METHODOLOGIES FOR MODELING AND ANALYSIS OF PERFORMANCE MEASUREMENT IN PRODUCT DEVELOPMENT

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DEDICATION

To,

The Prophet Muhammad (PBUH);	My Role Model in Life,
M. Amjad Amin;	My Gracious Father,
Meher-un-Nisa;	My Loving Mother, and
Batool;	My Caring Sister

Without their Guidance, Love and Support, I could not be able to achieve any thing in my life.

Muhammad Kamal Amjad

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ABSTRACT

Measuring the efficiency of a process is the most effective way of managing and monitoring it. The thesis addresses the state of the art in product design and development and its effects on the human society. The design process is reveled in a great detail and its impact on manufacturing is elaborated through literature review and personal experience.

Product development is knowledge based qualitative process. Measuring the performance of a qualitative process is not the same as done in quantitative processes like manufacturing. An effort has been made in this thesis to identify the requirements for the measurement of performance in product development and the methods available to analyze it. A critical survey of the literature available is done for the provision of available performance measurement techniques in product development. A single measurement and management technique is then advised through research as per the requirements of mechanical manufacturing sector of Pakistan. Software is then developed for an easy interaction with the approach.

The approach is then applied to a selected manufacturing facility to elaborate the outcomes of the performance measurement in a selected project from the facility. Selected results are also presented in the form of graphs and further insights to the approach are discussed.

Chapter 1
INTRODUCTION

1.1 Background

1.1.1 The Need of Performance measurement

Since the existence of his generation, mankind has always been developing new and state of the art technologies and systems. In this process both mental and physical efforts are required. Mankind has also learnt the advantages of team work and hence formed organizations where they co-operate and collaborate with each other to achieve a specific goal or set of goals. As the quantum of work increased, the value of time, money and effort was realized. At this point of time, the performance and its measurement was also started.

For an introduction, performance measurement can be defined as the process whereby an organization establishes the parameters within which programs, investments, and acquisitions are reaching the desired results [1].

Business today operates in a very tough environment that is constantly in flux. Customers have become increasingly demanding looking for better and innovative goods and services that are specifically customized to meet their unique needs. There is also an implicit requirement on the accuracy, timeliness, convenience, responsiveness, quality, reliability and after-sales-service offered to them at ever-low prices [2].

The need of performance measurement and its improvement has been the basic requirement of every industry and business since the start of the industrialization age, and especially in the above stated scenario. May it be a special customer based tailored project or an internationally standardized component, organizations have strived to improve their performance so that they could get more share and hence more profit in the market.

1.1.2 Performance and its Improvement

Performance can be defined as
a. The act of performing or the state of being performed;
b. The act or style of performing a work or role before an audience;
c. The way in which someone or something functions;
d. A presentation, especially a theatrical one, before an audience; or
e. Something performed; an accomplishment [8].

The improvement of performance can only be done through one way, i.e. to know where the performance is standing right now. The performance standards can be self-assessed or bench-marked.

The field of performance measurement is related to both management and engineering. Only a qualified professional can realize the importance of the processes involved in the life cycle of a component. Certain organizations have performance measurement and management centers where they constantly monitor the performance of their Self Accounting Units (SAUs).

1.1.3 Performance Management

Generally, the terms ‘performance measurement’ and ‘performance management’ are misunderstood. The performance management is more of a HRM process rather then involving technicalities involved in the making of a product. Performance management focuses on the performance of employees rather then the process itself.

By definition, performance management is the systematic process of
a. Planning work and setting expectations;
b. Continually monitoring performance;
c. Developing the capacity to perform;
d. Periodically rating performance in a summary fashion; and
e. Rewarding good performance [3].

1.1.4 The Design Process

The design process is referred in two different contexts: as a noun and as a verb. The design as a noun is defined as;
a. A preliminary plan or sketch for the making or production of a building, machine, garment, etc.;
b. The art of producing a building, machine garment etc.; or
c. The general arrangement or layout of a product [4].

Design as a verb is interpreted as ‘Design Process’ and may be defined as a process performed by humans aided by technical means through which information in from of requirements is converted into information in from of descriptions of a technical system, such that this technical system meets the requirements of mankind [5]. The human(s) involved in the process are called ‘Designer(s)’ and the system through which it evolves is called ‘Design System’.

Design process is considered to be the most important and crucial phase of the product life cycle as it affects all the downstream stages of the product life cycle in terms of cost and quality of the decisions made at the different levels of an organization regarding a product or system to be designed [6]. Management of the design process involves an approach where an organization makes decisions related to the design process in customer / market oriented manner as well as optimizing the design process. Design management further provides a link between design process, technology, tools and methods and management at different levels of an organization.

1.1.5 Performance Measurement in Design

The design of performance measurement systems appropriate for modern manufacturing firms is a topic of increasing concern for both academics and practitioners [7]. It is absolutely important to find the 'Design' or as a whole "Product Development Performance' in order to see how well the design or product development process works according to the intentions of the designer, company and the initially defined standards. The reasons to find out and measure the design development performance are appended as follows;

a. Identification of strengths and weaknesses;
b. Comparison against competitors;
c. Determination of the factors affecting performance;
d. Establishment of the nature of the effect;
e. Focusing on the process improvement initiatives;
f. Providing a basis for continuous improvement; and
g. Achieving the recognition of high performance [6].

Organizations are continually striving to find better ways for improving their business situation in terms of market share and increased profits. To achieve this milestone, they induct the performance measurement and improvement strategy immensely nowadays. These processes include redefining the key business processes and the selection and implementation of specific tools in support of these processes [9 – 11].

This trend is evident in all organizational activities such as manufacturing, marketing, sales, service etc. However, the impact of product development on overall organizational performance has been recognized as significant [13]. Therefore the analysis of performance in this area, i.e., how well the product development is being done is gaining importance. This adds to the vision of the organization as a quality focused and customer oriented organization and is basically the integral part of the continuous improvement process, adding towards the body of knowledge of Engineering Design, Total Quality Management (TQM) and Project Management.

1.2 Problem Statement

A considerable amount of work has been carried out in the field of performance measurement and analysis in manufacturing facilities and processes [12]. However, the ways in which tangible things like manufacturing performance is measured is considerably different than the intangible measures like design and product development which makes performance measurement more difficult in this area. The measurement of knowledge based activities which are the hallmark of product development present difficulties in the assessment of performance.

Moreover, the research validation in this area is a lengthy process as the product needs time when evolving through the product life cycle from conceptual phase to the manufacturing. Thus the concept of continuous improvement here presents time lag and intangible process measurements.

Pakistan, being an agricultural country, has a moderate infrastructure of purely mechanical and manufacturing industry. The manufacturing industry of Pakistan is generally producing the designs of foreign origin. A limited number of organizations have their design offices established in Pakistan, and even more limited organizations produce their own designs in these offices. Moreover, these design offices are not implementing the concept of performance measurement in product development. This fact will be highlighted in greater detail in the coming sections.

An effort is made here to identify the requirements of a performance measurement system in the product development scenario. The overall problem statement is elaborated in the following in points.

a. What is product development?
b. How product development is significant in manufacturing?
c. What is the basic process flows for the design process?
d. What is performance measurement and how it is measured in product development?
e. Is there an agreement in literature on the ways through which the performance is measured in product development?
f. How can the performance measurement in product development be applied in the manufacturing sector?

1.3 Research Areas

The research presented here will attempt to address the following topics.

a. The state of the art in general performance measurement;
b. The performance measurement system design;
c. The nature of performance measurement in design;
d. Models of performance measurement in design;
e. Analysis techniques presented in the models;
f. Metrics for performance measurement in design development; and
g. Industrial relevance.

1.4 Research Methodology

The research presented here is organized to answer the problems presented in section 1.2. First of all, the nature of the design process is presented and through discussion on its various aspects is presented. Work done in the field of performance measurement in product development is then critically reviewed. The latest models and software techniques available are introduced, analyzed and utilized to measure the performance of a manufacturing facility. The selection of the manufacturing facility is also done through defined criteria. The implementation of the performance measurement in product development of a selected project is then presented on the basis of understanding developed in the mentioned discussion. Graphs, Tables, Figures and Equations are extensively used to elaborate the concepts where required. The research presented here will cover the area of general performance measurement procedures. Emphasis will be placed in the field of performance measurement in product development and design which is a seriously neglected field in Pakistan. The research will aim to present some performance based solutions for the manufacturing facility studied. A schematic overview of the research methodology is presented in Fig. 1.1.

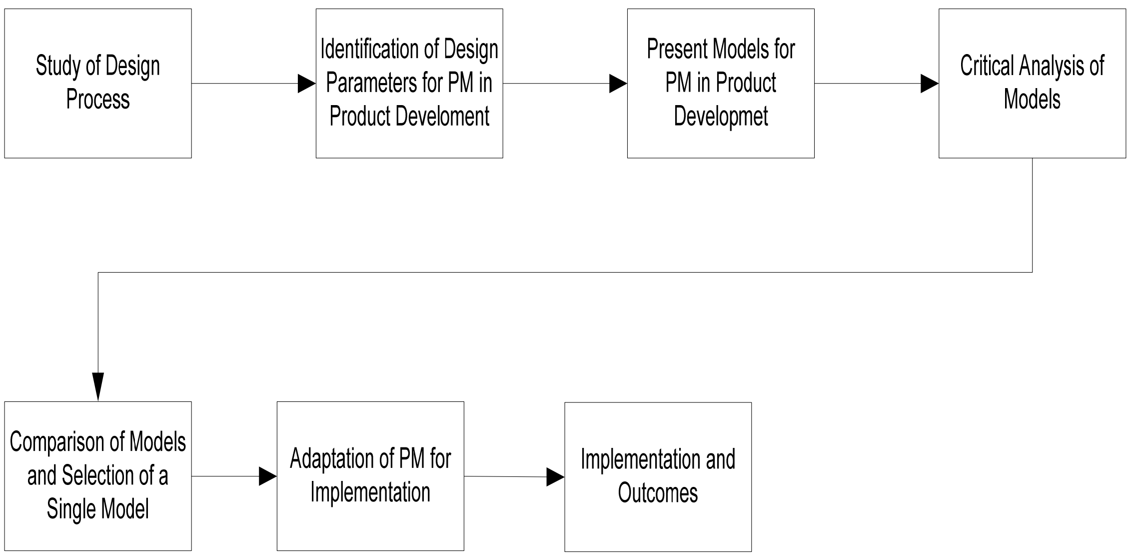

Figure 1.1 Research Methodology

1.5 Significance of Research

Pakistan is basically an agricultural country. Manufacturing facilities play very important role in enhancing the GDP of a country. Pakistan has some state of the art manufacturing facilities, mostly in the government and defense production sectors. However the private manufacturing sector is suffering severely because of following reasons;

a. Power and energy crisis;
b. Un-announced Load shedding;
c. Heavy taxes; and
d. Import restrictions.

Moreover, even where working efficiently, the manufacturing sector of Pakistan is not implementing the performance measurement in design and product development. Many organizations are paying attention towards the performance management in the HRM perspective, but a little interest is involved in the field of performance measurement and improvement at the product development stage. The idea is to just produce the items and throw them in the market with little interest in the performance measurement at development stage.

The performance, if addressed at product development level, will surely enhance the fictional capabilities of an organization and also ensure that the organization stays ahead with a competitive advantage. This will ensure that the customer gets what he wants and within the shortest possible time.

The research will have following significance in particular;

a. A well referenced source of literature review in design development and its performance measurement;
b. Techniques for the smooth application of methods in the industry;
c. Industrial relevance with respect to Pakistan; and
d. Analytical results beneficial for the companies which are interested in the measurement of design performance.

Chapter 2
THE DESIGN PROCESS

2.1 Definition of Design

The field of engineering requires the application of scientific knowledge to the solution of technical problems and to optimize these solutions within the requirements and constraints set by material, technological, economic, legal, environmental and human related considerations [5]. Designers contribute to the community by providing working ideas as solutions for the problems of mankind. Therefore, they apply their engineering knowledge for the betterment of the civilization.

Design is the planning that lays the basis for the making of every object or system and is the part and parcel of every engineering concept. The activity requires the designer to think of an idea to solve the defined problem. The person designing is called a 'Designer'. A preface with the word designer is usually added to specify the specialty of the profession, e.g., fashion designer, mechanical designer, piping designer etc. With such a large variance in disciplines and specialty, there is no single definition of the word design. However, technical design is considered here and is presented in the following.

2.1.1 Design as Noun

The oxford dictionary defines design as;

a. "A preliminary plan of sketch for making or production of a building, machine, garments, etc.;
b. The art of producing a building, machine, garments, etc.; or
c. A general arrangement or layout of product" [4].

Another definition of design is as follows;
"Design is an engineering activity that:

a. Affects almost all areas of human life;
b. Uses the laws of insights of science uses;
c. Builds upon special experience; and
d. Provides the prerequisites for the physical realization of solution ideas" [14].

2.1.2 Design as Verb

As a verb design is referred as 'Design Process'. Again, there is not a single definition of the verb as a huge multi-disciplinary base is present. Some of the definitions are as under.

a. "A process found by human, aided by technical means through which information in the form of requirements is converted into information in the form of descriptions of a technical system, such that this technical system meets the requirements of mankind" [5].

b. "Design is a process consisting of problem solving activities in which design solutions are generated to satisfy customer needs" [15].
c. "Design as a process of creating solutions in the form of products, processes or systems that satisfy the needs by mapping the functional requirements in the functional domain and design parameters of the physical domain, through proper selection of design parameters"[6] .
d. "To produce a design (of a machine, building etc.)" [4].

With considerable variance in the above described definitions, all indicate that design is a process of generating some solutions to a specific problem and then deciding on the best possible solution to satisfy the conceived requirements. Therefore, design is a systematic process of evolving a solution for the easiness of working and betterment of the civilization.

Dixon [16] and Penny [17] placed the work of engineering designers at the hub of cultural and technical streams, describing design process as a hub of all the society. This aspect is shown in Fig. 2.1.

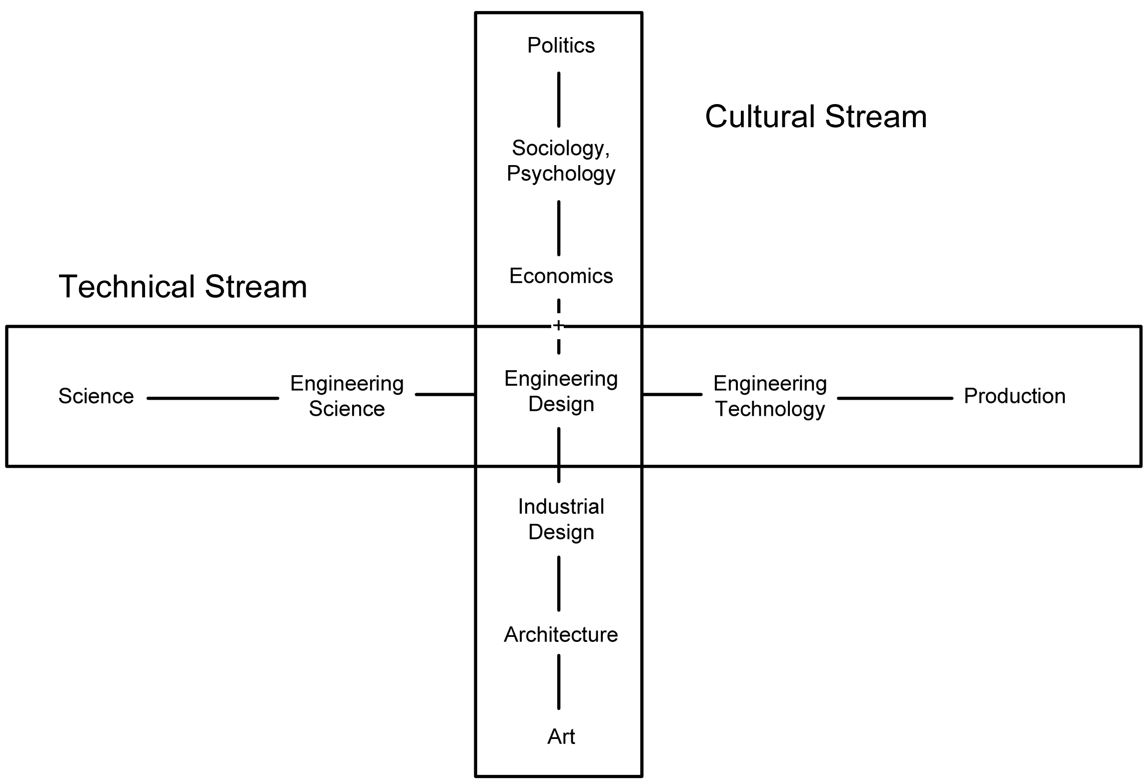

Figure 2.1 The Central Activity of Engineering Design

In the psychological viewpoint, designing is a creative activity that calls for a sound grounding in mathematics, physics, chemistry, mechanics, thermodynamics, hydrodynamics, electrical engineering, production engineering, materials technology and design theory, as well as knowledge and experience of the domain of interest. Initiative, resolution, economic insight, tenacity, optimism and teamwork are qualities that stand all designers in good stead and are indispensable to those in responsible positions [18].

In the systematic viewpoint, designing is the optimization of given objects within partly conflicting constraints. Requirements change with time; therefore, a particular solution can only be optimizing for a particular set of circumstances.

Design is an essential part of product life cycle. This cycle is originated by market need, customer demand or technology and is presented in Fig. 2.2 The lifecycle starts with planning and ends with disposal or recycling. The product life cycle is a representation of a process that converts raw material into economic products of high added values.

It can be seen that the market need or problem and potential goals of the company trigger the start of the product life cycle. When enough information about the problem is gathered, the problem is analyzed and solution is thought. This phase is called the product planning and task setting. The work is brought down into small pieces and proper management of the work is planned.

The design activity is started hereafter. The design team develops the ideas and produces a conceptual design for the product. The design then matures into final design and the product is sent to production and assembly. The product is then introduced into the market and a sales pattern is observed for the reference design after the customer uses the product.

The product sales describe the popularity of the product and decide the future and life cycle extension. If a product successfully meets the customer needs, the life cycle will elongate and if it fails to satisfy the customer, the product will die out very soon. Thus the customer plays an important role in deciding the future of the product, as it is rightfully said that customer is the king.

2.1.3 Product

Design is created for the solution of a problem. The solution of the problem may be tangible or intangible and is called a product. The product may be a material thing or a service. Product is defined as;

a. “Thing or substance produced especially by manufacture [5]” ; or
b. “A product is defined as something with being, form or shape created by physical labor and / or intellectual effort [44]”.

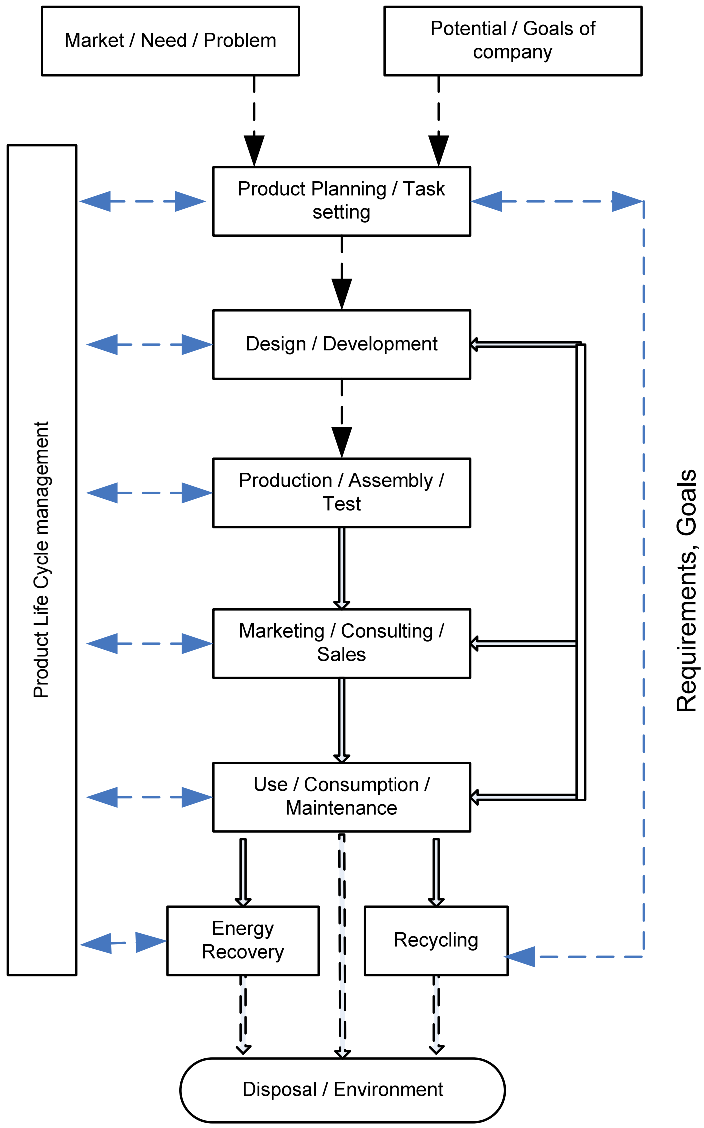

Figure 2.2 The Product Life Cycle, after [18]

2.1.4 Types of Design

Following are the main types of design.

a. *Conceptual design*: Conceptual design is a process in which a concept / sketch / plan is produced by evaluation different concepts against different criterion.

The conceptual design may only consist of a pencil sketch for the matter of reference and understanding of the general concept of the solution to the pre-determined problem. The level of detail of the conceptual design is generally low. Only the idea is represented for the discussion and reference purposes. The conceptual design patent of the P-38 Aircraft design is shown in Fig. 2.3.

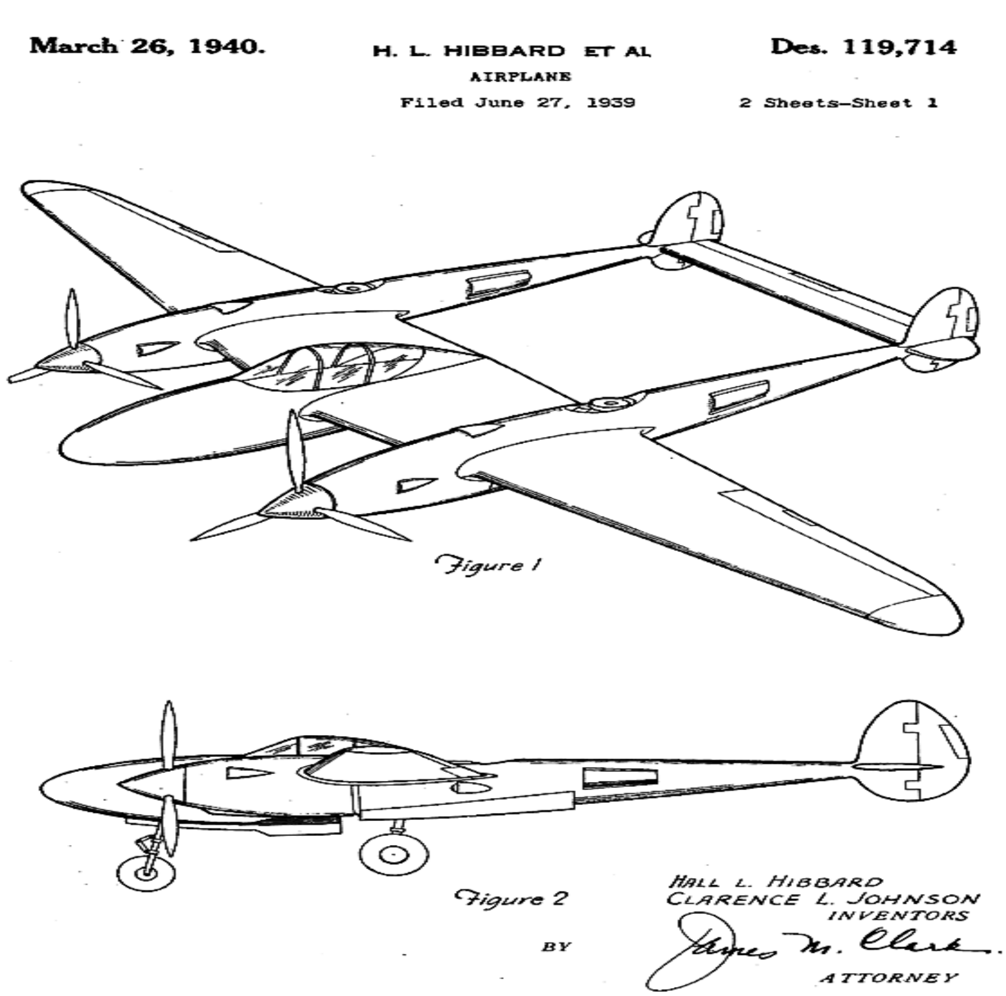

Figure 2.3 Conceptual Design Patent of the P-38 Aircraft, after [17]

b. *Configuration design*: It is a process in which a configuration / layout of different components in an assembly or a product is finalized.

   At this level, the individual product parts are presented through technical drawings. These drawings are later used for the manufacturing and production of the product.

c. *Parametric design*: It is a process of making relationships between inter and intra component dimensions of a product. The advantage of parameter design is that a component is associated proportionally with respect to other components in a product / assembly so that a change in one component or in one dimension of a component is automatically propagated in rest of the assembly saving extra time and effort. One has to change only the different design parameters of the product and the whole design is reviewed according to the specifications. This type of design is generally supported by computers. Intelligent software like Pro/E, Inventor, and AutoCAD etc. are used for this purpose. Fig. 2.4 illustrates the concept of a parametric design.

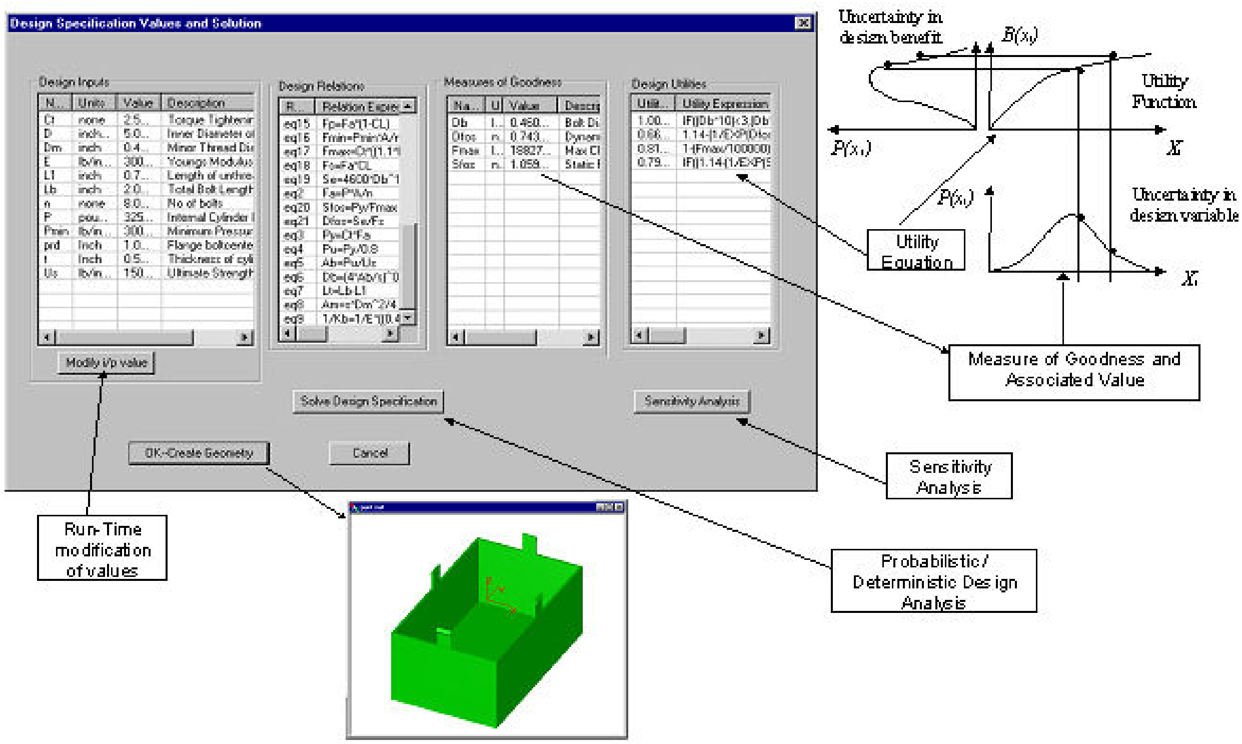

Figure 2.4 Parametric Design

2.2 Engineering Design

The term 'Engineering Design' is used to separate the other types of design from the technical design. Engineering design is a purposeful activity directed towards the goal of fulfilling human needs in the form of a product, particularly those which can be met by technological factors of our civilization [6].

2.2.1 The Position of Design Process in a Company

The design department is of a central importance in any company. This department describes the properties of every product throughout the Product Life Cycle. Moreover, the designers have a large influence on production, operation costs, quality, production requirements, tooling and time to manufacture. Therefore, the design department shares a heavy responsibility in the business strategy of any company and country.

The design department also plays a central role in the product development process. The position of the design department in a company and its links with other departments are shown in Figure 2.5. It can be seen that production and assembly depend on information provided from product planning, design and development. On the other hand design and development is driven by knowledge derived from production and assembly.

It can also be seen that the customer, market share, marketing advertisement and product planning directly contribute to the design process in the evolution phase. Moreover the production, acceptance testing, sales response, quality control, operating resources, material availability and test equipment also contribute to the design and development process through information interchange. Therefore, it is certified that the design department is functioning as a hub of information for the company.

As a matter of fact, no product can mature without the information, interaction between design and production departments. The first prototype is developed to evaluate the basic ideas of design department and to check the functionality of the concerned product. After the critical analysis of first prototype, the improvements based on the analysis are incorporated to the design of the product. Pilot production is then carried out in the form of the small batch. This helps in determining the effect of the large production number on the available resources of the facility. Moreover a technical change may also occur during the pilot production phase. Therefore there is a two way link between the design and production department during this phase. After the successful completion of the pilot production the design is finalized so that mass production of the product can be carried out according to the market research. This scenario is presented in Figure 2.6.

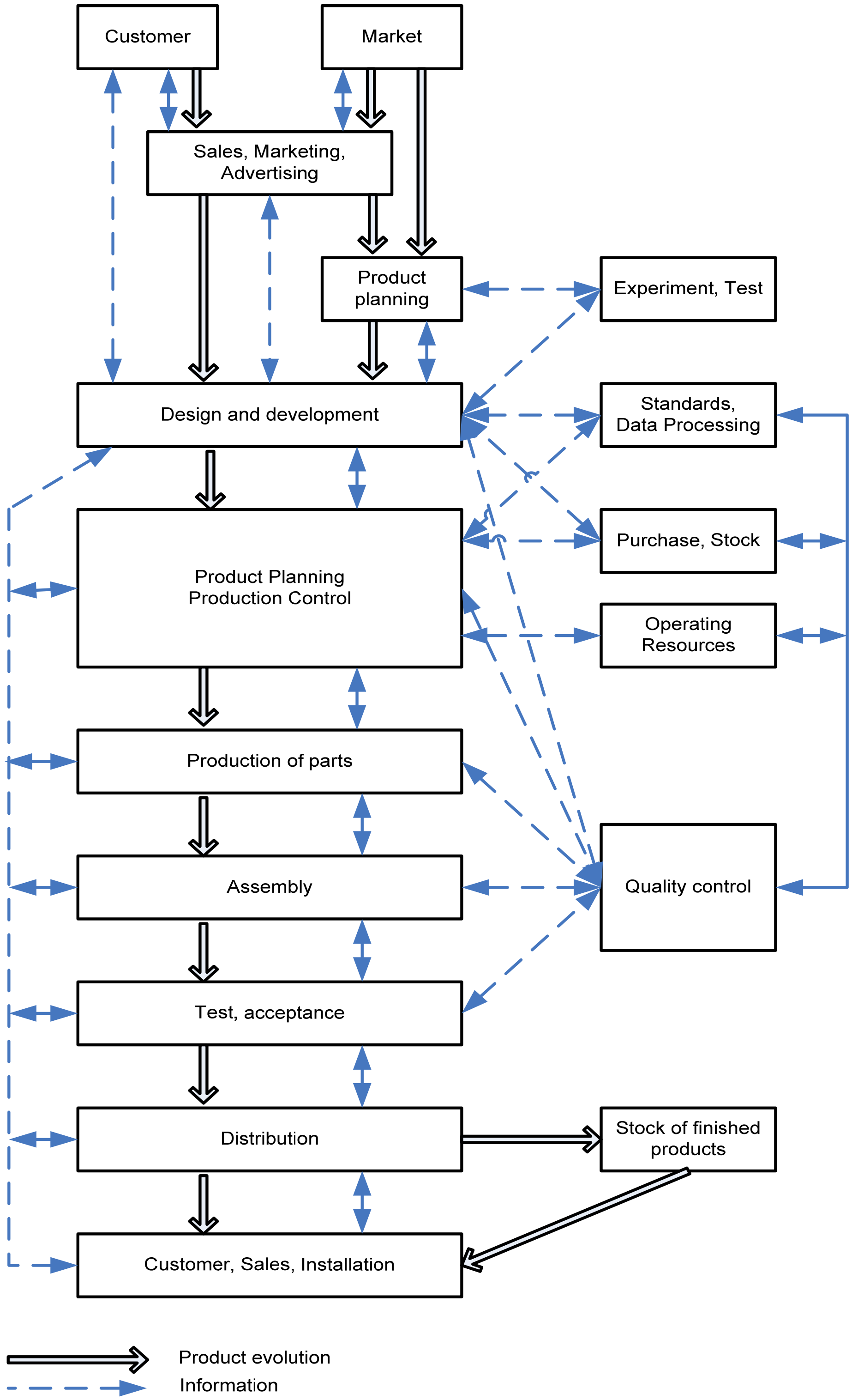

Figure 2.5 Information Flows between Departments, after [5]

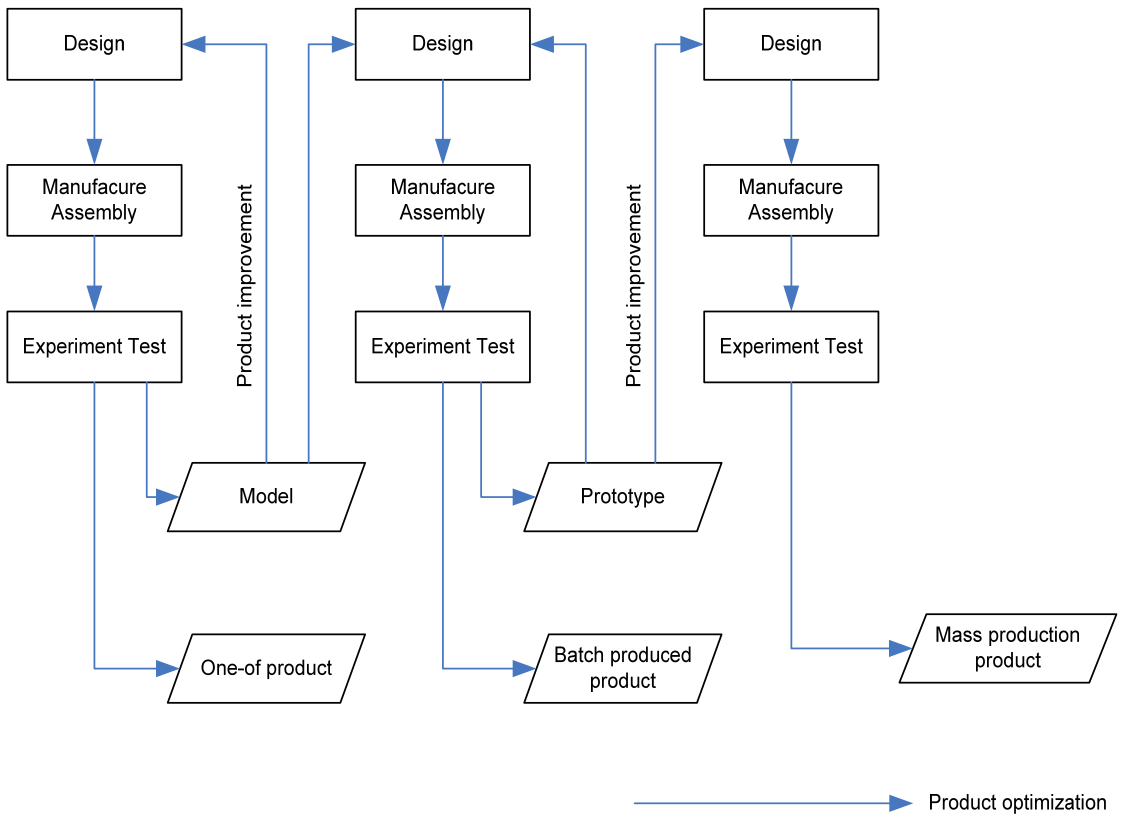

Figure 2.6 Stepwise Development of a mass-produced Product, after [6]

2.2.2 The Roles of Producer, Consumer and Designer

It is important to realize that may it be an engineering design or an industrial design; both are an integral part of a larger process of product planning and development. The bond of consumer-producer relation decides whether the product is successful or un-successful.

There is very little input that a customer can make into a product planning process. The decisive factor taken by the customer is to choose from the many available products. The mass of customers, all making their own decisions for a product contribute towards to the market for the manufacturer. The marketing team engaged in market research to evaluate the impact of revenue generated by the sales of a specific type of a product and the threat proposed by the same type of product offered by the competitors. The manufacturers in return develop their manufacturing strategies according to the market research. This cycle is shown in Figure 2.7.

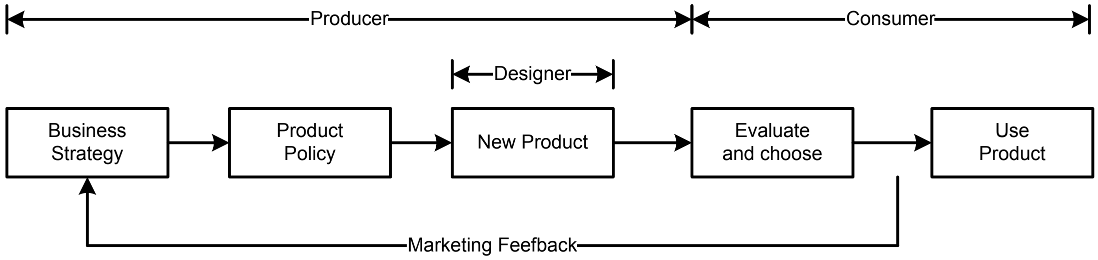

Figure 2.7 Role of Designer in the Company, after [22]

The role of the manufacturer starts from the establishment of a business strategy where new product policies and plans are developed and a new product is designed by the designer. The customer role is to choose the product form many available types and use it consequently. From here, the customer generates an impression of the product or manufacturer so as to decide whether he should buy it again or not and hence defining the satisfaction level. The marketing team gets this input and communicates into the manufacturer so that it can be incorporated in the business strategy.

2.2.3 Trends in Design Process

The most recent development in the design process is the evolution of computer based data processing. Computer Aided Design (CAD), Computer Aided Design and Drafting (CADD), Computer Aided Manufacturing (CAM), Computer Integrated Manufacturing (CIM) etc. have revolutionalized the concept and process of engineering design. This development has also produced new job opportunities. The computer also assists in the detailed designing analyzing and information management of the whole process.

The development of expert systems [19, 20] has increased the ease with which information can be retrieved and processed. CIM produces a parallel system with the design management for a better planning and control of the design process. This concept also facilitates the area of concurrent engineering, where the overall development time is reduced by focusing on the flexible and parallel activities of product, production, and quality optimization [21]. The trend is to bring forward the production planning into the design process.

The working methods of designer have incorporated the new technological developments like assembly procedures, micro-electronics and production. The integration of electro-mechanical systems has produced many exciting products. The field of MEMS is yet a more challenging and advanced while exciting field of technology.

As the conclusion of above discussion, it can be said that designers share a multi-disciplinary and challenging knowledge base which should be used through proper management to achieve good product development.

2.2.4 Innovation in Design

Innovation may be defined as
a. “To bring in new methods, ideas [4]; or
b. “Introduction of new idea into the market place in the form of new product or service or an improvement in organization or process [22].”

Innovation is important to society because of following reasons;
a. Providing the solutions to problems;
b. Wealth creation; and
c. Improved standard of living.

Innovation is also important to the organization;
a. Product innovation is a key factor of success;
b. Increased competition; and
c. Accelerating pace of technology development.

Innovation is furthermore important to the individual;
a. Financial returns;
b. Personal satisfaction;
c. Intellectual property; and
d. Entrepreneurship [23, 24].

Most companies have a continuous program of product development through which they continue to maintain and improve their market share. However, new products appear in the market after short intervals of time. These may include the same basic functional idea but some change in the appearance, usage or performance of the product. Examples of such products may include Fiber tip pens, Personal Computers, Cameras etc. Entirely new product comes into the market very rarely.

Such innovations may cause the company to increase its market share in terms of revenue and customer base, whereas many times an innovation may not produce desired results. This can be a result of lack or error in market research and may not even come up to the break-even point. Therefore, innovation is a risky business. It may pay well off but it can also cause complete financial loss in many cases. However, the rewards of successful innovation are so huge that the risk factor is minimized through financial assessments and companies continue to introduce innovative and new products in the market.

2.2.5 Technology Push and Market Pull

From many products available in the market, some products always seem to contain new ideas or may appear entirely different. As described above, such products contain the same basic idea and innovation is in some minor detail. It is also apparent that the decisive factor in the success of a product is the customer decision to buy it or not. If the customer wants to buy a product for any reason it comes out to be successful in the market. However, customers also vary according to their needs. All customers may not want to buy a Corvette V6 Car. Such products are tailored according to the customer's needs. Therefore, they are two strong aspects to new product development: the push that comes from technology and the pull of market needs. These aspects are usually called market pull and technology push. The situation is shown in Fig. 2.8.

Technology itself does not play any role in push; instead push comes from the developers and suppliers of the new technology and from the market of new products. In the real world a lot of product development comes out as a result of both technology push and market pull.

