	½ hr
24	Raw material head/store	3 days	25	Heat Treatment	2 days
25	Forman	1 hr	26	Quality Control	½ hr
26	Lathe Machinist	4 days	27	GRR Machinist	1 day
27	Quality Control	4 hrs	28	Quality Control	½ hr
28	Foreman	1 hr	29	Tool/Spare Section Head	1 hr
29	Milling Machinist	6 days	30	Finished Goods Store	2 hrs

30	Quality Control	4 hrs	31	Sales/Marketing	½ hr
31	Foreman	1 hr	32	Customer	
32	Heat Treatment	5 days			
33	Quality Control	4 hrs			
34	Foreman	1 hr			
35	GRR- Machinist	4 days			
36	Quality Control	4hrs			
37	Foreman	4 hrs			
38	Finished Goods Store	5 hrs			
39	Sales/Marketing	5 hrs			
40	Customer				

Previous

- Number of work flow steps is 40
- Average working time for one job to be completed is 40days.

Improved

- Number of work flow steps is 31
- Average working time for one job to be completed is 18days

The work flow in the next page is formed on the basis of concurrent engineering concept and it further shortens the prolonged flow. The old work flow shows it was taking 40 working days to produce a single product in an average. The company tried to improve this situation and it they found that it is possible to reduce in 31 steps with 18 working days. But by implementing a multidisciplinary team it is possible to reduce in to 10 days with 18 workflow steps.

No.	Improved work flow by Concurrent engineering **Work flow**	**Average time spent**
1	Customer	
2	-Sales/Marketing -Design -Maintenance - Process & production planners - Finance, -Logistics -Inspection - Cost	3 days
3	Sales/Marketing	1/2hr
4	Customer	1/2hr
5	Manager	1/2hr
6	Sales/Marketing	1/2hr
7	Process planner &controller	1hr
8	Tools & spare parts section	3hrs
9	Logistics	1/2
10	Store/raw material	1 day
11	Machine shop	4 days
12	Lathe Milling	
13	Grinding	
14	Heat treatment Inspection	
15	Production controller	2hrs
16	Finished good store	1/2
17	Sales/Marketing Customer	1/2
18		

- ❖ Number of steps 18
- ❖ Time elapsed 10days

Some of the items that are manufactured in Addis Engineering Center

No.	Items	QTY	Actual time(hrs.) total	Estimated time (hrs.)	Total Effect (hrs)	Overall impact	Remark
1	Swash plate	2	58	40	18 (delayed)	-	
2	Template	6	183	258	75 (early)	+	
3	Spinning disk	1	12	19	7 (early)	+	
4	punch	1	14:30	8:30	6(delayed)	-	
5	Spline bushing	1	28	12	16(delayed)	-	
6	Worm shaft	1	7	12	5 (early)	+	
7	Compression spring	500	267	82	185(delayed)	-	
8	Plug gauge	40	290	146	144 (delayed)	-	
9	Bend wire guide	8	26	43	17 (delayed)	-	
10	Bending die	1	37	27	10(delayed)	-	
11	Helical gear	2	26	41	15 (early)	+	
12	shaft	1	62	52	10 (delayed)	-	
13	First male die	1	65	37	28(delayed)	-	
14	Horse shoe gauge	1	50	27	23(delayed)	-	
15	Female die	5	167	170	3 (early)	+	

Figure10. Graphical representation of delivery delay in Addis Engineering Center.

For this particular research, 15 items, which are frequently coming to AEC for the last 5 years, is selected and analyzed. By looking only number wise; out of 15 items, only four are delivered to the customers on time and the rest (11) are delayed due to different reasons, which are indicated on the fish bone diagram.

The above illustration shows most of the time Addis Engineering Center is not delivering on time for its customers.

On time and early delivery to the customer $= \frac{4}{15} X100 =$ **26.67%**

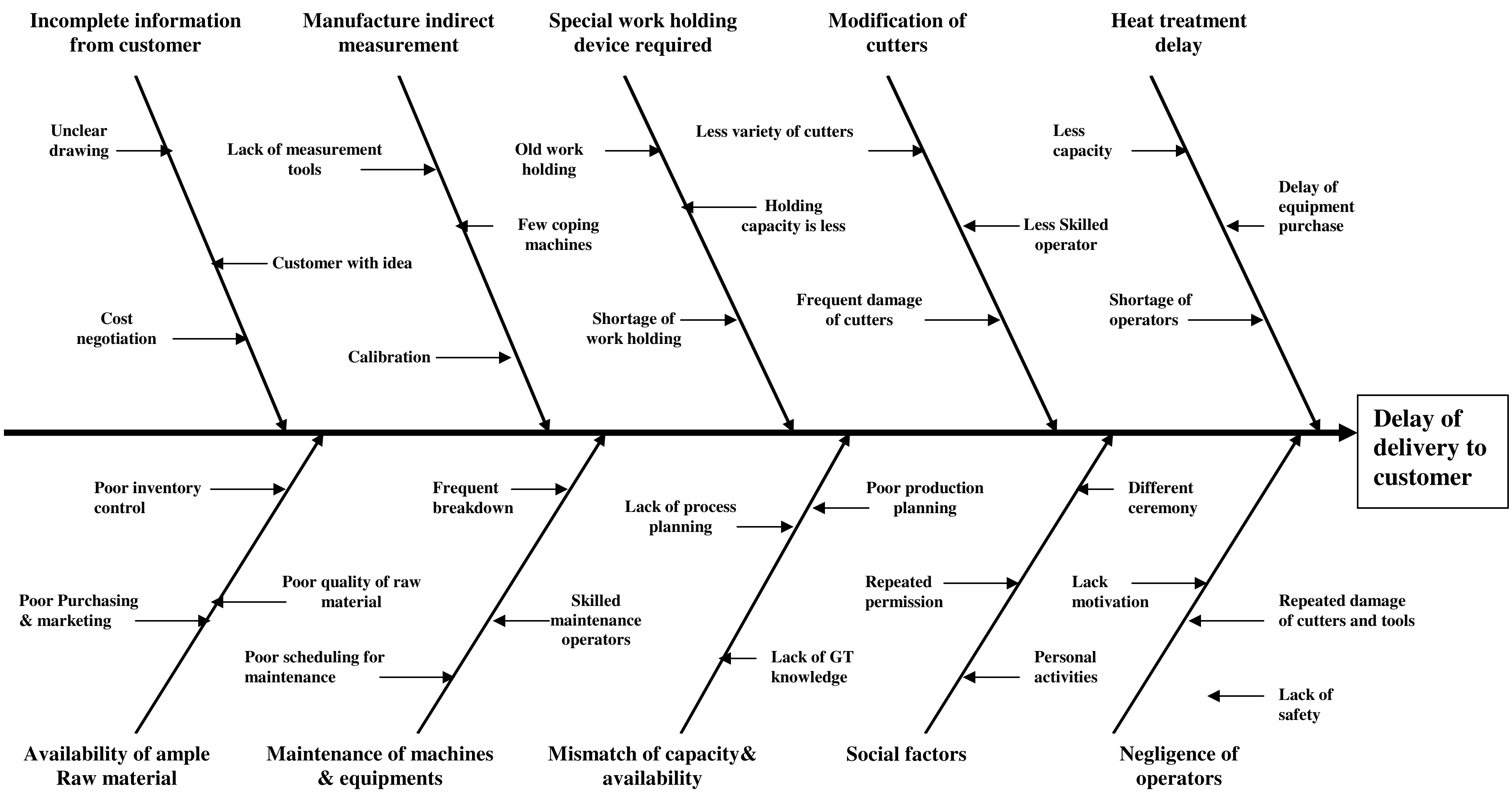
Delayed delivery for the customers $= \frac{11}{15} X100 =$ **73.33**

Item which is manufactured as a set or assembly in Addis Engineering Center

No.	**Items**	**QTY**	**Actual TIME (hrs.) per pc**	**Estimated time (hrs.) per pc**	**Effect**	**Total effect Per Pc.**	**Remark**
1	Male die	15	7	7:30	0:30(early)	7:30	
2	Shank holder	15	5	4	1 (delayed)	15	
3	Longer Bolt	15	6	3	3 (delayed)	45	
4	Punch guide	15	13	11	2 (early)	30	
5	Base plate	15	15	12	3 (delayed)	45	
6	Shorter bolt	15	2	4	2 (early)	30	
7	spacer	15	9.30	14	4:30 (early)	67:30	
8	Punch holder	15	9	8	1(delayed)	15	
9	Punch (Big)	15	9	9	on time	0	
10	Lower die	15	13	11	2 (delayed)	30	
11	stripper	15	8	6	2	30	

Most customers bring different type of components, which are not in the form of assembly or as a set. Few customers come with components, which require a skill of group technology, which minimizes production time more specifically set up time of the production processes. From the last five years experience, dies are repeatedly coming from different factories and institutions to Addis Engineering Center. Irrespective of their shapes and dimensions or sizes with an average of 15 dies are ordered to be manufactured in AEC. On manufacturing the dies, male die and shank holder could not produced in parallel because it violet design for assembly. Similarly, lower dies and strippers are produced one after the other. The rest components can be produced in parallel so that the production time can be minimized.

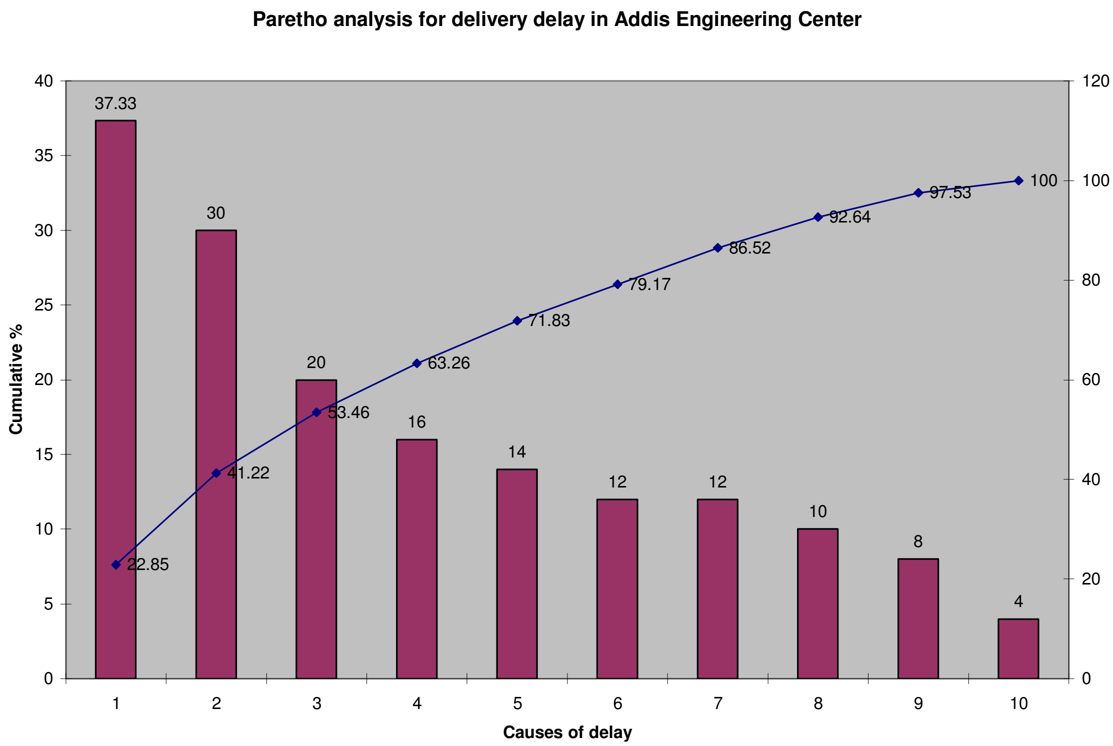
Figure 11 Fishbone diagram of Addis Engineering center for delay of delivery



Causes of production delay in Addis engineering center

- Incomplete information from customer
- Irregular shape may come so that the production shop is obliged to manufacture indirect measuring devices.
- Special work holding device may required.
- Modification of cutters
- Delay due to heat treatment, in most cases the size of the work piece may be more than the capacity of the heat treatment devices.
- Availability of ample raw materials
- Delay due to grinding dressing
- Machine maintenance
- Availability and capacity may not match with the amount of work order.
- Negligence of the operators
- Social reasons

S/N	Delivery delay causes in Addis Engineering Center	Frequencies			Average (three years)
		1996EC	1997EC	1998EC	
1	Modification of cutters	34	40	38	37.33
2	Availability of ample Raw material	32	28	30	30
3	Incomplete information from customer	24	20	16	20
4	Maintenance of machines & equipments	20	15	13	16
5	Negligence of operators	16	8	18	14
6	Manufacture indirect measurement	8	10	18	12
7	Social factors	10	14	12	12
8	Special work holding device	12	5	13	10
9	Heat treatment delay	10	6	8	8
10	Mismatch of capacity& availability	2	4	6	4



Interpretation of the Pareto curves:

It is important to identify the vital few from the trivial money and the paretho analysis is a tool, which is implemented to this research. A useful first step is to draw a vertical line from the **20- 30** percent area of the horizontal axis.