The market pull model, involves a lot of market research so that a customer needs and satisfaction level may be found out. There is a sustained and confirmed revenue base generated as a result of this model. Many companies, therefore, follow the market pull model.

The technology push model, on the other hand, emphasizes for the creation of new products through innovation. This model targets the development of new products. It is based on the theory that new innovations can create new demands and new markets. Market research usually cannot identify the need of product that does not exist.

This has been recognized by many companies that both market pull and technology push can create a more validated product development. However, there is no guarantee that a new product is developed according to both models. The reason may be too much financial investment or huge requirement of time.

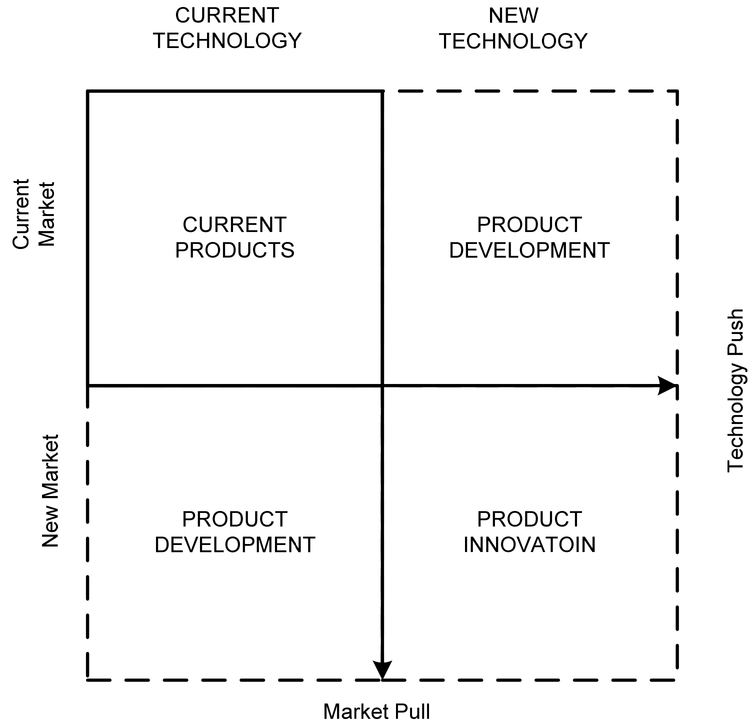

Figure 2.8 Technology Push and Market Pull, after [22]

2.3 Characteristics of Design Activity

It has been apprised above that design is a complex activity and it has many characteristics. In this section, the importance of co-ordination between other departments and design, and the complexities of the design process will be addressed in a brief manner.

2.3.1 Design Complexities

Engineering design is a complex process involving certain variables making it more complex. It is immensely important to understand these complexity variables for effective implementation of the design development process. These factors are described in Fig. 2.10.

It is certain that knowledge is an intangible resource and is a vastly varying asset according to the ability and experience of the designer and is a complex phenomenon. The source from which the knowledge is obtained also has a great impact on the validity and kind of knowledge. Knowledge management is the relevant field targeting this area.

The design product or the artifact is itself a complex object involving the ideas of the design team for the solution of the problem. Decision making has a profound impact on the overall strategy of the business and hence on the product itself.

Decision Support Systems (DSS) are available for the address of this complex activity.

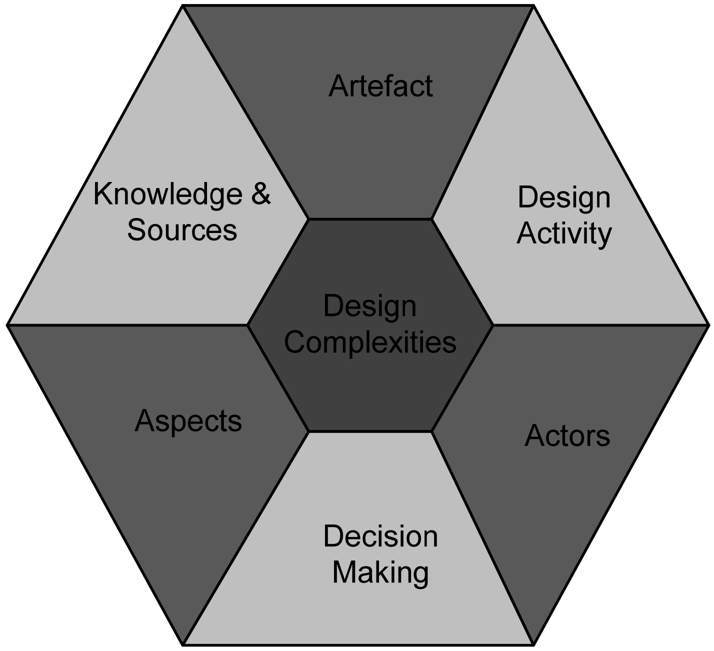

Figure 2.9 Design Complexity Contributors, after [6]

2.3.2 Design Co-ordination

Coordination refers to the interaction between different departments and activities. Design coordination is extremely important for proper execution of the planned project. A design coordination framework is proposed to support coordination of various aspects of design development. The ten modeling key elements of coordination are shown here in Fig. 2.11. These elements are namely Product Development, Decomposition, Technologies, Synthesis Matrix, Life Phase System, Product Life, Goal, Task, Activity and Resources.

If it is desired to monitor the design activity, the key elements required to be addressed will be presented here in the form of a set of frames. The industrialists and authors referenced here do not make any claim for completeness but believe that these are the most important aspects. These elements are presented through models in Fig. 2.12 and incorporate the factors which play an important role in the design co-ordination.

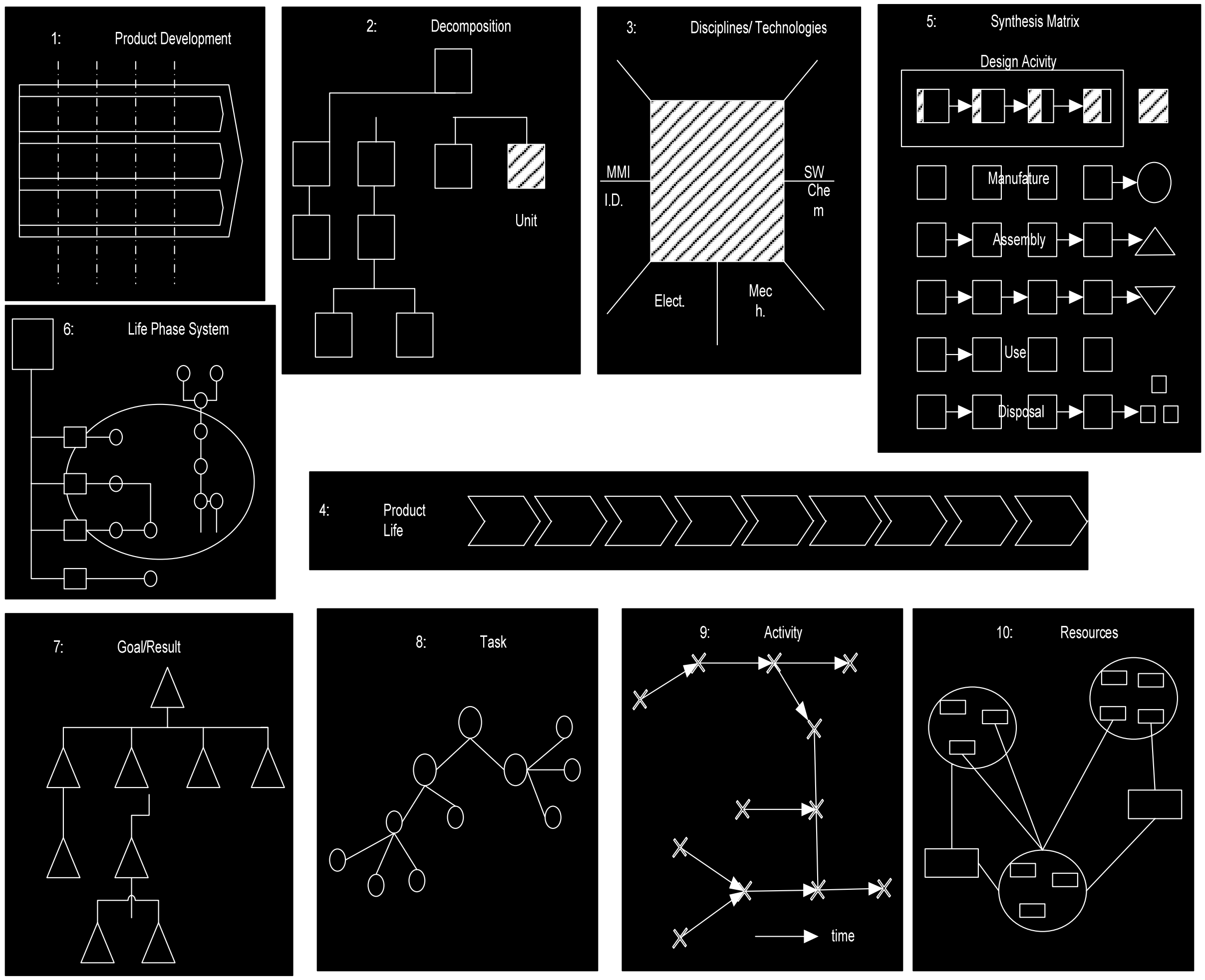

Figure 2.10 The Modeling Elements for Design Co-ordination, after [27]

The content for the model of product development differs widely in the literature from problem solving models to the models establishing a new business. The theoretical models for the product development are referenced in [28, 5, 29-33]. Such models may be related to a company and book or through a quality regulation like ISO-9000. The model of product development will be further elaborated in the coming chapters of the thesis.

Model of decomposition relates to the product breakdown into sub systems consisting of a design activity. The entities of the decomposition may be identified as blocks or part structures.

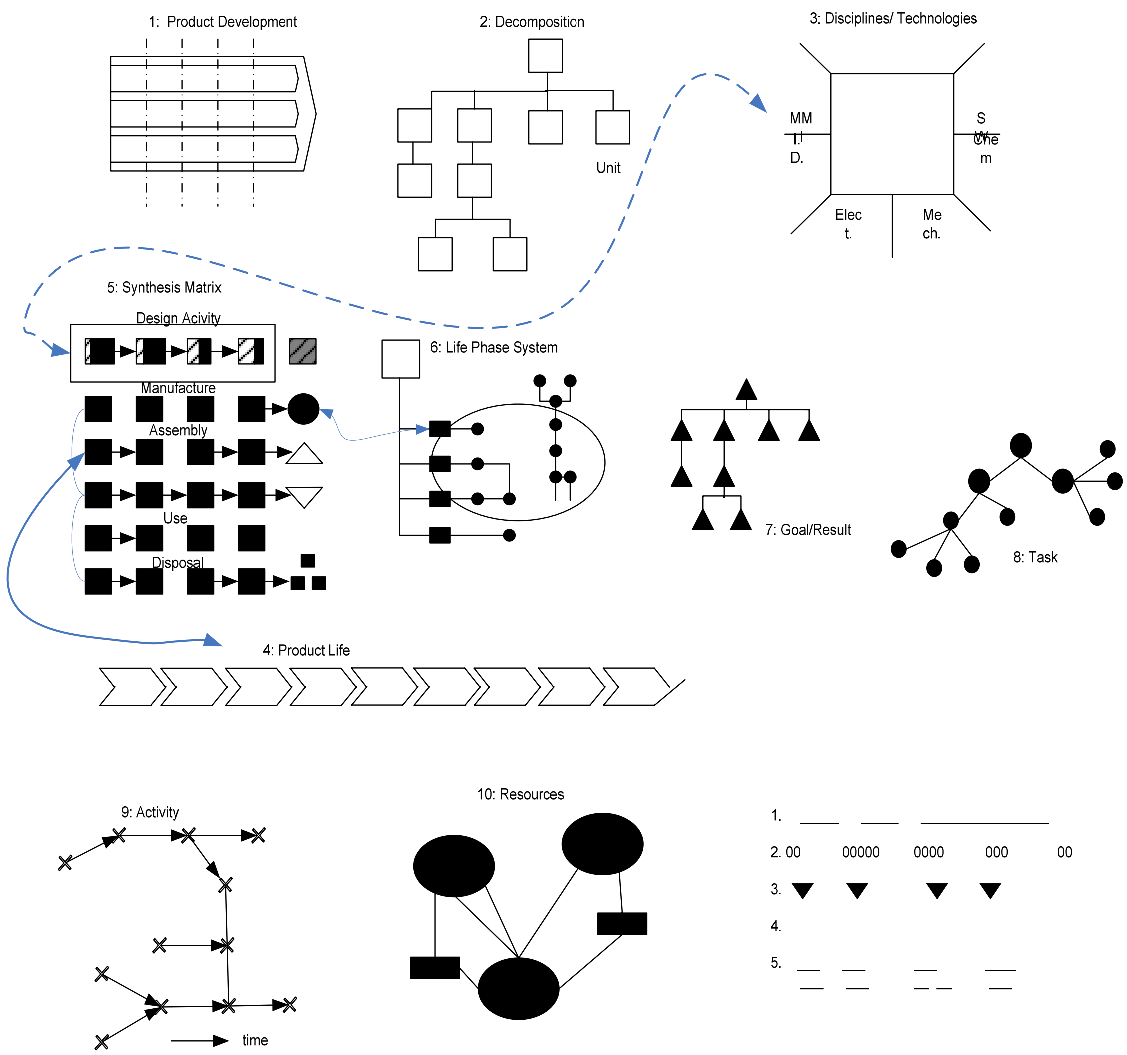

Figure 2.11 The Design Co-ordination Model Frameworks, after [27]

The model of discipline and technologies refers to the know-how into new business policies. This may be different for in an R&D organization and a production organization. It is necessary to divide the tasks of design activity into the related disciplines and manage these tasks such that the overall design activity time is optimized.

The product life model refers to the life phase of the product. Each life phase may be seen other system in which the product interacts with the system and the effective of that interaction determines the performance and ease of performing or surviving the actual phase. Such life phase system could be production, sales, transport or recycling systems.

The synthesis matrix model is the core of product development. This can be a symbolic diagram. A parallel product and production engineering process is advised here by adopting the concept of concurrent engineering [32, 34]. The process developed here is communicated to the life phase system model in which the different contribution from the synthesis activities is transferred to the concerned departments. This can be understood by the transfer of chosen assembly methods to the production department through assembly diagrams.

The product development goal is defined by the customer input and the business strategy of the company. State of the art in this are is the QFD Method [35]. The product development tasks are then initiated through the analysis of the previous models and they are translated to the activity model. The resource model refers to the availability of specific resources for the completion of the specified tasks as described in the product development task model and activity model. The design history model records the respective decisions and strategies which were taken during the course of development of the product by the management.

Design coordination occurs when changes in one frame propagates decisions about change in another frame. This is shown in the form of a matrix in Table 2.1[27]. Moreover, there are some relationships between elements of design coordination and design complexity factors. These relationships indicate the influence of the factors which are necessary to have coordination for effective execution of product development process and are represented in Table 2.2 [6].

	Effect On:	Product Development	Decomposition	Disciplines & Technologies	Product Life	Synthesis Matrix	Life Phase System	Goal/Results	Tasks	Activities/Plan	Resources	Design History
Cause here:”		1	2	3	4	5	6	7	8	9	10	11
Product Development	1	X	X	X	X	X	X	X	X	X	X	
Decomposition	2		X	X	X	X	X	X	X	X	X	
Disciplines & Technologies	3		X			X		X	X	X	X	
Product Life	4			X	X	X	X	X		X	X	
Synthesis Matrix	5		X		X	X	X	X		X	X	
Life Phase System	6						X	X		X	X	
Goal/Results	7			X	X	X				X	X	
Tasks	8	X		X	X			X	X	X	X	
Activities/Plan	9							X	X	X	X	
Resources	10	X		X				X	X	X		
Design History	11											

Table 2.1 Mechanism of Design Coordination, after [27]

DC Frames	Design Complexity factors					
	Artifact	Design Activity	Actors	Decision Making	Aspects	Knowledge/ Sources
1. Product Development		*				
2. Decomposition	*					
3. Disciplines & Technologies	*		*			
4. Product Life	*					
5. Synthesis Matrix	*	*			*	
6. Life Phase System					*	
7. Goals & Results					*	
8. Task		*				
9. Activity		*				
10. Resource			*			*
11. Design History				*		*

Table 2.2 Relationship between Elements of Design Co-ordination and Design Complexity Factors, after [27]

2.3.3 Other Characteristics

Some other self explanatory characteristics of design are represented in the following;

a. Creative;
b. Goal directed;
c. Constrained with respect to
    i. Natural laws;
    ii. Physics;
    iii. Technology;
    iv. Economics;
    v. Human Factors;
    vi. Legal Factors;
    vii. Manufacturing facilities;
    viii. Logistics;
    ix. Customer specified;
    x. Time;
    xi. Resources; and
    xii. Cost;
d. Uncertain with reference to
    i. Models;
    ii. Performance;
    iii. Environment;

e. Iterative and evolving;
f. Multiple solutions ;
g. Comparative ;
h. Innovative;
i. Analytical ;
j. Team based;
k. Multi disciplinary;
l. Hierarchical;
m. Divergent / convergent; and
n. Involves compromise [6].

2.3.4 Aspects of Design Development

The development of design process involves following key aspects [44, 27, 30];
a. Concurrent Engineering;
b. Decision support;
c. Design (process) management;
d. Product management; and
e. Team engineering.

The aspect of Concurrent Engineering involves dealing with following issues;
a. DFX: Design for X that is designing for a particular life cycle phase;
b. DFX Management: Management of different Design for X scenarios;
c. Life Cycle Issues: Different issues related to different life cycle phases;
d. Providence Design: Bringing downstream product life cycle issues earlier at design phase; and
e. XTD: X to Design (Fit a particular life cycle phase according to the design).

The aspect of decision support system deals with following issues;
a. Authority, Responsibility and Control;
b. Conflict Resolution;
c. Consistency Management;
d. Information Integration;
e. Information Integration;
f. Integration & Coherence;
g. Knowledge Management;
h. Effective Communication;
i. Multi Criteria Decision Management; and
j. Probability and Risk Assessment.

The aspect of design management deals with following issues.
a. Design Reuse;
b. Distributed Design Authority;
c. Planning, Scheduling and Control;
d. Process Modeling;
e. Task Management;

f. Right at first time, Rework and Iteration Control; and
g. Resource Management.

The aspect of product management deals with following issues.
a. Design Reuse and Standardization;
b. Integration and Control;
c. Integrity;
d. Evolution Management;
e. Configuration Management;
f. Variant Management; and
g. Viewpoint Management.

The aspect of team engineering deals with following issues.
a. Team Engineering Inter / Intra Integration;
b. Formation, Assessment, Enhancement and Empowerment; and
c. Negotiation Support and Management.

2.3.5 Evaluation of Issues in Design Development

An analysis of the above mentioned items which affect the process of design development is presented here after Anderson [30]. This analysis shows the amount of impact of each aspect and its importance. The analysis is carried out against the 7 major concerns of the enterprise, namely, cope with rapid design change, ability to deal with increasingly complex products, reduce non-recruiting engineering costs, achieve a better quality product, achieve a better quality product, meet the customer requirements, exploit new product technology, shorten product cycle time. Each issue in four aspects of Design Development is evaluated according to these criteria.
a. Change – Cope with rapid design change;
b. Comp – Ability to deal with increasingly complex products;
c. N Costs – Reduce Non recruiting engineering costs;
d. Qual – Achieve a better quality product;
e. Requ'ts – Meet the customer requirements;
f. Tech – Explore the new product technology; and
g. Time – Shorten product cycle time.

These criteria are given weightings on a rating scale of 1-5. Each issue is evaluated against each criterion using High Effect, Medium Effect and Low Effect as suitability indicators. The analysis is summarized in Table. 2.3. The Key at the end of the Table 2.3 summarizes the abbreviations used in the Table. The aspect which has no affect on the process is left blank with respect to the process.

	Enterprise's Requirement							
Priority	**3**	**1**	**5**	**3**	**5**	**3**	**5**	
Aspect of product Development	**Change**	**Comp**	**N Costs**	**Qual**	**Req'ts**	**Tech**	**Time**	**Totals**
Concurrent Engineering DFX	*		^	^			*	80
DFX Management	*		^	^			*	80
Life Cycle Issues				^	*		*	99
Providence		0		0	*	^	*	105
XTD	0			0			*	81
Decision Support Authority, responsibility and control	*			*			0	42
Conflict resolution	*	0					*	102
Consistency management	^	^		*			^	12
Effective communications	*			^			*	75
Information integration	*		0	^			*	90
Integration and coherence	*			^			*	81
Knowledge management		0		*		^	^	41
Multi criteria management		*		*	*			84
Probability and risk assessment	0	*	*	^			*	111
Design management and design experience reuse			0	0			*	69
Distributed design authority	*	*	*	*		0	*	162
Planning scheduling and control	^	0	^				*	56
Process modeling	^	*	^	0		^	0	44
Resource management	0			^			*	57
Right first time, rework & iteration control	0		*	0			*	108
Task management	^	^	^	0	0		*	78
Product management configuration management	0	*						18
Design reuse and standardization			*	0			*	99
Evolution management	*	0		*				57
Integrity and control	*						0	42
Integrity				*				27
Variant management	*						0	42
View point management	^	0						6
Team engineering inter/intra integration	*	*					*	81
Formation, assess't, enhance't & empower't	*	*		*			*	108
Negotiation support/management	*	*	*	*			*	153
Totals	**444**	**92**	**280**	**236**	**150**	**18**	**970**	**2290**

Key:	Change – Cope with rapid design change	* – High effect (9 points)
	Comp – Ability to deal with increasingly complex products	0 – Medium effect (3 points)
	N Costs – Reduce non-recruiting engineering costs	^ - Low effect (1 point)
	Qual – Achieve a better quality product	
	Req'ts – Meet the customer requirements	DFX – Design to X (fit product to life phase system)
	Tech – Exploit new product technology	XTD – X to the Design (fit life phase system to the product)
	Time – Shorten product cycle time	

Table 2.3 Analysis of Aspects of Design on Design Development Process

2.3.6 Overall Scoring of Each Aspect

The cumulative scores for each aspect of design development are calculated to determine their importance against each criterion. Similarly, the percentage of total score for each aspect against each criterion, as well as the percentage of the total score for each criterion against each aspect of design development, are also calculated and are summarized in Table 3.3. It can be seen that Decision support has the overall highest impact and the design management is on the second place. On the other hand, time plays the most vital role in fulfilling the requirements of the organization.

	Enterprise's Requirements															
Aspects of Product Devp't	**Change**		**Comp**		**N Costs**		**Qual**		**Req'ts**		**Tech**		**Time**		**Points**	**%**
Concurrent Engineering	63		3		10		51		90		3		225		445	19
	14	14	3	1	4	2	15	11	60	20	17	1	23	51		
Decision Support	153		25		60		102		45		3		250		638	28
	35	25	27	4	21	9	30	16	30	7	17	1	26	39		
Design Management	54		22		120		66		15		12		285		574	25
	12	9	24	4	43	21	20	11	10	3	66	2	29	50		
Product Management	93		15		45		63		-		-		75		291	13
	21	32	16	5	16	15	19	22	-	-	-	-	8	26		
Team Engineering	81		27		45		54		-		-		135		342	15
	18	24	30	8	16	13	16	16	-	-	-	-	14	39		
Total Points	444		92		280		336		150		18		970		2290	100
% of Total Points	19		4		12		15		7		1		42		100	

Key:

Points	
% of column total	% or row total

Table 2.4 Overall Scoring of Each Aspect, after [30]

These cumulative scores also indicate the relative importance of each criterion for each one of the four aspects of design development. The relation (*) is shown in Table 2.5.

	Enterprise's Requirements						
The Best Means	Change	Comp	N Costs	Qual	Req'ts	Tech	Time
Concurrent Engineering	-	-	-	-	*	-	-
Decision Support	*	-	-	*	-	-	-
Design Management	-	-	*	-	-	*	*
Product Management	-	-	-	-	-	-	-
Team Engineering	-	*	-	-	-	-	-

Table 2.5 Relative Importance of Aspects, after [30]

2.4 General Problem Solving / Decision Making Process

It is apprised in the previous discussion that design is a problem solving process. A problem or a need is felt by the society and is confronted by the designers. Therefore, the problem solving procedure is an essential part of product development and involves step-by-step analysis and synthesis. The qualitative to the quantitative approach is followed in this process, each new step being more concrete than the last.

The work of Dorner [25] shows that in order to solve problems successfully, it is necessary to develop an approach adapted to the specific problem and modified appropriately as the problem solving proceeds. When searching for solutions, it is very effective to view the problem from different perspectives, such as different levels of concretization.

According to Müller [26] the problem solving processes are process models that are suitable for describing in a rational way the approach necessary to make complex processes comprehensible and transparent. Thus these procedures are not descriptions of individual thinking processes and are not determined by personal characteristics.

A systematic approach aims to keep the iteration loop as small as possible in order to make design work effective and efficient. The division into working and decision making steps ensure the necessary and permanent links between objectives, planning, execution and control. With these links we can construct a general process for finding solutions to problems. A general problem solving process flow chart is presented in Fig. 2.13.

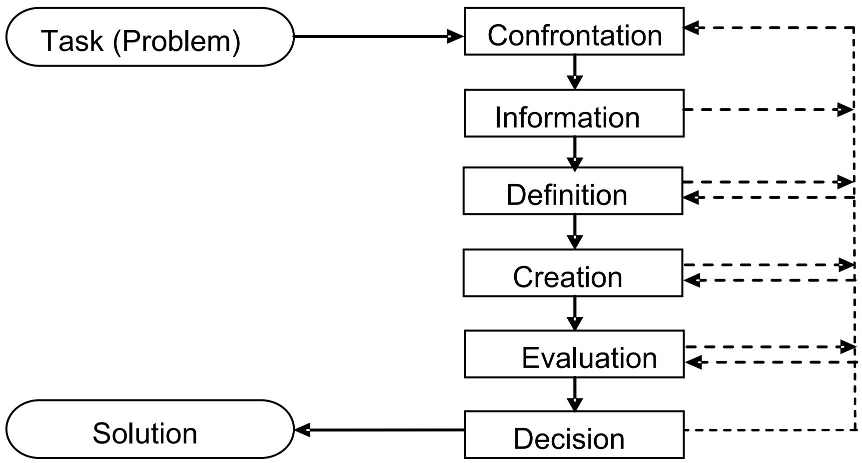

Figure 2.12 General Problem Solving Process, after [5]

2.5 Design (Product Development) Process Models

The design is a complex and many times a lengthy process. It requires input from all departments of the company and generates output to apparently all departments. Thus, keeping in view the importance and complexity of the design process, many authors have provided the process models for the design process. As design is a vast field, these models vary in shape and detail but all of them refer to the breakdown of the design activity so that the activity is carried out for maximum performance and optimization.

A number of industrial and engineering design process models have been proposed in the literature for the smooth operation of the design activity. These include those given in [22, 15, 5, 36, 37]. All the contributions are directed towards providing a compact and efficient engineering design process model with minimum time and effort and maximum optimized output. Some reference approaches are presented in Fig. 2.14 – 2.16. The comparative analysis of these models are out of the scope of this thesis, thus only the models are presented and further discussion on them may found as referenced.

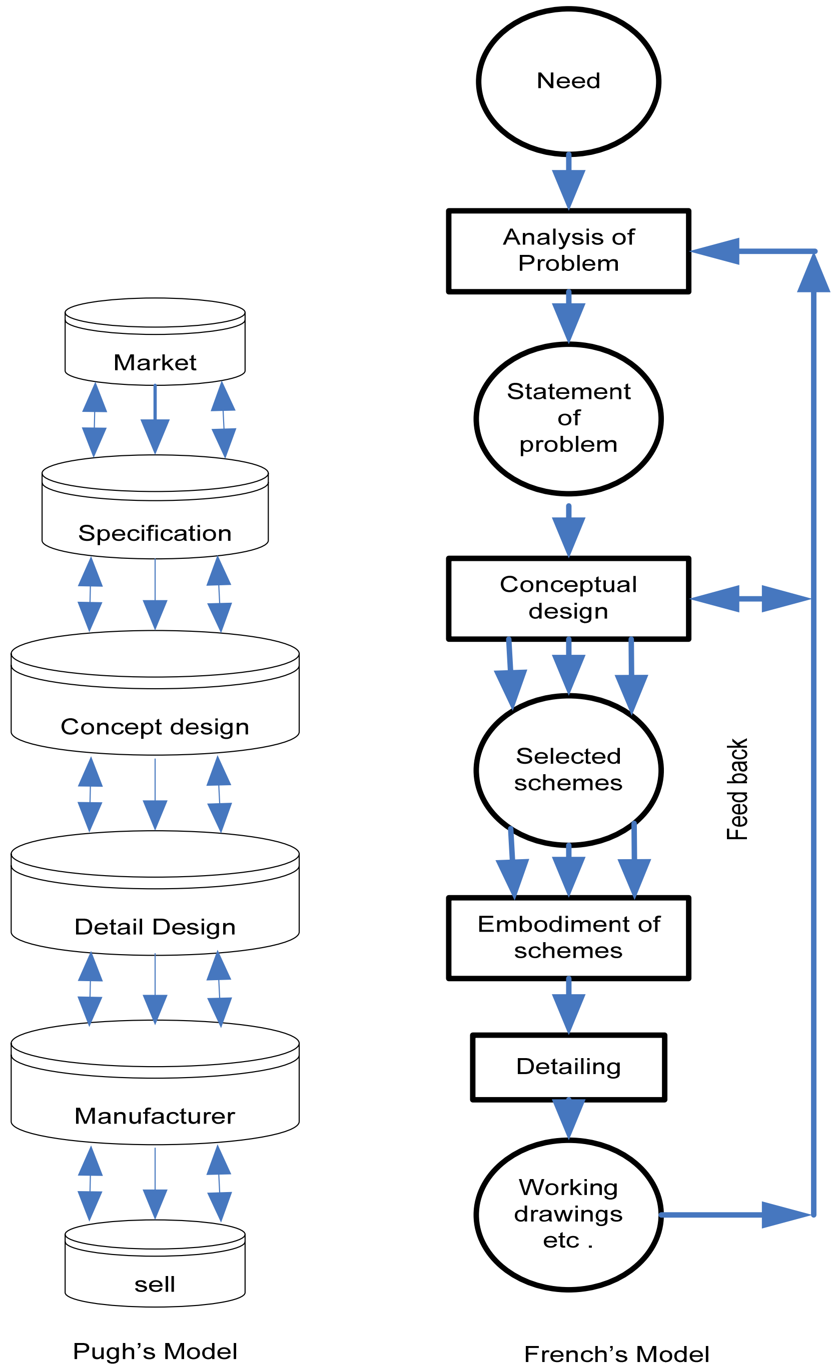

Figure 2.13 French's and Pugh's Model, after [36]

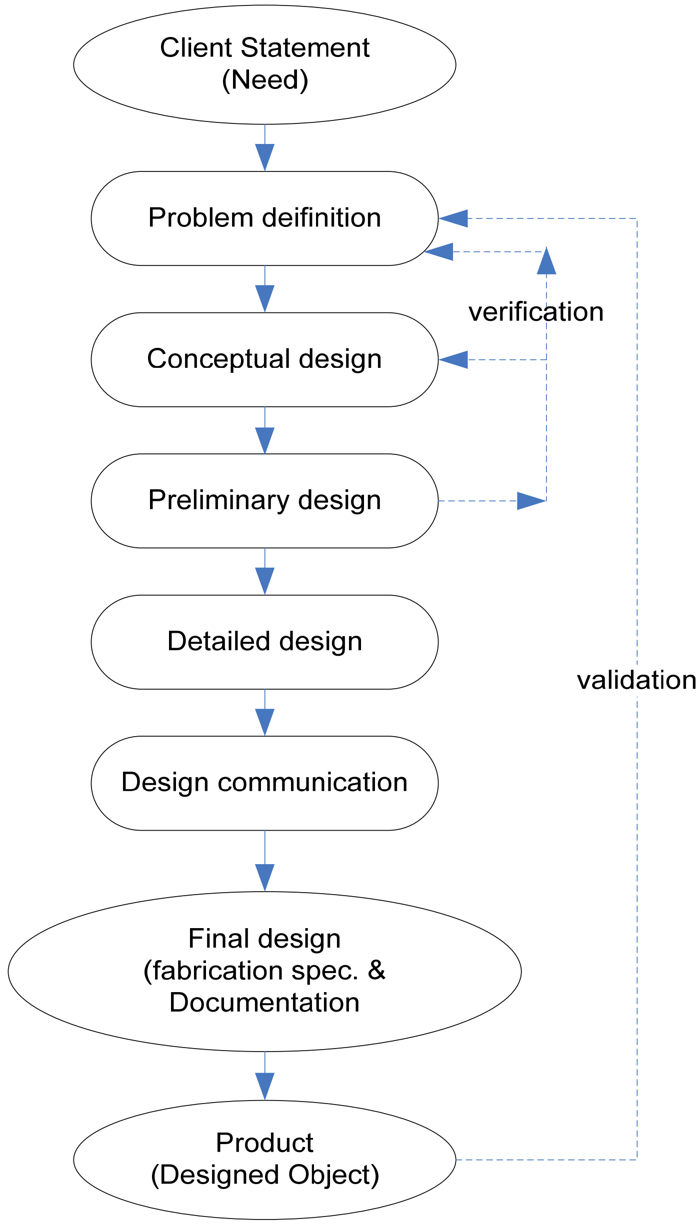

Figure 2.14 Dym's Model, after [37]

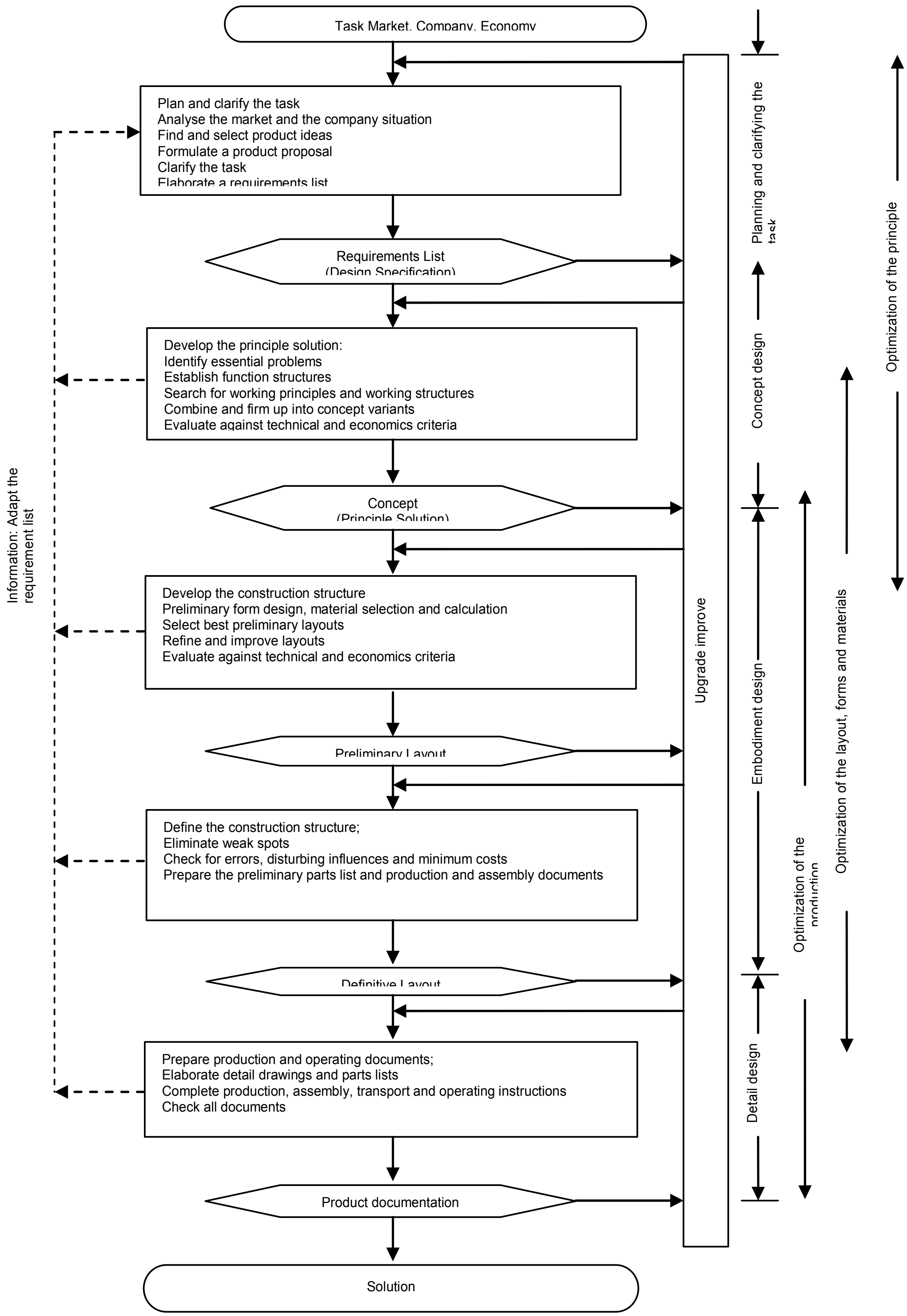

Figure 2.15 Pahl's Model, after [5]

In spite of the differences between the approaches, the design process may be divided into following distinct phases.

a. Task Clarification;
b. Conceptual design;
c. Embodiment design; and
d. Detail design [5].

2.5.1 Task Clarification

To start a product development, a product idea is needed that looks promising given the current market situation, company needs and economic out look plus the strategic mission and vision of the company.

The idea is purified and analyzed many times to produce a task definition of the product. The outcome is called Product Design Specification (PDS).

Irrespective of whether the task is based on a product proposal stemming from a product planning process or a specific customer order, it is necessary to clarify the given task in more detail before starting product development. The purpose of this clarification of the task is to collect information about the requirements that have to be fulfilled by the product, and also about the existing constraints and their importance.

This activity leads to the formulation of a requirements list that focuses on, and is tuned to, the interests of the design process and subsequent working steps. The conceptual design phase and subsequent phases should be based on this document that has to be updated continuously. The result of this phase is the specification of information in a requirements list.

This task can be further elaborated by the following steps;

a. Product planning;
b. Situation analysis;
c. Search strategies;
d. Selection of product ideas;
e. Product definition;
f. Clarifying the task; and
g. Listing the requirements.

2.5.2 Conceptual Design

After completing the task clarification phase, the conceptual design phase determines the principle solution this is achieved by abstracting the essential problems, establishing function structures, searching for suitable working principles and these combining those principles into a working structure. Conceptual design results in the specification of principle.

The specification of a principle requires to asses the essential aspects of a solution and reviews the objective and constraints. There may be many principle solutions. This solution can take many forms for example, a circuit diagram, a factory layout, a part drawing etc.

2.5.3 Embodiment Design

This phase involves the evolution of the idea starting from a concept to a technical system inline with technical and economical criteria. This phase results in the specification of layout as an output.

It is essential to produce several preliminary layouts or solution to scale simultaneously and to asses the pros and cons. After a successful and sufficient elaboration of layouts this design phase ends with evaluation against the predetermined technical and economical criterions. By appropriate combination and elimination of weak links the best solution can be obtained.

The final solution provides the check of function, strength, compatibility and the financial impact of the project. After the completion of this phase proper working should start on the detailed design phase.

2.5.4 Detail Design

This is the phase of design process in which the arrangements, forms, dimensions and surface properties of all the individual parts are finalized. The materials are specified production possibilities and cost is estimated. Furthermore all the documentation is produced in this process [18, 19]. The result of detail design phase is the specification of production. Following are the crucial activities during this phase;

a. Optimization of the principle;
b. Optimization of the layout, forms and materials, and
c. Optimization of the production.

The Fig. 2.15 shows an overlap in the above crucial activities to a considerable extent. It is, therefore, important that the optimization may be carried out with proper procedures.

The main phases of design cannot be limited as described above. Even the conceptual decision may require a scale drawing for the purpose of deciding the possible solutions. Also, the preliminary layout selected during the embodiment design may involve nothing more than rough sketches.

Chapter 3
MANUFACTURING AND PRODUCT DEVELOPMENT

3.1 Impact of Manufacturing on Society

3.1.1 Introduction

Chapter 2 presented the design process and general process models that are used in the process of design. The GDP of any country is driven by the fact that how much it is producing in the form of manufactured items / goods, may it be mechanical, agricultural, structural, electronics or any items. The manufacturing sector requires huge investment and returns great Return On Investment (ROI). Manufacturing requires proper investment in design and its development also. The impact of manufacturing on the society is presented here as a comparison between the manufacturing sector of Japan and US.

3.1.2 Comparison of Japan and US

The manufacturing sector saw both rise and fall during the last two decades. During 1980 – 1996, the productivity in manufacturing sector saw a 50% rise in Japan as compared to US. This fact is shown in Fig. 3.1. Due to productivity increase, Japan emerged as the leading industrial country of the country in late 1990s.

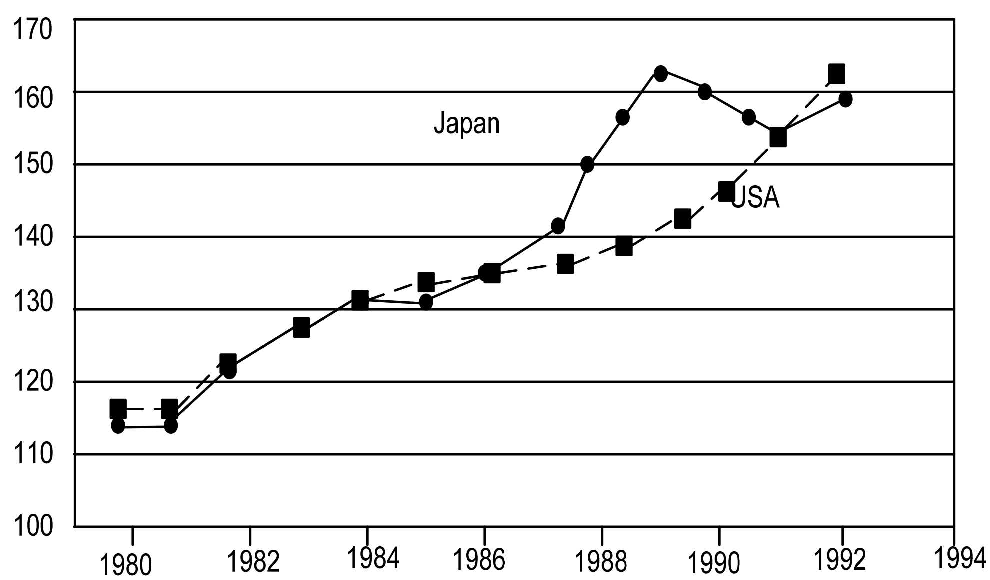

Figure 3.1 Productivity in Manufacturing, 1980 = 100, after [38]

(Gross value-added at 1985 prices per person employed)

The result that is observed in Fig. 3.1 is a result of huge investment that occurred during this period. It is almost 4 times as compared to US in that period. This fact is shown in Fig. 3.2.