These are often called the **vital few**, which have been highlighted for a special attention. It is clear that, if the objective is to reduce delay in delivering to the customers, the company should pay attention and eliminate the prolonged time spent modification of cutter and should have proper inventory control and supply system so that the raw materials are supplied on time with the required specifications

Dejen Aviation Maintenance and Engineering Complex production shop data

S/N	JOB DESCRIPTION	PRIORITY	QTY	REQUESTED BY	REQUESTED DATE	STARTED DATE(EC)	FINISHED DATE(EC)	ESTIMATED TIME	ACTUAL TIME (hrs)	EFFECT
1	Mfg of bend forming and flaring die components	2	10	Pipe. Repair shop	5/8/97	5/8/97	24/8/97	150	163	Delayed
2	Mfg of turn buckle	2	01	Engineering	5/8/97	6/8/97	10/8/97	10	12	Delayed
3	Mfg of rotary table support components	2	22	N.D.T	5/8/97	6/8/97	10/8/97	10	8	Early
4	Mfg of adapter	2	04	Avionics	6/8/97	6/8/97	108/97	13	12	Early
5	Mfg of tow bar	3	01		4/9/97	6/9/97	23/9/97	24	32	Delayed
6	Mfg of positioning nut, cutting and drilling of dolly components	3	01	L-39	4/9/97	10/9/97	15/9/97	15	20	Delayed
7	dolly components	2	01		4/9/97	6/9/97	16/9/97	60	52	Early
8	Mfg of anchor bolt with nut		4	Garage	01/10/97	02/10/97	03/10/97	3	5	Delayed
9	Mfg of adapter	2	1	Cafeteria	01/10/97	2/10/97	3/10/97	3	5	Delayed
10	Mfg of oil and fuel aggregate component	1	01	Power plant	01/10/97	1/10/97	3/10/97	4	5	Delayed
11	Mfg of pipe line adapter	2	01	Pipe and tube	19/11/97	19/11/97	25/11/97	12	10	Early

S/N	JOB DESCRIPTION	PRIORITY	QTY	REQUESTED BY	REQUESTED DATE	STARTED DATE(EC)	FINISHED DATE(EC)	ESTIMATED TIME	ACTUAL TIME (hrs)	EFFECT
21	Mfg of profile plate	2	02	structure	20/10/98	21/10/98	-		WIP	-
22	Mfg of helicopter hydraulic pump pusher	3	03	L.G (landing)	20/10/98	20/11/98	20/3/99	24	38	Delayed
23	Adapter	2	02	Hose and tube	28/10/98	17/11/98	10/11/98	14	12	Early
24	Mfg if adapter	2	03	Power plant	13/11/98	17/11/98	27/11/98	12	20	Delayed
25	Mfg Bolt and Nut	2	10	Power plant	17//11/98	18/11/98	20/11/98	6	8	Delayed
26	Mfg of Bracket support ring	2	01	Engineering	17/11/98	18/11/98	-	20	WIP	-
27	Mfg if cover	2	04	Garage	20/11/98	10/12/98	17/12/98	10	12	Delayed
28	Mfg of Hook	2	02	L-39	21/11/98	03/12/98	12/12/98	20	16	Early
29	Mfg of spur Gears	2	12	Design	26/11/98	19/12/98	14/12/99	60	112	Delayed
20	Mfg of fuel (pipe) line connector	2	08	power plant	19/10/98	29/10/98	28/11/98	25	38	Delayed

30	MFG OF BOLTS AND NUTS	2	08	POWER .P	2/12/98	3/12/98	9/12/98	3	-	-
31	Mfg of pipe line adapter	2	02	Block-4	3/12/98	3/12/98	17/12/98	10	12hr	Delayed
32	Mfg of Gear box stand Block	2	12	Power plant	3/12/98	4/12/98	-	-	WIP	-
33	Mfg of spline special tool	2	01	Power plant	4/12/98	4/12/98	-	-	WIP	-
34	Mfg of pins	2	02	Garage	10/12/98	10/12/98	11/12/98	3	3	On time
35	Mfg of special tools	2	01	Power plant	10/12/98	10/12/98	-	-	WIP	-
36	Mfg of six jaw wrench	2	01	Block -4	23/8/06	23/8/06	-	-	WIP	-
37	Pipe line adapter and plug	2	04	Hose and tube shop	18/12/98	23/12/98	30/12/98	14	16	Delayed

S/N	JOB DESCRIPTION	PRIORITY	QTY	REQUESTED BY	REQUESTED DATE	STARTED DATE(EC)	FINISHED DATE(EC)	ESTIMATED TIME	ACTUAL TIME (hrs)	EFFECT
38	Mfg Adapter	2	01	Utility	01/01/99	10/01/98	15/01/99	3	5	Delayed
39	Mfg of bulb support	3	06	L-39	23/01/98	30/01/98	06/02/99	5	8	Delayed
40	Mfg of pin	2	01	Utility	29/01/99	29/01/99	29/01/99	1	1	On time
41	Mfg of washer	3	02	L-39	29/01/99	30/01/99	30/01/99	3	3	On time
42	Mfg of mount shaft	2	01	Utility	30/01/99	06/03/99	11/03/99	12	16	Delayed
43	Mfg of bushing	2	16	Engineering	01/02/99	03/02/99	08/02/99	10	12	Delayed
44	Mfg of bushing	2	03	L-39	03/02/99	03/02/99	06/02/99	3	3	On time
45	Mfg of special tools	1	04	Power plant	07/02/99	15/02/99	20/02/99	12	16	Delayed
46	Mfg of Antenna holder	2	01	Head office	10/02/99	10/02/99	17/02/99	20	40	Delayed
47	Mfg of sand blast machine nozzles	2	21	Electro plating	20/02/99	21/02/99	30/02/99	15	48	Delayed
48	Mfg of wing bracket	1	01	Engineering	25/03/99	27/03/99	27/06/99	25	16	Early
49	Mfg of long runs	2	01	Engineering	21/02/99	28/02/99	20/03/99	40	60	Delayed
50	Mfg of blocks	2	01	Landing gear	20/02/99	20/02/99	20/02/99	3	5	Delayed
51	Mfg of adapter	2	03	Power plant	20/02/99	21/02/99	27/02/99	15	26	Delayed
52	Mfg of antenna holder	2	02	Head office	20/02/99	20/02/99	26/02/99	25	20	Early
53	Mfg of hose adapter	3	01	Electro plating	27/02/99	27/02/99	28/02/99	6	8	Delayed
54	Mfg of bolt & bus hinge joint	3	24	Head office	27/02/99	27/02/99	04/03/99	5	8	Delayed
55	Mfg of handle	2	02	Landing gear	28/02/99	03/03/99	04/03/99	8	6	Early

Dejen aviation maintenance and engineering complex is the second company for this research that it faces a delivery delay. As it is seen from the above data, one can reach to a conclusion that DAMEC has also a problem on delivering products on time. Mathematically it is possible to put the result as follows:

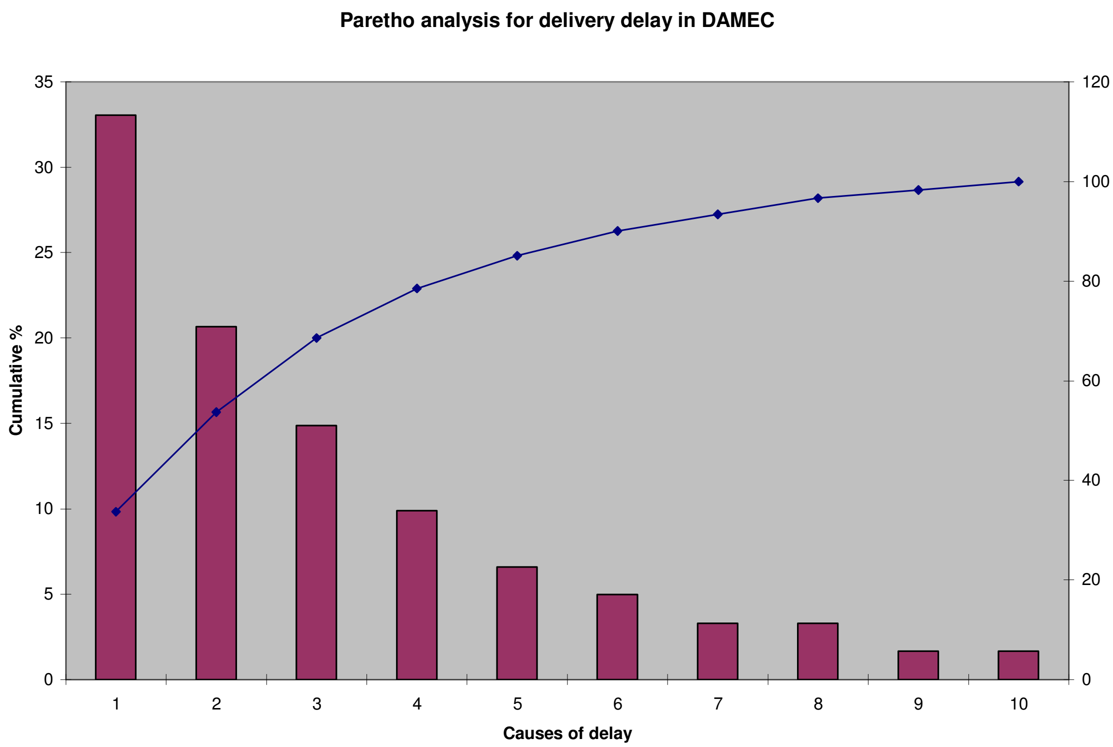
Products delayed on delivery = $\frac{31}{55}$ X 100 = **<u>56.36 %</u>**

Early completed jobs = $\frac{12}{55}$ X 100 = **<u>21.85 %</u>**

WIP and Items not recorded = $\frac{8}{55}$ X 100 = **<u>14.54 %</u>**

Products completed on time = $\frac{4}{55}$ X 100 = **<u>7.27 %</u>**

S/N	Delivery delay causes Dejen Aviation Maintenance & Engineering complex(DAMEC)	Average (three years) Freq.	Cumulative %
1	Availability of ample Raw material	33.05	33.71
2	Incomplete information from customer	20.66	53.71
3	Modification of cutters	14.87	68.58
4	Maintenance of machines & equipments	9.9	78.48
5	Negligence of operators	6.6	85.08
6	Manufacture indirect measurement	4.98	90.06
7	Special work holding device required	3.3	93.36
8	social factors	3.3	96.66
9	Heat treatment delay	1.65	98.31
10	Mismatch of capacity& availability	1.65	100



The Paretho analysis in Dejen Aviation Maintenance and Engineering Complex shows the vital few are availability of ample and quality raw materials and incomplete information that are coming from different departments. By avoiding the problems (delays) caused by these factors, it is possible to minimize the delivery delay, which in turn affects the performance of the company. This and other process like assembling and repairing have direct impact on the overhauling processes of the aircraft.

7.3 WASTES IN ADDIS ENGINEERING CENTER AND DEJEN AVIATION MAINTENANCE AND ENGINEERING COMPLEX

The wastes and their classifications which are presented in this paper are adapted from Toyota Company and presented in simplified way so that our industries can be benefited from it. Waste is a common phenomenon in most industries. Identifying the major wastes and production problems are very important to take correction action on the right time.

"Waste" may be defined as "any action, process or activity that consumes resources and does not directly add value for a stakeholder". For the sake of convenience, waste in Addis Engineering Center (AEC) can be classified and seen in the following sequence:

- Production waste
- Information waste
- Enterprise level waste

Waste in Production Operations:

• *Waiting*: A condition caused by a production operation waiting for maintenance, for material/parts from previous operation, tooling, operator readiness, etc., or production parts waiting in a queue (perhaps in batches).

• *Transportation*: Excessive movement of materials/tools between production operations, between facilities, or to and from storage

• *Over-Processing*: Using oversized equipment or equipment not designed for the task at hand, thereby requiring excess running time and costs; using equipment that has not been properly maintained, thereby requiring excess processing.

• *Excessive Inventory*: Maintaining stocks of raw materials in excess of current production requirements; or stocks of finished goods in excess of current customer demand; or stocks of work in progress as buffers between un-synchronized production operations.

• *Unnecessary Motion*: Human actions/motions beyond the minimum required to achieve the task at hand, i.e. tasks which, in themselves, do not add value.

• *Defective Products*: Parts, materials, sub-assemblies or products that do not meet specifications and which must be scrapped or reworked to bring into conformance

• *Overproduction*: Producing more than is required or producing before required; any work performed which is not "pulled" by the next stakeholder in the value stream.

Seven Types of Information Waste

Clearly, waste also occurs outside production operations. An important enterprise element in which significant waste can occur is the information system of the enterprise.

The seven types of information wastes discussed in this section are analogous to the seven types of manufacturing wastes for any environment where there is not a physical product involved. The handling, exchange or transportation, and processing of information has some unique and some common characteristics with the handling, transportation, and processing of physical material.

- *Waiting:* Idle time due to unavailable information
- *Transportation (unnecessary movement):* (In the case of information, this waste category is the same as *Excess Processing*, below.)
- *Excess Processing:* Processing information beyond requirements, e.g. unneeded precision
- *Inventory:* Information that is unused or is "work in progress"
- *Unnecessary Motion:* Any human movement necessitated by poor Information System design.
- *Defects:* Any element of data, information or intelligence that is erroneous.
- *Overproduction:* Producing and distributing more information to more people than is needed.

Enterprise Level Wastes

More broadly, waste occurs at the enterprise level in a wide variety of contexts. Many of these wastes can be mapped into seven fundamental categories. Some, however, are unique and require additional categories.

- *Waiting/Delays:* Idle time due to late decisions, excessive approvals, and unsynchronized enterprise processes

- *Excessive Transportation:* Unnecessary movement (including electronically) of administrative paperwork; multiple approvals and handoffs
- *Inappropriate Processing/Ineffectual Effort:* Effort expended that does not increase value to any of the enterprise's stakeholders; can occur within the workforce, within management ranks, or across the entire enterprise.
- *Inventory:* Unnecessary levels of any enterprise resource: capacity, space, workforce, suppliers
- *Excessive Motion:* Any human effort that does not increase stakeholder value
- *Defects/Rework:* Erroneous results from enterprise processes and decisions
- *Overproduction:* Any creation of enterprise outputs which does not increase stakeholder value.

In addition, two other categories are added to accommodate waste categories at the enterprise level.

- *Structural Inefficiencies:* Waste resulting from inappropriate organizational structure, policies or business model structure.
- *Opportunity Costs:* Wastes resulting from lost opportunities, e.g., untapped talent in the workforce.

PRODUCTION WASTE AND CAUSES IN AEC AND DAMEC

TYPES OF PRODUCTION WASTE	EXAMPLE	CAUSES
Waiting *Idle time in which no value is added*	Employee waiting for • tooling • equipment repair • quality inspector • material machine to complete operation	 • Poor scheduling, work coordination • Inadequate preventive maintenance • Lack of employee empowerment • Push system • One employee assigned to each machine
	Machine waiting for • tooling • equipment repair • quality inspector • material • employee • set-up changeover	 • same • same • same • same • Inattention; poor scheduling; unbalanced operations; no back-up or cross training of co-workers • Long set-up times; monolithic equipment
	Production order waiting for: • machine availability • transport to next operation	 • Push system; unbalanced operations • Poor coordination; functional process layout
Transportation *Excessive movement of material, tools or parts*	Materials/tools moved between functionally grouped equipment or processing centers, or between different facilities/sites	• Batch and queue (push) system • Functional process layout • Monolithic equipment/processes • Irrational facility/site locations

TYPES OF PRODUCTION WASTE	EXAMPLE	CAUSES
	Production orders moved to and from stores	• Push system; poor layout
	Finished items moved through multi-level distribution channels	• Traditional hierarchical distribution system
Over-processing *Effort expended which does not add customer value*	Work that could be combined with other operations via fewer individual parts or multiple operations on same equipment	• Poor product design • Poor process planning/manufacturing engineering
	Work performed on wrong-sized equipment, requiring excess running time, or excess operating costs	• Improperly sized equipment; poor maintenance; poor instructions and training
	Enhancements, precision beyond customer needs	• Lack of clear customer requirements; tendency for engineers to over-design
	Improper material	• Lack of current knowledge of alternative material capabilities
	Rework	• Inadequate preventive maintenance; lack of automated process controls; poor workmanship

TYPES OF PRODUCTION WASTE	EXAMPLE	CAUSES
	Production orders moved to and from stores	• Push system; poor layout
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	Enhancements, precision beyond customer needs	• Lack of clear customer requirements; tendency for engineers to over-design
	Improper material	• Lack of current knowledge of alternative material capabilities
	Rework	• Inadequate preventive maintenance; lack of automated process controls; poor workmanship

Production waste continued…

TYPES OF PRODUCTION WASTE	EXAMPLE	CAUSES
	Excessive testing	• Poor product/process design; lack of qualified performance certification system
Inventories *Accumulations of materials beyond JIT requirements*	Excessive raw materials and supplies	• Maintaining stocks of materials in excess of current production requirements; inadequate selection of suppliers; lack of JIT discipline in supply base; lack of coordination with suppliers; inaccurate inventory records
	Excessive finished goods	• Push system; building to forecast; multi-level distribution system; production to maintain employment level
	Excessive work in progress	• Push system; batch and queue; buffers between unsynchronized production operations; high variability in process times; “lost” production orders
	Obsolete and out-of-production parts and materials	• Waiting too long to dispose; frequent design changes; undisciplined configuration management; lack of understanding of “sunk cost”

Production waste continued…

TYPES OF PRODUCTION WASTE	EXAMPLE	CAUSES
Unnecessary Motion *Any human movement that does not add value*	Excessive reaching, bending, stretching	• Poor work design; lack of standard methods; poor work-space design
	Searching for tools, parts, materials	• Poor layout; poor facility design; poor housekeeping and organization
	Excessive walking for tools, parts, materials	• Poor facility design; poor tool and material access
	Excessive handling of work pieces	• Lack of one-piece flow; lack of cellular layout; stop and go processing
	Excessive force, energy required for operations	• Poor work design; lack of ergonomic standards; poor part design
	Long set-uptimes	• Lack of disciplined set-up minimization effort
Product Defects *Any item that does not meet specifications*	Defects occurring in internal production	• Poor process capability; poor standard operation specifications; inadequate training and instruction; lack of consideration of process capability during product design phase; lack of mistake-proofing discipline
	Defects occurring in supplier parts/materials	Inadequate quality certification/verification regimen

Production waste continued...

TYPES OF PRODUCTION WASTE	EXAMPLE	CAUSES
	Defects occurring during final test	• Poor calibration, lower skilled operators
	Defects discovered by customer after delivery	• Misunderstanding during acceptance of the job, improper information flow • Problem on production process and design stage
Over Production *Producing more or sooner than required*	Producing more than required	• Producing to forecast rather than to current customer demand; large lot production; producing to maximize machine/labor utilization; producing to avoid layoffs; producing ahead for planned marketing promotion; lack of coordination (demand management) with customers
	Producing before required	• Push production system; unsynchronized production operations; poor production planning and control system

INFORMATION WASTES AND CAUSES IN AEC AND DAMEC

TYPES OF INFORMATION WASTE	EXAMPLE	CAUSES
Waiting *Idle time due to unavailable information*	People waiting for information	• Lack of access; untimely updating of data bases; lack of interoperability among IS components; multiple approvals
Unnecessary Movement (same as ***"Excessive Processing"***, below)		
Excessive processing: *Information processing beyond requirements*	Excessive/custom Formatting	• Lack of standardization
	Numerous, Fragmented reports That Could be Combined	• Poor output design; lack of understanding of user requirements
	Unnecessary Detail and Accuracy	• Tendency to "over-design"
	Unnecessary Serial Processing	• Poor system design; lack of understanding of concurrent processing capabilities
	Excessive Approvals for Information Release	• Stove pipe, command and control mentality • Turf protection
	Excessive Information Distribution	• Broadcasting information to people other than those who need it; information overload

TYPES OF INFORMATION WASTE	EXAMPLE	CAUSES
Inventory *Information that is unused or is "work in progress"*	Too much information	• Poor understanding of user needs
	Multiple/redundant Files	• Tendency for everybody to maintain their own files (e.g., paper files of the same information maintained in several places, in addition to electronic files
	Outdated/obsolete Information	• Lack of "version control"; lack of disciplined system for updating new
	"Just-in Case" Information	• Collection, processing and storage of every element of data that the system designers can think of, whether or not a specific end-use has been identified
Unnecessary Motion *Any human movement necessitated by poor IS design*	Walking to Central Information Access Point	• Lack of distributed, direct access
	Excessive Keyboard, Mouse Operations	• Lack of training; poorly designed, incompatible user interfaces; incompatible software suites
	Retrieving Printed Instruction Manuals	• Lack of on-line access

Information waste continued…

TYPES OF INFORMATION WASTE	EXAMPLE	CAUSES
Defects *Erroneous data, information, reports*	Errors in Data Reporting/Entries	• Human error; poorly designed input templates
	Errors in Information Provided to Customers	• Lack of disciplined reviews, tests, verification
Over Production *Producing, distributing more information than needed*	Pushing, Not Pulling Data, Information	• Poor IS design
	Over dissemination	• Poor understanding of each user's requirements; "send all information to everyone", rather than targeted distribution to meet specific needs

ENTERPRISE WASTES AND CAUSES IN AEC AND DAMEC.

TYPES OF ENTERPRISE WASTE	EXAMPLE	CAUSES
Waiting/Delays: *Idle time due to late decisions, bottlenecks in enterprise processes*	In making decisions	• Unnecessary levels/steps in decision structure and approval processes; multiple handoffs • Information unavailable or inaccessible • Risk aversion mentality • Inflexible policies and procedures; excessive rules and regulations
	In administrative processes	• Undisciplined processes and practices • Variability in enterprises processes • Lack of standardization; lack of common tools and systems • Errors in data • Linear, serial task sequencing • Batch and queue mentality in enterprise processes • Lack of flow – lack of level scheduling of administrative processes • Unsynchronized enterprise processes • Delays in information processing, dissemination and consequent actions
Excessive Transportation *Unnecessary movement of administrative paperwork, multiple approvals/handoffs*	Movement of forms, reports, other paperwork	• Poor design of business processes

TYPES OF ENTERPRISE WASTE	EXAMPLE	CAUSES
	Multiple handoffs	• Unsynchronized enterprise processes
	Expediting Administrative Paperwork	• Poor design of business processes
	Dispersed Facilities	• Poor location decisions
Inappropriate Processing/ Ineffectual Effort: *Effort expended which does not increase stakeholder value*	Poor workforce performance	• Rigid job classifications, narrowly trained employees • Lack of congruence between reward structure and enterprise objectives • Lack of employee empowerment • Employee empowerment without accompanying training • Inadequate job skills • Poor employee selection & placement to facilitate Lean • Disheartened, de-motivated work force • Lack of consistent, timely communication
	Poor management performance	• Excessive QA inspections, re-inspects • Time spent in reacting, fixing problems • Excessive and uncoordinated initiatives • Confusion regarding roles, responsibilities • Excessive meetings; poorly prepared/facilitated meetings with no follow up • Excessive data collection and storage • Counterproductive performance measures