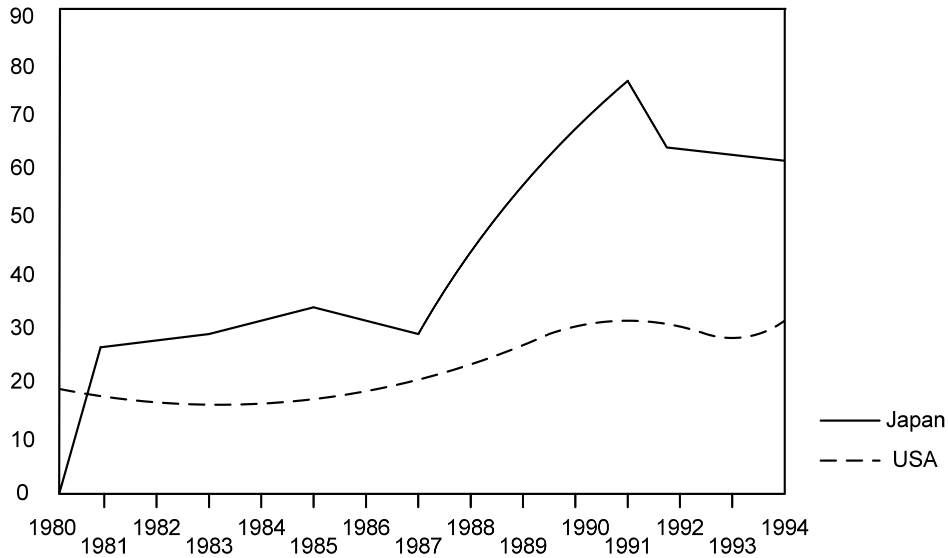

Figure 3.2 Investment in Manufacturing Sector, after [38]

The heavy investment in the manufacturing sector resulted in high productivity of the sector as shown in Fig. 3.3.

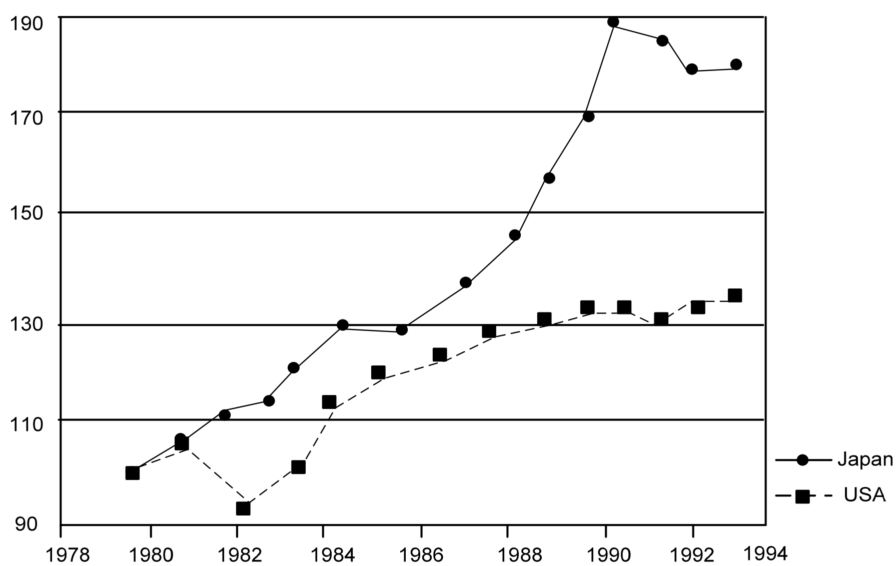

Figure 3.3 Productivity Comparison, after [38]

As the productivity increased, more manpower was required in the manufacturing sector. This resulted in increase of employment in this sector approximately by 20% in Japan, as shown in Fig. 3.4, hence providing more opportunities for the countrymen for job.

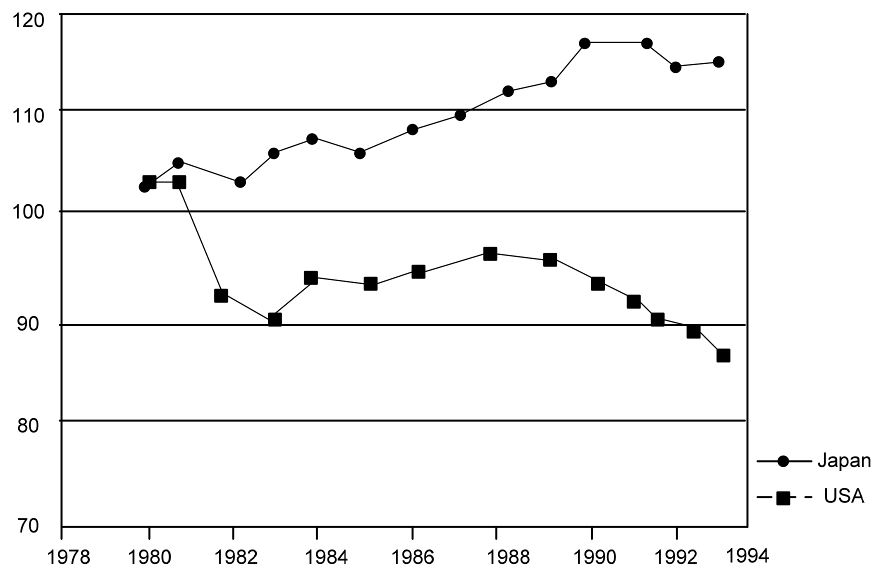

Figure 3.4 Employment Increase Comparison, after [38]

3.2 Product Development

As discussed above, the manufacturing trait has huge impact on the survival and growth of the society. Product development needs to be extremely efficient and effective if the ultimate goal, manufacturing, has to be achieved in a competitive environment. A brief overview of the product development will be presented here in the context of design development and management.

3.2.1 New Product Need

Each new product is developed in the response of either a particular need or a requirement arising from the customer / industry. As discussed in 2.2.5, the product need arises from the technology push and market pull. The arising need situation is followed by market research, product development and production hence providing the business to the organization. Therefore, the product need and its introduction is a business providing step in the economy. The fact is shown in Fig. 3.6.

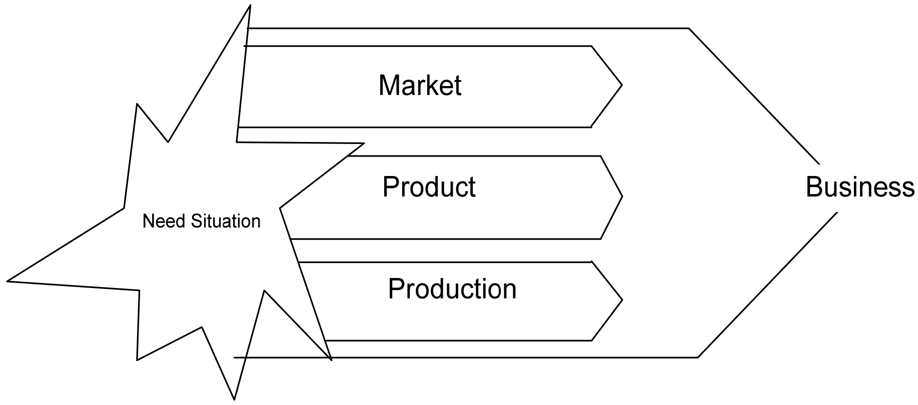

Figure 3.5 Product Need Situation Providing Business Opportunity

New product development describes the complete process of bringing a new product or service to market. There are two parallel paths involved in this process.

a. First involves the idea generation, product design, and detail engineering;
b. Second involves market research and marketing analysis [42].

The product development process is carried out in the manner as shown in Fig. 3.7.

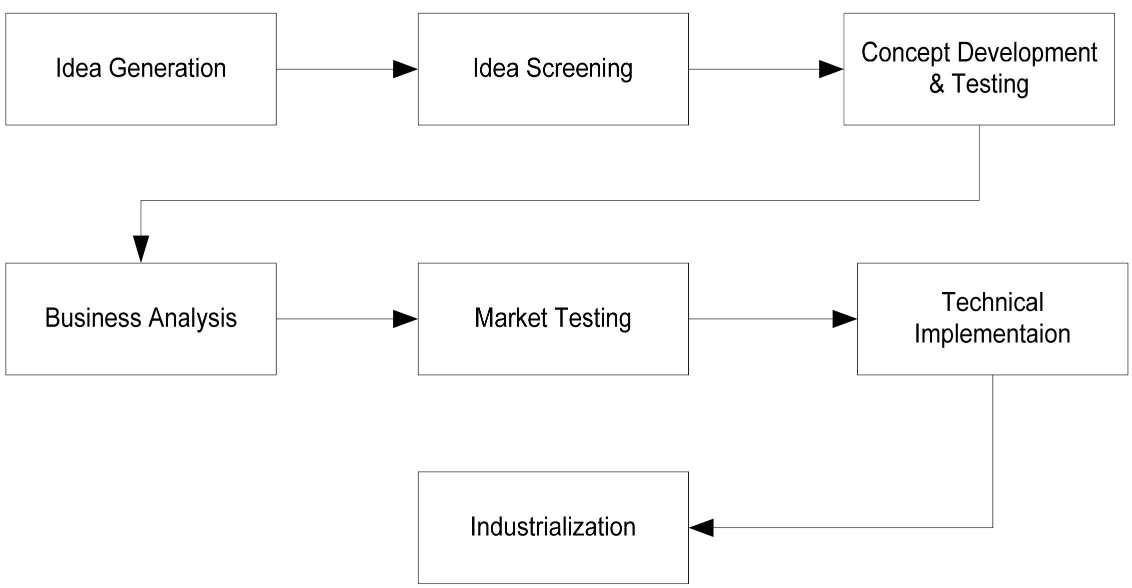

Figure 3.6 The Product Development Process

Idea Generation can be done from basic research using a SWOT analysis (Strengths, weaknesses, Opportunities & Threats), Market and consumer trends, company's R&D department, competitors, focus groups, employees, salespeople, corporate spies, trade shows, or Ethnographic discovery methods (searching for user patterns and habits) may also be used to get an insight into new product lines or product features [43].

Idea Screening is targeted to eliminate infeasible concepts prior to devoting resources to them. The main concerns can be the customer's benefit, technical feasibility to manufacture the product and the profit margin.

Concept Development and Testing includes developing the marketing and engineering details like, market and customer identification, product features, product usage, cost effectiveness and the testing of the developed concept through sample customer response.

Business Analysis is based on the estimation of likely selling price based upon competition, customer feedback and sales volume and the calculation of breakeven point.

Beta Testing and Market Testing includes physical prototype preparation, testing the product according to customer interactions and making necessary adjustments.

Technical Implementation includes resource estimation, operations planning, logistics planning etc. The commercialization is beyond the scope of product development where product is finally launched, advertised and marketed. Critical path calculation is useful at this stage [44 – 47].

3.2.2 Interdisciplinary Product Development

As described above, the need situation arises from the technology push and market pull. This situation drives the product development main areas namely marketing, engineering development and production, shown in Fig. 3.8. There are many disciplines that can be addressed during this development. It may involve mechanical design, electronics design, industrial engineering, and marketing management. Moreover, again in mechanical design, it may be a simple design for stress or it be a complex design to endure thermal and fatigue stresses.

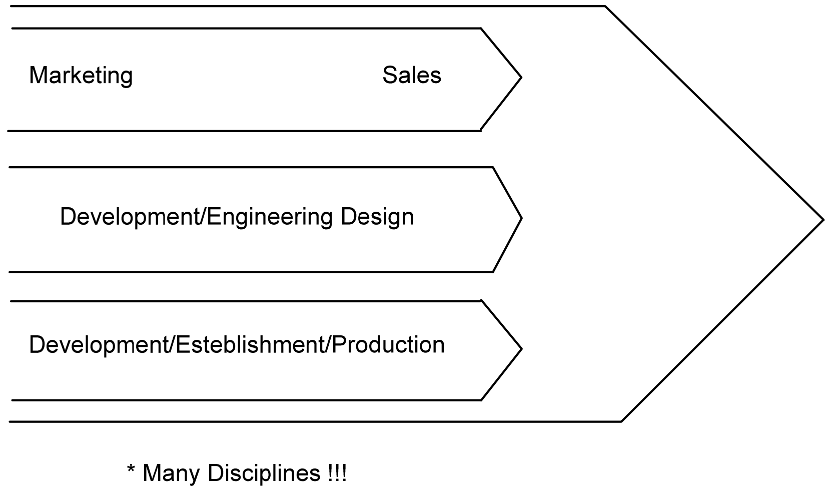

Figure 3.7 Multi-Disciplinary Nature of Product Development

There are different phases during the development of the product in each of these three areas of concern. Each phase requires time and the length of each phase depends upon the type and nature of the product to be developed. The time elapsed during these phases is schematically presented in Fig. 3.9. Each one of the three areas (Market, Product and Production) is processed simultaneously for the development of the product. Each phase is defined according to the processes performed to get a specific output from it. Therefore the product development phase is completed in the time elapsed as shown in the Figure. The activities required in three principal areas are also shown in Fig. 3.10.

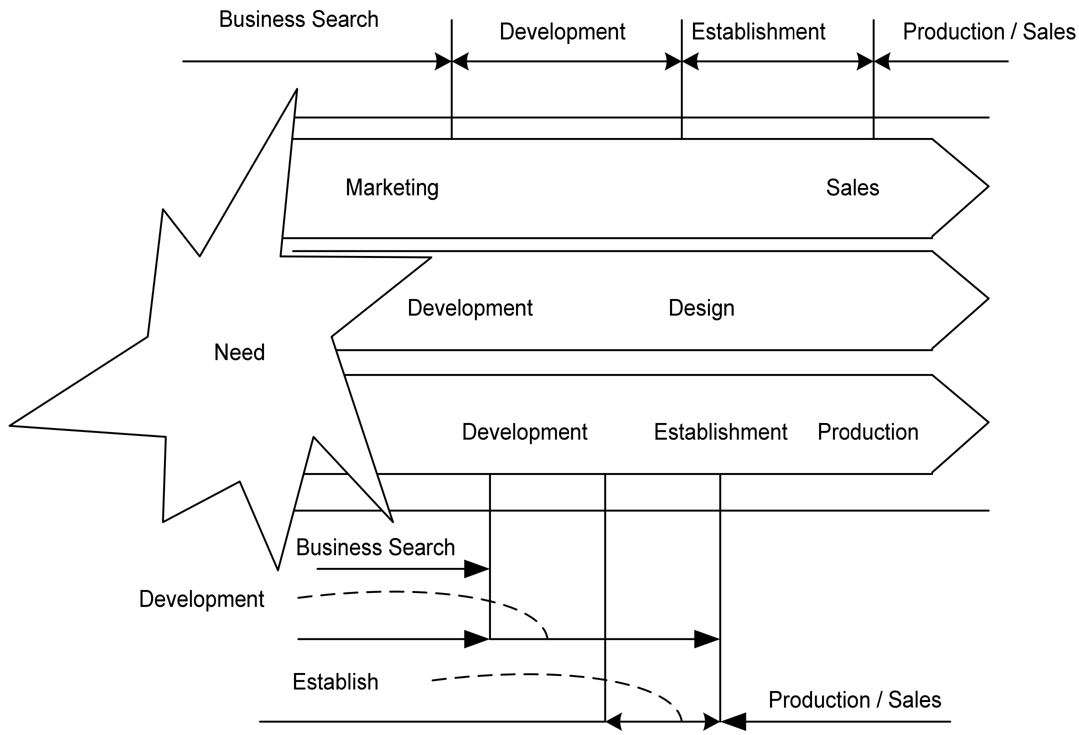

Figure 3.8 Time Division during Product Development Phases, after [39]

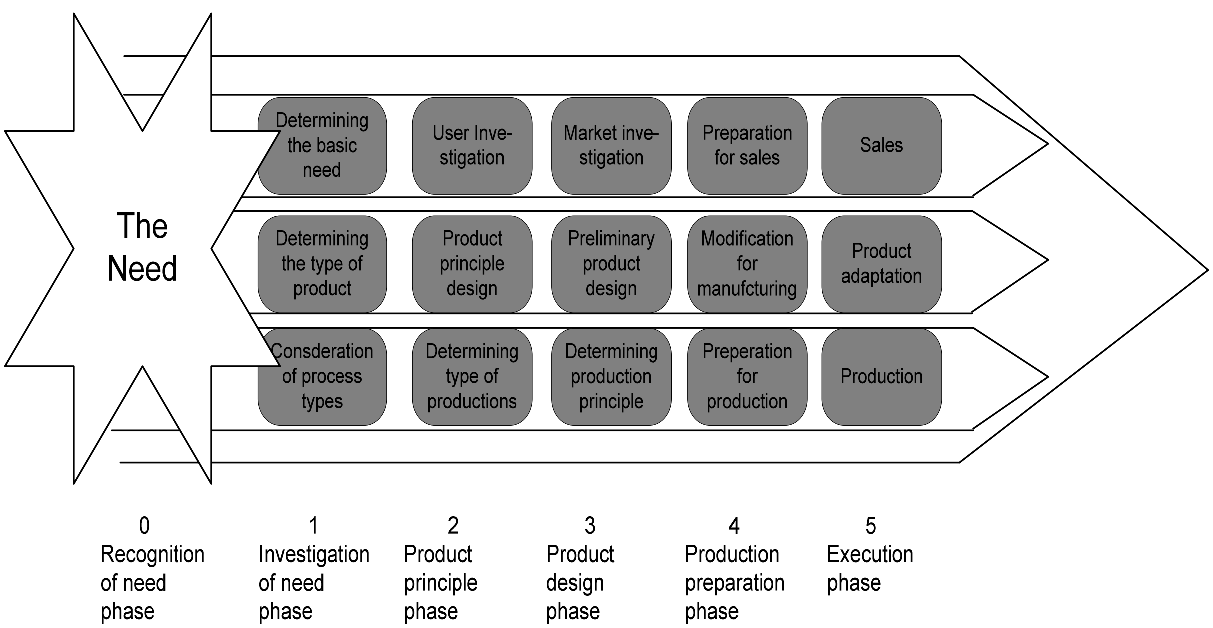

Figure 3.9 Activities in Product Development, after [39]

3.2.3 Product Life Cycle (PLC) Management

It seems necessary here that an introduction of product life cycle management is presented here. Product Life Cycle Management is the succession of strategies used by management as a product goes through its product life cycle [41]. A PLC is meant to assert that;

a. Products have a limited life,
b. Product sales pass through distinct stages,
c. Profits rise and fall at different stages of product life cycle, and
d. Products require different marketing, financial, manufacturing, purchasing, and human resource strategies in each life cycle stage.

According to the Product Development and Management Association (PDMA), superior and differentiated new products - ones that deliver unique benefits and superior value to the customer - is the number one driver of success and product profitability [48]. A typical PLC Management process is shown in Fig. 3.11.

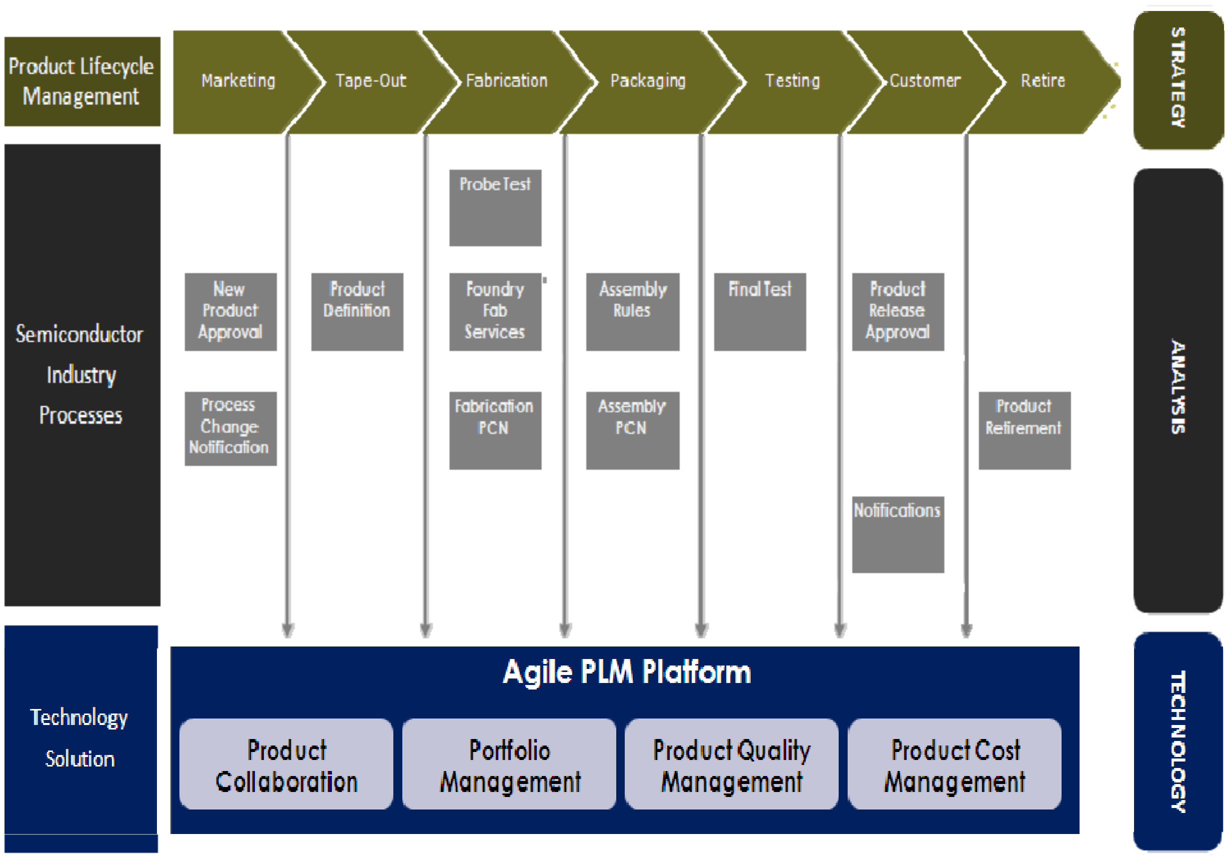

Figure 3.10 Typical Product Life Cycle Management Approach

Different stages in PLC Management and their hallmark characteristics are summarized as follows.

a. Market Introduction Stage
   i. Costs are high;
   ii. Low sales volumes to start;
   iii. Little or no competition - competitive manufacturers watch for acceptance / segment growth losses;
   iv. Demand has to be created;
   v. Customers have to be prompted to try the product; and
   vi. Makes no money at this stage.

b. Growth Stage
   i. Costs reduced due to economies of scale;
   ii. Sales volume increases significantly;
   iii. Profitability begins to rise;
   iv. Public awareness increases;
   v. Competition begins to increase with a few new players in establishing market; and
   vi. Increased competition leads to price decreases.

c. Mature Stage
   i. Costs are lowered as a result of production volumes increasing and experience curve effects;
   ii. Sales volume peaks and market saturation is reached;
   iii. Increase in competitors entering the market;
   iv. Prices tend to drop due to the proliferation of competing products;
   v. Brand differentiation and feature diversification is emphasized to maintain or increase market share; and
   vi. Industrial profits go down.

d. Saturation and Decline Stage
   i. Costs become counter-optimal;
   ii. Sales volume decline or stabilize;
   iii. Prices, profitability diminish; and
   iv. Profit becomes more a challenge of production/distribution efficiency than increased sales [43, 46]

3.2.4 Deliverables in Product Development Process

Each of the life cycle of the product processes some raw information and generates some useful information which is then processed during next process to provide the food for the next in turn process of the life cycle. Some typical deliverables in the product development process are schematically presented in Fig. 3.11.

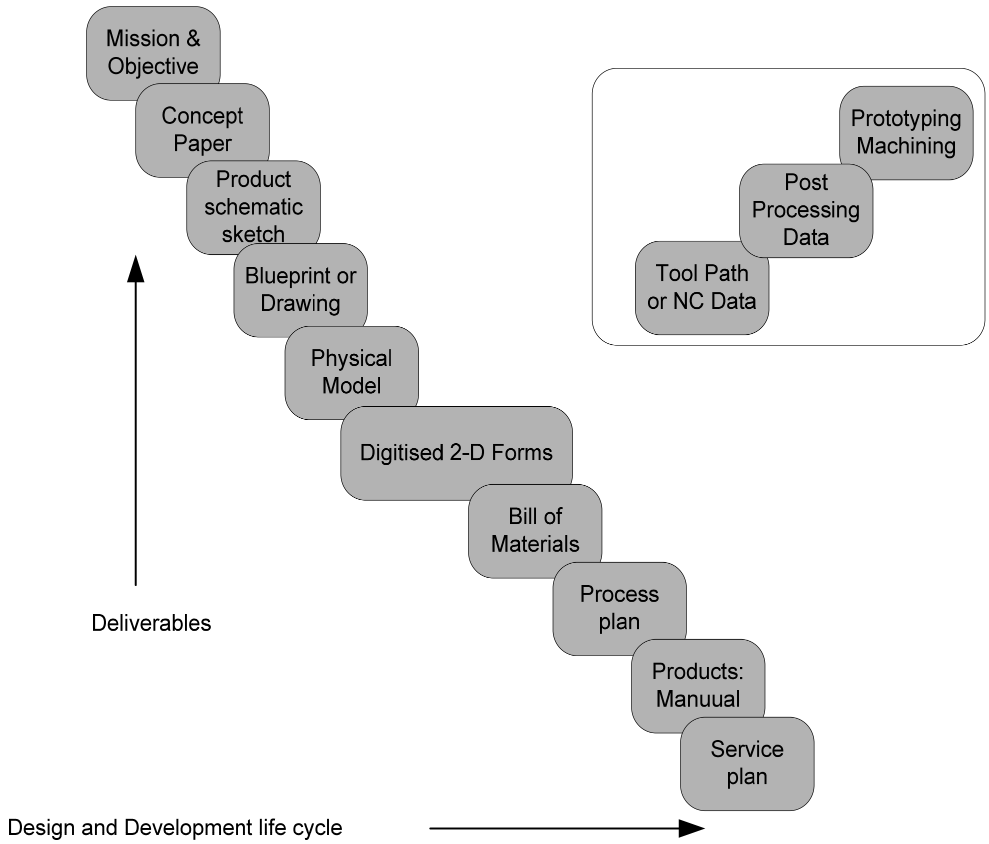

Figure 3.11 Outcomes of Product Development Process, after [39]

3.2.5 Advantages of Early Product Introduction

The company who introduces a new product in the market first gains a certain competitive advantages to companies who introduce similar products late in the market. These advantages are in the form of longer sales life and more residual market share as important advantages [6, 39]. The fact is shown in Fig. 3.12.

Company E introduces the product at some time T and company L introduces the product after a certain interval. Company E enjoys more market share due to early introduction. Another case is presented here that if company E loses quality or produces low quality of product, it will loose customer satisfaction and hence the market share. Therefore, company L can only advance if company E suffers or sets out of competition. Nevertheless, the advantage of early product introduction for company T remains the same.

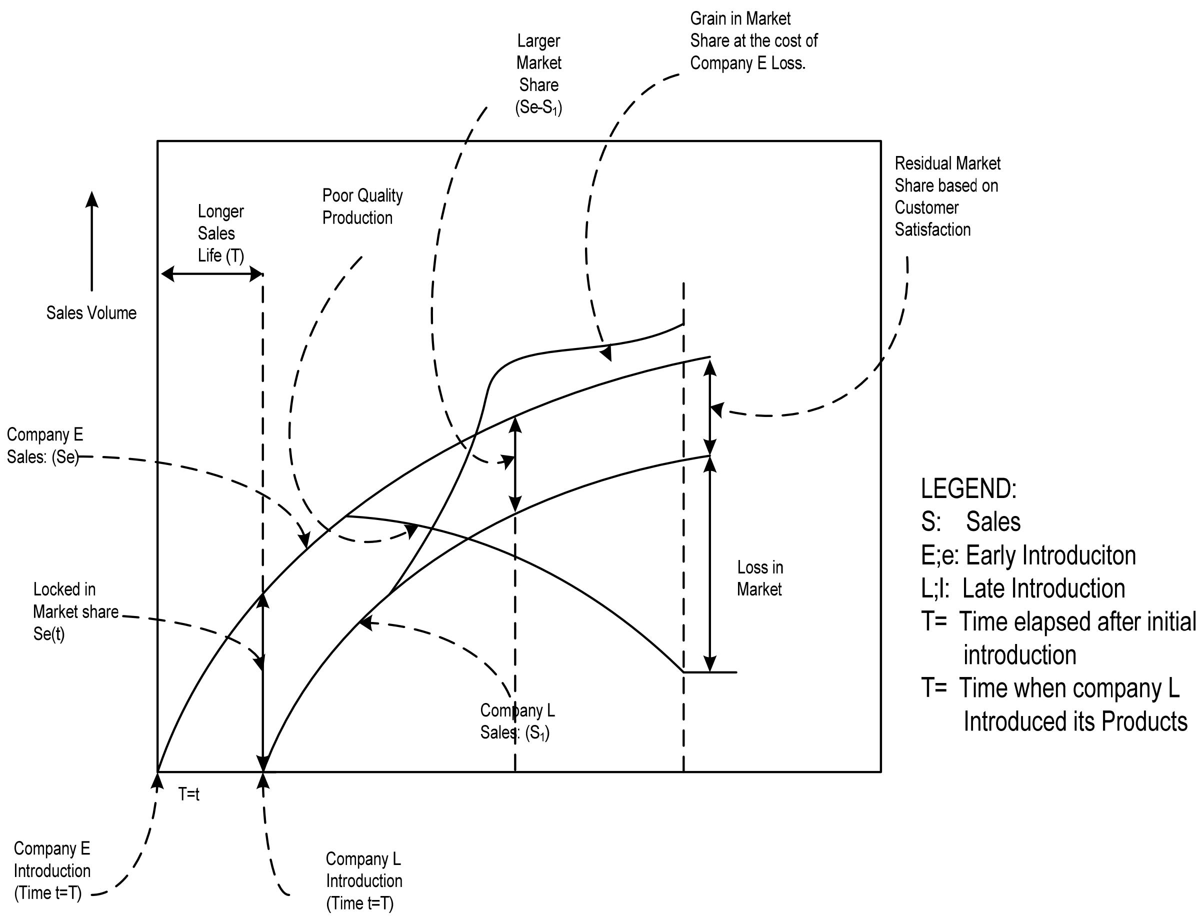

Figure 3.12 Advantages of Early Product Introduction, after [39]

3.2.6 Performance Indicators

In addition to introducing the product early in the market, the business concern or the company should also indicate some factors that should be minimized (like cost, manufacturing time, rework etc.) or maximized (like profit, customer satisfaction, increased life cycle time, some sales target etc.). These factors will later be considered when assessing or measuring the performance of the company. These factors are called as performance indicators and are used to manage the performance of the product.

While these indicators may be bench-marked from some leading organization, they can merely be self-developed. It is however advised to use some proven performance indicators as sated in [39, 43] etc. The concept of performance indicators is shown in Fig. 3.13. The arrows pointing inwards show the measures of performance that should be minimized, while the arrows pointing outwards show the measures of performance that should be maximized. Of course, this figure does not cover the complete horizon of the performance indicators and just serve the purpose to schematically represent the concept of performance indicators.

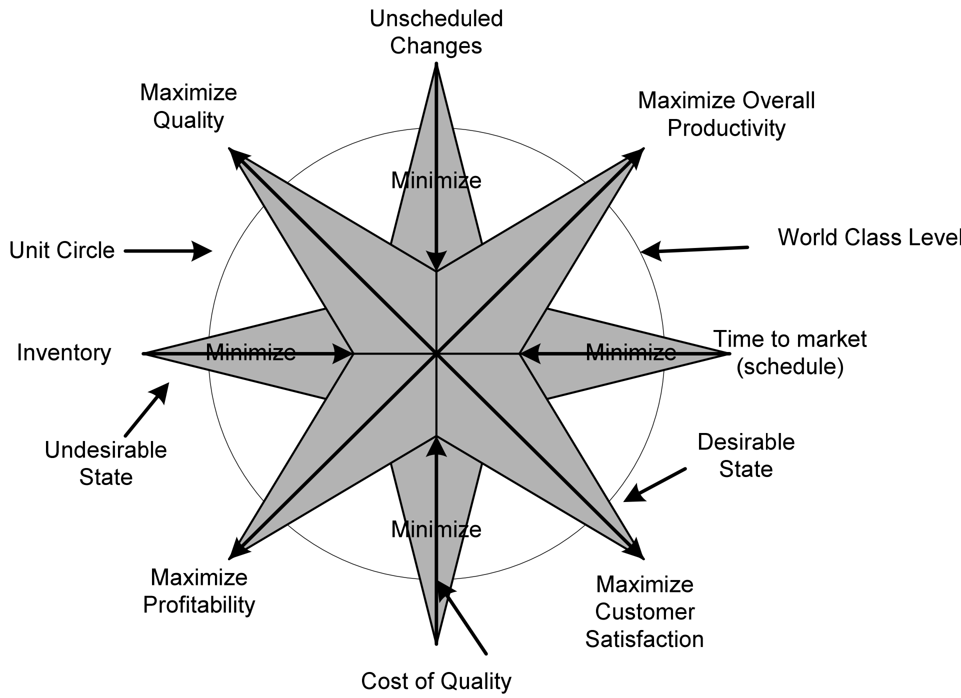

Figure 3.13 Concept of Performance Indicators, after [39]

3.2.7 Investment in Product Development

The investment at the initial stages of the product development gives a competitive advantage as compared to the investment made earlier. According to Anderson [39], following are the major operating costs incurred during the project life cycle;

a. Design: 11%;
b. Sales and Administration: 18%;
c. Production Planning: 6%;
d. Production: 25%; and
e. Purchasing and Contracting: 40%.

It can be seen that 40% cost is incurred during the purchasing and contracting phase. This finding is supported by the fact that each company cannot specialize in each and every component of the product, e.g., a pump manufacturer may not be a competitive enough manufacturer of a bearing or key etc., or it may be not be feasible for the manufacturer to manufacture these components within the factory. The company may choose, therefore, to subcontract certain components to a trusted manufacturer or even purchase the standard components from the market.

The investment made during the product development phase depends upon the type of the product under development. An entirely new product or idea may require extensive research and hence larger investment and vice versa. In return, the profit growth continues till the maturity phase of the product life cycle. Taken from the start of the product development process, products normally reach the maturity phase in the 14th year [43], as shown in Fig. 3.14.

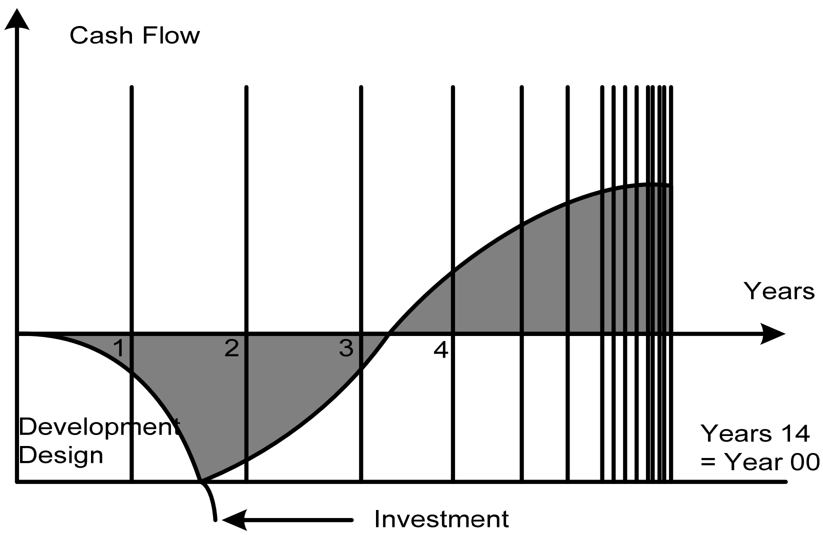

Figure 3.14 Investment till Product Maturity, after [43]

The Return On Investment (ROI) is also calculated during the planning phase so as to calculate the breakeven point. Some unforeseen factors like overheads, additional project costs, low sales, increased rework etc. the ROI can be less than what was expected. The planning phase should therefore address as many factors as possible. The ROI that was expected and that actually was obtained is shown in Fig. 3.15 with the factors that may have caused this.

The design process determines the overhead costs, the later manufacturing processes that need to be developed for manufacturing, the production technology, the strategy of production etc. This is based on the fact that the design process finalizes the product features and the rest of the product life cycle only serves to produce the paper idea into the reality. Thus the design process returns the highest investment as compared to other processes as shown in Fig. 3.16

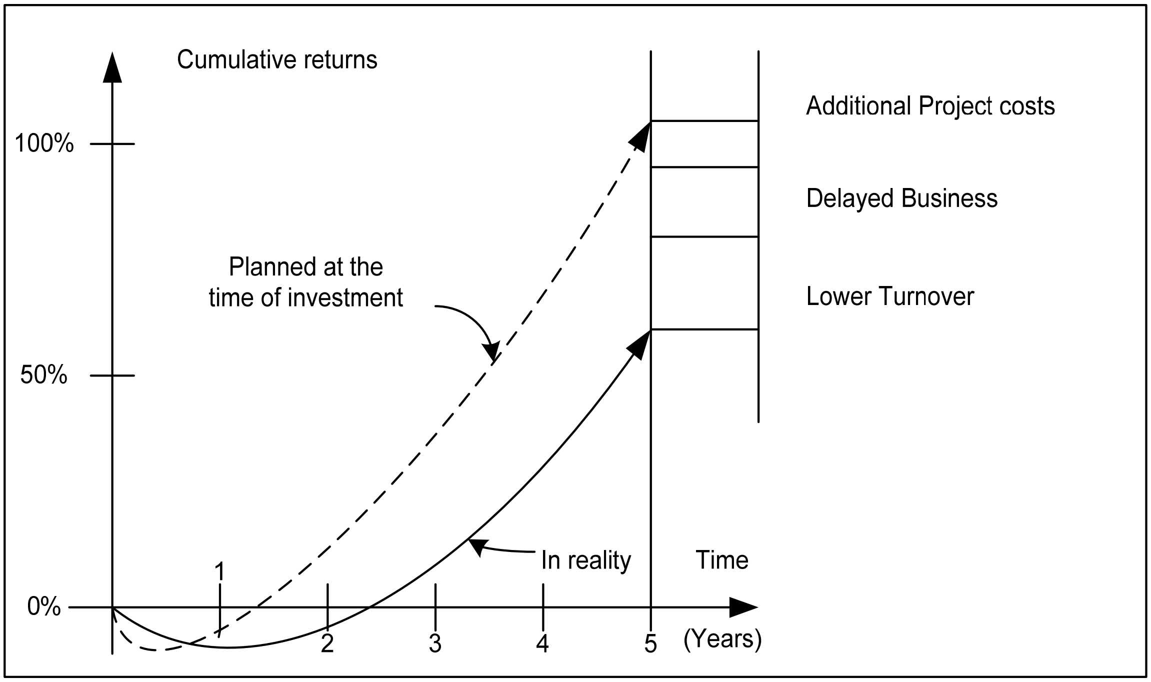

Figure 3.15 Actual vs. Planned ROI, after [39]

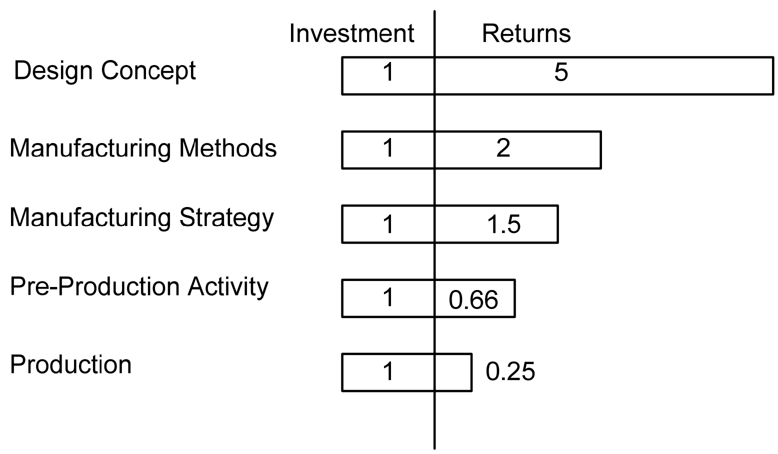

Figure 3.16 Investment vs. ROI for Different Processes

Investing in design is relatively inexpensive and risk free, as it is not a capital intensive activity. The manufacturing and marketing activity requires heavy capital investment. The design process does not require such heavy investments. Moreover, if any concern or comment is received about the product, the manufacturer has to revert back to the design process. Productivity improvement is also affected by the design process, as the design process determines the required manufacturing setup.

The companies who paid due importance to the design process received more ROI as compared to those who neglected the importance of design process at its proper life cycle phase. The following study, Fig. 3.17, represents the comparison of different performance indicators of the firms that assumed the design development as a key element and vice versa. The study is adopted from [39].