…

Enterprise waste continued

TYPES OF ENTERPRISE WASTE	EXAMPLE	CAUSES
	Poor enterprise performance	• Inefficient, ineffective process interfaces • Physical, information and conceptual disconnects – lack of connectivity and interoperability • Lack of standardized processes; lack of common tools, systems and platforms • Outdated, counterproductive financial systems and performance measures • Enterprise managers not on the same page • Inflexible policies & procedures, excessive rules and regulations and Organizational rigidity • Unsynchronized enterprise processes • Poor strategy and execution • Business systems are cumbersome and disconnected
Inventory *Unnecessary levels of capacity, space, work- force, suppliers*	Excessive capacity	• Poor planning
	Excessive Space	• Poor planning, re-deployment of freed up resources
	Excessive Workforce	• Poor planning, re-deployment of freed up resources
	Excessive Technical planning Staff	• Poor staffing planning
	Excessive Suppliers	• Lack of rationalized lean supply chain network

TYPES OF ENTERPRISE WASTE	EXAMPLE	CAUSES
Excessive Motion *Any human effort that does not increase stakeholder value*	Redundant activities	• Poor integration; cumbersome business systems
	Excessive and uncoordinated initiatives	• Lack of discipline and focus; chasing fads
	Wasted effort	• Excessive number of meetings, status reporting; • Unsynchronized enterprise processes
Defects/Rework *Erroneous results from enterprise processes and decisions*	Errors	• Physical, information and conceptual disconnects – lack of connectivity • Undetected errors in data entry and processing • Out of date policies and procedures – lack of configuration control • Variation in enterprise processes • Misinterpretation of data
	Incorrect, inappropriate decisions	• Optimizing within one function causes sub-optimal enterprise performance • Errors (defects) in enterprise processes • Unsynchronized enterprise processes • Misinterpretation of processed information • Confusion regarding roles and responsibilities • Lessons learned are not captured and archived • Decisions re-decided or changed later • Poorly prepared and facilitated meetings • Multiple handoffs

TYPES OF ENTERPRISE WASTE	EXAMPLE	CAUSES
Over-production *Any creation of enterprise outputs which does not increase stakeholder value*	Excessive dissemination of data, reports	• "Push" mentality prevails • Outdated policies and procedures • Wrong metrics
	Over-managing	• Lack of appropriate delegation, employee empowerment • Command and control mentality prevails
	Exuberant pursuit of illogical initiatives	• Too many "movements" (initiatives) being pushed, some at cross purposes, leading to diffusion of commitment • Failure to stay grounded in fundamentals • Over-reliance on "solutions of the month"
	Marketing campaign	• Belief that "pushing" sales via incentives will result in overall increase in sales volume, but usually results in short term demand amplification and then sharp drop in demand
Structural Inefficiencies *Wastes resulting from inappropriate organization, policies, business model structure*	Organizational structure	• Redundant activities; overlapping command and control • Failure to deploy critical resources horizontally along the value stream • Bloated middle management • Unclear chain of command • Unsynchronized enterprise processes

TYPES OF ENTERPRISE WASTE	EXAMPLE	CAUSES
	Supplier relations	• Tendency to view suppliers in an adversarial way • Failure to create "win-win" relationships • Reluctance to share detailed operations data
	Partner relations	• Lack of interconnectivity and interoperability • Reluctance to share detailed internal data
	Customer relations	• Failure to focus on customer needs and values • Failure to anticipate how we can help our customers be successful
Opportunity Costs *Wastes resulting from lost opportunities that are achievable*	Customer disconnects	• Remoteness from customer • Failure to focus on what customer values
	Untapped talent in workforce	• Failure to capitalize on the "whole person" by helping each employee grow to full potential; underutilization of people • Inappropriate reward/incentive systems
	Failure to view knowledge as a corporate asset	• Managers unaware of potential of knowledge management • No tradition of capturing lessons learned, of growing corporate knowledge base; lack of knowledge transfer internally
	Unmotivated workforce	• Workforce not empowered; people have no authority or accountability

WASTE TAXONOMY IN ADDIS ENGINEERING AND DEJEN AVIATION COMPANIES

	8 Types of Enterprise Waste							
Enterprise activities/behaviors which may contribute to Waste	**Overproduction:** parts, product, paper, deliverable (s)	**Waiting**	**Transport:** parts, product paper, deliverable (s)	**Over-processing**	**Inventories**	**Unnecessary Movement:** parts, paper, deliverables	**Defects/ Rework:** Deliverables and Process	**Non-Integration**: (P=people, M=money)
Poor Motivation				X			X	P
- improper incentives								
- lack of trust								
- lack of empowerment								
- empowerment without training								
- inefficient use								
- poor communications								
- bad fit								
Non-standard Processes/Systems/Tools		X					X	M
- variability in enterprise processes								
- uncommon part types								
Regulatory Agency							X	P
- non compliance (audits, documentation)								
Poor Integration						X		P,M
- redundant activities								
Wrong Metrics	X						X	P
- leads to wrong behavior								
- wrong financial systems								
Linear, Serial Task Sequencing		X					X	M

Lost Knowledge, Transfer										P
- lessons learned not captured or shared										
- knowledge not viewed as corporate asset										
Change Activity		X						X		
- rework										
- delays										
- shortages										
Poor Strategy & Execution		X						X		P,M
Labor Issues										P
- lack of cross –training										
- multiple classifications										
Schedules							X	X		M
- non-integrated										
- reschedules										
Obsolete Materials						X				
Business Systems			X		X		X	X		P,M
- cumbersome										
- lack of connectivity& interoperability										
- inefficient										
- information unavailable or inaccessible										
- multiple legacy ways										
Product/Process Specialization (Customer Specs)					X		X			M
- over specification										
- excessive QA inspections, re-inspects										
Buy-offs & Inspection					X					

Poorly Prepared & Facilitated Meetings								X		P
Approvals (verbal, written)			X		X					
Moves/Queues (people, product, paper)			X				X			
Multiple Handoffs			X	X	X		X	X		P
Expediting		X		X		X	X			P,M
- parts & paper										
Transportation							X			
Excess Equipment / Oversize Capital		X				X				M
Unbalanced Resource Allocation			X							P,M
- resources not deployed along value stream										
Organizational Structure		X	X		X		X	X		P
- unsynchronized enterprise processes										
- stovepipe										
- redundant activities										
- bloated middle management										
- unclear										
Equipment Down Time			X							
Bad Decisions			X					X		P,M
- late decisions										
- re decided or changed later, indecision										
- flavor of the month										
- unsupported request for business case										
Unsupported Initiatives					X		X	X		P,M
- exuberant pursuit of illogical initiatives										
- excessive & uncoordinated initiatives										
Too Many Suppliers		X		X		X	X			P,M

Excessive Data Collection & Storage					X			X		P,M
Facility			X	X				X		
- layout poor										
- poor location										
- excess space										
Excessive Number of		X	X		X		X			P
- meetings										
- status										
- reports										
Overlapping Command & Control		X			X					P
- excess command media										
- maintaining, updating & changing procedures										
Processes								X		P
- excessive process steps										
- inefficient, ineffective process interfaces										
- cumbersome										

7.4 IMPORTANT ISSUES ON CONCEPT SELECTION

Concept Generation

The goal is to choose the best of the concepts for development into products while expending the least amount of resources.

- ♦ How can the team choose the best concept, given that the designs are still quite abstract?
- ♦ How can a decision be made that is embraced by the whole team?
- ♦ How can desirable attributes of otherwise weak concepts be identified and used?

All Teams Use some methods for choosing a concept

- * **External Decision:** Concepts are turned over to the customer, client or some other external entity for selection.
- * **Product Champion:** An influential member of the product development team chooses a concept based on personal preference.
- * **Intuition:** The concept is chosen by its "feel". Explicit criteria or trade-offs are not used. The concept just "seems" better.
- * **Pros and Cons:** The team lists the strengths and weakness of each concept and makes a choice base upon group decision.
- * **Prototype and test:** The organization builds and tests prototypes of each concept, making a selection based upon test data.
- * **Decision methodologies:** This may include technology assessment, screening and decision matrices.

Benefits of Structured Methodologies

- ♦ **A customer-focused product** because concepts are explicitly evaluated against customer-oriented criteria, the selected concept is likely to be focused on the customer.

- **A competitive design:** By benchmarking concepts with respect to existing designs, designers push the design to match or exceed their competitor's performance along key dimensions.
- **Better product-process coordination:** Explicit evaluation of the product with respect to manufacturing criteria improves the product's manufacturability and help to match the product with the process capabilities of the firm.
- **Reduced time to product introduction:** A structured methodology becomes a common language among design engineers, manufacturing engineers, industrial designers, and project managers, resulting in decreased ambiguity, faster communication and fewer false starts.
- **Effective group decision making:** Within the development team, organizational philosophy and guidelines, willingness of members to participate, and team member experience may constrain the concept selection process. A structured methodology encourages decision making based on objective criteria and minimizes the likelihood that arbitrary or personal factors influence the product concept.
- **Documentation of the decision process:** A structured methodology results in a readily understood archive of the rational behind concept decisions. This record is useful for assimilating new team members and for quickly assessing the impact of changes in the customer needs or in the available alternatives.

Selection Matrix: - Prepare the selection matrix

Rate the concepts Use a datum and rank as follows:

+ better than datum

0 same as datum

- Worse than datum

Rank the concepts

- Score each concept by subtracting number of "-" from number of "+" then rank concept on basis of highest sum.

Combine and improve the concepts

Is there a generally good concept which is degraded by one bad feature? Can a minor modification improve the overall concept and yet preserve a distinction from the other concepts? Are there two concepts which can be combined to preserve the "better than" qualities while annulling the "worse than" qualities?

Select the set of highest potential concepts for further screening

Concept Scoring:-Concept Scoring is used to increase resolution and better differentiation among competing concepts

Prepare the selection matrix:-Add more selection criteria, add weights (could be from QFD)

Rate the concepts Use rating system:

1-Much Worse 3-Same 5-Much Better

2-Worse 4-Better5

Rank the Concepts

Once the ratings are entered for each concept, weighted scores are calculated by multiplying the raw scores by the criteria weights. The total score for each concept is the sum of the weighted scores:

$$S_j = \sum_{i-1}^{n} RijWi$$

Where

R_{ij} = raw rating of concept j for the i the criterion

W_i = weighting for i the criterion

n = number of criteria

S_j = total score for concept j

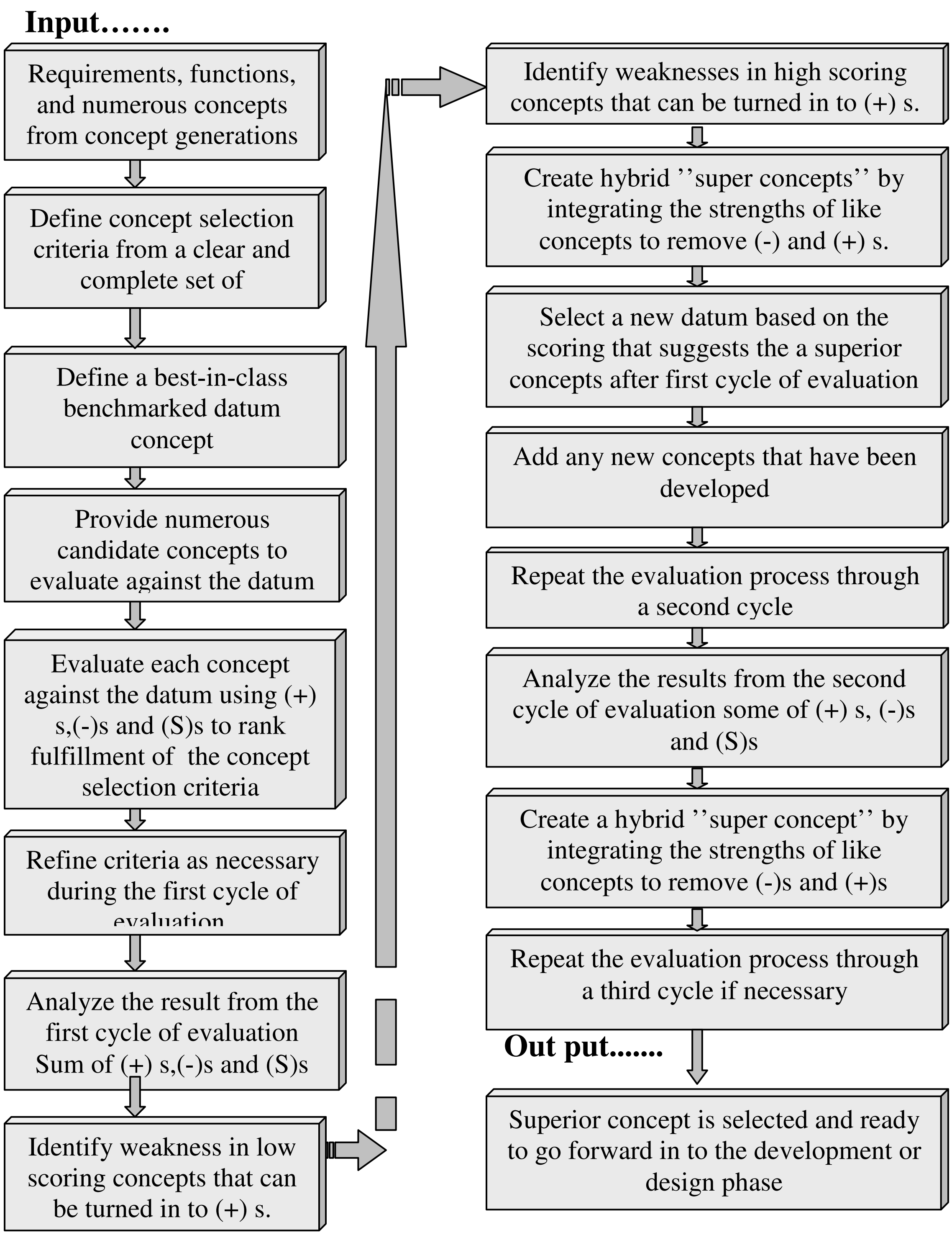
Finally, each concept is given a rank corresponding to its total score.

Combine and improve concepts Is there a generally good concept which is degraded by one bad feature? Can a minor modification improve the overall concept and yet preserve a distinction from the other concepts? Are there two concepts which can be combined to preserve the "better than" qualities while annulling the "worse than" qualities?

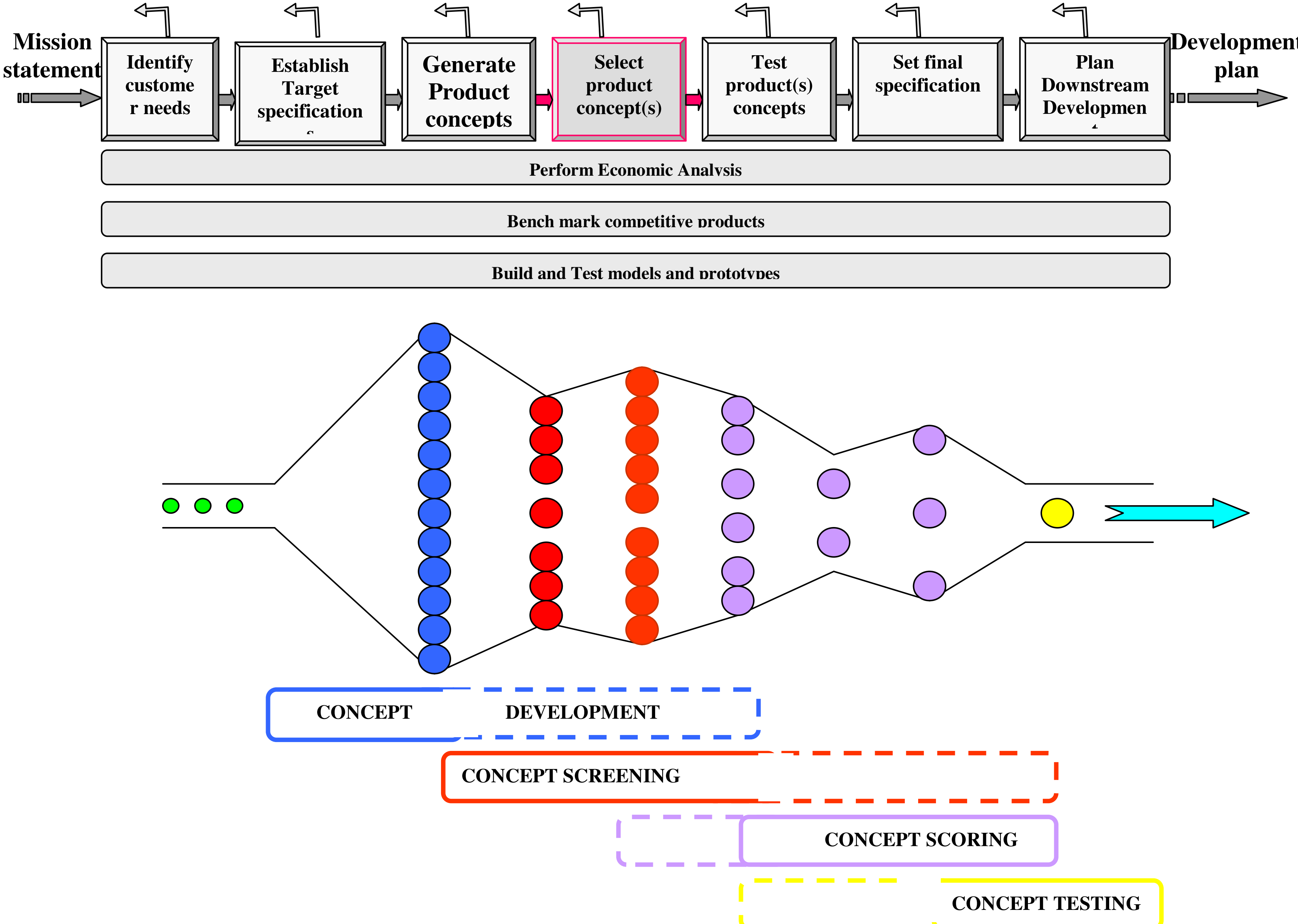
Select one (or a small set) of designs to develop

Concept Selection Process Flow Diagram

This visual reference of the detailed steps of the Pugh concept selection process illustrates the flow of tasks and responsibilities.



Concept development process and its funnel



Concept screening of different concept variants

		Concept Variants							
Selection criteria		A	B	C	D	E	F	G	REFERENCE
Ease of Handling		0	0	-	0	0	-		0
Ease of Use		0	-	-	0	0	+	0	0
Number of readability		0	0	+	0	+	0	+	0
Metering		+	+	+	+	+	0	+	0
Load handling		0	0	0	0	0	+	0	0
Ease of manufacturing		+	-	-	0	0	-	0	0
Portability		+	+	-	-	0	-	-	0
	Pluses	3	2	2	1	2	2	2	
	Same	4	3	1	5	5	2	3	
	Minuses	0	2	4	1	0	3	2	
	Net	3	0	-2	0	2	-1	0	
	Rank	1	3	7	5	2	6	4	
	Continue?	**Yes**	**Yes**	**No**	**No**	**Yes**	**No**	**Yes**	

		CONCEPTS							
		MASTER CYLINDER		**LEVER STOP**		**SWASH PLATE**		**DIAL SCREW**	
Selection criteria	**Weight**	**Rating**	**Weight score**	**Rating**	**Weight score**	**Rating**	**Weight score**	**Rating**	**Weight score**
Ease of Handling	5%	3	0.15	3	0.15	4	0.20	4	0.20
Ease of Use	15%	3	0.45	4	060	4	0.60	3	0.45
Readability of Settings	10%	2	0.20	3	0.30	5	0.50	5	0.50
Metering Accuracy	25%	3	0.75	3	0.75	2	0.50	3	0.75
Durability	15%	2	0.30	5	0.75	4	0.60	3	0.45
Ease of manufacture	20%	3	0.60	3	0.60	2	0.40	2	0.40
Portability	10%	3	0.30	3	0.30	3	0.30	3	0.30
TOTAL SCORE ***RANK***	100%	**2.75** **4**		**3.45** **1**		**3.10** **2**		**3.06** **3**	
CONTINUE OR NOT		NO		**DEVELOP**		NO		NO	

Concept scoring and ranking of product development in Addis engineering center

7.5 A GUIDE TO INTRODUCING CONCURRENT ENGINEERING IN ADDIS ENGINEERING CENTER

Concurrent Engineering (CE) is a management philosophy and is not restricted to manufacturing companies only. Company size may affects how CE is adopted and implemented, however SMEs as well as large companies can use CE. It involves systematic and simultaneous approach in developing a product or process while bringing up all the people who need to be involved in at the first place. In small companies who have very highly skilled and experienced people, Concurrent Engineering can be practiced without computer support or by using any formal techniques.

To ascertain whether the Concurrent Engineering is for you, ask yourself the following questions:

1. Does my company face any of the following problems in product development?
   - ❖ Increasing competitive pressure to develop new products
   - ❖ Product launch delays
   - ❖ Higher costs in processing and developing products than acceptable
   - ❖ A predominantly internally focused product development process
   - ❖ Little or not direct knowledge of customer requirements
   - ❖ No or low involvement by the marketing in early stages of product development
   - ❖ Shift in responsibility for product development from one function to another as the project progresses and transfer points often characterized by conflict
   - ❖ Poor transfer of learning from one product development project to the next.

2. Am I able to provide the necessary enablers to this process? / What is the state of my organizational readiness?
   - ❖ Willingness to change for improvement
   - ❖ Senior management commitment
   - ❖ Ability to encourage teamwork

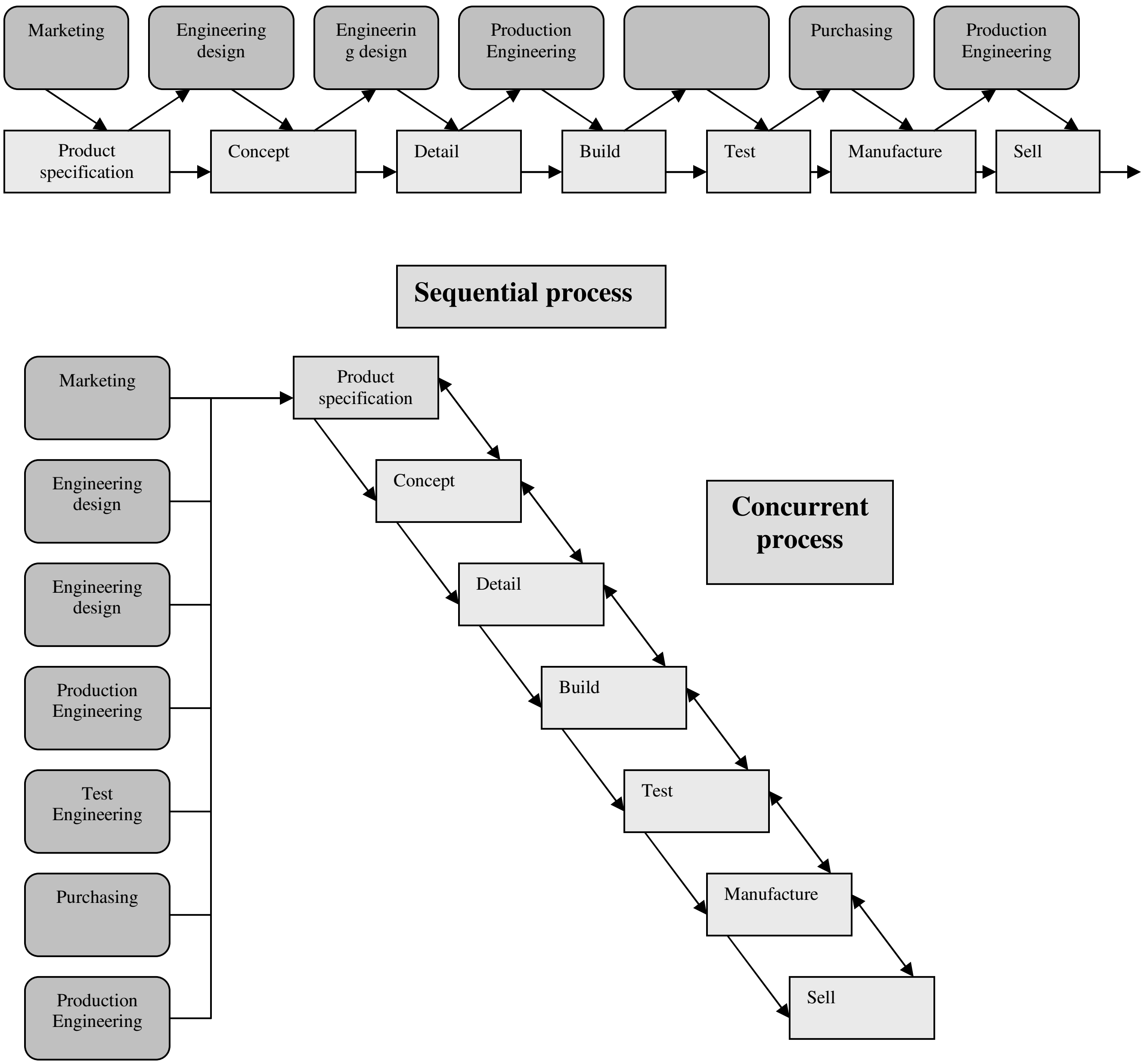


Figure 11 Sequential and concurrent development of new products.