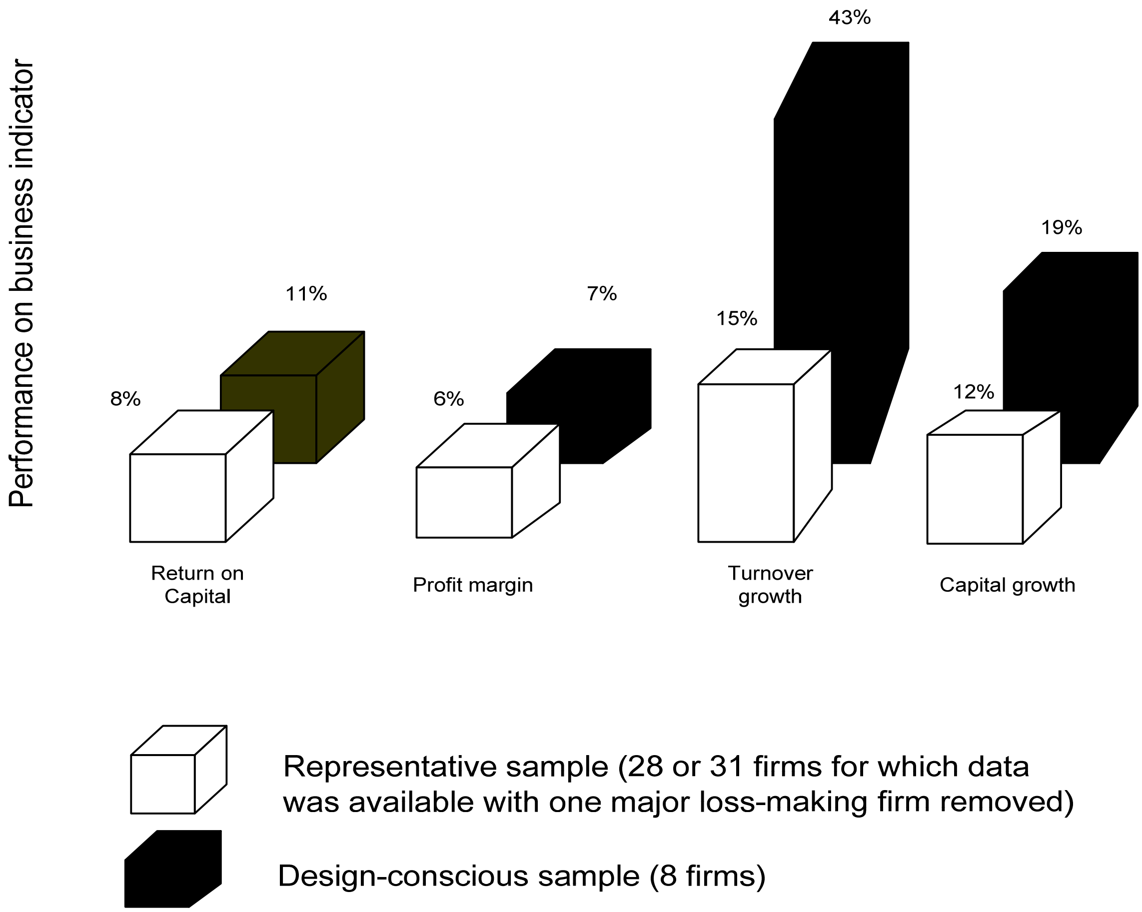

Figure 3.17 Comparison of Firms that Considered Design Development and Those Firms that overlooked it

Moreover, it is worth mentioning here, that if due to any reason, the development cost runs over, it does not cost a huge loss as compared to late shipments and production costs overrun. The following study (Fig. 3.18) shows that the 50% development cost overrun did actually cost only 3.5% loss in profit, while the shipment 6 months later caused 33% loss and the high production which were only 9% classified as too high caused 22% loss.

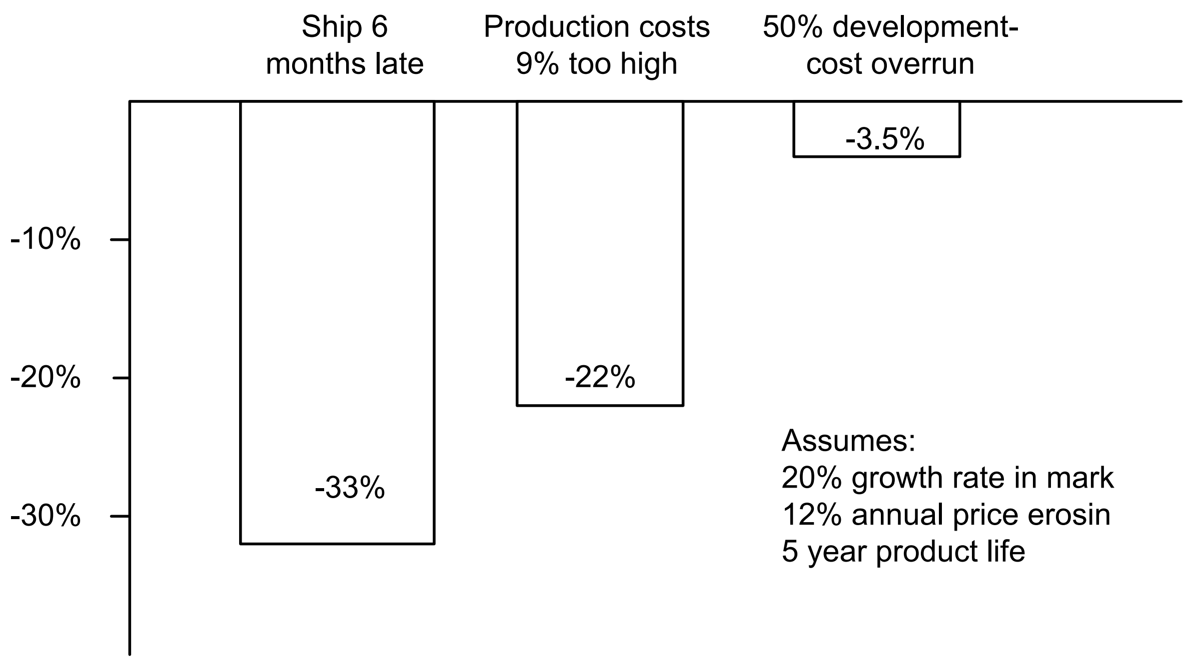

Figure 3.18 Other Losses Incurred in Profit as Compared to Those of Development cost Overrun

It is therefore concluded that the companies that invest more in the design development stage are at a competitive advantage rather than the companies overlooking the importance of the design phase or not duly investing (time, money etc.) in the stated phase. Moreover, the competitive advantage in manufacturing can be enhanced manifold by incorporating the competitive advantage in product development through performance measurement at the initial phase.

Chapter 4
PERFORMANCE MEASUREMENT: AN OVERVIEW

4.1 Introduction to Performance Measurement

The previous chapter presented the introduction of product development and the impact of its manufacturing on the society. It was also discussed that if a new product is launched before the prescribed time, it is a competitive advantage and returns huge ROIs and increased product life cycle. It was also concluded that for a business to be successful and profitable, it should be continuously measured and necessary changes should be made. In this chapter, the performance measurement phenomenon is described in general and it is especially elaborated for the product design development process.

4.1.1 Business Process Performance

Business process performance has been a great area of interest since the early 20th century. Many methods of business process improvement have been available since then [49]. Due to this interest in business performance measurement, a number of methods and tools, including software have been used or developed to aid in its implementation [9]. Business performance management (BPM) is a set of processes that help businesses discover efficient use of their business units, financial, human and material resources [50]. Business Process Improvement (BPI) is a systematic approach to help any organization optimize its underlying processes to achieve more efficient results [3]. While there are differences in the challenges that each type of industry poses, the fact remains that the core principles of BPI and how they apply to business improvement remain portable across industries and functions.

Due to growing concern of the industrial competitiveness, many companies are assessing ways in which their product, product quality and operations can be improved. US industry is of the view that quality of the products and services can best be addressed by focusing on improvement of the processes that create the products. This process approach is embodied in the Malcolm Baldrige National Quality Award (MBNQA) and is the central theme of the ISO 9000 standards. The definition of the process in this context is very broad and covers not only the processes through which the product is manufactured, but also the processes of design, strategy formulation, marketing etc. Therefore, BPM is the method by which an enterprise carries out its quality program [9]. Approaches to the study of processes have been termed process simplification, process improvement [51] and reengineering [52]. A model of Business Process Management is presented here after Elzinga [9] in Fig. 4.1.

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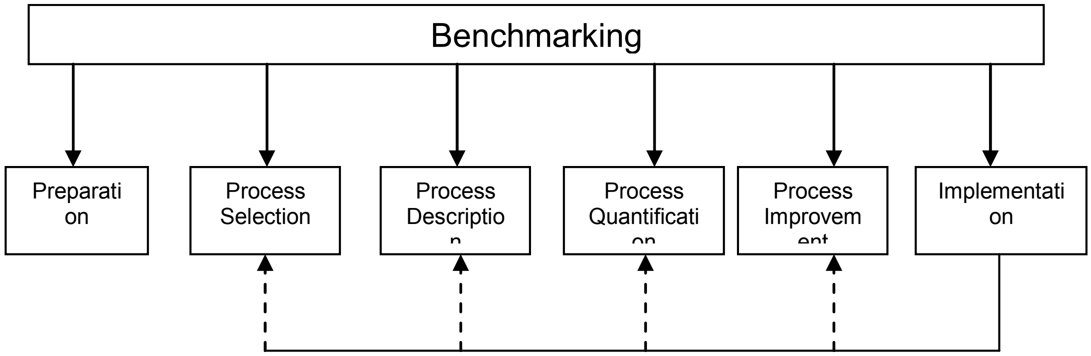


Figure 4.1 Business Process Management, after [9]

A preparation of BPM is done through the analysis of the organization's vision and mission statements. In the beginning of this process goal setting for the organization is done through a set of Critical Success Factors, CSF [53]. CSF is a methodology that systematically identifies those actions that are necessary to enable an organization to achieve its goals. According to [53], CSFs are the few key areas where things must go right for the business to flourish. It involves following two steps;

a. An interview with top management in which the mission and vision is reviewed and goals are established; and
b. The results of the first step are reviewed with management and measures to enhance the performance of each CSF are established.

CSF was first used by McKinsey & Co. in 1950s [54]. CSF was later proved to be helpful in application such as hotel & hospital management, asset management and in decision support systems [55, 56, 57, 58]. Process quantification may be done by using methods relating to activity based costing, e.g. activity based costing (ABC) [60]. When the process has been quantified the opportunities for improvement are selected. This decision making process may be undertaken with the help of traditional methods such as Gantt Charts, Pareto Diagrams etc. Cost factor, where intensively higher can be considered with the help of cost-value matrix. The processes will be selected based on cost benefit analysis and return on investment etc. a cost-value matrix is shown in Fig. 4.2.

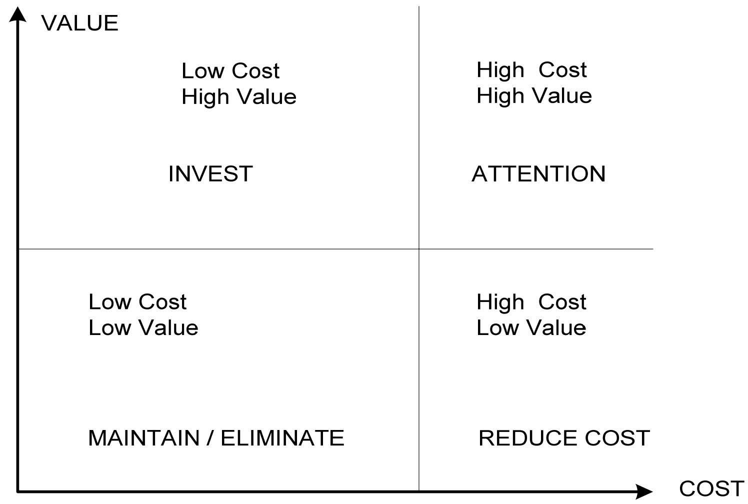


Figure 4.2 Process Cost-value Matrix

After the improvement opportunities have been identified, improvements to the process have to be recommended and implemented. The process gets into a continuous improvement cycle loop as shown in Fig. 4.1. In all of the process factors, benchmarking is done if required. According to Camp [59], benchmarking is a process of consistently searching for new ideas or methods and adapting them for their good features and their implementation to obtain the best results. A survey as reported by [9] concludes that;

a. BPM is a part of comprehensive quality program;
b. Companies develop individual BPM programs due to lack of common knowledge;
c. Driving forces are product quality, profit;
d. Impediments are lack of management concentration, employee retraining, a management view that companies are product driven rather than process driven;
e. There is a common and substantial overlap between BPM and ISO 9000.
f. It is more important to apply BPM to areas such as marketing, design and strategic planning; and
g. Top management and in–process employees are more responsive to BPM. The highest resistance to BPM is offered by middle management.

4.1.2 What is Performance Measurement?

There is no consensus on a single definition of the word performance, because it is interpreted and used differently in various situations and contexts [6, 9]. Performance is such an attribute of a system which may be interpreted differently by different people working in different professions [61]. A top management executive may define performance as value of current share, therefore reflecting the result of performance across all business process. A production manager may define performance as a number of products produced over a given time. Similarly, a product development specialist may define performance as percentage of turnover due to new products. A formal definition of performance is therefore required. Here, a number of definitions of performance are presented for further analysis.

a. *Performance*: Effectiveness i.e., measuring output to determine if they help to accomplish objectives and efficiency i.e., measuring resources to determine whether minimum amounts are used in the production of outputs [62]. This is with reference to research and development organization.
b. *Performance*: The level to which a goal is attained [63]. This is a general definition of performance.
c. *Performance*: Efficiency and effectiveness of a purposeful action [64]. This is with reference to general business.
d. *Performance*: A complex inter-relationship between seven performance criteria [65]. This is with reference to organizational system
    i. Effectiveness;
    ii. Efficiency;
    iii. Quality;
    iv. Productivity;
    v. Quality of work life;
    vi. Innovation; and
    vii. Profitability.

It can be observed that there is a vast difference between general definitions of performance. Neely [7, 12] states that performance measurement is a topic which is often discussed but rarely defined. Meyer [70] suggests that there is a massive disagreement as to what performance is. However, it is generally observed in a-d, as described above, that efficiency and effectiveness are the most common words which describe performance. Effectiveness is related to the attainment of goals and efficiency is related to the use of resources. Moreover, the relation between effectiveness and efficiency is not clearly defined. Following are the performance related definitions collected from the literature.

a. *Dimensions of performance*: Total product quality, lead time and productivity (level of resources used) [66]. This is with reference to product development.
b. *Dimensions of performance*: Focus in development, speed of development and R&D efficiency [67]. This is again with reference to product development.
c. *Dimensions of performance*: Development time, development productivity (use of resource) and total design quality [68].
d. *Dimensions of performance*: Efficiency, effectiveness and adoptability [69]. This is with reference to manufacturing.
e. Dimensions of performance: Time, cost, quality and flexibility [12].
f. *Performance measurement*: The acquisition and analysis of information about the actual attainment of company objectives and plans, and about factors that may influence this attainment [71].
g. *Performance measurement*: The process of determining how successful organizations or individuals have been in attaining there objectives [72].

h. *Efficiency*: Ratio of increase in (clarification + risk reduction + detail + documentation) to (increase in cost) [30].
i. *Productivity*: A measure of how well resources are combined and used to accomplish specific and desirable results [73].
j. *Design Productivity*: Efficiency and effectiveness [74, 75].

The references given above define performance measurement as its key dimensions. They primarily include the dimensions such as time, cost and quality. The meaning of time and cost is quite clear but the meaning of quality is again like performance in literature because of its varied interpretation and understanding. Other dimensions such as focus in development, adoptability and flexibility do not measure performance it self but influence it. As a matter of fact flexibility and adoptability are only appropriate within an environment where changes are required e.g. design, where rapid changes occur due to idea generation. Therefore, flexibility and adoptability will influence performance but do not constitute its dimension. As a summarization of above, following conclusions are outlined about the definition of performance and its measurement;

a. The definition of performance and performance measurement vary across the literature due to its different interpretation in different areas of interest;
b. The key elements of performance are not clearly defined and they are also not agreed;
c. The authors defining performance as efficiency and effectiveness have not clarified the meaning of the terms. Moreover, the literature lacks the procedures to measure efficiency and effectiveness of a process, so that to constitute performance; and
d. Many of the measures of performance described in literature relate to the performance in context of influence and not in context of its dimensions, i.e., they affect performance but they do not constitute performance itself.

4.1.3 Reasons for Assessing Performance

Business is targeted to obtain monetary benefit. This is obtained through customer base (the more customers the business attracts, the more is the profit), and the customer satisfaction. Companies have always tried to improve and/or maintain their performance so that to attract more customers and improve the customer satisfaction level. Therefore, performance measurement is a sub-division of a general management process which includes the concept of continuous improvement to obtain the satisfaction of customer. Performance measurement does not generate any monetary benefit itself but it is only a measure to assess where does the business stand in competition. Moreover, the analysis of performance reveals the weak areas for improvement.

Performance measurement of business is a general management task which is often not distinguished clearly from the process [49, 61, 72, 76, 77]. Sinclair et al. [72], in their analysis of 115 companies found that there was no separate management system for the performance measurement. However, following specific reasons for the performance measurement of a business process can be found in literature referenced at [61, 71, 78, 27, 50]. A summary of the reasons for measuring performance is presented below;

a. For benchmarking: Benchmarking [59, 79] is normally done to compare the business performance of the company with other competitors. Therefore, we have to measure the performance first in order to compare and benchmark it. This helps in assessing that whether the business performance is increasing or decreasing and therefore a comparison.
b. The performance measurement practice results in addressing the weak areas of the business process and provides an opportunity for continuous improvement. It also helps in decreasing the loop holes present in the technical and management practices.
c. As a result of previous performance attribute values the business performance can be planned and controlled in a better manner in the future. The analysis of performance against a specific plan generates guidelines for future planning and control with reverence to the past experiences.
d. Performance measurement provides insight to the business processes thereby identifying the factors influencing performance and the nature of their influence.
e. The results of performance improve organizational learning.
f. It motivates the employees to work in the same manner, or to improve their performance in a specific area for future benefits thereby, providing better opportunities for competition.
g. The benefits of performance measurement indicated here relate to the overall business aims of continuous improvement and customer satisfaction.

4.1.4 Improving the Performance

It was previously stated that many companies do not have a formal and separate performance measurement system. This system relate to the decision support area and it helps the organization to improve the decision making process. The performance measurement system definitely does not contribute towards the improvement of performance but provides a basis on which performance strategies may be made and improved. The performance improvement system is outlined in the Fig. 4.3. The process is cyclic in nature and repeats itself when required and can be applied to any business process such as design, manufacturing, logistics etc. The process is defined in terms of inputs, outputs, goals and resources. Therefore, one can compare the outputs and goals with inputs with reference to the resources available.

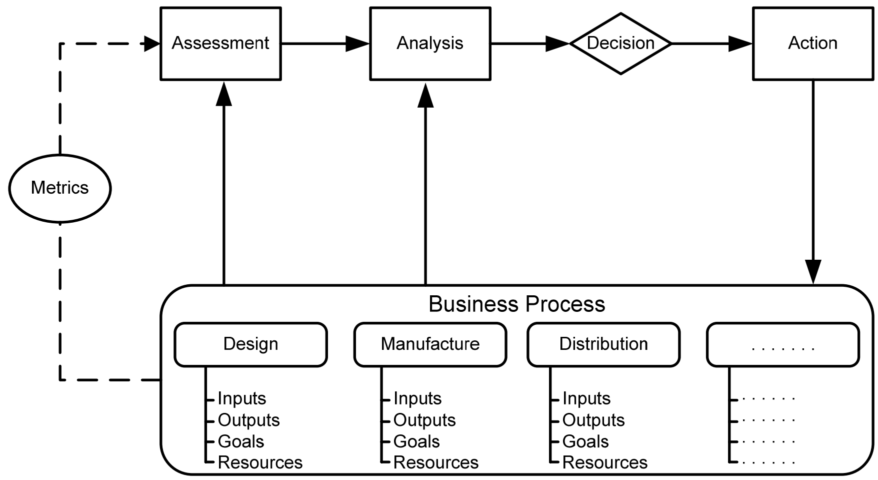


Figure 4.3 A Model of the Performance Improvement Process, after [13]

a. *Assessment:* Present performance of the system is assessed with the aim that these assessed values will be used for future comparison with the future values such that the performance has increased or not. This is done with the help of performance measures and matrices. The assessment is primarily related to the key elements of the particular business process as defined in Fig. 4.3 as inputs, outputs, goals and resources. The output may be interpreted as deviation from planned performance measures.
b. *Analysis:* Analysis is done to obtain detailed information on the causes high or low performance with respect to the decision making process for future reference and improvement. The analysis may be aimed at employing more resources to a certain process and its impact on the performance. The performance analysis provides more comprehensive information with respect to the business process performance.
c. *Action:* The output acquired from analysis provides necessary information for future decision process, and therefore, decisions can be made on analytical results and ground realities to achieve improved performance. The decisions may include the deployment of more resources, reorganization and reallocation of the present resources.

4.1.5 Performance Matrices

Fig. 4.3 depicts that before assessment matrices are required. Performance matrices are a specific element used in the performance improvement process. Performance matrices have always been given great interest in the literature and it has been a matter of concern to the researchers for how to measure the performance. There is a general agreement in the literature that these matrices differ in nature due to their varied application and are dominated by financial aspects [16, 80, 81]. It has been a tremendous research to develop generalized to cover the overall industry but it is suggested that it is not feasible to develop generalized matrices [82]. A number of researchers also suggest that the performance matrices may change for a specific business continuously as the performance measures change [70, 83]. Dixon [83] states that, each organization, each unit within each organization, and each unit within each organization at each point within its strategic, market and technological evolution will require its own unique set of performance measure.

These matrices are developed from the investigation of the activity or process which is under study. A model of the process may help to develop the matrices more easily. The more appropriate the matrices, the more accurate and fruitful the performance measurement.

4.1.6 Coherence

It is possible that the performance measurement procedure, as defined in Fig. 4.3, may be applied to many business processes in isolation and through different application processes. As a matter of fact performance is measured in many businesses in Pakistan in this manner. A review of literature suggests that this approach can result in sub-optimization, i.e., a specific business process may be performing very well but its high performance may have a negative impact on the overall performance of the organization and hence may deprive the organization from the benefit of performance measurement.

Coherence (aligning performance throughout the organization) is considered as a necessary element of the performance measurement system [12, 80, 84, 85]. According to de Hass [84] coherence is an attribute of the performance measurement system which helps to achieve scores on performance indicators by the group acting upon that system to contribute to the performance of interdependent groups and thereby to contribute to the performance of the organizational entity as a whole. The work reported by Hass is applicable for the concept of coherence to the general business process. For example; the manufacturing process must be aligned with the overall performance of the product development process to ensure that manufacturing positively contributes towards overall developments. Similarly, design and manufacturing performance should correlate to each other so that they can improve the business process as a whole.

4.2 Topics in Performance Measurement

It was discussed in previous chapters that performance measurement is a diverse and varying field due to its applications in almost every aspect of business. Here, different aspects of diversity of performance measurement are summarized;

a. *Different organizations and professionals*: A large number of business concerns are present today. They include government sector, hospitals, hotels, banks, non-profit organizations, financial services, manufacturing etc. Then if we breakdown into the manufacturing business, it may include manufacturing of mechanical, electronics, composites, medical, pharmaceuticals, clothes, sports items etc. In mechanical manufacturing again, the design machine tool and tool design etc. are present. Every process needs to be measured and improved in performance. Every process has different inputs and outputs and therefore every process will have different matrices. This indicates the diversity of performance measurement field.

b. *Intangible nature*: Many companies scale their performance with reference to the financial transactions and outputs during the current fiscal year. This approach generates a yearly report which cannot provide a further insult to the performance of the organization. Performance relates to the intangible and un-measureable aspects of the system. This presents another difficulty in this area.

c. *Employee involvement*: A performance measurement system will never operate properly, if the employee of the organization are not interested or empowered to generate the contribution towards the performance indicators.

d. *Forward looking and realistic*: A performance measurement system of an organization should properly co-relate with the mission and business statement of the organization so that weak areas of the business can be improved through a continuous process. Setting targets is the most intangible aspects of the system. Achieving the goals require more effort and many organizations prefer to obtain the goals and in turn provide short term benefits. Moreover, an organization should constitute its performance integrators with the consent of its management and working staff. So that the indicators can be achievable and realistic. For example, an organization cannot improve its productivity from 10% to 90% in a month.

4.2.1 Key Performance Indicators (KPI)

KPIs are financial and non financial measures or matrices used to help an organization define and evaluate, how successful it is, typically in terms of making progress towards its long term organizational goals [86]. KPIs basically monitor and indicate the betterment of the business process through business activity monitoring (BAM). Through KPIs a proper value is given to every critical business process and it is measured and inspected to see the performance. KPIs are implemented through techniques such as balanced scorecard. The concept of balance scorecard will be explained later.

There was a discussion on Critical Success Factors (CSF) in section 4.1.1. The KPIs should not be mixed up with CSFs. For example if a mission statement says that average revenue per customer should be increased from 10% to 11%, the average revenue per customer is the KPI, while providing a decent product so that the customer should buy it, is the CSF.

It is extremely important for an organization to clearly identify its KPIs so that it can head towards its goals with clarity. According to [86], following environment for identifying the KPIs is required;

a. Having a pre-defined business process;
b. Requirements for the business processes;
c. Having a quantitative/qualitative measurement of the results and comparison with set goals; and
d. Investigating variances and tweaking processes or resources to achieve short-term goals.

A KPI should follow a SMART criteria, where

S ➔ Specific purpose for the business;
M ➔ The selected business process should be Measureable so that we can obtain a proper value for KPI;
A ➔ The defined purpose should be Achievable;
R ➔ The KPI should be Relevant to the business; and
T ➔ There should be a Time phase in which the KPI should be measured.

Following are some typical KPIs for the stated business processes;

a. Marketing:
   i. New customers acquired
   ii. Turnover
   iii. Profitability of customers
b. Manufacturing:
   i. Overall equipment effectiveness
c. Supply Chain Management:
   i. Sales forecast
   ii. Inventory
   iii. Transportation

4.2.2 Performance Measures

It has been a matter of concern for the researchers to obtain a set of performance measures against which the performance of the department can be measured. Graham et al. [87] presented a set of 42 performance measures after consulting from 155 production managers. The manager's experience and position was considered in the study. This is shown in Table 4.1.

Item	Mean and (Standard Deviation)
Age (in years)	43.12 (9.14)
Experience in area managed (years)	15.10 (9.80)
Years in present position	5.70 (5.52)
Position (level) in company	2.57 (0.76)
Employees in department	188 (266)

Table 4.1 Manager and Position Data, after [87]

The identified performance measures in the study are tabulated in Table 4.2.

Performance Measures	Mean and (Standard Deviation)	Element
Variance between planned "output" and actual "output"	4.41 (0.96)	Product
Machine output rates	4.26 (1.25)	Machines
Machine downtime	4.26 (1.23)	Machines
Variance between standard amounts of materials required for jobs and actual amounts used	4.21 (1.16)	Materials
Incidence of quality control problems	4.17 (1.03)	Product
Rate at which delivery schedules are met	4.10 (1.37)	Customers
Variance between standard times allowed for jobs and actual times taken	4.07 (1.31)	Employees
Scrap or waste levels	4.06 (1.24)	Materials
Yield of material inputs to outputs	4.05 (1.35)	Materials
Incidence of delays in obtaining supply of materials	3.95 (1.30)	Suppliers
Absenteeism levels of employees in departments	3.85 (1.11)	Employees
Incidence of customer complaints	3.81 (1.27)	Customers
Customer service level (i.e., orders filled within required time)	3.80 (1.53)	Customers
Incidence of out of stock of products	3.74 (1.48)	Customers
Incidence of rework	3.72 (1.38)	Materials
Operating costs per machine	3.68 (1.56)	Machines
General "output" per employee	3.59 (1.51)	Employees
Accident levels of employees in department	3.53 (1.38)	Employees
Results of testing of company's products	3.45 (1.58)	Product

Incidence of disputes with unions	3.42 (1.54)	Unions
“output” to expense ratios	3.41 (1.56)	Global
Comparison of actual sales to forecasted sales	3.36 (1.67)	Global
Performance rating of employees in department by supervisors	3.32 (1.29)	Employees
Turnover rates of employees in department	3.15 (1.17)	Employees
Inventory turnover rates	3.12 (1.52)	Product
Profit per time period	2.90 (1.68)	Global
Incidence of supplier complaints	2.87 (1.50)	Suppliers
Return on investment	2.82 (1.72)	Global
Incidence of conflict between employees in department	2.81 (1.43)	Employees
Profit to sales ratios	2.70 (1.70)	Global
Sales per time period	2.66 (1.65)	Global
Incidence of conflict between my department and other departments	2.43 (1.35)	Other Subunits
Company’s market share	2.40 (1.67)	Competitors
Attitude of consumer bodies to company	2.40 (1.61)	Regulatory Bodies
Cost to the company of repairs under guarantee	2.19 (1.47)	Product
Call rates on products under warranty	2.15 (1.58)	Product
Wholesaler or retailer attitude to company	2.06 (1.53)	Resellers
Product service call rate	1.96 (1.40)	Product
Incidence of government body queries regarding activities of my department	1.94 (1.31)	Regulatory Bodies
Outlets knowledge of company’s products	1.91 (1.43)	Resellers
Results of market research surveys	1.75 (1.18)	Competitors
Space allotted by outlets to company’s products as compared to space allotted to competitors products	1.50 (1.16)	Resellers

Table 4.2 Usefulness of the 42 Measures, after [87, 88]

This can be easily seen in the study that production managers care for a narrow set of goals and focus on functionality based elements such as materials, machines and product. The element materials have the greatest amount of attention with three measures being represented in this group. Machines and product have two measures and customer and employees have one measure in this category. The result of the research has provided a useful set of performance measure and their utility for the department.

4.2.3 Impact of Innovation on Performance

As stated in chapter 02, innovation in product development and design has a great impact on performance. Gary et al. [89] presents a comparison of innovation success and failure studies according to a three dimensional framework, i.e. generality over innovations, decision focus and managerial controllability. Many authors compared the introduction of new industrial product performance in the perspective of innovation and found both successes and failures, like [90 – 97]. The authors have summarized the findings due to which the product innovation failed or succeeded. The findings are summarized and referenced in Table 4.3.

	Product Type in Data base	**Analysis Methods**	**Key Findings**
SAPPHO (Rothwell et al.) [90],	43 parts (22 in chemical processes, 21 in scientific instruments) of successful or unsuccessful U.K. projects.	Univariate analysis, Principal component analysis, Factor analysis, Cluster analysis	Successes and failures are different in 5 dimensions: strength and characteristics of management, marketing performance, understanding of customer needs, R&D efficiency in development, and communications.
Utterback et al. [91]	164 project of 59 European and Japanese firms in computer, consumer electronics, textiles, industrial chemicals, and automotive industries	Frequency analysis with Chi-Square tests	Major differences of successful projects from unsuccessful ones are: no initial difficulty in marketing, product advantage, competitive stimulus, project customness, project urgency, patent protection, and top management's initiative.
Cooper [92]	195 industrial products (102 successes and 93 failures) of 103 Canadian innovative firms	Factor analysis Discriminant analysis	Identified 18 factors describing projects. Found 3 key factors for success (product uniqueness/superiority, market knowledge/ marketing proficiency, technical/ production synergy and proficiency), and 6 barriers/facilitators.
Calantone & Cooper [93]	195 industrial products (102 successes and 93	Cluster analysis ANOVA, and Duncan multiple	More successful product scenarios are in order of Synergistic, close to old,

	failures) of 103 Canadian innovative firms	range tests	Innovative superior, Old simple, Synergistic, Innovative, high-tech.
Maidique & Zirger [94]	118 product innovation in U.S. electronics industry	Binomial significance tests and cluster analysis	Successful innovations are: better matched with user need, more effectively planned, more efficiently developed, closer to the firm's areas of expertise, and launched earlier.
Cooper [95]	122 Canadian industrial firms active in new product innovations	Factor analysis and Correlation analysis	A balanced, focused (technologically sophisticated, innovative, and strongly market oriented) strategy yields the best performance
Yoon & Lilien [96]	112 industrial products of 52 innovative French firms	Discriminant analysis	Life-cycle stages, expertise in marketing and marketing efficiency are major determinants of success or failure.
Baker et al. [97]	210 (product or process projects of 21 U.S. firms in favor industries (steel, pesticides, food, and industrial chemicals)	Discriminant analysis	Experience in production and marketing, top management's involvement, goal definition, and R&D marketing interaction are common determinants of success or failure. LOB (Line of business) specific determinants are business project fit, R&D science / technology interaction, project complexity, resource availability and patent or other protection.

Table 4.3 Studies Comparing Innovation Success and Failures

4.3 Performance in Design Development

Section 4.1 presented a general view of performance measurement with respect to business and illustrated the generic elements of performance measurement. Now, performance measurement in design is focused in this section. Design may be seen as a process of goal directed reasoning where there are many possible (good or bad) solutions and although the process can be supported methodologically, it can not be logically guaranteed [28]. The design process is inevitably targeted to obtain certain goals with whatever path followed. So, the concern is to reach the goal, not the path followed. Design engineers, themselves, and the design companies have developed various design development procedures. The design process models were explained in chapter 02 and are referenced at [22, 15, 5, 36, 37]. A critical review of the design process model is also presented in [101]. The literature also identifies two types of design models;

a. Descriptive Models: These models describe how the design process is carried out e.g., as referenced in [98, 99].
b. Prescriptive Models: These models teach or prescribe how the design process should be carried out e.g., as referenced in [5, 35, 36, 100].

The basic design cycle can be divided into following key activities;

a. Analysis
b. Synthesis
c. Evaluation [28].

This formulation presents a basis for the performance analysis. The continuous cycle starts with the identification of need (difference between current state and desired state). The analysis phase is aimed at clarifying the future state and the definition of goals. It has to be taken in view that in initial stages the information available in design cycle is incomplete and ambiguous [98], therefore producing initial information and goals. The synthesis step is aimed at the procedure adopted by the designer to achieve the goals that were established in the analysis activity. The evaluation activity involves the analysis that shows how much the goals are attained and to what satisfaction.

4.3.1 How to Analyze Performance in Design

It was later identified in section 4.1 that there lies a great disagreement between the definition of performance and literature. When the reference is made to performance in design development it can be of following types;

a. *Design Article Performance:* The design article means the design solution and its performance means the performance of the design solution in terms of its inherent properties e.g., the maximum safe temperature of an article which has to survive in a high temperature environment. This area of performance, the values are assigned to the each property of the solution according the customer needs in order to guide the decision making process. Therefore, this measures how well the design solution meets the initial goals.
b. *Design Activity Performance:* This refers to the design solution process performance. The resources such as engineers, software, tools etc. are utilized over time to inculcate cost. The designer and other support is the input for this process and the output is the product. The design cycle may be repeated many times in order to reach the goal. The overall design performance will be evaluated both by considering how well the product performance is and how well the activities required to produce the product were carried out. These areas are referred as product and process

performance and are schematically represented in Fig. 4.4. The figure presents a simplistic view of the relation between article performance and activity performance.

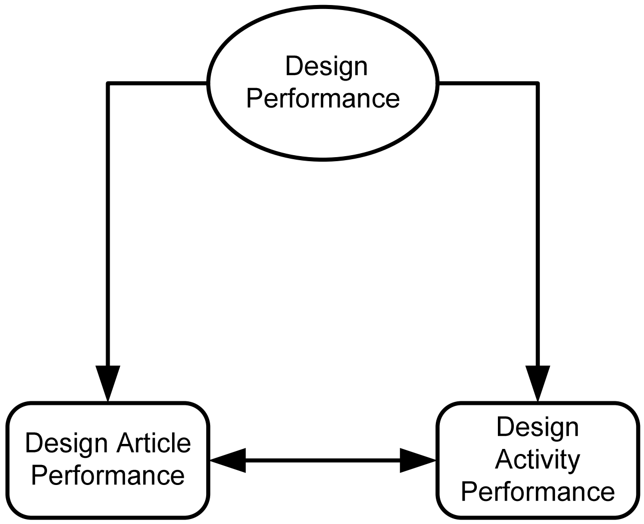


Figure 4.4 Constituents of Design Performance

4.3.2 Properties of Design Performance

Measuring the performance in design development is a complex activity. In other areas e.g., manufacturing, the measuring and analysis of performance is concerned with a measurable output. The number of manufactured products, time consumed, cost incurred and other resources can be measured, hence efficiency and performance can be evaluated. Brookes [102] compares the differences between the performance measurement in design and manufacturing. It is tabulated in Table 4.4.

	Manufacturing Operations	Product Introduction
Similarity between Processes	Very Similar	Dissimilar
Number of times process performed	Many times	Once
Time Lag for measuring output	Weeks	Years
Ability to measure output	Directly measurable	Indirectly measurable

Table 4.4 Comparison of Manufacturing and Product Introduction, after [102]

The performance measurement in design development activity is difficult due to following reasons;

a. *Knowledge Based Activity:* Design is a knowledge base activity. The inputs, outputs and other key elements are knowledge based e.g., the input of a design process may be a need and the output may be a concept. The value of an idea or concept is difficult to measure.
b. *Non-Repeatability:* Every project differs in its nature and requirements, therefore requiring different inputs and outputs e.g., a sugar cane crusher design may not involve complexities as offered by the design of an Airbus. The design cycle may repeat itself but the activities involved may be different each time. Due to the non-repeatable nature, the definition of input, output and goals are difficult and intangible.
c. *Product Life Cycle:* A product may take several years to be mature and marketed. There is a lot of time difference between the design activity and the customer response after the product is used by him. Therefore, one can measure the performance after the product is marketed and used, but it is quite difficult to measure the performance at the deign stage.
d. *Influencing Factors:* The factors which affect the product development performance are not clear as discussed earlier in this chapter.

4.3.3 The Scope of Analysis for Design Performance

Design or product development is a business process and it can be analyzed to asses the performance at many levels. It can range from assessing the performance of the overall product development cycle to the performance of a small design activity in the project. Therefore it is essential to define the range and level of the performance measurement program for the product development process. Range refers to the number of projects involved in the process and level refers to the depth of analysis in each project to a single activity level. It is extremely important to define the scope of the analysis at the initial stage so that the meanings of the performance indicators can be understood within the context of the whole organization. The concept is diagrammatically represented in Fig. 4.5.

According to Hales [103], a resolution of five levels allows the context of a design project to be completely identified. At the organizational level the performance measurement is related to the overall business area, whereas an area manager may only assess the performance of his area. The performance of different projects can be measured and analyzed to obtain a holistic view of the overall business performance. Cooper [104], has found that the performance analysis is generally bases on the success criteria i.e. how well the product has performed to achieve the major concerns of business such as market share and customer satisfaction. The lower level performance is generally related to the measurement of time and cost analysis.

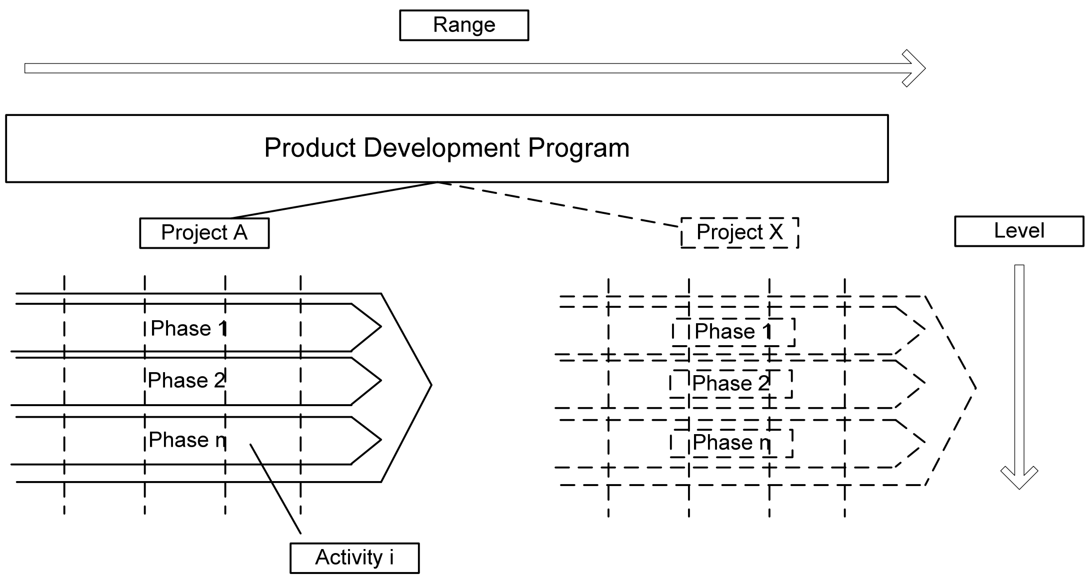


Figure 4.5 Scope of Analysis for Design Performance

4.3.4 Coherence and Goal Alignment

It was discussed in section 4.3.1 that design activity has to be assessed for performance in two areas, namely design article performance and design activity performance. These two distinct activities have their own definition of inputs, outputs and goals. These goals are required to be aligned to maintain the coherence. The concept of coherence was described earlier in 4.1.6. The alignment of goals in this respect is of two types;

a. Alignment within goals
b. Alignment across goals

This concept is illustrated here with the help of Fig. 4.6.

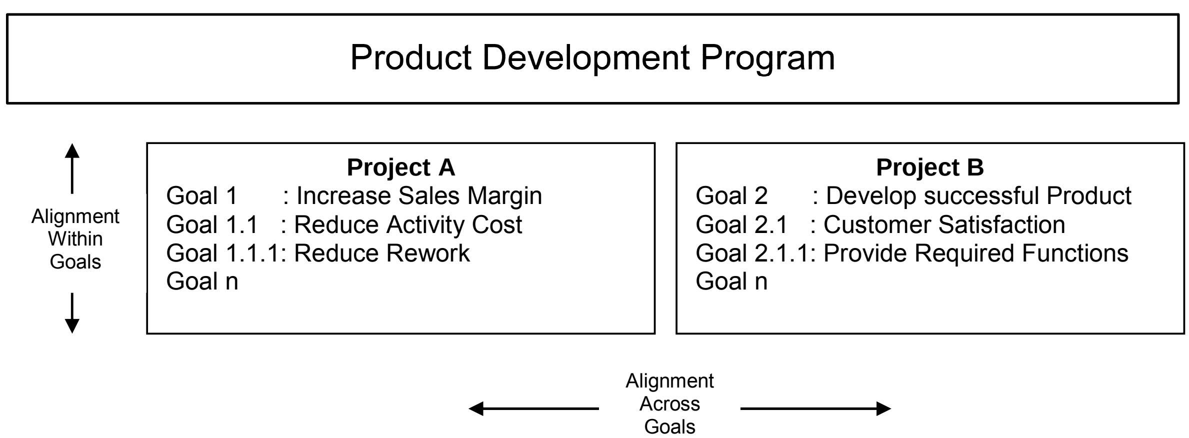


Figure 4.6 Alignment of Goals

The figure illustrates that a company is running two projects within a single product development program. The strategic goal of the company may be to increase the sales margin up to 10% on a specific product. This goal can be achieved through the reduction of activity cost, which can be reduced through reduction in rework. There is a need of alignment within these three goals as they are related in terms of sales, cost and rework. Similarly more specified goals are obtained through structure breakdown. The definition of these goals and their alignment to obtain a single specific goal is extremely important in order to measure performance and to maintain alignment within goals.

Similarly, the other project may have a strategic goal to develop a successful product. This can be obtained through customer satisfaction which in term can be obtained through providing the required functions as specified by the customer. Again the alignment within the goal of this project is also necessary, whereas, the alignment of goals across the Project A and Project B is similarly important.

The alignment of goals is requires to manage conflicting goals so that the performance can be measured correctly. The goal of an enterprise can be to minimize cost. When cost is minimized, the quality and therefore the customer satisfaction level will ultimately decrease which is definitely against the mission of the enterprise. Therefore, there should be compromise in theses goals as to what extent each goal has to be achieved so that the performance parameters may be defined accordingly.

Coherence within and across the goals is an extremely important element of performance measurement. When the goals within a project and in the whole organization are properly aligned and managed, coherence in the performance measurement may be achieved.

4.3.5 Benchmarking Performance

According to [59, 79], benchmarking is defined as “a continuous, systematic process for comparing performances of organizations or functions or processes against the "best in the world", aiming to not only match those performance levels, but to exceed them".

The following are questions relating to the benchmarking exercise:

a. Benchmarking What
   i. Performance bench marking
   ii. Process benchmarking
   iii. Strategic benchmarking

b. Who benchmarks:
   i. Internal benchmarking
   ii. Competitive benchmarking

iii. Generic (or functional) benchmarking

There are certain steps which must be performed, in the correct sequence, in the benchmarking process. These are:

a. Planning
    i. Identify what is to be benchmarked.
    ii. Identify comparative companies.
    iii. Determine data collection method.

b. Analysis
    i. Determine performance gap
    ii. Project future performance level

c. Integration
    i. Communicate findings and gain acceptance
    ii. Establish function goals

d. Action
    i. Develop action plans
    ii. Implement action and monitor progress
    iii. Recalibrate bench marks

e. Maturity
    i. Leadership position attained
    ii. Practices fully integrated into processes

The following approach may be adopted to implement benchmarking procedure in product development process;

a. Determine Product Development goal breakdown structure
b. Define performance goal breakdown structure
c. Identify scope of analysis
d. Develop appropriate metrics
e. Conduct analysis and measurement
f. Identify key areas for further improvement [6, 59].

Chapter 5
METHODS FOR PERFORMANCE MEASUREMENT IN DESIGN DEVELOPMENT

5.1 Introduction

The intangible nature of performance measurement in design development was revealed in the previous chapters. In this chapter, the models of performance measurement in product development and their critique is presented in a condensed form. These state of the art models are selected from the vast amount of literature present on the topic and they are being applied widely in Western countries and being talked about in the literature. This chapter forms the basis for the further work in the thesis and the test model which will be applied to the industry is taken form here. Before going to introduce the models, it seems necessary that a general overview of the research in performance should be given.

5.1.1 Trends in Performance Measurement Research

In literature, the general performance measurement approaches can be found more easily. Design performance is a topic that is not found more often. Some of the work is generic in terms of general business performance measurement and other addresses more specific parts such as product development, manufacturing, logistics etc. The type of research also varies i.e. it may include the approaches to the performance measurement of design development, implementation of the approaches, the development of theoretical models etc.

According to Neely [49], 3615 articles were published in the area of performance measurement during the years 1994 – 1996. This shows the amount of interest in the field of performance measurement. It is also identified that performance in product design is relatively undeveloped as compared to the areas such as manufacturing and maintenance [102]. According to Skinner [112];

> *"A major cause of companies getting into trouble with manufacturing is the tendency for much management to accept simplistic notions in evaluating performance of their manufacturing facilities the general tendency in many companies to evaluate manufacturing primarily on the basis of cost and efficiency. There are many more criteria to judge performance*".

The measurement of performance present certain difficulties and they are identified in previous chapters and are also supported in [102, 105, 106]. This originates from the intangible nature of inputs and outputs data involved in the design activities e.g. knowledge, market influence, design quality etc. Management accounting was the only way to measure business performance till 1970s. Then its decline started as the only way of measuring performance and the interest was inclined towards measuring the more intangible performance measures [77, 83, 107, 108]. According to Johnson & Kaplan [108] traditional accounting methods are unsuited to organizations where the product life cycle is short and research and development assume increased performance.

Globerson [138] presented the rules and guidelines for the design of a general performance measurement system to support the overall strategy of the enterprise. The outlines of the guidelines are as follows;

a. Performance criteria must be chosen from the company's objectives;
b. Performance criteria must make possible the comparison of the organizations that are in the same business;
c. The purpose of each performance criteria must be clear;
d. Data collection and methods of calculating the performance criterion must be clearly defined;
e. Ratio based performance criteria are preferred to absolute numbers;
f. Performance criteria should be under the control of the evaluated organizational unit;
g. Performance criteria should be selected through discussions with the people involved (Customers, Employees, and Managers); and
h. Objective performance criteria are preferable to subjective ones.

Similarly, Maskell [139] defines the seven principles of the design of generalized system based performance measurement approach;

a. The measures should be directly related to the firms manufacturing strategy.
b. Non-financial measures should be adopted;
c. It should be recognized that measures vary between locations – one measure is not suitable for all departments or sites;
d. It should be acknowledged that measures change as circumstances do;
e. The measures should be simple and easy to use;
f. The measures should provide fast feedback; and
g. The measures should be designed so that they stimulate continuous improvement rather than simply monitor.

Most of the performance research was targeted to measure the performance of the organizations in order to identify the generic relationships with the help of historical data. Statistical tools were heavily used to analyze the data for the conclusion.

Clark and Fujimoto [66] compared the product development performance of the auto mobile industry in Europe, Japan and the US. The research was based on the past results of 29 development projects in 20 car manufacturing industries. The points of particular interest were;

a. Lead time;
b. Productivity; and
c. Effectiveness/Quality.

The research was aimed as a specific manufacturing sector and their management approaches. The key areas which provided outcome were;

a. Project strategy;
b. Manufacturing capability;
c. Integrated problem solving; and
d. Organizations and leadership.

The research specified the above mentioned four elements were necessary to achieve high levels of product development performance. However, the authors did not design the four elements into a measurement system and therefore, not described a model or methodology to identify factors influencing the performance. The research was based heavily on the collected data, which, the authors had specified, was rarely available and the research was time consuming and costly (the reference research took approximately 5 years).

Another research selected here was performed by Loch et al. [139] which presented an analysis of the electronics industry. The study involved 95 companies in Europe, Japan and the US. The aim of the authors was to combine firm and project level use of performance and distinguish between performance in the development process, performance of the output of the process and eventual business success. The authors also suggest that process performance influences output performance through the operational management of the development projects. The aim was to develop casual relationships between the development process performance, development output performance and the overall business success while keeping in view that additional areas such as the performance of manufacturing and marketing / sales also influence business success. A schematic representation of the research is presented in Fig. 5.1.

The analysis provides identification of relationships which are statistically significant for the analysis of casual links from product development to business success. However, there were no process variables with significant relationships with the output measures “new product productivity” and “design quality”. It was suggested that these measures will be developed by assessing the qualifications of the designers. It should also be noted that the development productivity is a very important driver of business success.

Griffin [140] analyses the impact of engineering design tools on efficiency and effectiveness using data from the Product Development and Management Association’s (PDMA) 1995 best practices in product development survey. The data was collected from 383 respondents of a detailed questionnaire.

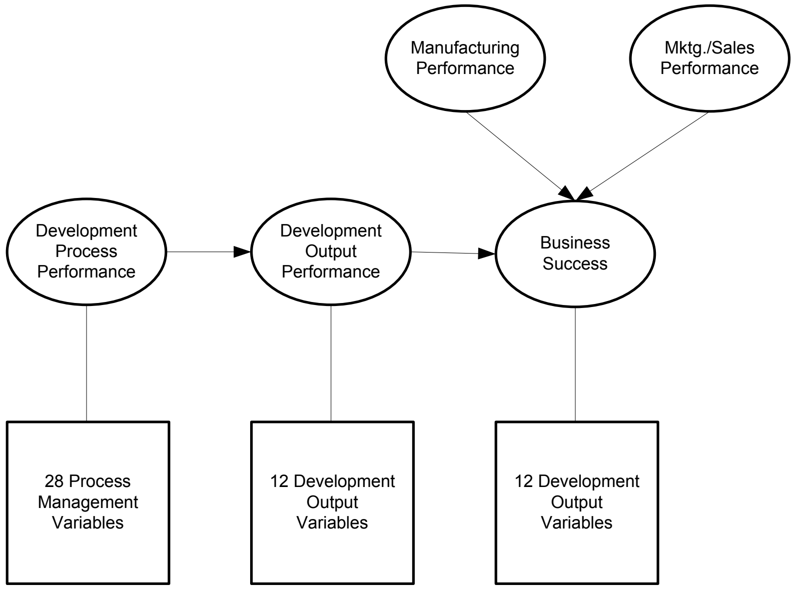


Figure 5.1 Framework of Development Performance, after [139]

This study shows that there is a lack of consistency in this type of research in terms of the elements studied and hence a unified conclusion cannot be drawn from here. Moreover, the validity of certain parameters is also questionable and some bias is also observed in this type of research.

5.1.2 Research Trends in Design Activity Performance Models

Significant literature review on design activity modeling was presented in Chapter 02. This area has gained a large interest during last 30 – 35 years, including the development of prescriptive and descriptive models [109, 110]. Following different kinds of models were developed due to different view points in the design process model research;

a. Prescriptive Models describing activities in design and their logical sequence [29, 36, 111];
b. Models describing cognitive nature of design [98]; and
c. Models relating design within an overall model of product development.

All authors have tried to develop such a model which helps in understanding the design process, so that the performance may be improved. As discussed earlier, design performance relates to design article performance and design activity performance i.e. the activities required to produce that design. Therefore, design and design activity goals are referred in performance measurement and these two areas should be distinguished from each other in the performance measurement system. The goals of the two entities of design performance differ in the following way;

a. Design Goals: Aspects of designed product such as dimensions, behavior in the expected environment, factor of safety etc.

b. *Design Activity Goals:* Aspects of the design activity that how it was performed, cost incurred and time taken.

Andreasen [30, 39] and Hales [103] provide information related to design development in the business context. Andreasen describes the importance of the need for the greater efficiency in product development. The Integrated Product Development Model (IPDM) after [30] supports the integration of procedures, aims, methods, and attitudes to provide a more coherent approach to product development as compared to those that are implemented in the function oriented organizations with schematic procedures.

Smithers' [98] model describes the design process as knowledge based exploration activity. The model proposed does not present a solution to manage the design activity. French [15] has the viewpoint that the evaluation of the design process is necessary at every stage but again does not present the reference to measure the goals related to design product development and design process.

Blessing [110] also identifies the process of evaluation during the design process but management of the activities is out of the scope of the research. Similarly, Hales [103] also identifies the need to address aspects of design and the process in managing the design project but again the coherence between the design article and design activity performance measurement is not clear.

The need for coherence between and within goals is also supported by literature as referenced in [12, 61, 83 – 85, 113 – 115]. Martin [115] follows the work of Dixon [83] as he presents the Performance Measurement Questionnaire (PMQ). De Hass [84] focuses on the behavior of individuals in the organization but does not address coherence. Neely [12] focuses on the product development procedures but the paper doesn't suggest any measurement to include coherence.

From the review of design performance models presented above, it is clear that there is a reasonable consensus on the activities that are performed during that design process. This statement was also justified and supported in the discussion during Chapter 02. The literature has also an agreement on the type of activities and their solution and the evaluation of output. One of the key weaknesses of the performance measurement system used by many firms is that they have a uni-dimensional focus. The frameworks which presents the solution of this problem only provide some areas in which performance measurement might be useful but do not provide any insight to identification, introduction and usage of these measures for the management of business. A key concern is to develop a general understanding of a framework and the easiness of the implementation of the proposed system.

In the next sections, an effort will be made to present, analyze, and review the major performance measurement systems related to design process. The section will also present models which do not directly address the area of performance measurement in product development, but can be redesigned to suit the nature of work in design. The critique of the performance measurement approaches will be taken form the literature and the author's point of view will also be added. It should be kept in mind that the Pakistani industry is generally a manufacturing concern for the foreign designs. The performance measurement system, where exists, measures the performance of the human resource. The companies having the performance measurement system in their business processes have not addressed the importance of differentiating the significance of performance measurement in product development. A sample approach will be taken from this section for implementation in the manufacturing sector.

5.2 Activity Based Costing

Activity-Based Costing (ABC) is a costing model that identifies activities in an organization and assigns the cost of each activity resource to all products and services according to the actual consumption by each. It assigns more indirect costs into direct costs [116]. This approach helps in organizations to establish the true cost of its products, eliminate the unprofitable products, identify the profit winners and manage the cost centers. ABC is a traditional performance measurement system. This approach has been used to support the decisions of in-house manufacturing, vendor out sourcing, identification of major cost centers, their management, measurement of the profit of the product and the business improvement possibilities.

The concepts of ABC were developed in the U.S. during 1970s and 1980s. Cooper, Kaplan and Bruns refined these concepts in Harvard Business review. The traditional cost accounting was used to arbitrarily add a percentage of indirect costs to direct costs for justification of the project spending. As the percentages of indirect cost were increased by a huge amount this approach became invalid.

The methodology steps of ABC can be summarized as follows;

a. Identification of cost centers
b. Cost allocation to product
c. Determination of fixed cost
d. Determination of variable cost
e. Identification of cost drivers
f. Calculation of cost driver rate

The phenomenon of attaching the indirect cost to the products become difficult when there are many products coming out of the same manufacturing system. Products use common resources differently and a mechanism for the weightage of cost allocation process is required so that the performance measurement system can be impartial towards the cost centers and cost drivers. The measure of the use of the said activity by each of the product is known as the cost driver.

In the perspective of performance measurement, ABC can be utilized as a cost based system. The cost of the resources can be calculated and the profit generated can be viewed as the output. This can generate a cost based performance of the system. Similar approach can be applied to the design and product development process such that to identify the resources and to evaluate the out come.

The limitations of ABC are specially encountered in the product development scenario. The cost impact of the resources can be calculated as the resources can be easily identified. The calculation of the earned value of a certain design or a design activity outcome is unclear and no support in this regard is present in the literature.

The ABC system cannot present any approach to justify the performance measures. This has been a great concern of the research to identify the performance measures. Similar approaches in the literature are also found. Some of them are;

a. Through put counting [117 – 120];
b. Shareholder value analysis [121];
c. Brand evaluation[122, 123]; and
d. Research studies exploring the needs of managers [124, 125].

5.3 Performance Measurement Matrix (PMM)

The performance measurement matrix follows the concept of ABC in adopting the financial measures as performance criteria. The overheads are integrated here into the cost elements. The concept of PMM is illustrated through Fig. 5.2. Following types of cost are addressed in the PMM.

a. External Non-cost;
b. External Cost;
c. Internal Non-cost; and
d. Internal Cost.

The Strength of the PMM is in the way that it interprets the different classes of business performance. The model, however does not answer that how the internal or external elements are interlinked. Moreover, the links between the business elements are not coherently adopted in this model. The main criticism on this model is related to the performance measures i.e. the measures are not clearly defined and generated in accordance with the business process and no methodology for identifying these measures is integrated.

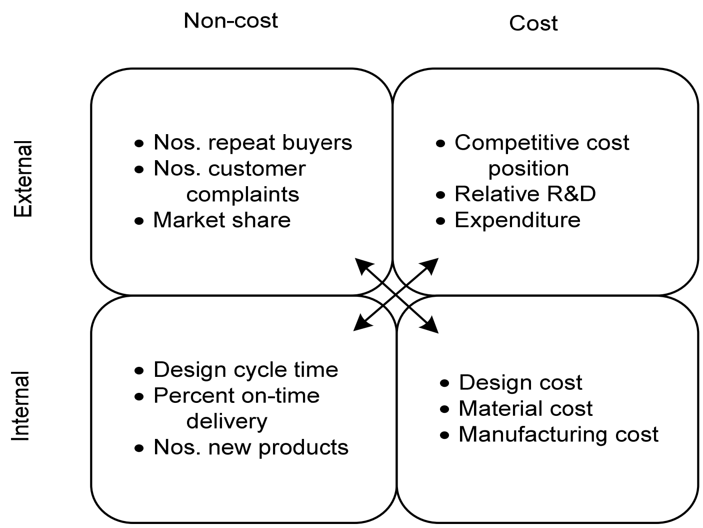


Figure 5.2 The Performance Measurement Matrix, after [126]

With reference to the performance measurement in product development, the model can be adopted to measure the performance in an easy way as it is clearly defined. The internal non-cost measures such as design cycle time, percent on time delivery etc. can be adopted as performance measures in this regard. This model also presents the cost measures such as relative R&D expenditure, design cost, material cost etc. as the model clearly defines the internal and external cost and non-cost measures itself, the author suggest that more performance measures cannot be defined in the PMM. This presents another difficulty while applying the PMM to the product development area. However, one can use the concept and apply the PMM in the performance measurement of product development as deemed necessary. Separate research programs will be required for the separate projects each time and hence a generalized PMM cannot be developed. Moreover the matrices not well packaged and does not make explicit links between the different dimensions of performance and the input and output of the development process.

5.4 Results and Determinants Framework (RDF)

RDF is presented as an alternative for the PMM as a result of the above mentioned criticism. It was developed by Fitzgerald et al. [127] as a result of their study of performance measurement in the service sector. This model suggests that there are two basic types of performance measures in any organization or any process and they are as follows.

a. Measures relating to results
   i. Competitiveness
   ii. Financial Performance

b. Measure relating to Determinants of Result
   i. Quality
   ii. Flexibility
   iii. Resource Utilization
   iv. Innovation

A schematic representation of the RDF is presented in Fig. 5.3. This model is based on the fact that the results achieved in any business process is determined by some factors which are named here as the determinants. The results are lagging performance indicators whereas determinants are leading performance indicators. This concept suggests that the success in any process is determined by the leading indicators giving the result in the form of lagging indicators.

Results (Lagging Indicators)	Financial performance Competitiveness
Determinants (Leading Indicators)	Quality Flexibility Resource Innovation

Figure 5.3 The Results and Determinants Framework, after [127]

The model has defined the determinants of the results in a clear way, hence overcoming the criticism of PMM. The financial performance will again be measured by a method such as ABC, again facing the criticism of the process. Moreover the factors such as competitiveness, flexibility and innovation are knowledge based and proper quantification mechanism of the indicators is not defined in the model. This leaves the measurement and management of the indicators on the user base resulting in vastly different opinions. This model is completely suitable for product development and can be used in any design process. Again, the designer or the process manager must ensure the complete and proper measurement mechanism of the indicators, failing to which will result in miss leading information. The RDF was the first model that targeted on the measurement indicators.

5.5 Models for Time-Based Competition

Some authors and organizations have attempted to be even more prescriptive by proposing very detailed and specific measurement framework as one presented by Fitzgerald. Meanwhile, the organizations are also facing time based competition in the product development area, enforcing the research interest towards the development of measures for time based competition. The measures for time based competition presented by Azzone et al. [128] is a typical example in this regard. These measures focus on the organizations that have chosen a time based competition strategy. The strategy defines three types of time measures in the competitive environment;

a. R&D Engineering Time
b. Operations through-put Time
c. Sales and Marketing Order Processing Lead Time.

The principal concept is elaborated in Table 5.1.

	Internal Configuration	External Configuration
R&D engineering time	Number of changes in projects Delta average time between two subsequent innovations	Development time for new products.
Operations through-put time	Adherence to due dates Incoming quality Distance traveled Value-added time (as a percentage of total time) Schedule attainment	Outgoing quality Manufacturing cost
Sales and marketing order processing lead time	Complexity of procedures Size of batches of information	Cycle time Bid time

Table 5.1 Measures for Time-based Competition, after [128]

The Institute of Chartered Accountants of Scotland (ICAS) [129] has also developed such a framework in which the performance measures are identified in the following perspectives.

a. Business Planning
b. Monitoring Operations.

Similarly, the Du Pont Powder Companies Pyramid of Financial Ratios [130] also addresses the financial and non-financial performance measures. The Du Pont Pyramid of Financial ratios is shown in Fig 5.4. It is accredited that

> *"In 1903, three Du Pont Cousins consolidated their small enterprises with many other small single unit family firms. They then completely re-organized the American Explosive Industry and installed an organizational structure that incorporated the "Best Practice" of the day. The highly rational managers at Du Pont continued to perfect these techniques, so that by 1910 that company was employing nearly all the basic methods that are currently used in managing big business".*

It can be easily seen that ICAS and Du Pont contributed significantly towards defining the financial and non-financial performance measures and indicators.

Especially the Du Pont Pyramid presents a very comprehensive insight towards the financial perspective of the performance measurement. The concept presented by ICAS and Du Pont can successfully be integrated in the RDF for better understanding and precise results. However, the Du Pont approach presents certain difficulties while integrating towards product development as it contains more financial measures and do not address the knowledge base nature of the design process. The model of Azzone et al. is substantially adequate and promising towards the measurement of product development performance when compared to Du Pont Pyramid.

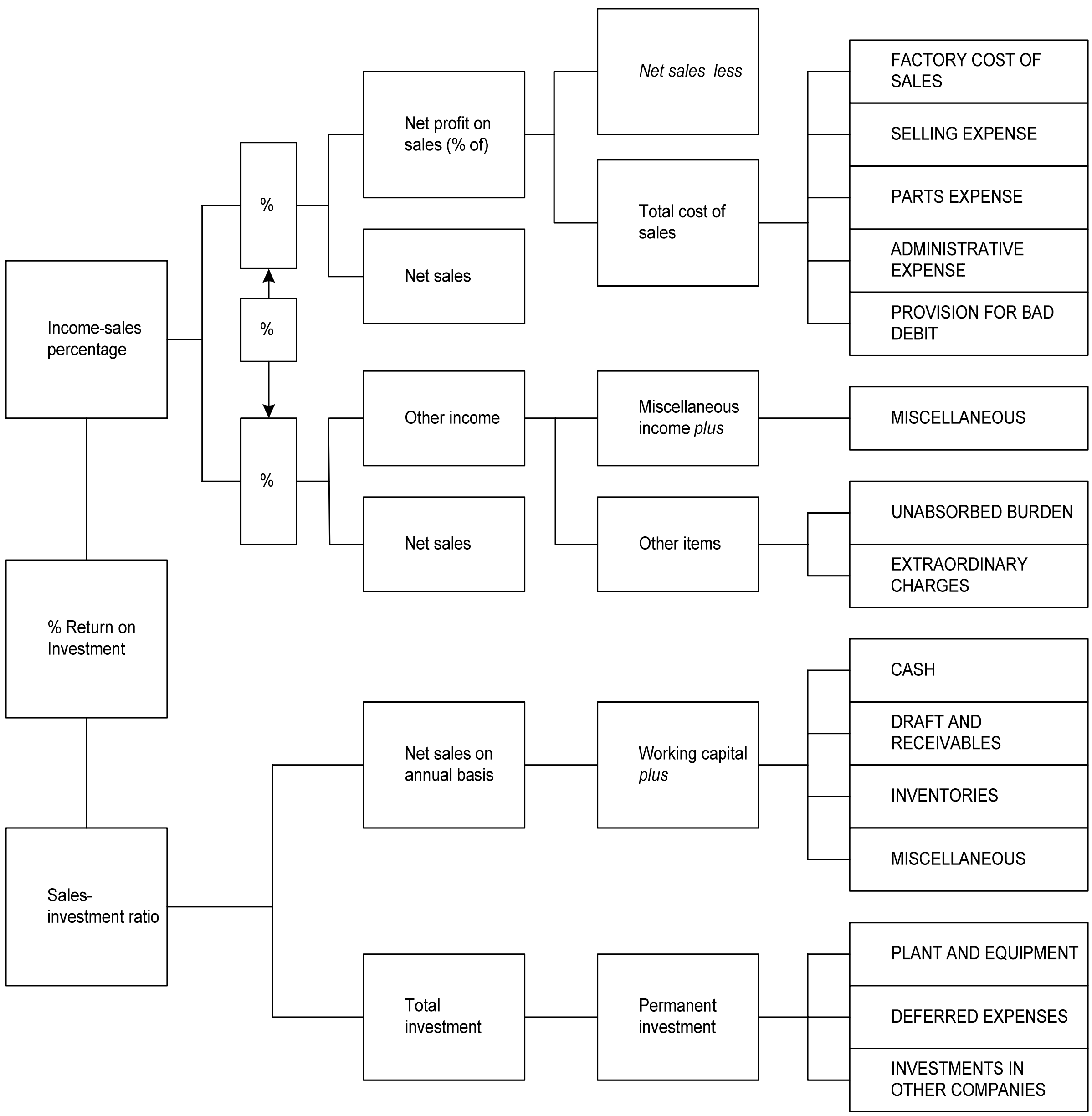


Figure 5.4 Du Pont Pyramid of Financial Ratios, after [130]

5.6 Inputs, Process, Outputs, Outcomes (IPOO) Model

This model was presented by Brown [131] and is schematically shown in Fig 5.5. This is a horizontal type of model which encourages the executives to pay attention to the horizontal flows of materials and information. The model significantly differentiates between input, process, outputs, and outcomes and declares these as four performance measurement parameters. The analogy of backing a cake is used to explain its model. In this regard input measures would be concerned with volume of flour, quality of eggs etc, process measures will be the oven temperature and backing time, the output measures will be concerned with the quality of cake and the outcome measures will be concerned with the satisfaction of the customers.

This is a conceptually appealing and clarifying model which differentiates between the four performances parameters to obtain a predefined goal and consequently defining the further measures included in the four categories. It should be noted that the previous emphasis on the financial aspects of the product is not clearly visible here. The model can be successfully applied to a product development process just by simple modifications. Again, the model does not address the quantification of the knowledge parameters such as “Design of products and services”. The model falls at one extreme of process focused frameworks, completely eliminating the hierarchical aspect.

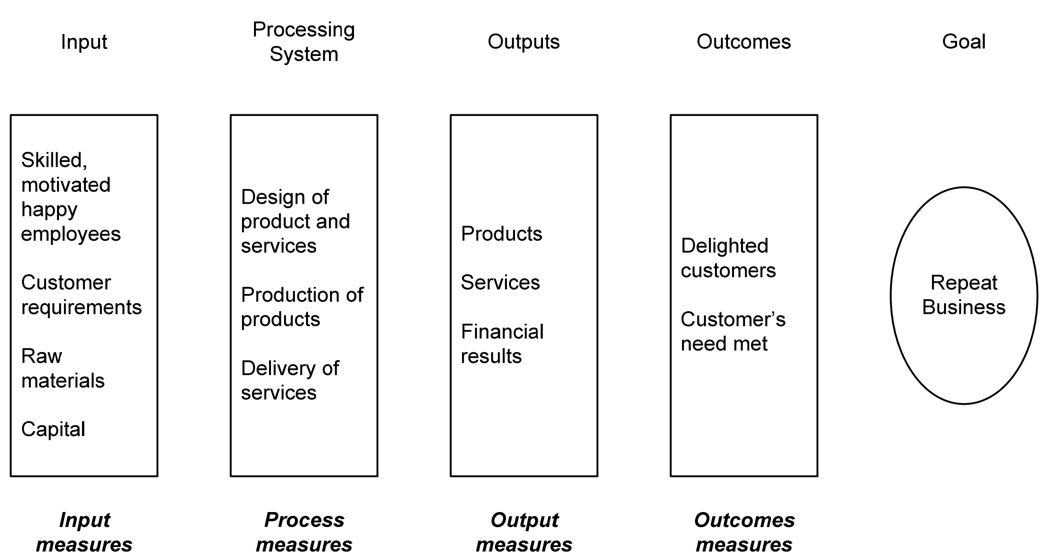


Figure 5.5 Input, Processes, Outputs, Outcomes Model, after [131]

5.7 Performance Pyramid

This is a popular performance measurement model developed by Lynch and Cross [132]. The model is schematically shown in Fig. 5.6. As the name suggests, the model is a pyramid falling in the middle of hierarchical and horizontal performance measurement models. It ties together the hierarchical view of performance measurement with the process view. It also makes explicit the different between measures that are of interest to external customer's satisfaction, quality and delivery, and measures that are primarily of interest within the process, namely, productivity, cycle time and waste.

The model derives the performance measures from the vision of the enterprise, dividing into market and financial measures. The pyramid then grows towards the base to define each of the influencing factors of the performance measurement. The idea can successfully be applied to the performance measurement in design development with emphasis on marketing and financial aspects, thereby controlling the quality, delivery, cycle time and waste. However, the model has overlooked the importance of resource base in the design development process which is a key element in this area and defines the nature of output for a subject product. Moreover, the mechanism of interlink and measurement between the measures is not adequately defined. The model is just a presentation of idea and cannot be applied efficiently to achieve tangible results.

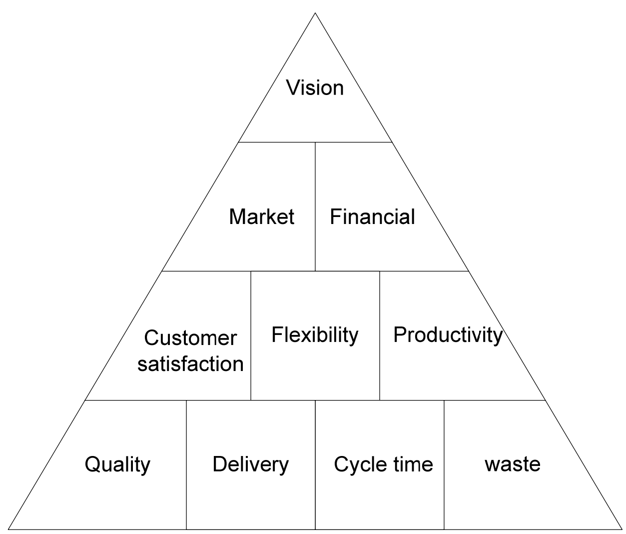


Figure 5.6 Performance Pyramid, after [132]

5.8 Performance Measurement Questionnaire (PMQ) Approach

This approach, presented by Dixon [83], aims at aligning strategy, actions and measures. The questionnaire contains a list of improvement areas. Such as new product introduction and customer satisfaction, and performance factors, such as unit labor costs and meeting project mile stones.

The questionnaire is circulated in the firm and the respondents are asked to rate the importance of an improvement area in relation to the long term existence of the company, as compared to support being provided by current measures. The analysis is then carried out through comparing the perceive importance given to the factors by the company as compared to the importance currently being given for the same measurement factor. The outcomes of the data analysis are as follows;

a. *Alignment;* it is analyzed by comparing the importance of improvement areas and emphasis on particular measures with the strategy of the company.
b. *Congruence;* it is analyzed by comparing the importance of improvement areas to the support of measures and comparing the importance of performance factors to the emphasis on measuring it.
c. *Consensus;* it is measured by comparing results across different functions and level in the organization.
d. *Confusion;* it is analyzed by the detailed analysis of consensus within a particular book

The author suggests that the degree of alignment between the improvement areas and the strategy is not clear from the answers of the questionnaire and the alignment is carried out in a subjective manner. The approach does not allow the improvement measures to be rated in terms of how well they support the strategy or any particular area for that matter. Moreover, the analysis of congruence, consensus and confusion is of limited value if the improvement measures do not support the strategy.

5.9 The Business Excellence Model

This is another wide range popular measurement framework presented by European Foundation for Quality (EFQ) and outlined in Fig. 5.7. The model consists of two distinct sub sets of performance factors.

a. Enablers; and
b. Results.

The underlining principle of the model is that the enablers are the levers that the management can pull to deliver future results. The model is also used for the assessment of organizations for the European Quality Award. It is now the most widely used organizational framework in Europe and it has become the basis for the majority of national and regional quality awards. The model is a practical tool that can be used in a number of different ways.

a. As a tool for Self-Assessment;
b. As a way to Benchmark with other organizations;
c. As a guide to identify areas for improvement;
d. As the basis for a common Vocabulary and a way of thinking; and
e. As a structure for the organization's management system.

The governing body states that;

> "*Excellent* results *with respect to Performance, Customers, People and Society are achieved through Leadership driving Policy and Strategy, which is delivered through people, Partnerships and Resources and Processes".*

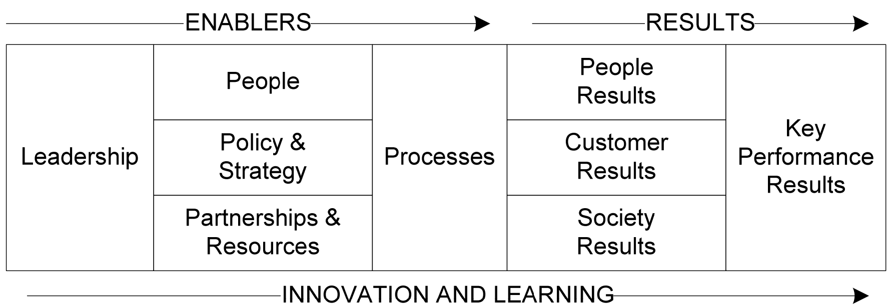


Figure 5.7 The Business Excellence Model

To obtain the award, the organization has to provide proper evidence that the processes;

a. Which are key to the success of the business are identified?
b. Are systematically managed?
c. Are reviewed and targets are set for improvement?
d. Are improved using innovation and creativity?
e. Are changed and the benefits evaluated?

The terms used in the model are so wide that they can be interpreted in many ways and hence one has to decide the performance measures himself for a certain process. This presents a major difficulty in the implementation of the model.

Keegan et al. [134] suggests that the process of deciding what to measure consists of following three steps;

a. Looking into the strategy;
b. Deriving an appropriate set of measures; and
c. Operationalization of the process.

The first and third steps are difficult in practice and self explanatory. For the second step it is suggested that the best approach is to start with five generic measures namely;

a. Quality;
b. Customer Satisfaction;
c. Speed;
d. Product / Service Cost Reduction; and
e. Cash Flow from Operation.

It is then suggested that the rest of the measures should be derived ensuring that they are;

a. Integrated, both hierarchically and across the business functions; and
b. Based on a thorough understanding of the organizations cost drivers.

However, the implementation process is not suggested in the approach. Wisner and Fawcett [135] proposed a nine step process for the same purpose that assumes that measures should be derived from strategy and suggests that the measurement system should be periodically refreshed. The nine steps are schematically shown in Fig. 5.8.

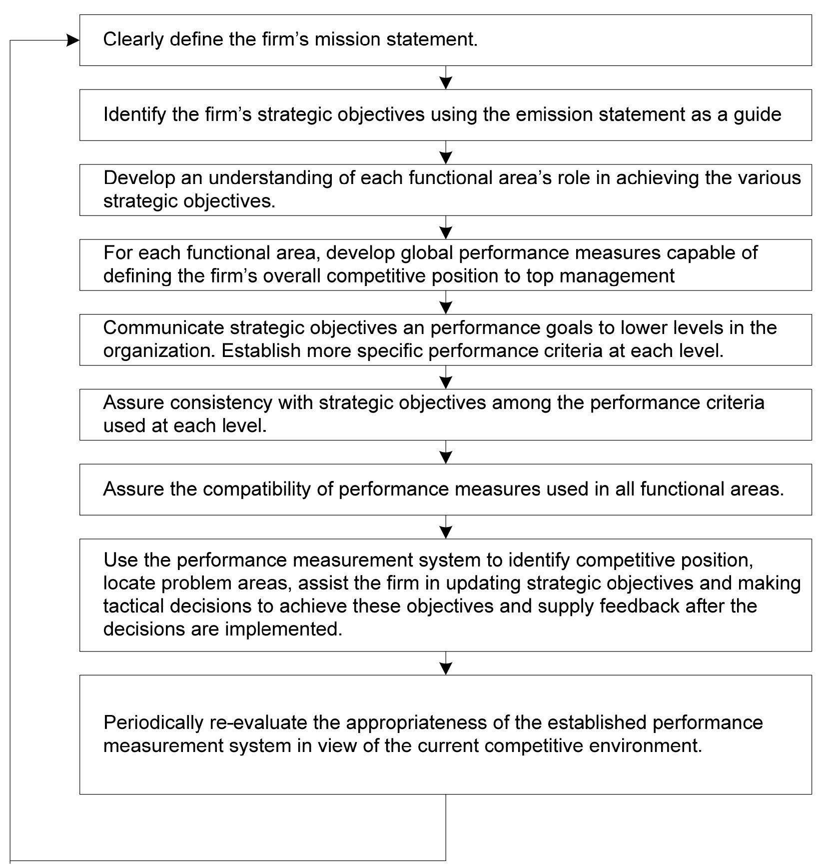


Figure 5.8 Defining the Performance Measures, after [135]

5.10 The Balanced Scorecard (BSC) Approach

The balance scorecard [76] is becoming one of the most widely used performance measurement and management model in the industry. The BSC aims at achieving strategic alignment as the authors state that;

> *"Translates vision into a clear set of objectives which are then further translated into system of performance measurement that effectively communicate a powerful and forward looking strategic focus to the entire organization".*

The approach is defined in Table 5.2

1.	**Preparation:** Identify the business unit for which a top-level balanced scorecard is appropriate.
2.	**Interviews – first round:** Process facilitator interviews all the firm's senior managers and asks them to identify the company's strategic objectives and possible performance measures for the scorecard.
3.	**Executive workshop- first round:** Senior management group debate the proposed mission and strategy statements until they reach a consensus. The process facilitator then asks the senior managers to answer the following questions: "If I succeed with my vision and strategy, how will my performance differ for shareholders; for customers; for internal business processes; for my ability to innovate, grow and improve?" A draft balanced scorecard is developed on the back of this.
4.	**Interviews – second round:** Process facilitator summarizes the output from the first executive workshop and discusses it with each senior manager. The facilitator also seeks opinions about issues involved in implementation.
5.	**Executive workshop – second round:** Larger workshop at which the senior manages and their direct reports debate the mission and strategy statements. "the participants, working in groups, comment on the proposed measures, link the various change programs under way to the measures, and start to develop an implementation plan". Stretch targets are also formulated for each measure.

6.	**Executive workshop – third round** "The senior executive team meets to come to a final consensus on the vision, objectives, and measurements developed in the first two workshops; to develop stretch targets for each measure on the scorecard; and to identify preliminary action programs to achieve the targets. The team must agree on an implementation program, including communication of the scorecard to employees, integrating the scorecard into a management philosophy, and developing an information system to support the scorecard".
7.	**Implementation:** New implementation team formulates detailed implementation plan. This covers issues such as: how the measures can be linked to database and information systems; how the scorecard can be communicated throughout the organization; and how a second level set of metrics will be developed.
8.	**Periodic reviews:** Each quarter or month, a book of information on the balanced scorecard measures is prepared for both top management review and discussion with managers of decentralized divisions and departments. The balanced scorecard metrics are revisited annually as part of the strategic planning, goal setting, and resource allocation processes.

Table 5.2 Designing a Balanced Scorecard, after [76]

The four uses of the scorecard are as follows;

a. The Financial Perspective;
b. The Customer Perspective;
c. The Internal Business Perspective; and
d. The learning and Growth Perspective.

The proposal of the scorecard was a result of the wide criticism of using purely financial or operational measures [80, 107, 137]. The authors outlined measures illustrating balance between;

a. Analyzing the Achievement of Short and Long Term Objectives;
b. Financial and Non-financial Measures;
c. Lagging and Leading Indicators; and
d. External and Internal Performance Perspectives.

The process identifies the means to link measures to strategy and proposes following mechanisms to achieve the strategic alignment.

a. *Cause and Effect Relationship;* Represented as a set of hypotheses.
b. *Performance Drivers;* A combination of Lagging measures and Leading measures (outcomes and drivers). The lagging measures will evaluate the result of performing in relation to the leading measures.
c. *Linkage to Financials;* Casual path from all measures on a scorecard are linked to financial objectives, again promoting a cause and effect culture.

Although the BSC is a comprehensive performance measurement and management tool following criticism in the literature is observed for the same.

a. The three interlinking measures defined above are dependant on the ability of performing a cause and effect analysis and provides no structural approach to define the analysis.
b. It does not quantify the relationship and the fact that a number of causes may have same effect on the performance and hence does not support the prioritization of the causes so that the outcome can be significantly addressed.
c. The suggestion that casual path for all the measures on a scorecard should be linked to financial objectives is difficult in the business environment where intangible assets continue to increase. If financial goals are supreme, the innovation and creativity and hence the customer satisfaction may suffer.

Kaplan and Norton found that companies are using Balance Scorecard to:

a. Drive Strategy Execution;
b. Clarify Strategy and make Strategy Operational;
c. Identify and Align Strategic Initiatives;
d. Link Budget with Strategy;
e. Align the Organization with Strategy;
f. Conduct Periodic Strategic Performance reviews to Learn and Improve Strategy.