Before implementing concurrent engineering and be successful, it is important to realize the following questions.

- ❖ How could implementing Concurrent Engineering be useful in your organization?
- ❖ How will you form teams?
- ❖ How will you open communication?

- ❖ How will you change processes?
- ❖ How will you implement technology?

Concurrent Engineering involves:

- ➢ Doing things simultaneously
- ➢ Focusing on the Process, being open to change
- ➢ Converting hierarchical organizations into teams
- ➢ Balancing and prioritizing needs of customers, suppliers, quality control, marketing, sales and manufacturing

Understand the Advantages- Industry Experience

CE has led to dramatic benefits for a large number of companies from various industries. Some of the findings are presented here as a pointer towards the potential benefits of this best practice.

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

Table 4 Benefits Obtained from Concurrent Engineering [7]

By executing design in parallel, improvements occur in many areas such as communication, quality, production processes, cash flows, and profitability. The reduction of time to market, which has strategic importance, allows companies to increase their market share and reduce design changes and iterations. Product designs are more easily manufacturability, serviceable and are of higher quality. Once the designs are released to manufacturing, production progresses quickly to full volume because the process is well defined documented and controlled.

World-class companies have achieved remarkable performance using concurrent engineering.

Boeing's Ballistic System Division achieved the following improvements.

- 16% to 46% in cost reduction in manufacturing
- Engineering changes reduced from 15-20 to 1-2 drafts per drawing
- Materials shortage reduced from 12% to 1%
- Inspection costs cut by a factor of 3

NCR used CE to develop a new cash register and achieved the following benefits:

- reduction in parts and assembly line;
- 65% fewer suppliers;
- 100% fewer screws or fasteners;
- 100% fewer assembly tools;
- 44% improvement in manufacturing costs;
- A trouble-free product introduction.

Other examples are: Rolls-Royce reduced the lead-time to develop a new aircraft engine by30%; McDonnell Douglas (American Aerospace manufacturer) reduced production costs by 40%; and ITT (waste treatment and water service) reduced their design cycle-time by 33% for its electronics counter measuring systems.

Understand the Advantages-Strategic benefits of concurrent engineering:

Concurrent Engineering (CE) philosophy is dedicated to the improvement of customer satisfaction through improved quality, reduced costs and faster product development.

Concurrent Engineering leads to:

- ✓ Improved customer satisfaction
- ✓ Improved quality
- ✓ Reduced cost
- ✓ Reduced new product development time
- ✓ Reduced time to market
- ✓ Reconciliation of conflicting requirements in product development

Understand the Difficulties

The reasons for failing to implement CE successfully may be repeated in most companies. However, substantial positive results have been obtained by many companies with poor CE implementations.

- ✓ Implementation of CE is a major challenge for management.
- ✓ Many cross-functional change initiatives have high rates of implementation failure.
- ✓ Concurrent engineering is a particularly problematic cross-functional initiative as it involves, for its implementation, a radical cultural change in an area that is extremely complex and highly pressurized.
- ✓ Overall finding from the cases that firms often underestimated the difficulties of implementing new approaches.
- ✓ Barriers exist in organizations that inhibit the successful implementation of CE. The two types of barriers are organizational and technical.
    - ♦ Organizational barriers include lack of management support, protective functional managers, inadequate reward systems, lack of customer involvement, lack of supplier involvement, and fear of loss of creativity. As an illustration rewards based on departmental goals rather than organization-wide objectives can lead to sub optimization of the organization's performance.
    - ♦ Technical barriers include availability of proper computer-aided design/manufacturing and communication tools.
- ✓ Implementing concurrent engineering principles in an industrial context often give less than satisfactory results in practice because of practical problems such as:
    - Inadequate training and expertise in the concurrent development process
    - Difficulty in synergizing cross-disciplinary labor functions
    - Difficulty in managing or controlling technical processes in the concurrent development process.

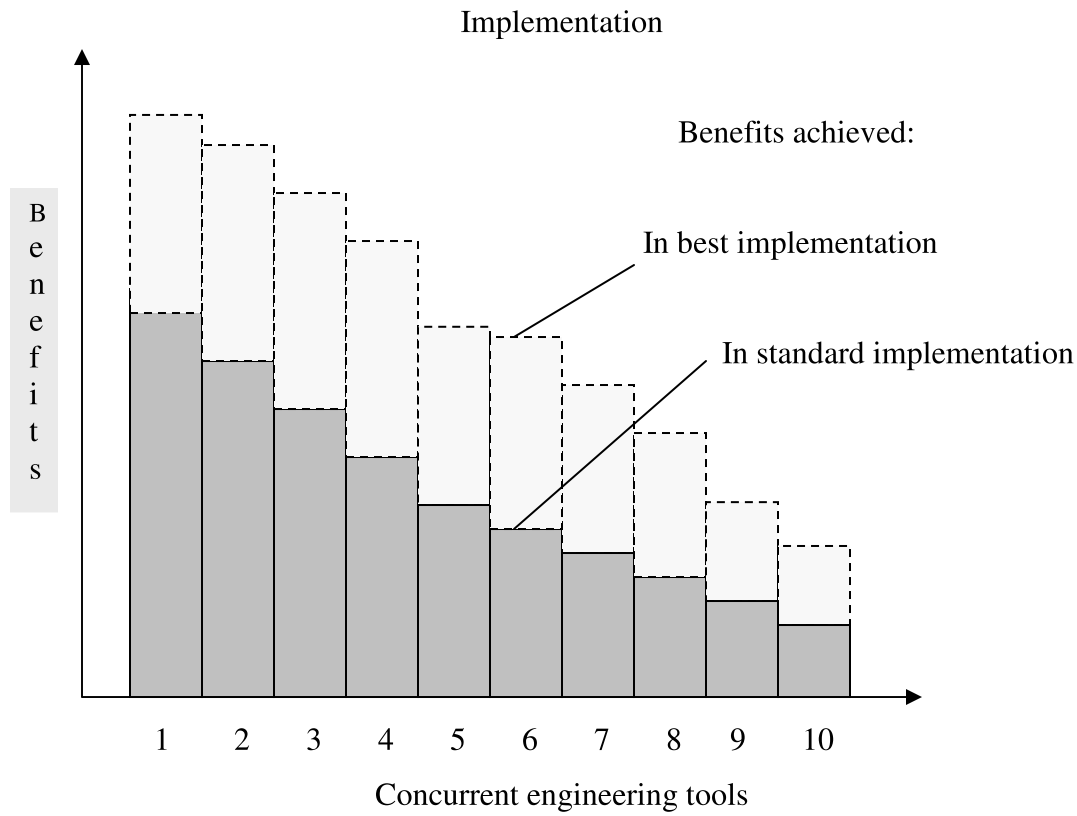
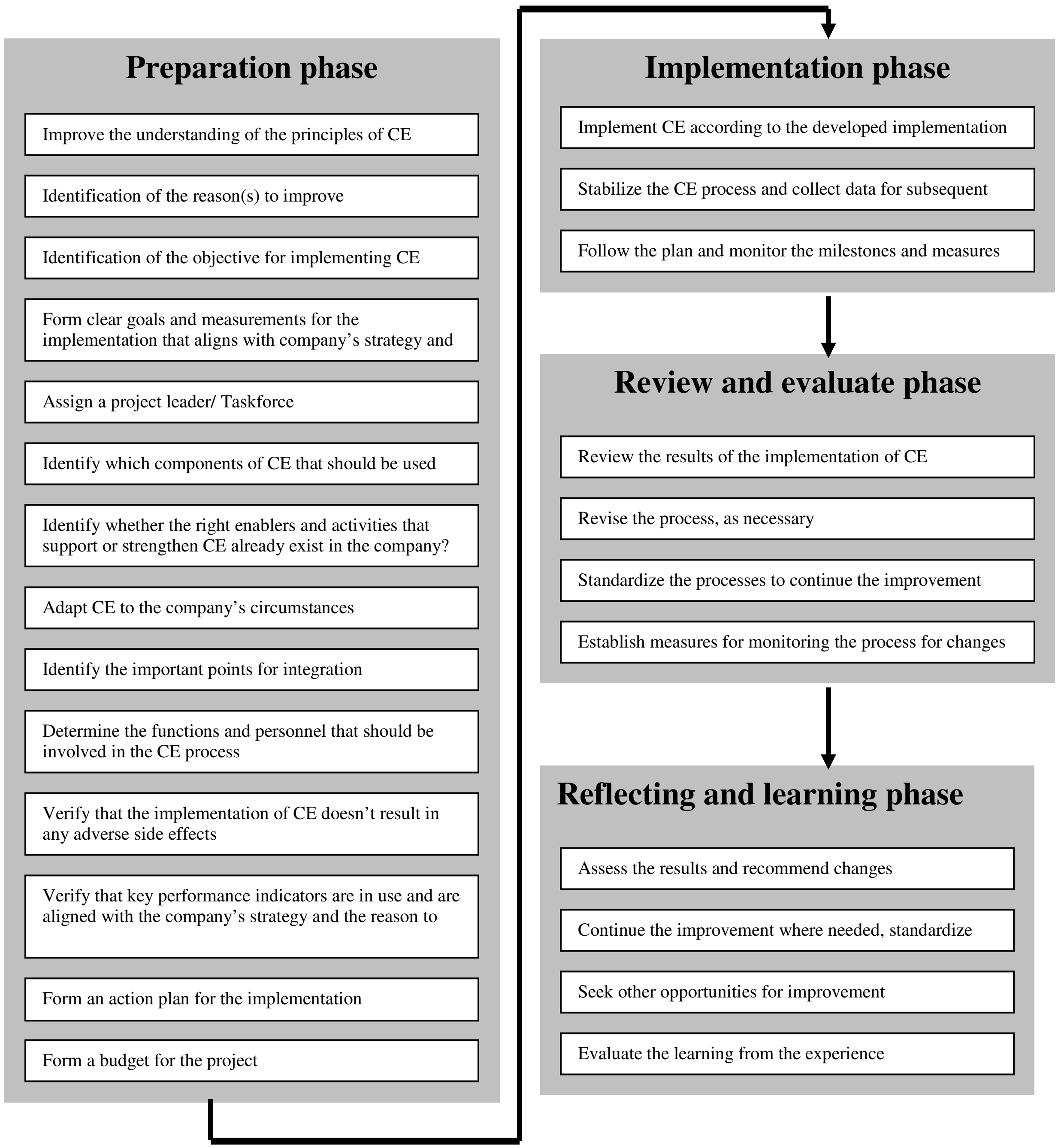


Figure12 variability in benefits achieved from CE tools under best and norm condition

7.6 IMPLEMENTATION METHODOLOGY

Implementation of Concurrent Engineering can be considered along the following Phases: 1. Preparation

2. Implementation
3. Review and Evaluate
4. Reflecting and learning



Preparation phase

- ✓ *Improve the understanding of the principles of CE*

Before any further work is done the principle of CE need to be understood by everybody involved in the organization.

- ✓ *Identification of the reason(s) to improve*

What are the reasons to implement CE?

· Strategy driven (proactive)

· Identified through the use of benchmarks (reactive)

· Highlighted by the occurrence of problems (crisis)

- ✓ *Identification of the objective for implementing CE*

Based on the reason to improve, one must know what the objective (s) is/are.

- ✓ *Form clear goals and measurements for the implementation that aligns with the company's strategy and the reason(s) to change*

This information has to be considered while identifying strategies and objectives.

- ✓ *Assign a project leader*

In this stage assign a project leader who can provide necessary knowledge, skills and experience about CE to others.