The BSC approach can be used to ensure balance in the selection and use of performance measurement in the overall business. However, the scorecard does not have a mechanism to ensure coherence within the performance measurement, which is the basic requirement of the design development process as outlined in the previous chapters. The support and research provided by other authors provide some insight to the requirement of coherence and the mechanism for the integration of this requirement in to the scorecard. As this approach is a question and process based approach, user may get different results on the basis of the answers of the questions.

5.11 The PERFORM Approach

This methodology was developed by O'Donnell F.J. [13]. The approach will be summarized in this section and the details of the approach will be presented in the upcoming sections where the methodology is applied.

This methodology was developed from the understanding of the design performance phenomenon. Formalism for design development performance provides the basis for modeling performance in any situation and deriving measures for its evaluation. After the development of initial model, PERFORM approach provides a means to identify areas for performance improvement. The methodology is cyclic in nature and is presented in Fig. 5.9. The key elements of the methodology are as follows;

a. *Design Development Performance Formalism:* This formalism provides an approach a modeling performance in design development so that the measurement and management of the performance can be easily done. A fundamental nature of the performance design development is kept in view while developing the formalism.
b. *Resource Impact Model:* Two areas of influence, namely, effectiveness and the impact of resources are selected for analysis. The nature of there influence is analyzed the resource impact model explores the nature and impact of the resources on the design development process. Furthermore, elements such as Potential / Actual Exploitation and Ease of Exploitation are also developed as a part of the framework.
c. *Analysis Approach (PERFORM):* The analysis approach combines the two elements as defined above and uses a matrix to allow the limitation of relationships between resources and goals. The result of the analysis allows the identification of resources that may be exploited further to achieve greatest performance improvement.

The overall methodology provides a satisfactory means to develop a performance measurement and improvement tool for the design development process in an organization. In the coming sections, a summary of each of the above elements is provided for the initial understanding of the model, while more insight to the model can be observed in the appendices as indicated above.

5.11.1 A Formalism for Design Development Performance

An understanding of the design development process in this formalism is developed. The fundamental understanding of the design development process encapsulates following elements;

a. *Design Activity Management (DAM) Model*: The knowledge based capability of the design and its intangible nature is modeled here and the design management activities are distinguished.
b. *Design Performance (E^2) Model*: Efficiency and effectiveness are identified as the core elements of the design development process and its performance.

The concept of efficiency and effectiveness is clearly defined keeping in view the knowledge based and intangible nature of design.

c. *Performance Measurement and Management (PMM) Model*: This model integrates the two concepts described above. The E^2 model is related to the DAM model in order to describe the process of measuring and managing performance as part of design and design management activities.

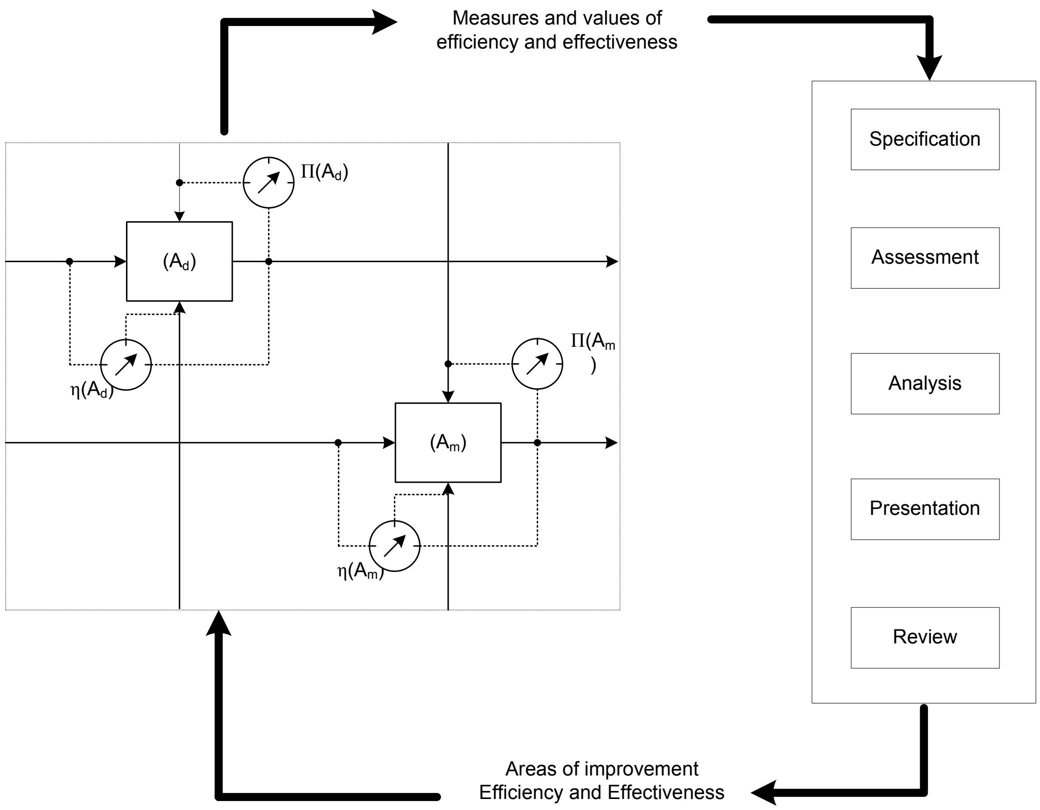


Figure 5.9 A Methodology for Design Performance Modeling and Analysis

The process of design is considered as a knowledge transformation act to change input to an output under the direction of certain constraints and goals using specifically defined resources. This concept is illustrated in Fig. 5.10

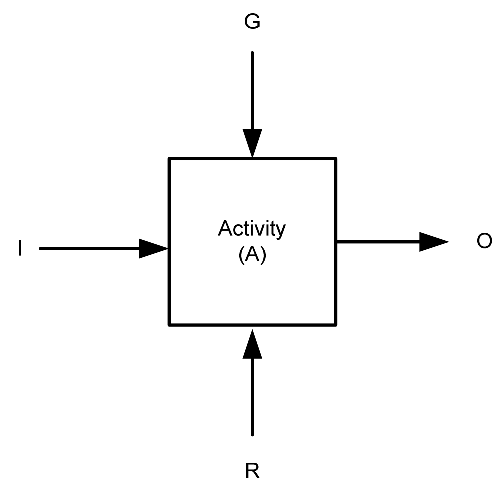


Figure 5.10 Design: Knowledge Processing Activity

Where;

I	=	Knowledge input:	Knowledge present prior to the activity
O	=	Knowledge output:	Knowledge present as a result of activity technique place
G	=	Knowledge goals:	Knowledge that directs and constraints the activity
R	=	Resources:	Knowledge that acts on the input to produce the output.

The DAM model distinguishes the pure design activities and the activities that are followed to manage the design process. The overall model therefore, distinguishes between the design activity and the design management activity. This concept is shown in Fig. 5.11

The design performance is defined in the E^2 model as efficiency and effectiveness where efficiency relates input, output and resources knowledge within the activity and effectiveness describes the relationship between the actual and intended output knowledge i.e. output of the goal. The E^2 model is shown in Fig. 5.12.

The definition of efficiency and effectiveness provides a basis for the determination of appropriate matrices in order to measure and evaluate the design performance. The PMM model is developed with the mutual understanding of the E^2 model and the DAM model. This model describes the use of efficiency and effectiveness to support decision making and control (represented as dashed lines) of design and design management activities under changing conditions. This concept is shown in Fig. 5.13

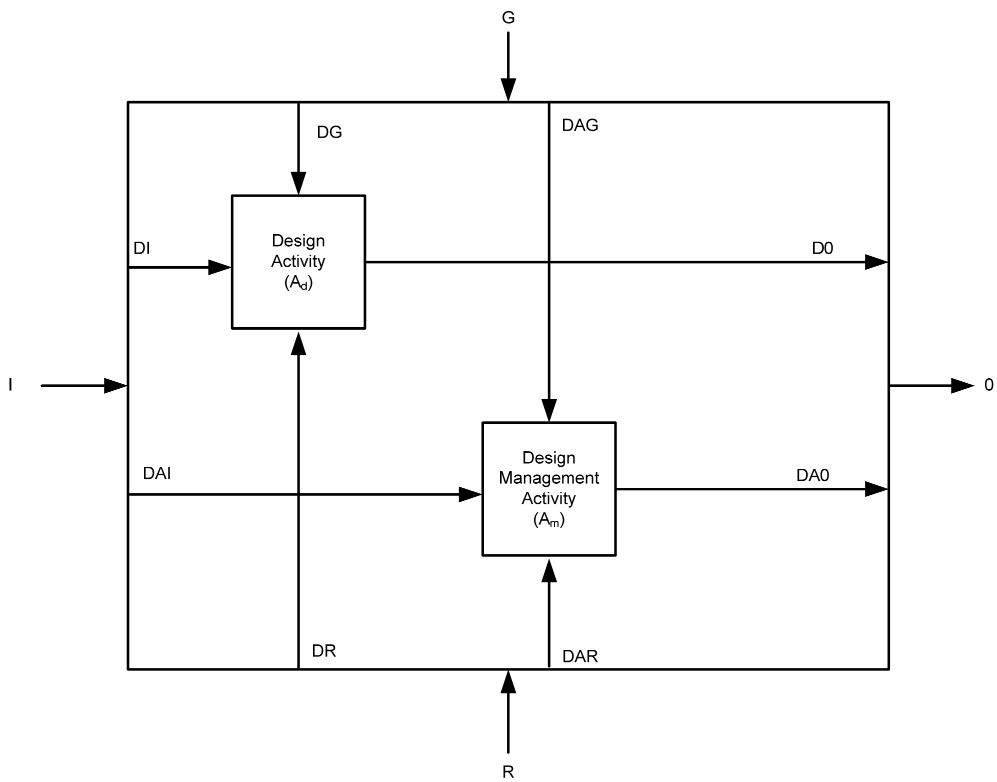


Figure 5.11 Design Activity Management (D

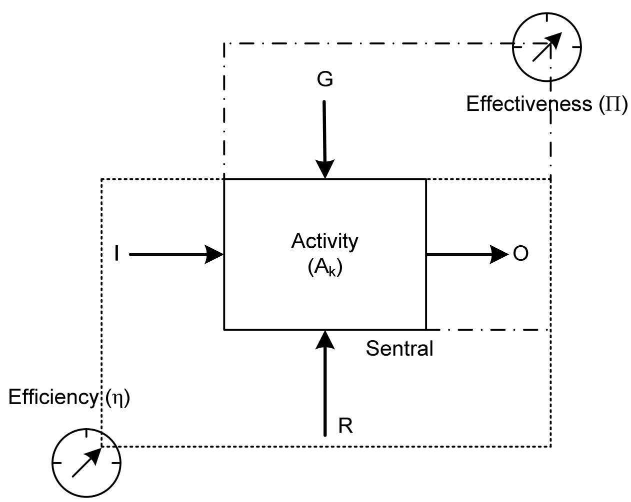


Figure 5.12 The E2 Model

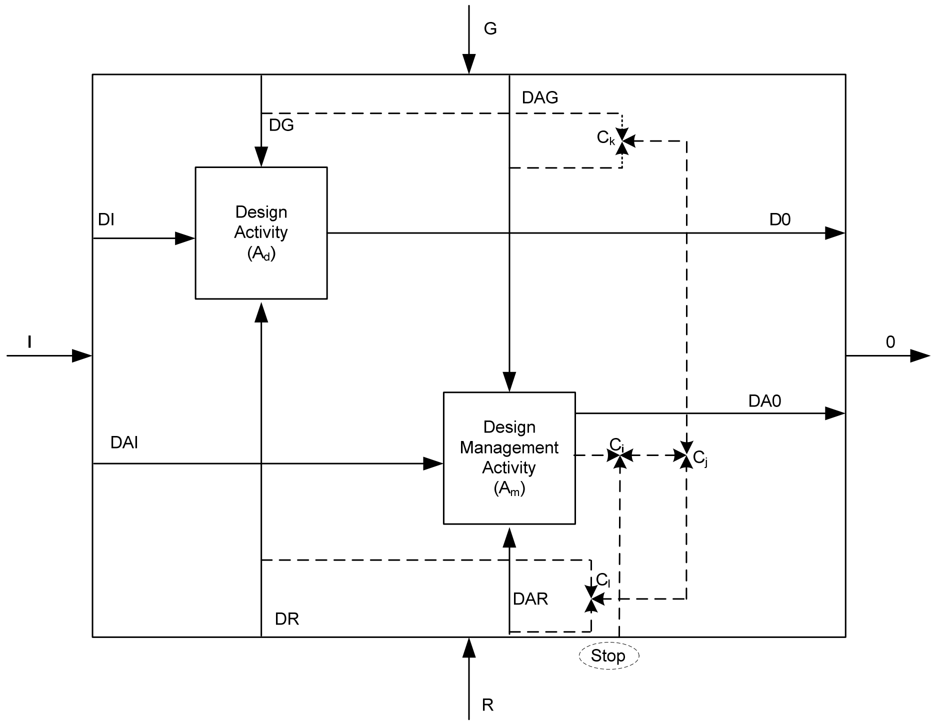


Figure 5.13 Performance Measurement and Management (PMM) Model

The overall concept is presented here through three models describing the nature of performance in design development and formulating the concepts to the respective models. The models are then used to identify the areas in which analysis is required to be carried out. The basic concept is emerging from the knowledge based design process activity as shown in Fig. 5.10.

5.11.2 Performance Analysis

It has been made clear in the above discussion that the performance of the design development can be analyze in a better way if concentration is given to the analysis of effectiveness and efficiency. There are number of factors influencing effectiveness such as; Strategy and goals, but the resources used to carry out design and design management activities are considered to have direct impact on the effectiveness. The key area of the performance analysis is identified as the relationship between resources and the level of effectiveness achieved.

The impact of resource is defined as the capability of the resource to act upon the input in a manner that achieves the desired output. Different resources may be exploited in a different way and will produce different quality and quantity of outputs producing different levels of effectiveness. The relationship between the exploitation of a resource and the effectiveness achieved is addressed in the Resource Impact Model as impact profile. The relationship is assumed as linear for simplification whereas it may be a complex function in certain situations. The concept is shown in Fig. 5.14

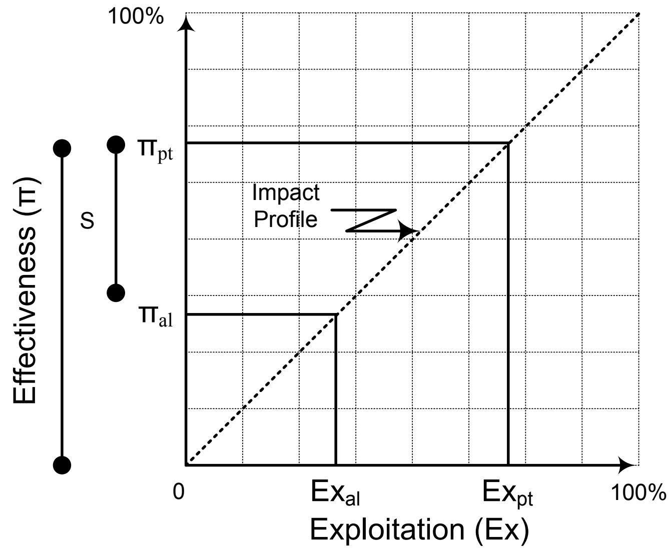


Figure 5.14 The Resource Impact Model

The model provides the concept to analyze the impact of different resources on the effectiveness of a certain design activity. The concept is to identify the actual and potential exploitation of a certain resource and its impact profile in relation to a certain goal. When the impact of the certain resource is identified on the effectiveness, the effectiveness and hence the performance can be improved by exploiting the resource in a more managed way. The relative estimation of impact allows the comparison of scope for improvement across the number of goals. The resource effectiveness may also be defined which indicates the weighted impact. This approach can be applied to the analysis of resource impact in an environment where multiple goals with different priorities are pursued.

5.11.3 Analysis Approach

The elements of the resource impact model define the implementation of the PERFORM approach. It assumes that the impact of resource on a goal may be estimated using the judgment of individuals with appropriate knowledge. The approach provides a structured concept for capturing the knowledge of the subject individuals. The approach also incorporates the quality function deployment, which is a widely used industrial tool. The approach takes the initiative to collect the information from the individuals which are involved in design management in the role of the analysis team. The analysis team defines the elements within the PERFROM matrix. The matrix defines resources in rows and goals in columns. The intersection of a row and a column provides the cell where the impact of a resource on a goal may be defined. The completed matrix will be of the shape as shown in Fig. 5.15.

				G_j	….	G_m	
				W_j	….	W_m	
R_i	E_i	$Ex_{i(al)}$	$Ex_{i(pt)}$	Im_{ij}	….	Im_{im}	
….	….	….	….	….	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	Im_{nj}	….	Im_{nm}	

Figure 5.15 The PERFORM Matrix

The matrix concentrates on the following aspects within an activity;

a. Resources (R_i upto R_n)
b. Goals (G_j upto G_n)
c. Goal Priorities (W_j upto W_m)
d. Actual and Potential Exploitation of the Resources ($Ex_{i(al)}$ and $Ex_{i(pt)}$)
e. Ease of Exploitation of Resources (E_i)
f. Impact Relationships between Resources and Goals (Im_{ij})

Dedicated software is suggested to analyze the data resulting from the matrix which allows the representation of impact of a number of resources on a specific goal or vice versa. The result of analysis supports the management and decision making process with respect to the improvement in performance. The resources which have a high impact on a number of goals may be identified and their current exploitation may be seen clearly from the analysis. The effect of further exploitation of a certain resource may also be simulated. This is only a supporting decision making process which is in no way the supplement to the management decisions.

5.12 Conclusion and Further Course of Action

An attempt was made in the above sections to critically analyze the literature for the presence of performance measurement models in the area of design and product development. The author was only able to find traces of performance research with little direct relevance to the performance measurement model in the area of design development. This idea is supported continuously throughout previous chapters and especially in Section 5.1.

Certain parameters for the design of performance measurement system are identified clearly in the literature but authors differ in their opinion and it is very difficult to assess a decisive approach. There is an overwhelming need identified in the literature to address the non-financial measures in order to assess the performance measurement for knowledge based activities as compared to the classical performance measurement tools which were more altered towards management accounting. Certain authors have devised knowledge based models in order to assess the performance of design activity performance.

The balance scorecard approach is a well structured organization to assess the performance in the respective area but, as identified previously, the approach lacks the mechanism to integrate the concept of coherence and alignment across the goals which is a basic need for the performance measurement system in the product development area.

The formalism presented in Section 5.11 is considered as the most appropriate methodology to assess the performance measurement in the design development activity. The authors have clearly defined each and every aspect of the process and the formalism is being practiced in many UK and USA manufacturing industries. The same formalism will now be applied to a manufacturing sector of Pakistan to assess the performance of its design activities and identify the room for improvement.

Chapter 6
DESIGN PERFORMANCE EVALUATION USING PERFORM

6.1 Introduction

The PERFORM approach consists of three conceptual modeling frameworks which form the theoretical basis of the approach. The models are conceptual backgrounds on which the approach is build. The frameworks constituting the approach are

a. The DAM Model
b. The E^2 Model
c. The PMM Model

The DAM Model formalizes the design activity and the design management activity into a single horizon, yet distinguishing between them with reference to inputs, outputs, goals and resources. The resources act on inputs with reference to goals and produce output.

The E^2 Model presents the concept of performance measurement in a knowledge based environment by defining the performance as sum of efficiency and effectiveness. The efficiency is the amount of knowledge gained with the use of specified resources; i.e. the input problem is converted to output solution using resources and the ratio of knowledge gained to resources used is defined as efficiency. The effectiveness is the degree to which the output knowledge result meets the requirements of the predefined goals and constraints. Thus efficiency involves input, output and resources while effectiveness involves goals and outputs. The model completely describes the mechanism of performance evaluation in a knowledge based environment.

The PMM Model provides mechanism to measure and manage performance in design process. The values of effectiveness are used to support and manage the local control of the activities in the model. The model also supports coherence and the measurement of efficiency

.

After providing theoretical background, the approach defines the means through which the performance can be controlled through resources. The Resources Input Model (RI) describes the mechanism through which a resource may be exploited up to its potential level to gain effectiveness. The impact of a resource is defined as the capability of the resource to act upon the input in a manner that achieves the desired output. Different resources may be exploited to achieve different levels of effectiveness.

The PERFORM matrix is formed after the specification and prioritization of goals and resources. The matrix has weighted goals in columns and resources with case of exploitation, actual exploitation and potential exploitation in rows. The certain impact of resources utilization (with specific amount of utilization) can be represented in the matrix at the intersection of reference weighted goal and resources. This matrix requires experienced individuals for completion as the weights of the goals, impacts and exploitation levels can only be assessed and till now there is no certain method or research writing present in the literature regarding this problem. Moreover, dedicated software support in the case of large projects is strongly recommended as the matrix elements grow enormously as the resources and goals grow.

The analysis technique for the PERFORM matrix is described in the next section. More theoretical background on the approach can be found as referenced and certain important concepts can also be found in the appendices. The analysis technique has been adopted from approach with certain modifications.

6.2 Analysis Technique

The analysis of the matrix is carried out after it is completely filled with weighted goals and resources with exploitation levels. At the intersection of reference goals and resources the impact is represented as shown in Fig. 6.1.

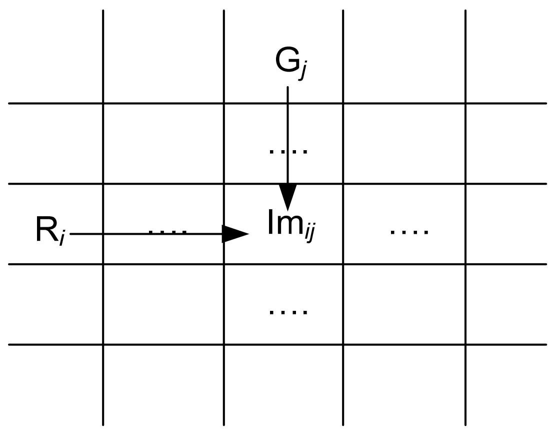


Figure 6.1 Data Representation in Matrix

The impact of the resources is represented here as High (H), Medium (M) and Low (L) with reference to certain resources. The impact profiles can be estimated based on knowledge of inherent resource attributes. The concept is based on Quality Function Deployment (QFD) [142, 143, 144] to establish the relationships between customer needs and characteristics of the design concept. The typical impact profiles for H, M and L as described are shown in Fig. 6.2.

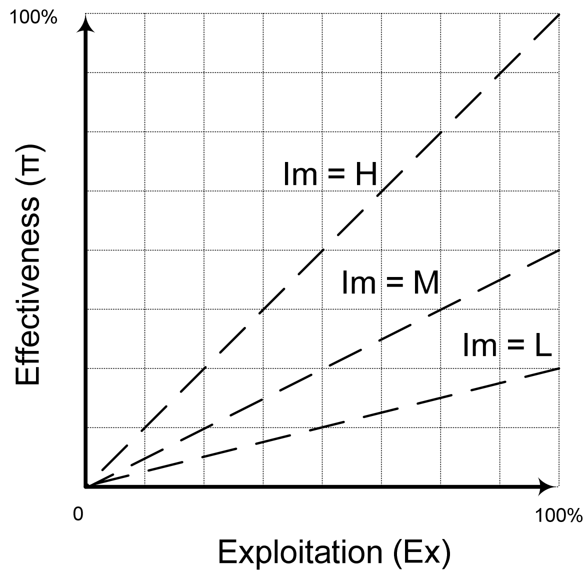


Figure 6.2 Representation of Impact in the Resource Impact Model

6.2.1 Formation of Matrix

Prior to defining the PERFORM matrix, the relationship existing between goals and resources can be represented in a simple matrix for the sake and simplicity. The matrix consists of resources in rows and goals in columns. A sample matrix is shown in Fig. 6.3.

The impact of the resources on the goals is represented as H, M & L in the reference columns. It can be seen that R2 is contributing towards all goals while G2 is using every resource. The resources which do not have any impact on a certain goal can be left blank. The matrix presented in Fig. 6.3 can be analyzed by multiple criteria decision making [145]. Various goals may be described as criteria having weights, while the multiple resources are alternate means of achieving goals. Approaches such as rank-sum rule [28] & the datum method [146] are present to support such decision making. The PERFROM approach uses QFD as a tool for this purpose.

	G_1	G_2	G_3	G_4	G_5	
R_1		M				
R_2	M	L	H	L	M	
R_3		H	M	H		
R_4		M	L			

Figure 6.3 Relations between Resources and Goals

6.2.2 Finalization of Matrix

Quantitative values are assigned to the qualitative values for the purpose of analysis and calculation. The values are represented in Table 6.1. The values described here are practiced by QFD specialists [142, 143, 144].

Data Element	**Notation**	**Numerical Value**	**Description**
Ease (E)	L / M / H	1 / 3 / 5	Ease of exploitation of resource
Exploitation (Ex)	%	0 – 100	Exploitation of resource
Impact (Im)	L / M / H	1 / 3 / 9	Impact of resource on goal
Priority (W)	L / M / H	1 / 3 / 5	Priority of goal

Table 6.1 Representation of Data in Matrix

The data elements are now represented in the PERFORM matrix as shown in Fig 6.4 to support the analysis. The matrix contains goals, weightings and exploitation levels for resources**.** In Fig. 6.4,

R_i = Resource *i*, *i* = 1 …… n;
G_j = Goal *j*, *j* = 1 …… m;
W_j = Priority of goal *j*;
Im_{ij} = Impact of resource *i* on goal *j*;
E_i = Ease of further exploitation of resource *i*;
$Ex_{i(al)}$ = The actual exploitation of resource *i*; and
$Ex_{i(pt)}$ = The potential exploitation of resource *i*.

				G_j	….	G_m	
				W_j	….	W_m	
R_i	E_i	$Ex_{i(al)}$	$Ex_{i(pt)}$	Im_{ij}	….	Im_{im}	
….	….	….	….	….	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	Im_{nj}	….	Im_{nm}	

Figure 6.4 The PERFORM Matrix

6.3 Analysis Parameters

Various analysis measures can be defined within the PERFORM matrix. The measures which are selected here are as follows.

6.3.1 Resources Effectiveness Measures (REM)

REM is a single measure defined here to provide the basis for the definition and analysis of other measures. The measure incorporates the impact (Im_{ij}) of a resource (R_i) on a goal (G_j) with priority (W_j). The measure is defined as follows in Fig. 6.5.

This can be defined mathematically as

$$\pi_{Ri} G_j = W_j \,\mathrm{Im}_{ij}$$

Equation 6-1

This measure has following usefulness.

a. Comparison *1:* A comparison of the resource effectiveness for a specific resource (R_i) against different goals can be done. (G_j … G_m) e.g. for the effectiveness of resource R_l on G_k with weight W_k,

$$\pi_{Rl} G_k = W_k \,\mathrm{Im}_{lk}$$

				G_j	….	G_m	
				$\mathbf{W_j}$	….	W_m	
R_j	E_i	$Ex_{i(al)}$	$Ex_{i(pt)}$	$\mathbf{Im_{ij}}$	….	Im_{im}	
….	….	….	….	….	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	Im_{nj}	….	Im_{nm}	

Figure 6.5 Measure 1: Resource Effectiveness Measure (REM)

b. Comparison 2: A comparison of the effectiveness of different resources (R_i . . . R_n) in relation to the same goal. e.g. for a same goal G_k,

$$\pi_{Rx} G_k = W_k \,\mathrm{Im}_{xk}$$

And,

$$\pi_{Ry} G_k = W_k \,\mathrm{Im}_{yk}$$

c. *Finding 1*: The goals that are not impacted by a resource and those most impacted can be identified by assuming equal weightage for all goals. This concept was elaborated in Fig. 6.3.

6.3.2 Analysis Measures

These measures provide an analysis of resource effectiveness (individual and groups) based on the assumption that all resources are exploited equally. The goals defined here are the sub-goals of a higher level goal (G_o). Following three measures are used for this analysis.

a. *Measure 2*: The resource effectiveness in relation to the higher level goal (G_o) can be calculated by summation of the individual values obtained using Measure 1 for a particular resource across a specific row of a matrix as shown in Fig. 6.6. Mathematically;

$$\pi_{Ri}(G_o) = \pi_{Ri}(G_j \to G_m) = \sum_{j=i}^{m} W_j \,\mathrm{Im}_{ij}$$

Equation 6-2

				G_j	….	G_m	
				$\mathbf{W_j}$	**….**	$\mathbf{W_m}$	
R_i	E_i	$Ex_{i(al)}$	$Ex_{i(pt)}$	$\mathbf{Im_{ij}}$	**….**	$\mathbf{Im_{im}}$	
….	….	….	….	….	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	Im_{nj}	….	Im_{nm}	

Figure 6.6 Measure 2: AM 1

This measure has following usefulness;

i. Comparison *3:* A comparison of the input of particular resources (R_i) on the overall goal (G_o) e.g. for two resources R_x & R_y, the comparison can be made using Eq. 2 separately both for R_x & R_y against G_o involving respective resource impacts.

ii. Finding 2. The resources that have a high impact on the overall goal G_o can be distinguished from those with title or no impact and critical resources can be found.

b. *Measure 3.* The specification phase supports the creation of particular resource areas e.g. Design Management in which a number or resources are grouped together. The resource effectiveness for a resource area may be determined through summation of the individual resource effectiveness values; i.e. summation of column against all goals as shown in Fig. 6.7. Mathematically;

$$\pi_{Ri \to Rn}\left(G_j\right) = \sum_{i=1}^{n} W_j \,\mathrm{Im}_{ij}$$

Equation 6-3

				G_j	….	G_m	
				$\mathbf{W_j}$	….	W_m	
R_i	E_i	$Ex_{i(al)}$	$Ex_{i(pt)}$	$\mathbf{Im_{ij}}$	….	Im_{im}	
….	….	….	….	**….**	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	$\mathbf{Im_{nj}}$	….	Im_{nm}	

Figure 6.7 Measure 3: AM 2

This measure has following usefulness;

i. *Comparison 4:* A comparison of the effectiveness of different resources areas (R_i….R_k, R_k …..R_n) against a particular goal (G_j) e.g. comparing the effectiveness of Design Management resources to the effectiveness of Decision Support resources in relation into the goal of meeting the program; e.g.

$$\pi_{Ri \rightarrow Rn}\left(G_j\right) = \sum_{i=1}^{k} W_j \, \mathrm{Im}_{ij}$$

And,

$$\pi_{Rk \rightarrow Rn}\left(G_j\right) = \sum_{k=1}^{n} W_j \, \mathrm{Im}_{kj}$$

ii. *Comparison 5:* A comparison of the effectiveness of a particular resource area (R_i … R_n) across different goals e.g. comparing the effectiveness of Design Management resources (R_i … R_n) against a goal of meeting the program (G_o) to their effectiveness against a goal reduced rework (G_j).

$$\pi_{Ri \rightarrow Rn}\left(G_o\right) = \sum_{i=1}^{n} W_o \, \mathrm{Im}_{ij}$$

And,

$$\pi_{Ri \to Rn}\left(G_j\right) = \sum_{i=1}^{n} W_j \operatorname{Im}_{ij}$$

c. *Measure 4*: The effectiveness of a number of resources against the higher level goal (G_o) can be defined as shown in Fig. 6.8. Mathematically;

$$\pi_{Ri \to Rn}\left(G_o\right) = \pi_{Ri \to Rn}\left(G_j \to G_m\right) = \sum_{i=1}^{n} \sum_{j=1}^{m} W_j \operatorname{Im}_{ij}$$

Equation 6-4

				G_j	….	G_m	
				$\mathbf{W_j}$	**….**	$\mathbf{W_m}$	
R_i	E_i	$Ex_{i(al)}$	$Ex_{i(pt)}$	$\mathbf{Im_{ij}}$	**….**	$\mathbf{Im_{im}}$	
….	….	….	….	**….**	**….**	**….**	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	$\mathbf{Im_{nj}}$	**….**	$\mathbf{Im_{nm}}$	

Figure 6.8 Measure 4: AM 3

This measure has following utility;

i. *Comparison 6*: A comparison of the effectiveness of particular resource areas (R_i … R_n), e.g. comparing the effectiveness of Design Management to that of Decision Support against the higher level goal (G_o) e.g. for resource area (R_i … R_k) & (R_k … R_n) against (G_j … G_m = G_o):

$$\pi_{Ri \to Rk}\left(G_o\right) = \sum_{i=1}^{k} \sum_{j=1}^{m} W_j \operatorname{Im}_{ij}$$

And,

$$\pi_{Rk \to Rn}\left(G_o\right) = \sum_{k=1}^{n} \sum_{j=1}^{m} W_j \operatorname{Im}_{kj}$$

6.3.3 Improvement Measures (IM)

The measures defined above provide insight to the effectiveness of resources on goals to obtain relationships that describe the use of certain resources against goals. To identify the room for improvement further analysis is made.

The basic aim of the improvement measures is to identify the difference between the actual effectiveness and potential effectiveness of resources or resource groups. The potential effectiveness can be achieved through exploiting the resources beyond the actual level of exploitation. Potential effectiveness is based on the potential exploitation of the resource ($Ex_{i(pt)}$) and the actual exploitation is based on the actual exploitation of the resource ($Ex_{i(al)}$). Further measures to enhance the analysis are defined as follows.

a. *Measure 5:* The potential (P) and actual (A) effectiveness of a resource in relation to a specific goal (G_j) may be defined as shown in Fig. 6.9 & 6.10 respectively. Mathematically;

$$P\pi_{Ri}(G_j) = W_j \, \mathrm{Im}_{ij} \, Ex_{i(pt)}$$

Equation 6-5

And,

$$A\pi_{Ri}(G_j) = W_j \, \mathrm{Im}_{ij} \, Ex_{i(al)}$$

Equation 6-6

				G_j	….	G_m	
				$\mathbf{W_j}$	….	W_m	
R_i	E_i	$Ex_{i(al)}$	$\mathbf{Ex_{i(pt)}}$	$\mathbf{Im_{ij}}$	….	Im_{im}	
….	….	….	….	….	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	Im_{nj}	….	Im_{nm}	

Figure 6.9 Measure 5: IM 1.1

				G_j	….	G_m	
				$\mathbf{W_j}$	….	W_m	
R_i	E_i	$\mathbf{Ex_{i(al)}}$	$Ex_{i(pt)}$	$\mathbf{Im_{ij}}$	….	Im_{im}	
….	….	….	….	….	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	Im_{nj}	….	Im_{nm}	

Figure 6.10 Measure 5: IM 1.2

The usefulness of this measure is as follows;

i. *Finding 3:* The difference between the actual and potential effectiveness to identify the room and impact of improvement after the exploitation of resources to the potential level and the resources (cost, manpower etc) to do so. Therefore, scope in improvement ($\zeta(\pi_{Ri})$) in effectiveness (π_{Ri}) of a resource (R_i) in relation to a specific goal (G_j) is,

$$\zeta\left(\pi_{Ri}\right) = P\pi_{Ri}(G_j) - A\pi_{Ri}(G_j)$$

Equation 6-7

Or,

$$\zeta\left(\pi_{Ri}\right) = \left(W_j \operatorname{Im}_{ij} Ex_{i(pt)}\right) - \left(W_j \operatorname{Im}_{ij} Ex_{i(al)}\right)$$

b. *Measure 6:* The potential and actual effectiveness of a resource (R_i) with respect to a higher level goal (G_o) is determined as shown in Fig. 6.11 and 6.12 respectively. Mathematically,

$$P\pi_{Ri}\left(G_j \rightarrow G_m = G_o\right) = \sum_{j=1}^{m} W_j \operatorname{Im}_{ij} Ex_{i(pt)}$$

Equation 6-8

And,

$$A\pi_{Ri}\left(G_j \rightarrow G_m = G_o\right) = \sum_{j=1}^{m} W_j \operatorname{Im}_{ij} Ex_{i(al)}$$

Equation 6-9

				G_j	….	G_m	
				$\mathbf{W_j}$	**….**	$\mathbf{W_m}$	
R_i	E_i	$Ex_{i(al)}$	$\mathbf{Ex_{i(pt)}}$	$\mathbf{Im_{ij}}$	**….**	$\mathbf{Im_{im}}$	
….	….	….	….	….	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	Im_{nj}	….	Im_{nm}	

Figure 6.11 Measure 6: IM 2.1

				G_j	….	G_m	
				$\mathbf{W_j}$	**….**	$\mathbf{W_m}$	
R_i	E_i	$\mathbf{Ex_{i(al)}}$	$Ex_{i(pt)}$	$\mathbf{Im_{ij}}$	**….**	$\mathbf{Im_{im}}$	
….	….	….	….	….	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	Im_{nj}	….	Im_{nm}	

Figure 6.12 Measure 6: IM 2.2

The usefulness of this measure is as follows;

i. *Finding 4:* The difference between the potential and actual effectiveness identifies room for improvement with reference to a specific resource in relation to a higher level goal and hence cost of improvement can be identified e.g. the scope of improvement ($\zeta(\pi_{Ri})$) in effectiveness (π_{Ri}) of a resource (R_i) in relation to a higher level goal ($G_j \rightarrow G_m = G_o$) is,

$$\zeta(\pi_{Ri}) = P\pi_{Ri}(G_j \rightarrow G_m = G_o) - A\pi_{Ri}(G_j \rightarrow G_m = G_o)$$

Equation 6-10

Or,

$$\zeta(\pi_{Ri}) = \sum_{j=1}^{m} W_j \,\mathrm{Im}_{ij}\, Ex_{i(pt)} - \sum_{j=1}^{m} W_j \,\mathrm{Im}_{ij}\, Ex_{i(al)}$$

c. *Measure 7:* The effectiveness of a number of resources i.e. resource areas against a particular goal (G_j) in the context of potential and actual effectiveness is determined as shown in Fig. 6.13 and Fig. 6.14 respectively. Mathematically;

$$P\pi_{Ri \rightarrow Rn = R}(G_j) = \sum_{i=1}^{n} W_j \,\mathrm{Im}_{ij}\, Ex_{i(pt)}$$

Equation 6-11

And,

$$A\pi_{Ri \rightarrow Rn = R}\left(G_j\right) = \sum_{i=1}^{n} W_j \operatorname{Im}_{ij} Ex_{i(al)}$$

Equation 6-12

				G_j	….	G_m	
				W_j	….	W_m	
R_i	E_i	$Ex_{i(al)}$	**$Ex_{i(pt)}$**	**Im_{ij}**	….	Im_{im}	
….	….	….	**….**	**….**	….	….	
R_n	E_n	$Ex_{n(al)}$	**$Ex_{n(pt)}$**	**Im_{nj}**	….	Im_{nm}	

Figure 6.13 Measure 7: IM 3.1

				G_j	….	G_m	
				W_j	….	W_m	
R_i	E_i	**$Ex_{i(al)}$**	$Ex_{i(pt)}$	**Im_{ij}**	….	Im_{im}	
….	….	**….**	….	**….**	….	….	
R_n	E_n	**$Ex_{n(al)}$**	$Ex_{n(pt)}$	**Im_{nj}**	….	Im_{nm}	

Figure 6.14 Measure 7: IM 3.2

The usefulness of this measure is as follows;

i. *Finding 5:* The difference between the potential and actual effectiveness identifies room for improvement with reference to a resource group in relation to a specific goal and hence cost of improvement can be identified .e.g. the scope of improvement ($\zeta(\pi_{Ri \rightarrow Rn = R})$) in effectiveness ($\pi_{Ri \rightarrow Rn = R}$) of a group of resources ($R_i \rightarrow R_n = R$) in relation to a specific goal (G_j) is,

$$\zeta\left(\pi_{Ri \to Rn=R}\right) = P\pi_{Ri \to Rn=R}(G_j) - P\pi_{Ri \to Rn=R}(G_j)$$

Equation 6-13

Or,

$$\zeta\left(\pi_{Ri \to Rn=R}\right) = \sum_{i=1}^{n} W_j \operatorname{Im}_{ij} Ex_{i(pt)} - \sum_{i=1}^{n} W_j \operatorname{Im}_{ij} Ex_{i(al)}$$

d. *Measure 8:* A final analysis is carried out by relating a number of resources to a higher level goal in relation to potential and actual exploitation. This is represented in Fig. 6.15 and 6.16 respectively. Mathematically,

$$P\pi_{Ri \to Rn=R}\left(G_j \to G_m = G_o\right) = \sum_{i=1}^{n} \sum_{j=1}^{m} W_j \operatorname{Im}_{ij} Ex_{i(pt)}$$

Equation 6-14

And,

$$A\pi_{Ri \to Rn=R}\left(G_j \to G_m = G_o\right) = \sum_{i=1}^{n} \sum_{j=1}^{m} W_j \operatorname{Im}_{ij} Ex_{i(al)}$$

Equation 6-15

				G_j	….	G_m	
				W_j	**….**	**W_m**	
R_i	E_i	$Ex_{i(al)}$	**$Ex_{i(pt)}$**	**Im_{ij}**	**….**	**Im_{im}**	
….	….	….	**….**	**….**	**….**	**….**	
R_n	E_n	$Ex_{n(al)}$	**$Ex_{n(pt)}$**	**Im_{nj}**	**….**	**Im_{nm}**	

Figure 6.15 Measure 8: IM 4.1

				G_j	….	G_m	
				W_j	**….**	**W_m**	
R_i	E_i	**$Ex_{i(al)}$**	$Ex_{i(pt)}$	**Im_{ij}**	**….**	**Im_{im}**	
….	….	**….**	….	**….**	**….**	**….**	
R_n	E_n	**$Ex_{n(al)}$**	$Ex_{n(pt)}$	**Im_{nj}**	**….**	**Im_{nm}**	

Figure 6.16 Measure 8: IM 4.2

The usefulness of this measure is as follows;

i. *Finding 6:* The difference between the potential and actual effectiveness identifies room for improvement with reference to a resource group in relation to a higher level goal and hence cost of improvement can be identified. This is a macro-level measure e.g. the scope of improvement ($\zeta(\pi_{Ri \rightarrow Rn = R})$) in effectiveness ($\pi_{Ri \rightarrow Rn = R}$) of a group of resources ($R_i \rightarrow R_n = R$) in relation to a higher level goal ($G_j \rightarrow G_m = G_o$) is,

$$\zeta(\pi_{Ri \to Rn=R})(G_j \to G_m = G_o) = P\pi_{Ri \to Rn=R}(G_j \to G_m = G_o) - A\pi_{Ri \to Rn=R}(G_j \to G_m = G_o)$$

Equation 6-16

Or,

$$\zeta(\pi_{Ri \to Rn=R})(G_j \to G_m = G_o) = \sum_{i=1}^{n} \sum_{j=1}^{m} W_j \, \mathrm{Im}_{ij} \, Ex_{i(pt)} - \sum_{i=1}^{n} \sum_{j=1}^{m} W_j \, \mathrm{Im}_{ij} \, Ex_{i(al)}$$

Equation 6-17

6.3.4 Return On Investment (ROI)

ROI is targeted to provide an indication of the return (in terms of increased effectiveness) from the investment of resources (time, money, people etc.) to further exploit a resource. The investment could be in the form of training the engineers or providing a modeling software etc. The measure is defined only for higher level goals as resources target to accomplish many goals at a single time. The measure is defined as shown in Fig. 6.17. Mathematically,

$$RoI_{Ri}(G_j \to G_m = G_o) = \sum_{j=1}^{m} W_j \, \mathrm{Im}_{ij} \, E_i$$

Equation 6-18

				G_j	….	G_m	
				$\mathbf{W_j}$	….	$\mathbf{W_m}$	
R_i	$\mathbf{E_i}$	$Ex_{i(al)}$	$Ex_{i(pt)}$	$\mathbf{Im_{ij}}$	….	$\mathbf{Im_{im}}$	
….	….	….	….	….	….	….	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	Im_{nj}	….	Im_{nm}	

Figure 6.17 Measure 9: ROI

The usefulness of this measure is as follows;

a. Measure 9: This measure may be applied across all the individual resources to allow the comparison of the RoI in each of them. The results will provide indication of areas where investment is required to obtain effectiveness. The relations will incorporate E_i instead of E_x.

6.3.5 Normalization of Results

Normalization of results is required for the comparison of various results against a common reference or datum. The effectiveness of the resources against goals is normalized using the Total Effectiveness (π_T) of all the resources against the higher level goal (G_o). This is shown in Fig. 6.18. Mathematically;

$$\pi_T = \pi_{Ri \to Rn = R}\left(G_j \to G_m = G_o\right) = \sum_{i=1}^{n} \sum_{j=1}^{m} W_j \, \mathrm{Im}_{ij}$$

Equation 6-19

Where,

m = Total number of goals in the analysis scope
n = Total number of resources in the analysis scope

As an example, the effectiveness of a particular resource against a higher level goal (G_o) is normalized as;

$$Normalized \pi_{Ri}\left(G_j \to G_m = G_o\right) = \frac{\sum_{j=1}^{m} W_j \, \mathrm{Im}_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{m} W_j \, \mathrm{Im}_{ij}}$$

				G_j	….	G_m	
				$\mathbf{W_j}$	**….**	$\mathbf{W_m}$	
R_i	E_i	$Ex_{i(al)}$	$Ex_{i(pt)}$	$\mathbf{Im_{ij}}$	**….**	$\mathbf{Im_{im}}$	
….	….	….	….	**….**	**….**	**….**	
R_n	E_n	$Ex_{n(al)}$	$Ex_{n(pt)}$	$\mathbf{Im_{nj}}$	**….**	$\mathbf{Im_{nm}}$	

Figure 6.18 Measure 10: Total Effectiveness

The use of normalization helps in comparing the values obtained from the application of different measures e.g. the effectiveness of a particular area of resources could be directly compared with the effectiveness of an individual resource, where both are expressed as a percentage of the Total Effectiveness (π_T). This shows the contribution of that resource to overall resource area.

6.4 Approach for Application to Industry

The formalism presented above is a lengthy exercise for implementation in the industry. An application approach is devised here for initial implementation in the industry. The approach is divided as shown in Fig. 6.18. Upcoming chapters will elaborate the different phases of the approach.

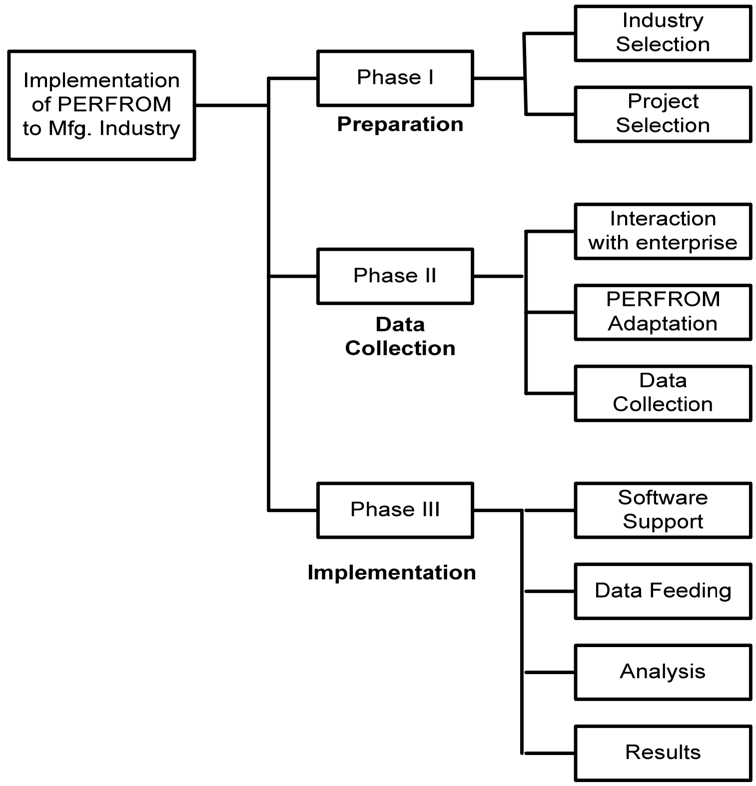


Figure 6.19 Approach for Application to Industry

Chapter 7
THE MANUFACTURING FACILITY

7.1 Introduction

It was described in previous chapter that a manufacturing facility will be selected for the implementation of the PERFORM approach. This chapter incorporates the Phase – 1 of the approach presented in Fig. 6.19. The Phase – 1 of the approach is presented here in Fig. 7.1 for ready reference. It can be seen that the Phase – 1 of the approach comprises of the preparation for the implementation of the PERFORM approach. The manufacturing facility and the projects of the selected facility will be selected during this phase.

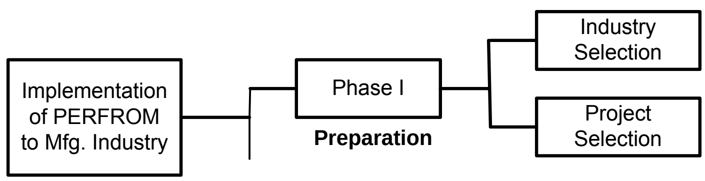


Figure 7.1 Phase – 1 for Implementation of PERFORM

7.1.1 Industry Selection

Pakistan has a large manufacturing which contributes towards the GDP of the country. However, the manufacturing sector of the country has suffered severely during the last decade due to the present energy crisis and heavy tax policies. Nevertheless, the following points were kept in view for the selection of the manufacturing facility.

a. *Design department*: The Company must have the design department, or a centre which performs the activities of the design process, as the design management performance can only be measured in the deign department and not in any other department.
b. *Manufacturing facility and Product Sales*: The Company under consideration must have the manufacturing facility so that the design of the company may be manufactured and sold to the customer to assess the reliability of the design and the customer satisfaction level.
c. *General repute:* The general repute of the company was also kept in view during selection.
d. *Locality:* The locality and access of the company was also kept in view as there is a limited amount of time and resources available for research.
e. *Invitation feedback:* Nine (9) firms in the vicinity of Wah / Rawalpindi / Islamabad / Hasanabdal were contacted during the selection phase through emails and personal contacts. An introduction of the approach was made clear and a timeline of three (3) weeks was set for the response. The names

of the companies that were contacted are with-held here. Following companies responded to the offer.

i. Pakistan Tobacco Company (PTC), Jehlum
ii. Qarshe Industries (QI) Pvt. Ltd., Hattar
iii. KSB Pumps Co. Ltd., Hasanabdal

PTC has a state of the art automated manufacturing facility and a wide product range but was dropped due to the locality and lack of technical expertise for the products. QI is present in the near vicinity but it failed to comply with the requirement of the design department and the lack of technical expertise was again felt here. However, KSB is present in the vicinity with a purely mechanical-cum-manufacturing based product portfolio and the state of the art production facility with a solid technical base of the design department. Moreover, the author has served in the company as a design engineer and significantly aware of the company's profile and working style. Considering the merits of KSB, the company was selected for the test implementation of the PERFORM approach.

An introduction of KSB will be presented in the next sections. The information presented here is primarily referenced in [147 – 153]. Some information presented here was collected from the company resources which are with-held here on request.

7.1.2 The KSB Group: Company Introduction and History

KSB is a German Multinational company of international repute and is a leading manufacturer of pumps, valves, hydraulic systems and package solutions for fluid transfer systems. KSB is 1 group that shares 4 regions, 5 continents, 6 strategic business areas, 116 countries and round about 12,000 employees. KSB uses state of the art technologies for developing its products.

KSB was founded by Johannes Klein, Friedrich Schanzlin and August Becker in Frankenthal, Germany, in 1871. Therefore the company's existence dates back to over 130 years now. In 1887, it turned into a pubic company. The company then acquired different major plants in Germany. In 1941, first subsidiary on the American continent was found in Argentina.

KSB Germany has attracted different brands of international fame and developed its subsidiaries in different countries of the world. KSB has global presence, broad product range, strong fans e.g. AMRI, SISTO, GIW and PSA (logos shown in Fig. 7.2) and breakthrough thinking strategy with highly qualified employees. KSB has a market volume of € 9.7 billion and stands tall in competition with Flow Serve.

Figure 7.2 The Brand Fans of KSB

A typical data of sales for the year 2002 is shown in Table 7.1. The milestones in the development of the company are also tabulated in Table 7.2.

Parameter	Value
Order Intake	€ 1,200 million
Sales	€ 1,180 million
Income	€ 34 million
Employees	11, 948

Table 7.1 Typical Sales Data for Year 2002

Year	**Achievement / Milestone**
1871	Founded by Johannes Klein, Friedrich Schanzlin and August Becker in Frankenthal
1887	The firm is turned into a public company
1924 – 1934	Acquisition of further German plants in Homburg / Saar, Nuremberg (later Pegnitz) and Bremen Subsidiaries in a number of European countries
1941	First subsidiary on the American continent (Argentina)
1953	First subsidiary in the Asia-Pacific area (Pakistan)
1957	Production start-up in Brazil
1959	Foundation of KSB Pumps Limited, India
1960	Foundation of KSB-Stiftung
1986	Acquisition of Pompes Guinard S.A., Paris
1989	Acquisition of AMRI S.A., Paris, the largest European manufacturer of butterfly valves
1991	Takeover of the East German Pumpenwerke Halle
1994	Majority holding in KSB Shanghai Pumps Co., Ltd.
1996	100 % interest in slurry pump manufacturer GIW Industries, Georgia / USA
1997	Purchase of MIL Controls, Kerala / India, a manufacturer of control valves to ANSI standards

Table 7.2 Historical Development of the Company

The company has global presence as described above. The phenomenon of global presence is summarized in Table 7.3.

KSB Sites in Americas	KSB Sites in Europe	KSB Sites in Middle East	KSB Sites in Asia / Pacific
Canada	Germany	Turkey *	India *
USA *	France	Saudi Arabia *	Pakistan *
Mexico *	Rest of Europe = 16	UAE	Thailand
Chile		South Africa *	Singapore
Argentina			Indonesia *
Venezuela			Japan
Brazil *			China *
			Taiwan
			South Korea
			Australia *

Table 7.3 Global Presence of KSB

* = With production plant

The company also maintains its R&D and development activities throughout the world. The fact is supported through Table 7.4.

Location	R&D / Development Activities
Germany	All business areas (except Mining), Casting
France	Building Services Pumps, Industrial Pumps, Water/Waste Water Pumps, Butterfly Valves
Luxemburg	Diaphragm Valves
Italy	Industrial Pumps
USA	Mining, Butterfly Valves, Casting
Brazil	Water Pumps, Energy Pumps, Oil Pumps, Casting
India and Pakistan	All business areas (except Mining), Casting
China	Energy Pumps, Water Pumps, Casting
South Africa	Water Pumps, Industrial Pumps, Energy Pumps, Diaphragm Valves
Indonesia	Casting
Singapore	Valves

Table 7.4 Worldwide R&D and Development

As a single source of supplies for Pumps, Valves, Control systems, Mixers and Service, the business areas and the respective customers are shown in Table 7.5.

The sale of the KSB group is also shown in Fig. 7.3 through pie chart, which identifies the fact that the most sales was made in Europe. The sale of the company is growing since its existence. The typical data for sales of the company versus the order intake through the years 1994 – 2001 is shown in Fig. 7.4.

Business Areas	Customers	Applications
Building Services	Wholesales, contractors, consultants	Domestic water supply, Drainage, Sanitation, Heating, Ventilation & air-conditioning
Industry and Process Engineering	Plant engineers, OEMs, industrial companies	General industry, Process engineering , Hot water and heat transfer liquid systems
Water	Plant engineers, water companies (also public)	Water extraction including seawater desalination, Water treatment, Water transport
Waste Water	Plant engineers, waste water companies (also public)	Effluent treatment plants in industry and the public sector, Sewage pumping stations
Energy	Plant engineers, power stations	Fossil-fuelled power stations, Combined cycle power stations, Nuclear power stations
Mining	Equipment suppliers	Mining, Suction hopper dredges, Oil sand industry

Table 7.5 Business Areas, Customers and Applications

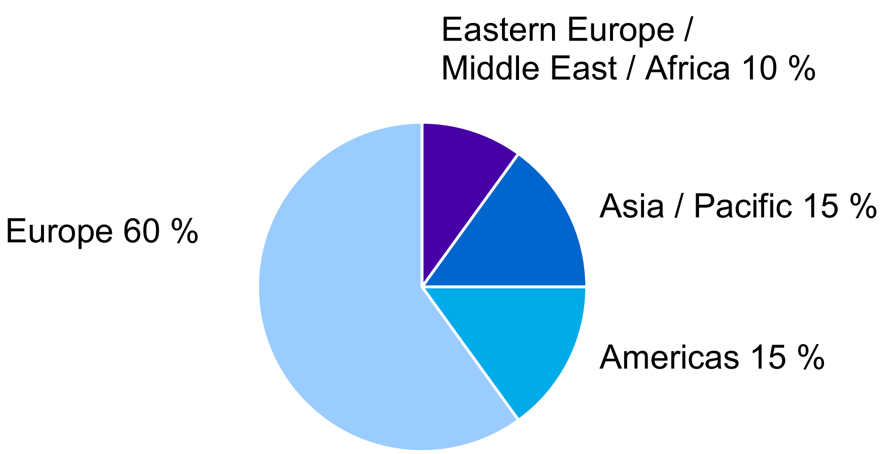


Figure 7.3 Worldwide Sales Contributions

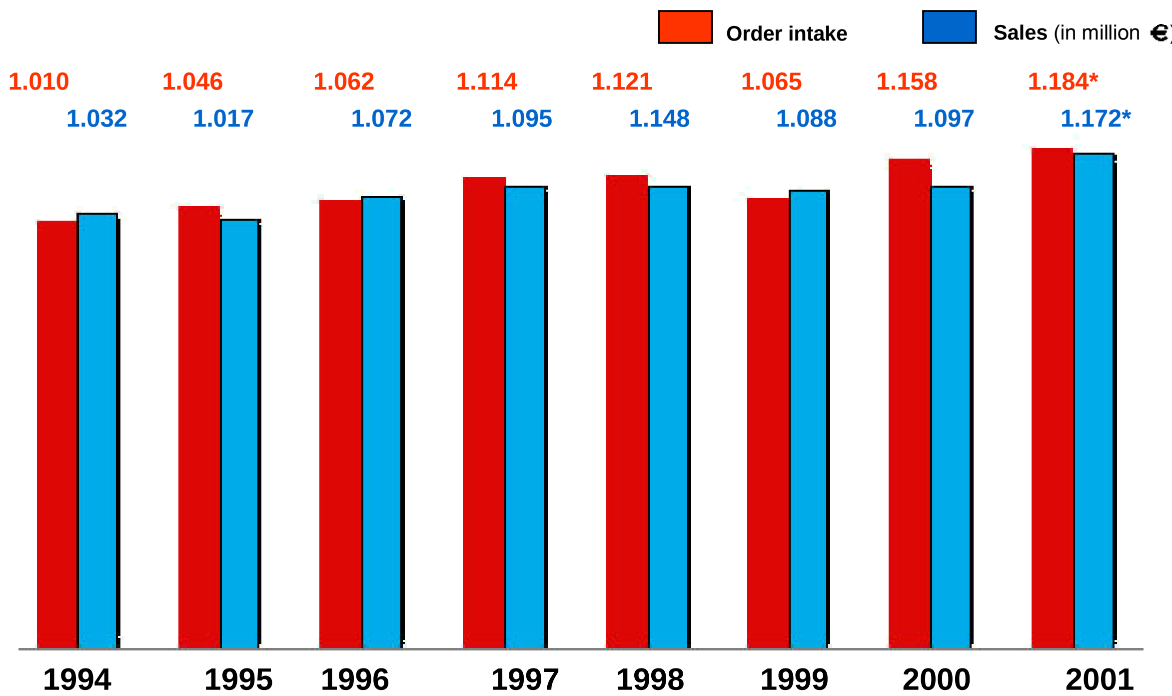


Figure 7.4 Order Intake vs Sales

7.2 KSB Pakistan

Continuing its tradition, KSB Germany developed KSB Pumps Company Limited in Pakistan in 1953. Since then KSB Pakistan has also developed as a leading manufacturer of pumps, valves and systems solutions. KSB Pakistan has a production facility, generally referred to as works in Hasanabdal. The works has a foundry which produces state of the art pump components and other specially ordered castings, discs, engine blocks for example. The works has a main production shop which constitutes of production machines, pump test bed, assembly areas, tool stores and quality control setup.

In addition to its manufacturing facility, KSB Pakistan's head office is situated at Lahore. Sales and Services offices span over the whole country including at Rawalpindi, Peshawar, Multan, Quetta and Karachi. That's the reason behind the company's success that it provides solution and services fast, efficient and wherever the customer needs.

During the last three decades, the Company has rapidly expanded its production range to include a large variety of pumps to serve various sectors of the economy. The new pumps for local production have been selected to particularly meet the requirements of sugar, paper and other process and chemical industries apart from meeting the requirements of drinking water supply, sewage disposal and surface drainage schemes.

The latest additions have been pumps of large capacity which are specifically meant for irrigation and drainage applications. Pumps are produced in various metallurgical executions including cast iron, Ni-resist cast iron, bronze and stainless steel. KSB pumps are produced strictly in accordance with the design and specifications of KSB AG Germany, in order to maintain standards of the highest quality.

7.2.1 Mission

The mission statement of the Company states;

> *"We manufacture and market a selected range of standard and engineered pumps and castings of world class quality. Our efforts are directed to have delighted customers in the water, sewage, oil, energy, industry and building services sectors.*
>
> *In line with the Group strategy, we are committed to develop into a centre of excellence in water application pumps and be a strong regional player. We want to market valves, complete system solutions and foundry products including patterns for captive, automotive and other industries. We will develop a world class human resource with highly motivated and empowered employees.*
>
> *The measure of our success is being a clear market leader, achieving quantum growth and providing attractive returns to stakeholders."*

7.2.2 The Production Plan for Pakistan

KSB Germany has strategically divided its product design issues and manufacturing overall the world depending upon the market nature and the economy of the reference country. Every country does not and in fact cannot produce each product.

Similarly, Pakistan has its own product range, capacity and capabilities. Important product sales in Pakistan include ETA, KWP, KRT and DWT etc. Significant international products include the state of the art SNW, PNW and PNZ Engineered Pumps Series, which brings a major international and national return. KSB Pakistan is the only International manufacturer of this series in the whole KSB group and in the whole world. It has provided these prestigious pumps for many countries including Germany, Thailand, Indonesia, Dubai, Egypt and of course Pakistan. Recently, the first ever order of the SNW pump in steel execution has been produced for a site in Karachi. The products of the KSB Pakistan and their uses are tabulated in Table. 7.6. The uses and the technical specs of the products are out of the scope of this thesis.

Pump Types / Applications	ETA	ETA 300-35	ETACHROM	DWT - B	RPK	KWP	KVP	OMEGA	OMEGA V	WKF	MOVI V	MOVI	HLP	MK / MKA	SNW	PNW	PNZ	ALTA	SUBS	UPV	KRTU
Agricultural drainage				●		●	●							●	●	●	●				●
Boiler feed application in power stations / industry	●									●	●	●									
Cooling cycles in air-conditioning system	●		●																		
Cooling water supply				●											●	●	●				
Crude oil	●				●							●							●	●	
Domestic water supply						●	●							●							●
Drainage of cellars / basins				●				●	●	●	●	●						●	●	●	
Fire fighting																			●	●	
Garden irrigation				●																	
Ground water recovery	●	●		●				●	●				●						●		
Irrigation				●															●	●	
Lowering of surface water level						●	●														
Paper and pulp			●		●																
Petrochemical industry	●		●		●																
Pharmaceuticals									●	●	●										
Pressure boosting					●	●															
Sewage				●											●	●	●				
Storm water	●	●	●			●		●	●												
Sugar industry	●		●																		
Water pollution control															●	●	●				
Water recirculation	●	●		●				●	●						●	●	●		●		
Water supply (municipal, industrial)								●	●												
Water treatment																					

Table 7.6 Types of Pumps and their Uses

The sale of the factory has also observed a continuous rise during the last decade as shown in Fig. 7.5. The current market size for the company (DWT & SNW/PNW) is 100 M US $, while the current turn over is 0.5 M US $.

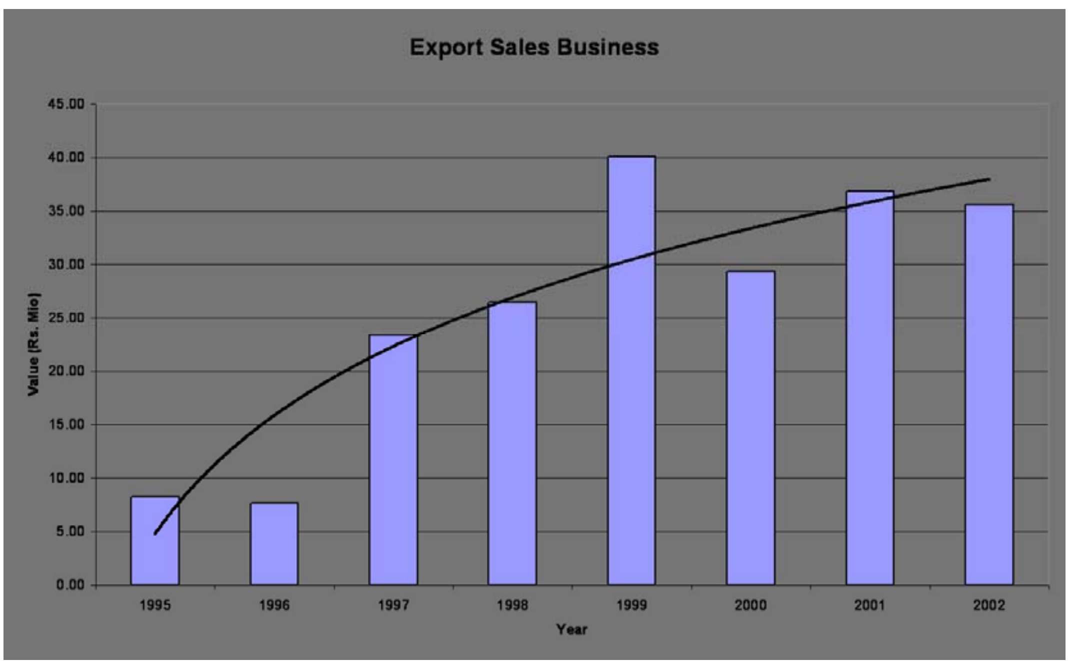


Figure 7.5 Export Sales Values for Pakistan

The typical local sales figures data for KSB Pakistan during 2004 – 2006 is presented through Table 7.7 and Fig. 7.6.

Sr.No.	Description	Value (Million)	Period
1	WASA – Lahore, Main Outfall	Rs. 25	Quarter-IV, 2004
2	MDA – Sewage Schemes – I (CMF)	Rs. 100	Quarter-I, 2005
3	RDA – Refurbishment & new Pumps	Rs. 38	Quarter-IV, 2004
4	Bannu – Drought Relief Package	Rs. 33	Quarter-II, 2005
5	Chashma Right Bank Canal (CRBC)	Rs. 450	Quarter-III, 2005
6	MDA – Sewage Schemes – II (ADB)	Rs. 100	Quarter-I, 2005
7	New Murree Water Supply Project	Rs. 150	Quarter-I, 2005
8	NDP – Lift Irrigation Schemes	Rs. 100	Quarter-II, 2005
9	Baloki Lift Irrigation Scheme	Rs. 40	Quarter-II, 2005
10	NDP - Sukhur Airport	Rs. 15	Quarter-IV, 2004
11	Chutiari Command Area Project	Rs. 35	Quarter-III, 2005
12	RDA – Sewage Disposal Stations Project	Rs. 75	Quarter-IV, 2005
13	Khairpur Ghotki Drainage Project	Rs. 150	Quarter-I, 2006

Table 7.7 Local Sales Data

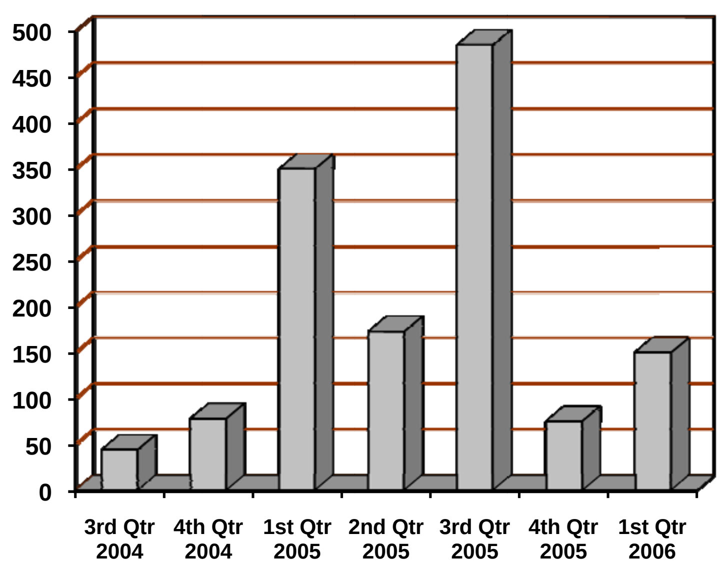


Figure 7.6 Bar Chart for Sales during 2004 – 2006

KSB Pakistan has state of the art manufacturing facility with following salient features.

a. Foundry production of all castings
    - Single piece weight up to 800 kg
    - Grey Cast Iron
    - Austenitic Cast Iron D2
    - Zinc-less Bronze
    - Aluminum Multiple Bronze
    - Austenitic Stainless Steel
b. Complete In-House Machining Facility of all Components
    - Optimized Tool Engineering
    - In-house development of tooling Jigs and Fixtures
    - Dynamic Balancing of Rotor
    - Hydrostatic Pressure Testing of pressure retaining parts
c. Mechanized Assembly Stations
    - Appropriate tooling to meet product's specific assembly requirements
d. Hydraulic Performance Testing
    - Open loop testing facility - Flexibility in installation
    - Calibrated Instrumentation and equipment to test complete range
e. Vendor Development
    - Welding technology qualification for fabricated parts up to size DN 800
    - Standardized manufacturing Lead Time
f. Material Planning
g. Quality Assurance
    - Quality Control Plan (QCP) developed jointly by QA (Pak) & QA (FT)
h. Logistics
    - Transportation security of product and export document control

The strategic business fields of KSB Pakistan's export are as follows.

a. Agriculture
    - Irrigation and Drainage pumping stations
b. Industry
    - Cooling Water Pumps
c. Storm and Raw water pumps
d. Flood Control and Dock Pumps
e. Municipal Water Supply

7.3 The Design Office

The design department at the company provides the technical solutions to the problems which arise time to time during the manufacturing, assembly, usage etc. of the products. The department primarily provides technical background for the development of new products and the service of the commissioned projects. The same office serves for the international sales. The product category of the design department is as follows.

a. Standard execution
   - Hydraulic selection
   - Metallurgy selection
   - Seal selection
   - System integration (solutions)
   - Interface modifications
   - Base frames & foundations
   - Adaptabilities
b. Engineered execution
   - Pump design
   - Mechanical design
   - Thrust load calculation / bearing arrangement
   - Seal technology
   - Metallurgy
   - Hydraulic selection
   - Pump station design / intake chambers

7.3.1 The Information Flow

The design office serves as a hub of technical activities through out the company. A flow-chart of the information flow of the department throughout the company is presented in Fig. 7.7. This should be read in accordance with information presented in Chapter 02.

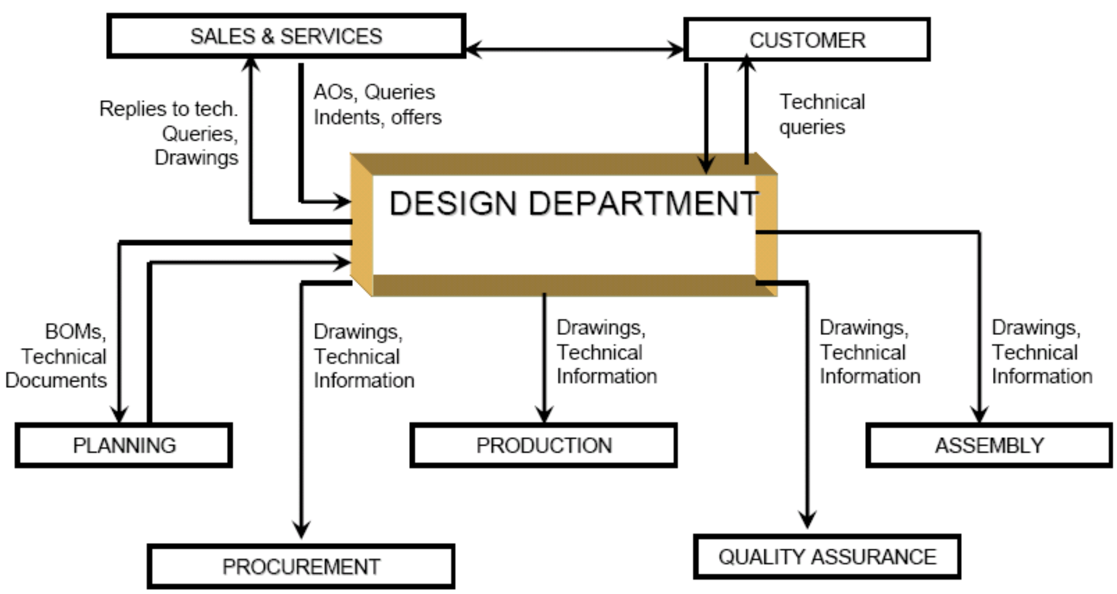


Figure 7.7 Information Flow from Design Office

7.3.2 The Working of Design Office

It was pointed out in 7.4.1 that the design office has a very close technical collaboration with the internal (planning, production, procurement, quality assurance and assembly) and external (national and international sales and services) customers. A more detailed schematic representation of the internal working of the design department is shown in Fig. 7.8.

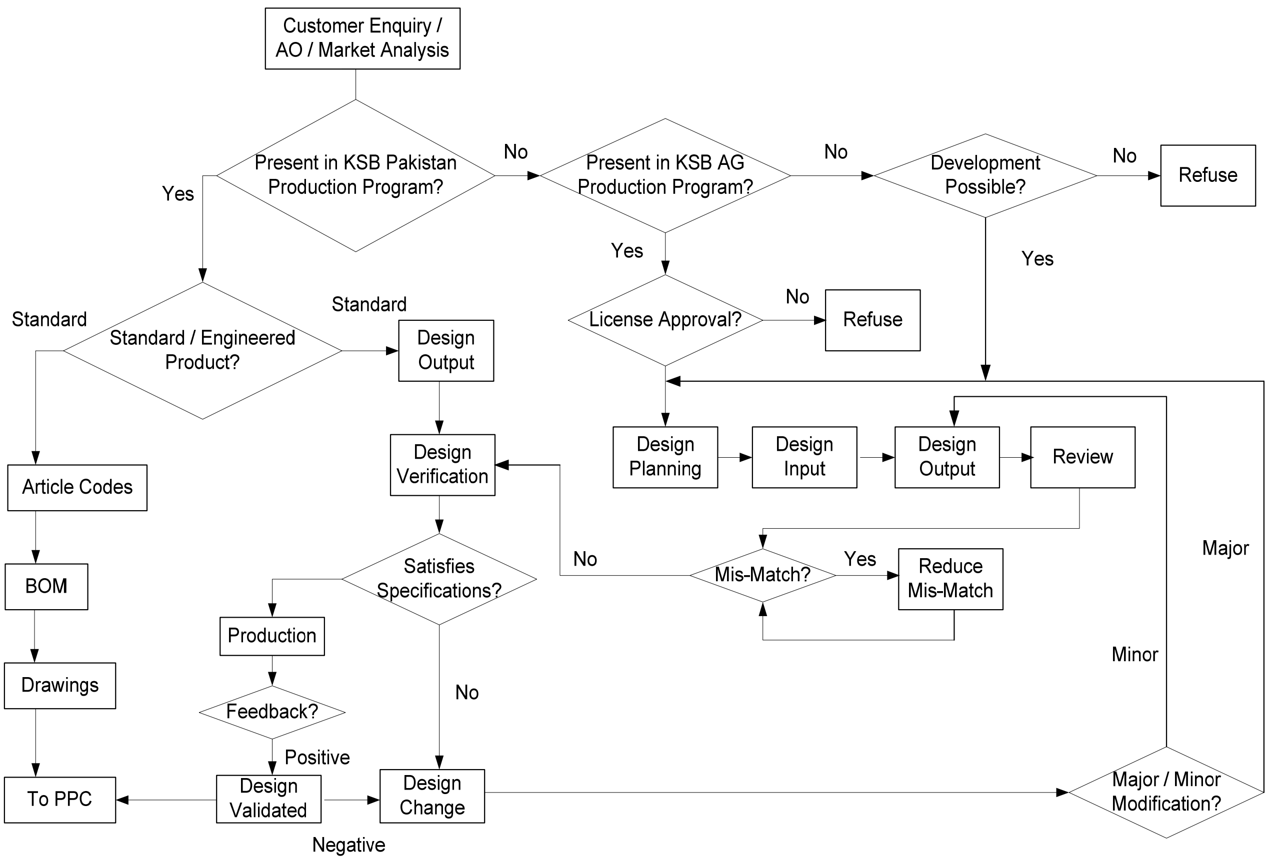


Figure 7.8 The Flow Chart of Design Office

The core functions of the design department are as under;

a. Creation of article masters;
b. Creation & maintenance of BOMs;
c. Preparation & maintenance of drawings;
d. New product development; and
e. Project planning for exports.

As a process, design needs inputs and work on them to generate outputs. The design process is a self-repeating loop. The typical design process flow diagram of the company's design office is schematically represented in Fig. 7.8. This diagram is in accordance with the discussion presented in Chapter 02.

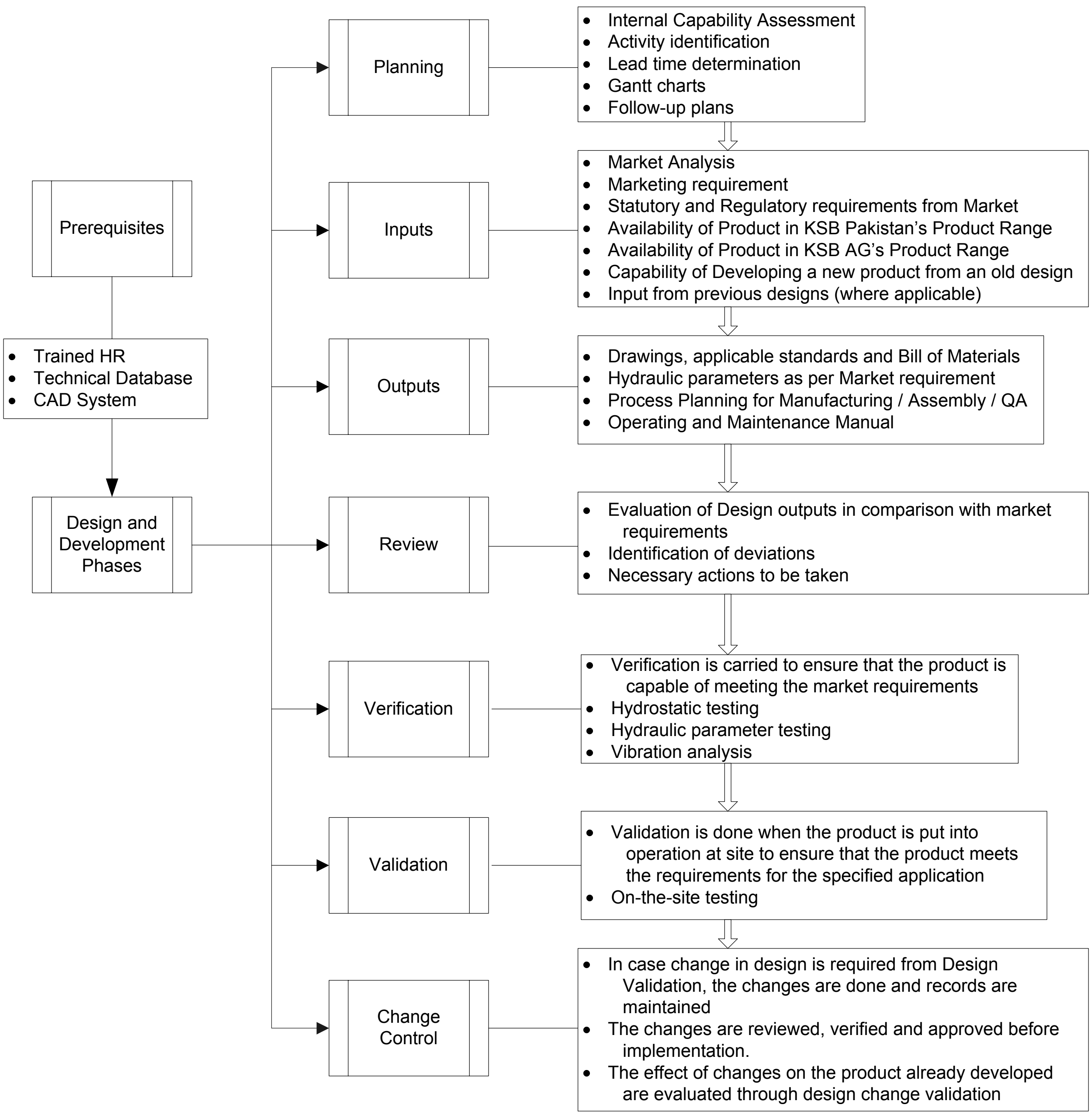


Figure 7.9 The Design Process Flow Chart

7.4 Selection of Design Project for Performance Evaluation

The second part of Phase – 1 consists of selecting the design and development projects for performance evaluation. It was discussed in sections 7.3 and 7.4 that the company has a dedicated design office which serves to approximately each department of the company. The marketing department searches for orders and the orders reach the design office in the form of Acceptance Orders (AOs). The AOS are referred to the standard or engineered cells depending upon the nature of the order. The design office encounters typical design issues during the execution of engineered (tailored) orders and solution for after-sales customer problems.

The design office specializes in the execution of tailored orders through the engineering cell. The design of SNW / PNW / PNZ / DWT (engineered execution) pumps is the cutting edge of the engineering cell. Thus the projects of the engineering cell during 1995 – 2005 were evaluated for the selection of a reference projects. Special attention was given to the exports orders.

A sample of 10 projects was evaluated and reviewed for performance measurement in the design development process. The evaluation method consisted of following steps.

a. *Availability of Data*: The company did not have the procedure of maintaining the data in soft form till 90s. Therefore the projects which had the complete data both in soft and hard form were considered. Moreover, attention was also given to the presence of complete technical data pack in the form of drawings, project timelines, use of resources (manpower, software, material etc), response of customer after delivery and the overall impact of the project. Several data in this regard is confidential as advised by the company is with-held here on request.
b. *Project Timelines*: The organization has adapted the means of timely execution of the project as per the demand of market and the competitive environment as offered by the competitors. Many other companies have launched its products in the market, so the organization had to meet with the deadlines of time but this was not the case till 90s. The timelines of the project are defined in the form of Gantt charts using MS Project Professional 2003. The availability of the reference plan was considered as the basic requirement for the design management performance evaluation.
c. *Nature of Project*: As discussed earlier, the company is involved in two types of projects namely the standard execution and the engineered execution projects. Typical design problems are encountered in the engineering cell only as the standard cell is more of a production type constituent of the department. The standard cell recommends the standard components of the orders with reference to the AOs and do not involve any design problem solving as they are the standard products which vary only in defined areas. Therefore, only the projects of the engineering cell were reviewed for the reference study.

d. *Presence of Design Issues*: Even in the engineered cell, every project does not involve the typical design and development problems. Many projects just have a small alteration in the main design of any product. There are a few projects in which a complete review of a design process and new additional design to the present product is required to be made. It is worth mentioning here that the facility in Pakistan does not involve the development of completely new products as the production license of any product is the property of KSB AG. Nevertheless, there are many complete design problems in the recent projects of the company especially after the sales of engineered orders to the Pakistani manufacturing facilities. The project selected here contains a proper design and development issue rather then just a routine engineered order.

e. *Completion*: Many engineered orders take a long time during the design development and its manufacturing and testing through the final delivery e.g. the project IEZ-420: Gharb Tahta which was the property of Egypt required 40 products to be made. Five separate projects were present in these 40 products. The project took approximately 14 months for completion. Similarly IEZ-425, IEZ-438, IEZ-445 and IEZ-460 approximately took 10 months on the average for completion. It was therefore decided that the projects under execution will not be considered for performance evaluation as there was a time constraint.