- ✓ *Identify which components of CE that should be used*

The components and activities in the list below is a selection of the most common used, it is mainly based on summary of the basic concepts of CE.

- Organizational support
  - -Support of the top management
  - -Support from the functions
  - -Elevation of the project
- Multi-functional teamwork
  - -Collective team responsibility
  - -Team autonomy (independence)
- Elimination of barriers to integration
  - -Leadership required for the whole project

-Project staff dedicated for life of project

- Clear objectives and strategies

-Team contract

-Budget responsible

- Knowledge

  -Using existing knowledge

  -Training personnel for the task

- Experience

Take into account the effects of the firm's organizational culture and prior experience

- Skills

  -Talented and competent employees, managers and team members

  -Willingness to collaborate and learn

  -Ability to recognize one's own strengths and weaknesses

- Information technology

  -Client/Server hardware and networking software

  -Database software

  -Analysis and simulation software

  -Communication technology

  -Environment/desktop software

  -Computer aided tools

✓ *Identify whether the right enablers and activities that support or strengthen CE already exist in the company?*

The enablers can be:

a) Culture of change
b) The positive attitude
c) Good communication between different units/functions associated with the product life cycle
d) Open organizational structures such as matrix management and teamwork
e) The knowledge and skills to understand the company's own needs and potential solutions
f) Supplier and customer involvement

g) Knowledge about CE and its components

✓ *Adapt CE to the company's circumstances*

Explore if there are any specific circumstances that need to be considered. A SWOT analysis can be very helpful in this stage to ensure that the company's circumstances are considered.

✓ *Identify the important points for integration*

Explore what activities can be performed in parallel? The priorities for the project need to be considered when deciding this issue.

✓ *Determine the functions and personnel that should be involved in the CE process*

Below are the most common functions that are involved in a NPD process.

- Product development
- Manufacturing engineering
- Marketing
- Main suppliers and customers
- Service
- Purchasing
- Sales
- Finance
- Specialist vendors (e.g. machine tools and other key components)

✓ *Verify that the implementation of CE doesn't result in any adverse side effects*

When implementing CE one must make sure it matches with all the other concepts and strategies already existing within the enterprise. If there is a mismatch somewhere it has to be solved before the implementation process begins.

✓ *Verify that key performance indicators are in use and are aligned with the company's strategy and the reason to change*

The CE process should not be measured by the same measurements as of the departments/units but have separate NPD measurements. Below are some examples of suitable measurements for the CE process:

- Project schedule/Shipment date
- Market penetration goal
- Revenue goal
- Product cost goal
- Development cost goal
- Functionality
- Expected volumes

- ✓ *Form an action plan for the implementation*
- ✓ *Form a budget for the project*

Implementation phase

- ✓ *Implement CE according to the developed implementation plan*
- ✓ *Stabilize the CE process and collect data fore subsequent assessment*
- ✓ *Follow the plan and monitor the milestones and measures*

Review and evaluate phase

- ✓ *Review the results of the implementation of CE*

Did the concurrent engineering processes produce the desired effect? Did any unintended consequences or adverse side effects result?

- ✓ *Revise the process, if necessary*
- ✓ *Standardize the processes to continue the improvement*
- ✓ *Establish measures for monitoring the process for changes*

Reflect and learning phase

- ✓ *Assess the results and recommend changes*
- ✓ *Continue the improvement where needed, standardize where possible*
- ✓ *Seek other opportunities for improvement*
- ✓ *Evaluate the learning from the experience*

Concurrent engineering implementation schedule and cost benefit analysis

S.No	Description	Duration	Duration	Duration	Duration	Estimated Cost
1	**Preparation Phase** workshop on concurrent engineering by external professionals for Top management	21 days				Training cost, lost time of 30 persons @120 birr per person per day **=75,600 birr**
2	CE steering committee formation from TOP management team					
3	CE attitude survey (profile of organization, quality costs, organization strength/weakness, advocators & resistors.					
4	**Planning Phase** Strategic planning workshop (By CE steering committee): Create vision, guiding principles, set broad strategic objectives, develop quality policy, identify critical success factors& critical processes, baseline employee satisfaction and customer satisfaction.		10 days			Workshop running expenses, lost time of 30 persons @100 birr per person per day, **=30,000 birr**
5	Plan the implementation approach and asses the implementation guide.					
6	**Execution Phase** Form multidisciplinary teams/site steering committees from each department and identify team facilitators.			70 days		For 60 Lost time@70birr per person per day, training costs, Lost services because of inefficiency during first months, 294,000 birr
7	Specific training and team-forming workshops for site steering committees.					
8	create awareness on customer/ supplier relationship					
9	Company-wide implementation/improvement projects for CE (CE Value, customer/supplier frame work, systems and techniques).					
10	Modify infrastructures as necessary (procedures/processes, organizational structure, reward/recognition system, union rules etc.)					
11	**Evaluation Phase** Feedback/ follow-up workshops				5 days	10,000 birr
				Total	**106 days**	**409,600 birr**

Monetary benefit of concurrent engineering implementation

S.No	Benefit obtained form CE	Estimated value obtained(birr/year)
1	Increased revenue generation	150,000
2	Benefit from Elimination of delivery delay	100,000
3	Better employee participation and communication	50,000
4	Elimination of redesigning process	100,000
5	Improved customer service and reducing the scrap	50,000
6	Better ability to manage new product development	50,000
Total		**500,000**

Total benefit obtained is 500,000birr per year

Total cost required to implement Concurrent engineering is 399,600 birr

Payback period is $= \frac{409,600}{500,000}$ year = 0.8192 year.

It is approximately 10 months.

7.7 PROPOSED MODEL OF CONCURRENT ENGINEERING IMPLEMENTATION FOR AEC

A typical model of CE in the realization of a product is shown in Figure 5. The CE model relies on a CE team that is responsible for the total product life-cycle, from idea to finished product. Such a team brings together design, engineering, and manufacturing expertise.

The CE model shown in below although elaborate is of very short duration, and the principal action occurs in the design stage. The market analysis phase defines the new product idea in terms of market requirements and suggests selling price and production cost targets which then serve as input to the "design wheel" in Figure 5. The *domain experts* that constitute the CE team are engaged in the design phase to ensure that the functional goals are met while adhering to *cost targets* and other constraints.

The Marketing department typically initiates new product ideas. Such ideas are based upon market research, where the customers' needs are studied. The marketing department is not totally independent in conducting this marketing research. Various other departments contribute information such as the manufacturability of a certain product proposal and help the marketing department in formulating a more precise idea for a new product. Eventually, the idea that is presented to the design team has more clearly defined design goals and objectives. An outcome of the marketing analysis is the setting of the *Selling Price and Production Cost Targets*.

Production realization phases with concurrent engineering design

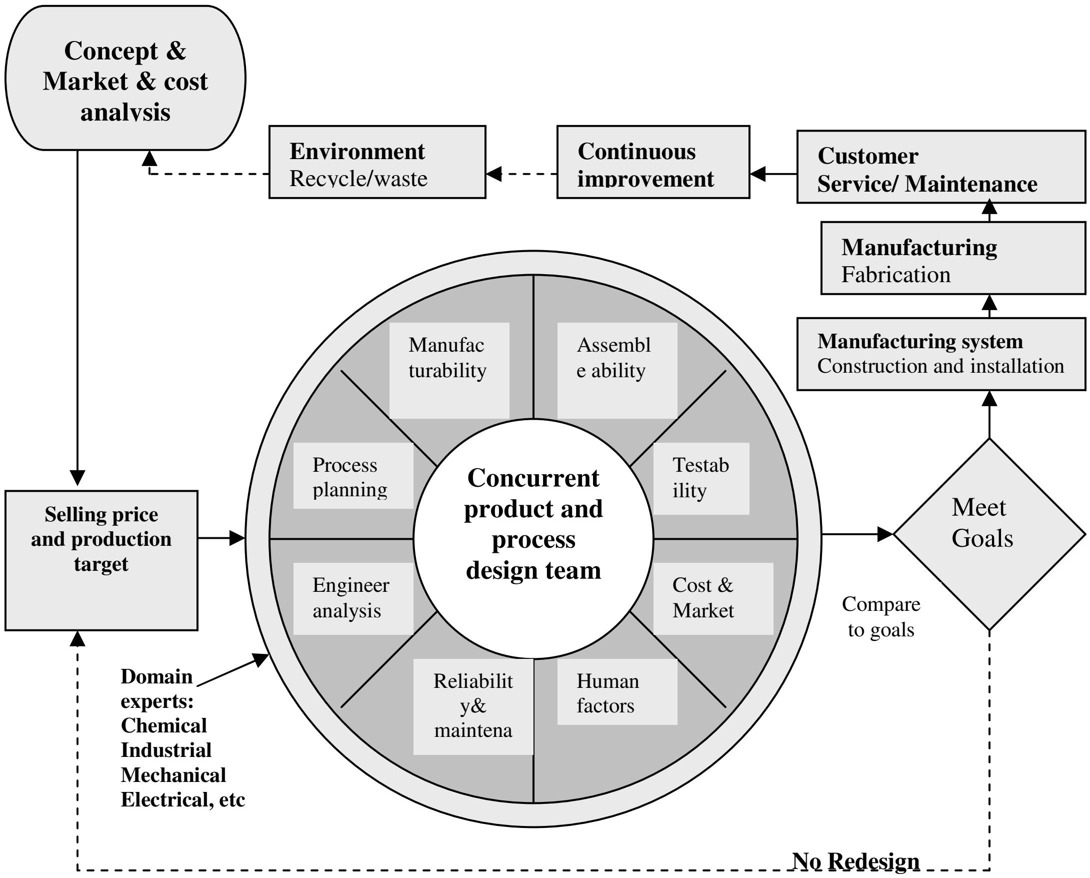


Figure 5 concurrent engineering Model

The principal difference in the concurrent design engineering versus the traditional design engineering is in the design approach. In the CE design stage, a suggested design is submitted to the CE team. The advantage of the CE team involvement in the design stage is that the domain experts from the engineering, manufacturing, marketing, sales, packaging, inspection, service, assembly and environmental departments will improve the design of the product with implementation of their knowledge and working simultaneously with the design team.

A good feature of this CE phase is that by designing the product the CE team also designs the process for the manufacturing of the product. The team decides of what kind of equipment is going to be used, the layout of the machines, etc. In the traditional model, in this stage, only people from the design department are involved, and the big decisions are mostly left to a designer.

CHAPTER EIGHT

8. CONCLUSION, RECOMMENDATIONS, AND FUTURE OUTLOOK

8.1 CONCLUSIONS

This paper is done in Addis Engineering center of Ethiopia as a case study in product development and improvements in Concurrent engineering and its implementation perspective.

Industrial competition is today truly global with fragmented markets and customers expecting to get the best product at the best price with immediate availability. Customer demands require a high degree of quality & flexibility, low-cost and short delivery times.

Success in manufacturing requires continuous development and improvement of how the products are developed and produced.

The study depicted or assessed Addis Engineering center and Dejen Aviation Maintenance and Engineering complex did not achieve the delivery time to the customer. Some of most frequently coming products are analyzed and 60 to 80 % of these products are not delivered on time to the customers.

The company is following the traditional way of product development that is sequentially design and production method, which highly affect time to market. Time is very important consideration in concurrent engineering. The unnecessary and long workflow of Addis Engineering Center has its contribution for the customer requirements on the eyes of achieving the delivery time. By forming multi disciplinary team in designing and quality inspection, the company can reduce the workflow steps from 40 to 30. This in turn reduces the average time for production of a single product from customer order to the delivery of finished products.

This thesis tries to show and exemplify the most common types of wastes in AEC and DAMEC. Identifying the types and depths of waste helps the companies to take the remedial action by prioritizing the most occurring and influential ones through production and new product development processes. There are three types of wastes namely production waste, information waste and enterprise level waste.

Different tools are used for analysis purpose like Paretho diagram, fishbone diagram and SWOT analysis of the company. In addition to these, the interview and discussion with responsible personnel are done. At the result, there is no formal procedure to select different concepts for design. Therefore, this research has tried show the concept development process can be done with different variants starting from customers' specifications and requirements to the design development stage. These is done in the following sequence, prepare the selection matrix, rate the concept, rank the concept, combine and improve the concepts, select one or more concepts, and reflect on the results and the processes.

Concurrent Engineering is not a quick fix for a company's problems. It is a business strategy addresses important company resources. The major objective this business strategy aims to achieve is improved product development performance. Concurrent Engineering is a long-term strategy, and it should be considered only by organizations willing to make up front investments and might need years for long-term benefits. The implementation guide, which is presented in this thesis, is simplified and can be implemented with out sophisticated software applications in Ethiopian industries. This could be achieved by forming multi disciplinary team

8.2 RECOMMENDATIONS

To make Concurrent Engineering a real success, all the necessary information concerning products, parts and processes, has to be available at the right time. Addis Engineering Center is following sequential method of production systems. Customers are complaining due to long delivery time of products. This paper tries to testify that AEC could be benefited by implementing concurrent engineering concepts in the organization.

Based on the study conducted in the company, the following recommendations are made:-

- Making Concurrent Engineering a success is really a management issue. If management doesn't get it right then it's not going to matter much whether Concurrent engineering is implemented or not.
- The implementation of Concurrent Engineering addresses three main areas: people, process, and technology. It involves major organizational changes because it requires the integration of people, business methods, and technology and is dependent on cross-functional working and teamwork rather than the traditional hierarchical organization.
- Getting the design correct at the start of the development process will reduce downstream difficulties in the workflow. The need for expensive engineering changes later in the cycle will be reduced. So, the company should pay attention during the first area of product development.
- Proper process planning and production planning systems should be practiced instead of estimating by experience. In addition to this, the product cost analysis should be done based on formal procedure so that the customers do not flock to the competitors.
- To be successful with Concurrent Engineering, companies should initially compare themselves to their best competitors (i.e. benchmark), develop metrics and develop a detailed implementation plan.
- Many companies have problems introducing Concurrent Engineering. The warning signs may be one or some of the following. unwillingness to institutionalize Concurrent Engineering , maintenance of traditional functional

reward systems maintenance of traditional reporting lines ,no training in teamwork ,unrealistic schedules , no changes in relationships with vendors ,a focus on computerization rather than process improvement. So, Addis engineering center should see the upper mentioned points before implementing integrated product development.

- Sometimes, only design engineers and manufacturing engineers are involved in Concurrent Engineering. In other cases, the cross-functional teams include representatives from purchasing, marketing, production, quality assurance, and other functional groups. Sometimes customers and suppliers are also included in the team. There fore, the company should take in consideration the evolvement of customers and suppliers so that the implementation of concurrent engineering can be effective.
- The company should strive on continuous improvements and work on quality concepts intervention across the company boarders so that it facilitates the implementation of concurrent engineering.

8.3 FUTURE OUTLOOK

There is growing awareness and interest in the adoption of Concurrent Engineering (CE) in the Industry because CE has the potential to make production and projects less fragmented, improve product quality, reduce product or project duration and reduce total project cost. So as to be competent and to survive in the present dynamic global market, the product development processes should be at better condition.

Marketing today is integrated with sophisticated software for best data information management systems. This study can be used as a starting point for the future researchers. It is believed that if concurrent engineering is supported by friendly user interface, reliable and fast information flow would be there concurrent engineering between team members.

Bill of material and labor estimation sheet

Customer: ordinance

Workshop: Tools and spare parts

S/N	TITLE OF PART	CODE NO.	MTL. TYPE Cheek. std	DIMENTION PER PC	KG. PER PC	ORDERED PCS	TOTAL KG	OPERATION / WORKERS GRADE / TOATAL ACTUAL/PLAN WORK TIME						CAL. TIME	EFFECT& REMARK
1.1	Punch	1513-0409	19614	ϕ 55x105	2.056	01	2.056	**L**	**M**	**HT**			Sub-total		
								III	III	F.O					
								4	4	1.5			9.5		
1.2	Die	1513-1604-12	19614	ϕ 80x41	1.698	01	1.698	**L**	**M**	**HT**					
								II	III	F.O					
								3	4	1.5			8.5		
1.3	Die holder	1513-12-0032	11600	ϕ 100x153	9.904	01	9.904	**L**	**M**						
								II	II						
								5	2				7		
1.4	Lower plate	1513-13-0081	11373	f-200x30x150	7.418	01	7.418	**M**							
								II							
								16					16		
1.5	Bolts	1513-12-0175	12050	ϕ 12x25	0.023	8	0.186	**L**	**M**						
								II	II						
								8	4				12		
1.6	Compression spring	1513-23-0026	12090	ϕ 4 x1000	0.103	4	0.414	**L**	**HT**						
								II	F.O						
								2	1				3		

Prepared by______________ Checked by_________________

Received by______________ Approved by________________

Bill of material and labor estimation sheet

Customer: ordinance

Workshop: Tools and spare parts

S/N	TITLE OF PART	CODE NO.	MTL. TYPE	DIMENTION PER PC	KG. PER PC	ORDERED PCS	TOTAL KG	OPERATION						CAL. TIME	EFFECT& REMARK
								WORKERS GRADE							
								TOATAL ACTUAL/PLAN WORK TIME							
1	housing	1513-12-0029	11600	ϕ 75x236	8.593	25	254.844	**L**	**M**	**HT**			Sub-total		
								III	III	F.O					
								335	300	3			638		
2	Trapezoidal Double start Thread	1513-12-0018	11600	ϕ 30x188	1.095	25	27.383	**L**	**M**	**HT**					
								II	I	F.O					
								150	9	2			161		
3	handle	1513-13-0010	11373	ϕ 14x145	0.184	25	4.599	**L**	**HT**						
								I	F.O						
								25	6				31		
4	Locker hinge	1513-13-0040	11373	s-16x16x65	0.137	25	3.428	**M**	**HT**						
								II	F.O						
								75	1				76		
5	Bigger pin	1513-12-0001	11600	ϕ 10x47	0.030	25	0.760	**L**	**HT**	**GRR**					
								I	F.O	II					
								7	3	7			17		
6	Smaller pin	1513-23-0005	11600	ф 4 x18	0.0018	50	0.093	**L**							
								I							
								5					5		

Prepared by______________ Checked by_________________

Received by______________ Approved by________________

Bill of material and labor estimation sheet

Customer: ordinance

Workshop: Tools and spare parts

S/N	TITLE OF PART	CODE NO.	MTL. TYPE	DIMENTION PER PC	KG. PER PC	ORDERED PCS	TOTAL KG	OPERATION						CAL. TIME	EFFECT& REMARK
								WORKERS GRADE							
								TOATAL ACTUAL/PLAN WORK TIME							
7	extractor	1513-12-0022	11600	ϕ 40x25	0.258	25	6.056	**L**	**M**	**HT**			Sub-total		
								I	II	F.O					
								25	38	3			66		
8	screw	1513-12-0005	11600	ϕ 8x30	0.012	25	0.310	**L**	**M**	**HT**					
								I	I	F.O					
								13	9	1			23		
9	Wing nut	1513-13-0040	11373	ф 16x16x36	0.076	25	1.899	**M**	**HT**						
								II	F.O						
								50	2				52		

Prepared by______________ Checked by_________________

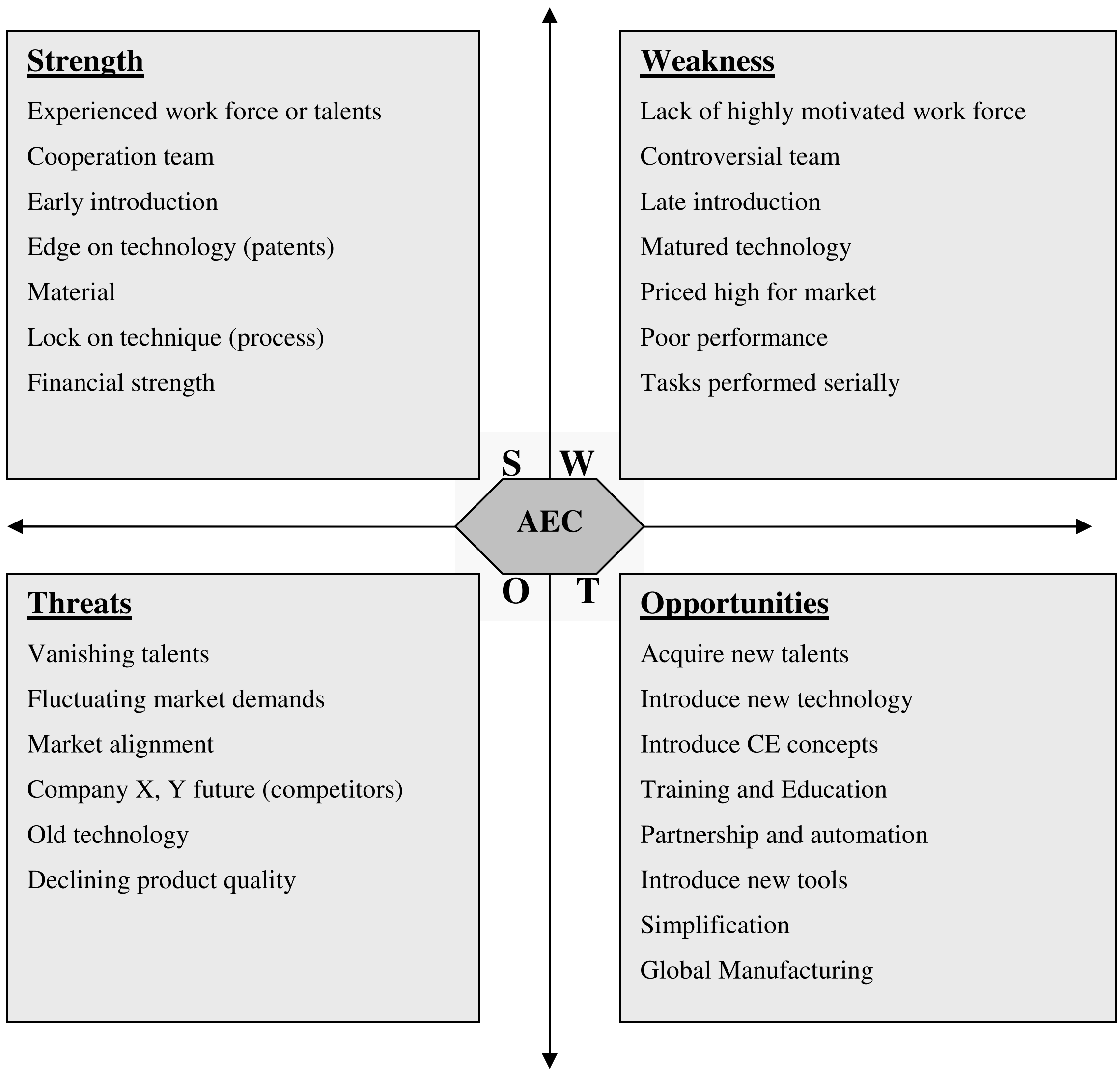
Received by______________ Approved by________________

Technological procedures

Job order	Ord. pcs	Drawing no.	Designation of tools	Title of parts	Cost sheet no.	Customer
4-8-109	O1	322D-06-08	First male	Die	Pts/233/97	Kombolcha Textile Factory
Material type	**Code no.**	**Dimension**				
15124	1513-13	Φ255X101				

S/N	Machine	Work description and tool	Pcs time	Setting time	Total work time	Worked by		Good pcs	Scrap pcs	Inspected by/on
1	L	Face both ends, turn to Φ230±0.5mm, make the step			21 hrs					
		to219.7±0.3 and Groove the 5X1 then Drill Φ 28±0.2,								
		Φ 32±0.3 and form R28,R5 and chamfer according to								
		The drawing								
2	HT	DIN-1-2080 harden it to HRC 42+5			13 hrs					
3	GR1	Grind holes to Φ 28±0.2, Φ 32±0.3 clean one side			14 hrs					
		(face) at the same time								
4	GRR	Grind Φ 219.7-0.1 to and finish			6 hrs					
5	LP	Polish R28,R5 and the face according to the drawing			3 hrs					

Prepared by/on	Approved by/on	Remark	Note



SWOT analysis of Addis Engineering Center

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[22] http://cs.wpi.edu/~dcb/CERA/Jnl-descr.html

[23] http://www.ceraj.com/

[24] http://www.eng.nus.edu.sg/LCEL/

[25] http://library.gsfc.nasa.gov/SubjectGuides/ConEng.htm