Depending upon the factors presented above, the project IEZ-425 was selected for performance evaluation. The project consisted of 08 PNW Engineered products of German origin and was taken from Thailand. The products were meant to be mounted on a specialized base on a dam. The standard bases of the product could not be used for the purpose. Therefore, a complete new design of the base plate and the hydraulic / mechanical strength analysis was also required. A complete problem statement is formulized as follows;

> "*To design and develop a PNW PB4 400 – 350 pump according to the acceptance order and to exceed* customer *satisfaction. The technical aspects of the order shall be taken from the acceptance order and the maximum design activity time will be one week (07 days)".*

The statement will be further elaborated during the discussion and adaptation of the PERFORM approach during next sections.

Chapter 8
APPLICATION OF PERFORM

8.1 Introduction

The previous chapter provided with the understanding of the environment of the company in which the PERFORM system is intended to be applied. The company is a multinational manufacturing concern in which tailored customer orders are manufactured according to the timelines. After sales service is also a value added aspect of the company. The project selection was also made on a defined criteria and a problem statement was evaluated for a preliminary design performance measurement. As a Phase-II of the application of PERFORM, the implementation technique is schematically presented in Fig. 8.1.

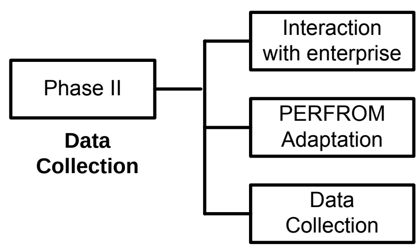


Figure 8.1 Phase-II of PERFORM Application

8.1.1 Interaction with the Enterprise

The conceptual background for the application of PERFORM in the manufacturing sector of Pakistan has been developed during the last chapters. The selected company did not have any process based performance measurement system in the design department. Therefore, a strategy to introduce the concept to the company was formulized and its main steps are as follows;

8.1.2 Preparation

In the preparation phase, personal preparation was made to introduce the company on the technique. Following steps were carried out during this phase;

a. *Invitations to company's key executives available at Works, HA:* In this phase proper invitations were sent manually and through emails to the key company executives which are holding the high management posts of the company. Due to the limited resources, the executives present at the Works, Hassanabdal were contacted. However, it may be noted that the key executives on whom the performance of the company depends are located at Works. The site and sale offices only have sales personnel whose input was taken through emails. Moreover, two of the key project engineers from KSB

AG were also involved through video conferencing and their valuable input was also taken. The names and designations of the executives are withheld here on request.

b. *Preparation of orientation material:* As there was no mechanism for the knowledge based performance measurement as a whole in the company and especially in the design office, the audience had to be briefed and convinced about the importance and outcomes of the performance measurement. For this purpose, a brief presentation consisting of 30 slides was made which introduced and elaborated the different concepts in design management and its performance measurement. The presentation was backed up with printed material which described the design management and its performance measurement relatively in greater detail with referencing. Moreover, a case study of a UK based manufactured of bicycles was also included in the printed matter to further enhance the understanding and outcomes of implementing a performance measurement system in design.
c. *Collaboration with marketing dept:* The marketing department at Rawalpindi was contacted to obtain the data presented in Chapter 07 and to obtain input regarding the customer satisfaction in Punjab.
d. *Preparation of input templates:* The PERFORM matrix requires assessed input from the audience for the matter of producing results. A template was developed for this purpose so that every individual can provide his input on the concerning phase of the performance measurement procedure. The templates were also aimed for the sake of comparative analysis between the inputs of the different departmental heads. Moreover, the templates also held during the brainstorming session during which the inputs, outputs, goals and resources for the reference design project were finalized.
e. *Formation of supporting software in MS Excel ® 2003:* Numerous equations were defined in the previous chapters for the sake of developing the areas in which the improvement of performance is required. With only four goals four resources, there are 16 relations to be analyzed. The data gets huge as the number of goals and resources increase. Therefore, a solution template was also made during the preparation session so that the agreed inputs could be entered in the template and on spot results could be viewed. Standard built in formulas were used for the formulation of graphs.

8.1.3 Procedure

The introductory session was consisted of two phases during which the audience was briefed about design management and its benefits. Elaboration of the procedure is given in following sections. The audience was provided with the printed material which was prepared during preparation phase.

a. Orientation – First Session
    i. *Importance of PM in design:* The importance of performance measurement in design development was introduced to the company. The presentation comprised on the concept presented in the thesis in Chapter

02 & 03. The case studies in the chapters were also the part of the presentation.

ii. *Company standing:* The data collected from the marketing *department* during the preparation phase was presented before the audience to describe the current standing of the company. Moreover, the gray areas for the implementation of performance measurement in design and product development were also highlighted.

iii. *Threats from local and International manufacturers:* KSB Pakistan has been the sole manufacturer of Pumps since 1957. *Recently*, certain local and international manufacturers have been introduced into the market which is presenting sales and customer loss to the company. The idea here was to motivate the company executives to incorporate the concept of performance measurement as a competitive advantage to obtain increased sales growth and customer satisfaction.

After the session, feedback performance was given to the participants to obtain their comments about the session. The feedback confirmed that the participants had a principal agreement on the importance of the performance measurement in design development. It also identified that the participants were agreed for the implementation of the PERFORM approach.

b. Orientation – Second Session

i. *Introduction to PM Models:* State of the art performance *measurement* models were introduced to the participants during this phase. The session dominantly consisted of the models already presented in the thesis. The aim of this section was to elaborate the amount of research which has been the area of interest for the manufacturing concerns like the company itself.

ii. *Introduction to PERFORM:* During this section, the PERFORM *approach* was introduced to the participants for the sake of developing their understanding. The merits of the approach over the other models were also discussed and expected outcome of the approach was also discussed.

iii. *Presentation of a Case Study:* A case study of the PERFORM implementation was discussed in this section for the sake of developing a more through understanding of the procedure.

This session was followed by a question and answer session during which the questions of the audience regarding the implementation of PERFORM were discussed. The outcomes of these sessions are summarized as follows;

a. *Consensus on importance of PM in Design:* The participants principally agreed that there should be a performance measurement system in the design office.

b. *Clarification of models and their analytical abilities:* The participants were apprised on the nature and analytical abilities of the different models and their procedure of implementation and their expected outcomes.

c. *No PM system for design:* The participants also agreed that currently there was no performance measurement system in the design office. This identified the requirement of a performance measurement system in the design office.

8.2 PERFORM Adaptation

PERFORM is a complex procedural approach. A proper mechanism for the implementation and adaptation of the approach is suggested as a first case in any organization according to its specific needs. Following steps were devised during the adaptation of PERFORM at KSB.

8.2.1 Preparation

During the preparation phase, the participants were introduced that following steps will be carried out during the PERFORM application.

a. *Scope:* The scope of the analysis will be defined and finalized as discussed in chapter 04 of the thesis.
b. *Goals:* The over all goal and the subsequent goals will be defined in this phase.
c. *Priorities:* Goal priorities will be finalized and agreed in this phase.
d. *Resources:* The resources will be finalized similarly during this section.
e. *Assessment for actual and potential exploitation:* The impact of the resources on the goal---s will be identified and finalized. Moreover, the assessment for actual and potential expectation of the goals will also be finalized during this phase.

8.2.2 Data Collection

Data was collected on the templates prepared during the preparation phase. A comparative study was made on different inputs. The participants had to provide separate inputs on each phase of the process. This was followed by a brainstorming session in which every aspect was finalized and agreed. The agreed data is presented in the following sections;

a. Selected Technical Data of IEZ-425: The selected technical data of the project is presented in Table 8.1. An expert from the basic engineering of the project is summarized in Fig. 8.2 to elaborate the working of the design office.

Design Aspect	**Value**
Order number	IEZ – 425
Project	Djerdap III, Gaj Nova
Pump type and size	PNW PB4 400 – 350
Discharge	400 l/s = 1440 m3/hr
Stage Head	6.82 m
Efficiency	78
Motor power	45 kW
Motor speed	1470 min-1
Nominal speed	1465 min-1
P/n Ratio	0.031
Blade Angle	10°
Material combination	02
Mounting arrangement	CD
Bearing arrangement	3
Setting depth	ET (mm) = 4630

Table 8.1 Selected Data of IEZ-425

Pump shaft max. length (ZN 961) = $\sqrt{\frac{11\times10^6\times d(cm)}{n\times2}}$ = $\sqrt{\frac{11\times10^6\times6}{1465\times2}}$

= 150.08cm = 1500 mm

Column & Top Shaft max. length (ZN 961) = $\sqrt{\frac{11\times10^6\times d(cm)}{n\times1.3}}$ = $\sqrt{\frac{11\times10^6\times4}{1465\times1.3}}$

= 151.9 cm = 1519 mm

Flender coupling selected = B180
Ref. Flender Catalogue
For P/n = 0.031
Motor stub shaft Ø = 60

Residur bearing required = C35 (1 x 1 x 2) + 2 (spare)
C45 (1 x 1 x 2) + 2 (spare)
C55 (1 x 1 x 2) + 2 (spare)

Angular contact ball bearing = 7218 BE (1 x 1 x 2) + 2 (spare)
Ref. Bearing Calculation Sheet

Cylindrical coupling selected = Cylindrical coupling 35 for P/n = 0.031 (ZN 961)

Additional requirements
PT 100 = Length 170
Pressure gauge = 0-1 Bar, 160mm, G1/2

Figure 8.2 Basic Engineering for IEZ-425

b. *Inputs of the Design Process*: The inputs of the design process are tabulated in Table 8.2. The inputs are classified as Design Inputs (DI) and Design Activity Inputs (DAI) as desired by the model.

c. *Outputs of the Design Process*: The outputs of the design process are tabulated in Table 8.3. The outputs are classified as Design Outputs (DO) and Design Activity Outputs (DAO) as desired by the model.

		Design Outputs(DO)
S.No	**Representation**	**Description**
1.	DO 1	Design brief (as specified by customer)
2.	DO 2	Technical feasibility
3.	DO 3	Estimated price
		Design Activity Outputs (DAO)
S.No	**Representation**	**Description**
1.	DAO 1	Time elapsed

Table 8.2 Design Process Outputs

d. *Design Goals and Priorities:* The goals of the design process are tabulated in Table 8.4. The Goals are classified as Design Goals (DG) and Design Activity Goals (DAG) as desired by the model. The agreed priorities of the respective goals are mentioned after them in parenthesis. The priorities and weights are with reference to Table 6.1.

		Design Goals (DG)
S.No	**Representation**	**Description**
1.	DG 1	Cosmetic appearance (L)
2.	DG 2	Technically feasible (H)
3.	DG 3	Price within range (L)
4.	DG 4	Serve customer needs (M)
5.	DG 5	Grow expertise within department (M)
6.	DG 6	Meet / Exceed Performance targets (M)
7.	DG 7	Maintain quality standard as defined by MBK (H)
8.	DG 8	Form relations in Gaj Nova for future orders (L)
		Design Activity Goal (DAG)
1.	DAG 1	Complete within 7 days (M)
2.	DAG 2	Increase profit (L)

Table 8.3 Design Process Goals

e. *Design Resources:* The resources of the design process are tabulated in Table 8.5. It is assumed here that the same designer is responsible for the design goal and the design activity goal. Therefore, the resources are not classified as design resources and design activity resources. Instead common design resources are devised here. The resources are further classified in five groups i.e. Communication, Expertise, Management, IT Systems and Manufacturing. The company has separate areas of expertise in the mentioned groups.

Design Resource Group: Communication (DR 1)

S. No	Representation	Description
1.	R 1.1	Technical team meetings
2.	R 1.2	Product brochures
3.	R 1.3	MBK group support
	Design Resource Group: Expertise (DR 2)	
S.No	**Representation**	**Description**
1.	R 2.1	Hydraulics
2.	R 2.2	Pump design
3.	R 2.3	Flow induced vibrations
4.	R 2.4	CAD / CAM
5.	R 2.5	Project management
6.	R 2.6	Risk management
7.	R 2.7	Documentation
8.	R 2.8	After sales service
	Design Resource Group: Management (DR 3)	
S.No	**Representation**	**Description**
1.	R 3.1	Team management
2.	R 3.2	Knowledge management
3.	R 3.3	COMET
4.	R 3.4	Quality management system (QMS)
5.	R 3.5	Life cycle management (LCM)
6.	R 3.6	Supply chain management (SCM)
	Design Resource Group: IT Systems (DR 4)	
S.No	**Representation**	**Description**
1.	R 4.1	Hardware
2.	R 4.2	CAD Software
3.	R 4.3	ERP Software
4.	R 4.4	Technical Data Pack (TDP)
	Design Resource Group: Manufacturing (DR 5)	
1.	R 5.1	Foundry
2.	R 5.2	CNC group
3.	R 5.3	Conventional group
4.	R 5.4	Tooling
5.	R 5.5	Assembly line
6.	R 5.6	Testing and qualification

Table 8.4 Design Resources

8.3 Conclusion

In the above sections a preliminary formulation for the adaptation of PERFORM at KSB Pumps Co. Ltd. has been developed. The material presented above is a result of repeated brainstorming sessions till two days. The input of the participants is out of the scope of this thesis and is withheld with the company. The company executives agreed upon the above information on the sake of simplicity and learning purposes. The next chapter will address the input of data to the PERFORM matrix, its analysis and selected results

Chapter 9
RESULTS AND CONCLUSIONS

9.1 Introduction

The previous chapter presented the basic formulation for the implementation of PERFORM to a selected project. This chapter will present the final shape of PERFORM matrix after the input from the users and hence the analysis and the selected results. The process diagram of this chapter is shown in Fig. 9.1.

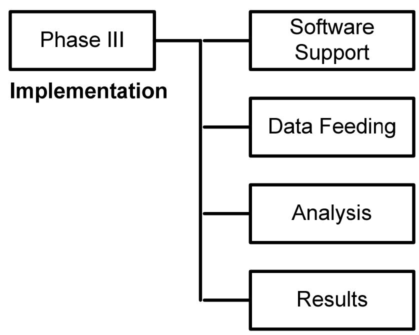


Figure 9.1 Phase-III Implementation

9.2 Software Support

Microsoft Excel ® 2003 was used as the basis for calculation of the analytical parameters of PERFORM. Simplified MS Excel formulae and templates were used to develop the measures defined in Chapter 6. The software was also used to calculate the customized graphs for thorough understanding of the results. The sheets of the workbook were interlinked so that if an impact of the resource were to be changed, the final results would be automatically updated. This was particularly useful to introduce and demonstrate the effect of resources on the goals. Participants requested for certain changes for the analysis purposes and the results were shown to them in a typical time of 10 minutes.

9.3 Data Feeding

After the agreement of the participants was obtained on the goals, resources, weights and priorities, the data was transferred to the Excel sheet. The finalized form of the Excel sheet is presented in Table 9.1. The numerical shape of the matrix is also shown in Table 9.2

It can be seen that the goals are defined separately while the resources are defined in resource groups as discussed in Chapter 08. The agreed impact values were then entered into the template. The template in return provided results as graphs which will be used to analyze the output. The software form of the reference template is also provided in a CD with the thesis.

				Goals									
Goal Priority (W)				L	H	L	M	M	M	H	L	M	L
Resources	Ease, E	Potential Degree of Exploitation, Ex(pt) %	Actual Degree of Exploitation, Ex(al) %	Cosmetic Appearance	Technical Feasibility	Price within Range	Customer Needs	Growth in Departmental Expertise	Meet Performance Targets	Quality Standard (MBK)	Relation Formation	Time (7 Days)	Increase Profit
Communication													
Technical team meetings	M	70	50	M	H	L	L	M	H	L	L	M	M
Product brochures	L	50	20	M	L	L	L	L	L	L	H	L	H
MBK group support	M	100	70	L	H	L	M	L	L	M	H	L	M
Expertise													
Hydraulics	M	100	60	M	H	L	H	M	H	M	L	L	L
Pump design	H	100	70	M	H	M	H	M	H	M	L	L	L
Flow induced vibrations	L	100	50	M	H	L	H	M	H	M	L	L	L
CAD / CAM	M	100	70	H	H	M	H	M	H	M	H	M	L
Project management	H	80	50	L	M	M	M	H	H	L	H	H	M
Risk management	M	80	40	L	M	M	M	H	H	L	H	H	H
Documentation	L	70	30	M	H	L	M	M	L	H	H	M	L
After sales service	M	100	70	M	H	L	H	L	L	H	H	L	H
Management													
Team management	M	100	70	M	H	L	M	M	H	L	L	H	H
Knowledge management	L	50	20	L	H	M	L	M	M	L	L	M	H
COMET	L	50	40	L	L	L	M	H	H	H	L	H	L
QMS	M	70	20	L	M	L	H	L	H	H	H	L	H
LCM	L	70	20	L	L	M	L	M	H	H	H	L	L
SCM	M	70	50	M	H	M	H	M	H	L	L	H	H
IT Systems													
Hardware	M	50	40	H	H	L	L	M	H	L	M	L	L
CAD Software	L	80	50	H	H	M	M	H	H	L	L	M	L
ERP Software	L	50	40	L	L	M	M	H	H	H	L	M	H
TDP	M	100	60	M	H	L	H	M	L	H	H	L	L
Manufacturing													
Foundry	H	100	50	H	H	M	L	M	M	H	L	M	L
CNC group	M	100	60	H	H	H	L	M	M	H	L	M	M
Conventional group	L	100	70	L	M	L	L	M	L	H	L	M	L
Tooling	H	100	60	H	H	H	M	L	H	H	M	M	H
Assembly line	M	100	80	M	H	L	L	M	L	M	L	M	L
Testing and qualification	H	100	50	L	H	H	H	L	H	H	H	M	L

Table 9.1 Final Shape of PERFORM Matrix

				Goals									
Goal Priority (W)				1	5	1	3	3	3	5	1	3	1
Resources	Ease, E	Potential Degree of Exploitation, Ex(pt) %	Actual Degree of Exploitation, Ex(al) %	Cosmetic Appearance	Technical Feasibility	Price within Range	Customer Needs	Growth in Departmental Expertise	Meet Performance Targets	Quality Standard (MBK)	Relation Formation	Time (7 Days)	Increase Profit
Communication													
Technical team meetings	3	70	50	3	9	1	1	3	9	1	1	3	3
Product brochures	1	50	20	3	1	1	1	1	1	1	9	1	9
MBK group support	3	100	70	1	9	1	3	1	1	3	9	1	3
Expertise													
Hydraulics	3	100	60	3	9	1	9	3	9	3	1	1	1
Pump design	5	100	70	3	9	3	9	3	9	3	1	1	1
Flow induced vibrations	1	100	50	3	9	1	9	3	9	3	1	1	1
CAD / CAM	3	100	70	9	9	3	9	3	9	3	9	3	1
Project management	5	80	50	1	3	3	3	9	9	1	9	9	3
Risk management	3	80	40	1	3	3	3	9	9	1	9	9	9
Documentation	1	70	30	3	9	1	3	3	1	9	9	3	1
After sales service	3	100	70	3	9	1	9	1	1	9	9	1	9
Management													
Team management	3	100	70	3	9	1	3	3	9	1	1	9	9
Knowledge management	1	50	20	1	9	3	1	3	3	1	1	3	9
COMET	1	50	40	1	1	1	3	9	9	9	1	9	1
QMS	3	70	20	1	3	1	9	1	9	9	9	1	9
LCM	1	70	20	1	1	3	1	3	9	9	9	1	1
SCM	3	70	50	3	9	3	9	3	9	1	1	9	9
IT Systems													
Hardware	3	50	40	9	9	1	1	3	9	1	3	1	1
CAD Software	1	80	50	9	9	3	3	9	9	1	1	3	1
ERP Software	1	50	40	1	1	3	3	9	9	9	1	3	9
TDP	3	100	60	3	9	1	9	3	1	9	9	1	1
Manufacturing													
Foundry	5	100	50	9	9	3	1	3	3	9	1	3	1
CNC group	3	100	60	9	9	9	1	3	3	9	1	3	3
Conventional group	1	100	70	1	3	1	1	3	1	9	1	3	1
Tooling	5	100	60	9	9	9	3	1	9	9	3	3	9
Assembly line	3	100	80	3	9	1	1	3	1	3	1	3	1
Testing and qualification	1	100	50	1	9	9	9	1	9	9	9	3	1

Table 9.2 The Numerical Shape of PERFORM Matrix

9.4 Analysis

Selected analysis graphs from each measure are presented in this section. These measures were introduced in Chapter 06 of this thesis.

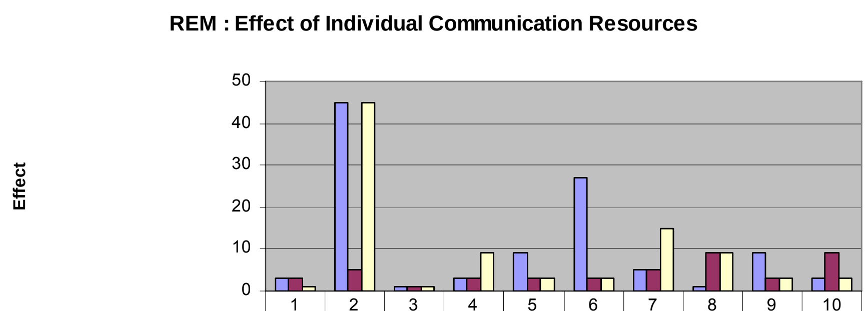
9.4.1 Measure 1: REM

The resource effectiveness measure of the technique was applied through the matrix across the overall goal for individual resources to obtain the graphs shown in Fig. 9.2 – 9.6. It can be seen that 45 is the highest ranking amongst the effectiveness values.

Resources with Highest Effectiveness Rating (45)	Technical Feasibility	Quality Standard (MBK)
Communication		
Technical team meetings	X	-
MBK group support	X	-
Expertise		
Hydraulics	X	-
Pump design	X	-
Flow induced vibrations	X	-
CAD / CAM	X	-
Documentation	X	X
After sales service	X	X
Management		
Team management	X	-
Knowledge management	X	-
COMET	-	X
QMS	-	X
LCM	-	X
SCM	X	-
IT Systems		
Hardware	X	-
CAD Software	X	-
ERP Software	-	X
TDP	X	X
Manufacturing		
Foundry	X	X
CNC group	X	X
Conventional group	-	X
Tooling	X	X
Assembly line	X	-
Testing and qualification	X	X

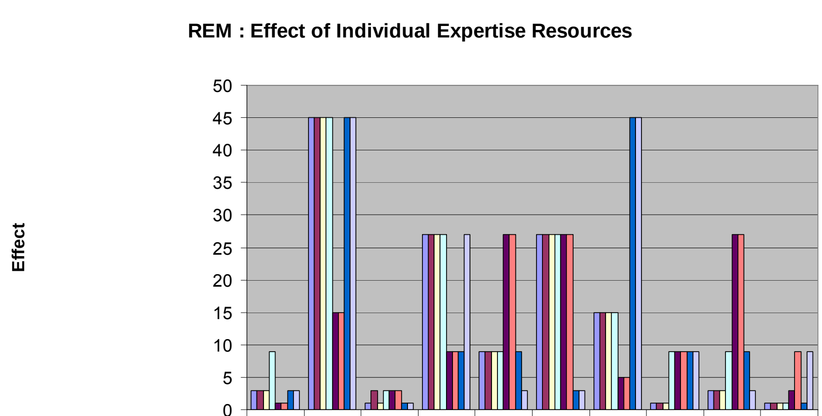
Table 9.3 Resources Having Highest Effectiveness as per REM on Individual Goals

Table 9.3 shows the parameters which attain the highest ranking of 45 against the organizational performance standards. An 'X' has been placed in front of the resources which affect the goals to the highest level. It can be easily seen that the Technical Feasibility and Quality Standard (MBK) are affected the most through resources. This shows the effectiveness and importance of the measures with respect to the predefined goals of the organization.



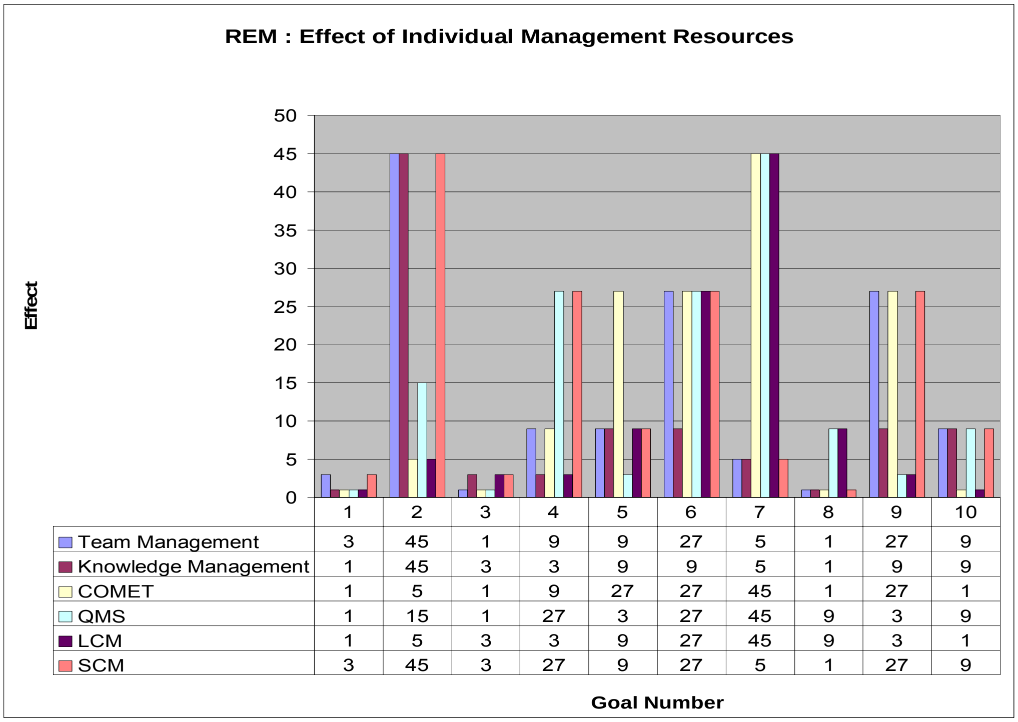
Goal Number	1	2	3	4	5	6	7	8	9	10
Technical Team Meetings	3	45	1	3	9	27	5	1	9	3
Product Brochures	3	5	1	3	3	3	5	9	3	9
MBK Group Support	1	45	1	9	3	3	15	9	3	3

Figure 9.2 REM: Effect of Individual Communication Resources



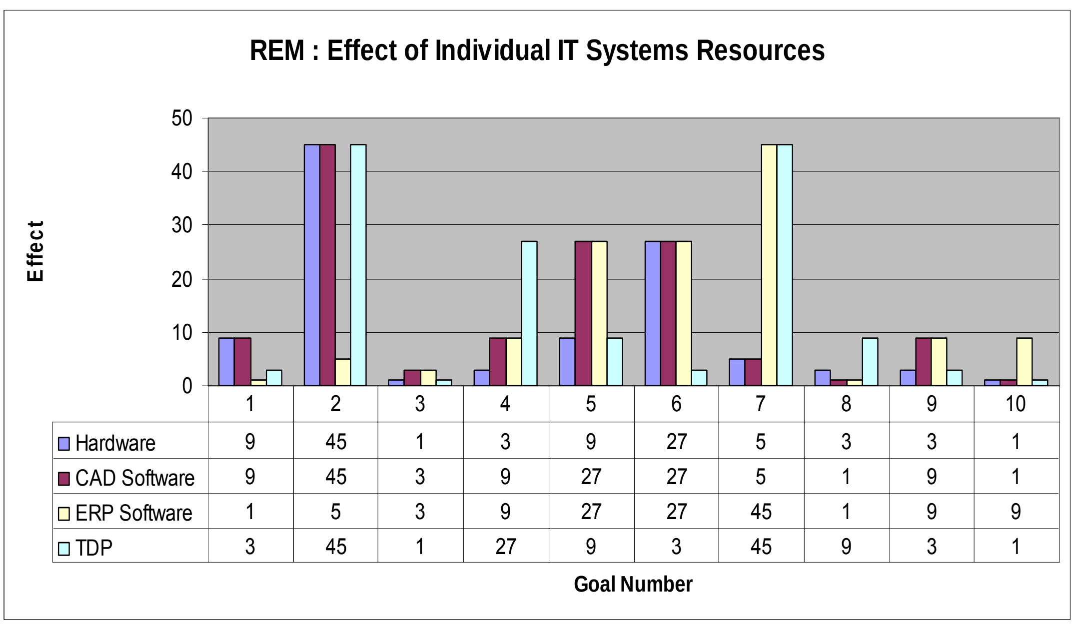
Goal Number	1	2	3	4	5	6	7	8	9	10
Hydraulics	3	45	1	27	9	27	15	1	3	1
Pump Design	3	45	3	27	9	27	15	1	3	1
Flow Induced Vibrations	3	45	1	27	9	27	15	1	3	1
CAD / CAM	9	45	3	27	9	27	15	9	9	1
Project Management	1	15	3	9	27	27	5	9	27	3
Risk Management	1	15	3	9	27	27	5	9	27	9
Documentation	3	45	1	9	9	3	45	9	9	1
After Sales Services	3	45	1	27	3	3	45	9	3	9

Figure 9.3 REM: Effect of Individual Expertise Resources



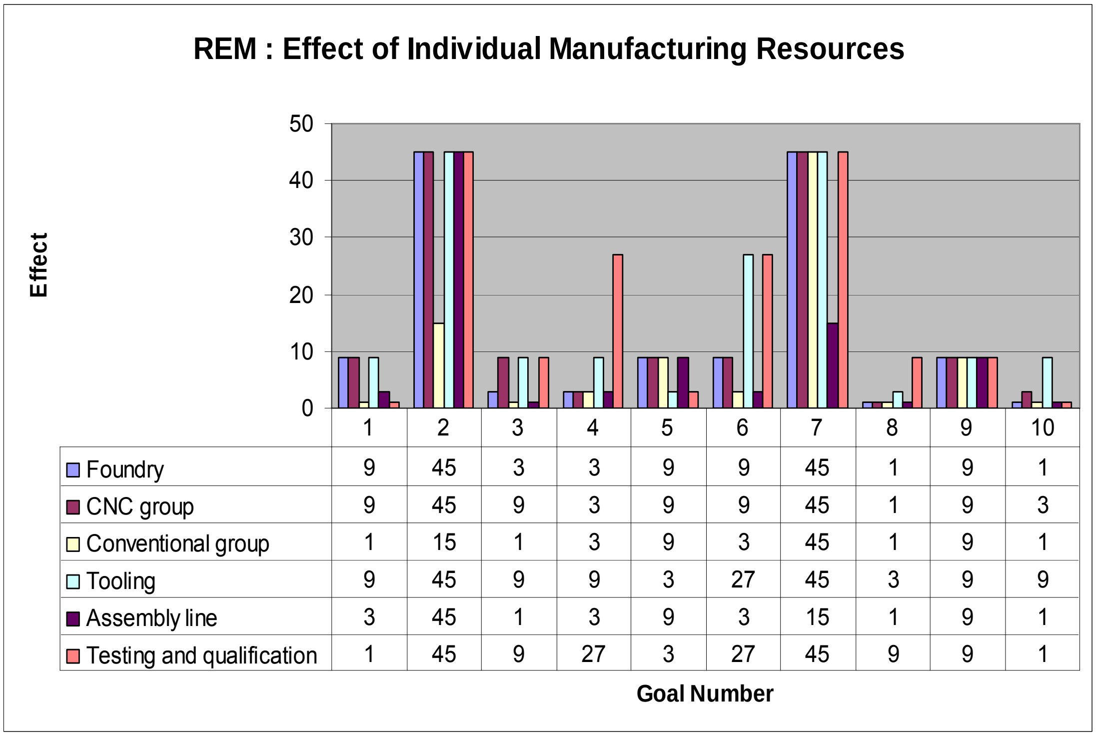
Goal Number	1	2	3	4	5	6	7	8	9	10
Team Management	3	45	1	9	9	27	5	1	27	9
Knowledge Management	1	45	3	3	9	9	5	1	9	9
COMET	1	5	1	9	27	27	45	1	27	1
QMS	1	15	1	27	3	27	45	9	3	9
LCM	1	5	3	3	9	27	45	9	3	1
SCM	3	45	3	27	9	27	5	1	27	9

Figure 9.4 REM: Effect of Individual Management Resources



Goal Number	1	2	3	4	5	6	7	8	9	10
Hardware	9	45	1	3	9	27	5	3	3	1
CAD Software	9	45	3	9	27	27	5	1	9	1
ERP Software	1	5	3	9	27	27	45	1	9	9
TDP	3	45	1	27	9	3	45	9	3	1

Figure 9.5 REM: Effect of Individual IT Systems Resources



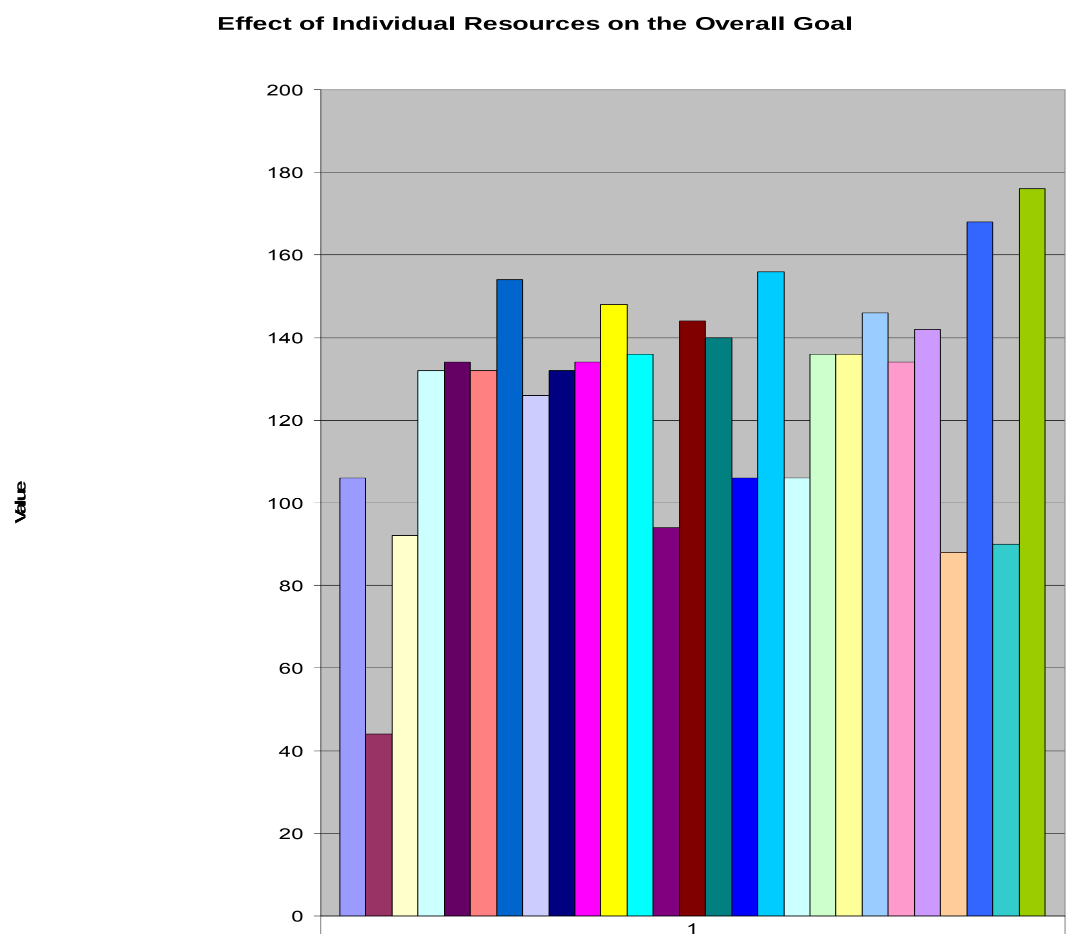
Goal Number	1	2	3	4	5	6	7	8	9	10
Foundry	9	45	3	3	9	9	45	1	9	1
CNC group	9	45	9	3	9	9	45	1	9	3
Conventional group	1	15	1	3	9	3	45	1	9	1
Tooling	9	45	9	9	3	27	45	3	9	9
Assembly line	3	45	1	3	9	3	15	1	9	1
Testing and qualification	1	45	9	27	3	27	45	9	9	1

Figure 9.6 REM: Effect of Individual Manufacturing Resources

9.4.2 Measure 2: AM1

This measure compares the effectiveness of separate resources against the overall goal of the enterprise. The results of the calculations are shown in the form of a graph in Fig. 9.7. It can be easily seen that the testing and qualification of the equipment to conform the quality standards as specified by the MbK has gained the highest ranking of 176, whereas the tooling used in the manufacturing of the product has gained the rating of 168. Moreover, the CAD / CAM facility of the organization has gained the highest ranking in the expertise resource group.

This measure can be used to identify the individual resource which is contributing the maximum to the overall goal of the organization. It proves helpful in increasing, managing and effectively utilizing the most effective resource as identified by this measure. Moreover, the management can pull this resource for maximum output so that maximum performance can be achieved. Optimization of the resource utilization may be required if it is desired to maximize more than one resource.



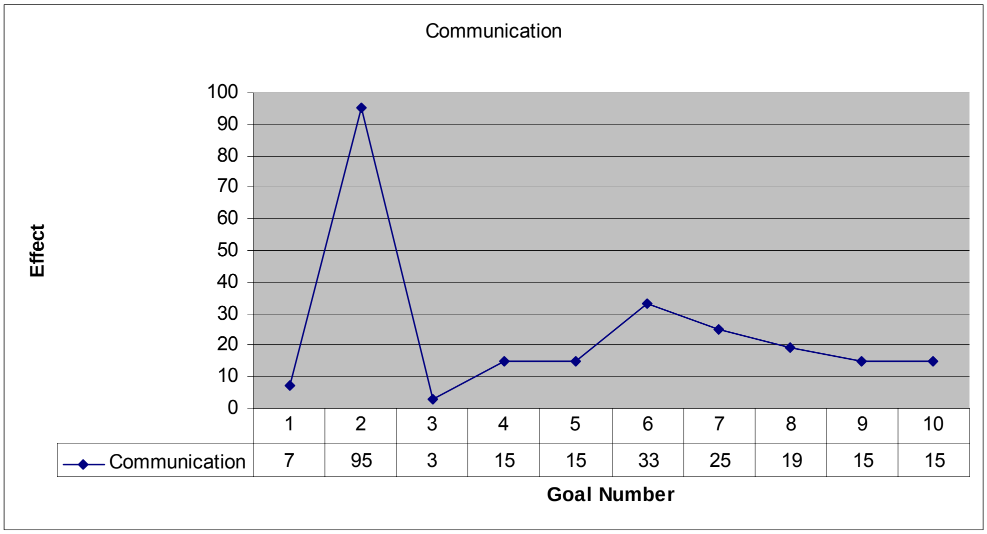
	1
Technical team meetings	106
Product brochures	44
MBK group support	92
Hydraulics	132
Pump design	134
Flow induced vibrations	132
CAD / CAM	154
Project management	126
Risk management	132
Documentation	134
After sales service	148
Team management	136
Knowledge management	94
COMET	144
QMS	140
LCM	106
SCM	156
Hardware	106
CAD Software	136
ERP Software	136
TDP	146
Foundry	134
CNC group	142
Conventional group	88
Tooling	168
Assembly line	90

Resources

Figure 9.7 Effect of Individual Resources on Overall Goal

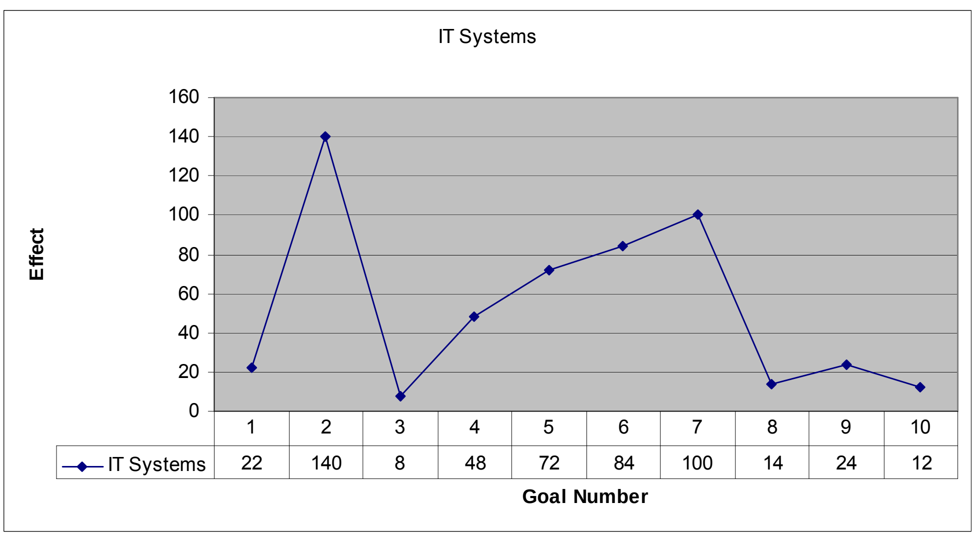
9.4.3 Measure 3: AM 2

This measure shows the effectiveness of individual resource groups on the individual goals i.e. the resources are viewed here as resource groups whereas the goals are considered as individual goals. Individual resource elements of the resource groups and their effect can also be observed in the graphs. The results of the measures are presented in Figs. 9.8 – 9.12. The total impact as per this measure is also shown in Fig. 9.13.



Goal Number	1	2	3	4	5	6	7	8	9	10
Communication	7	95	3	15	15	33	25	19	15	15

Figure 9.8 Effect of Communication Resource Group on Individual Goals



Goal Number	1	2	3	4	5	6	7	8	9	10
IT Systems	22	140	8	48	72	84	100	14	24	12

Figure 9.9 Effect of IT Systems Resource Group on Individual Goals

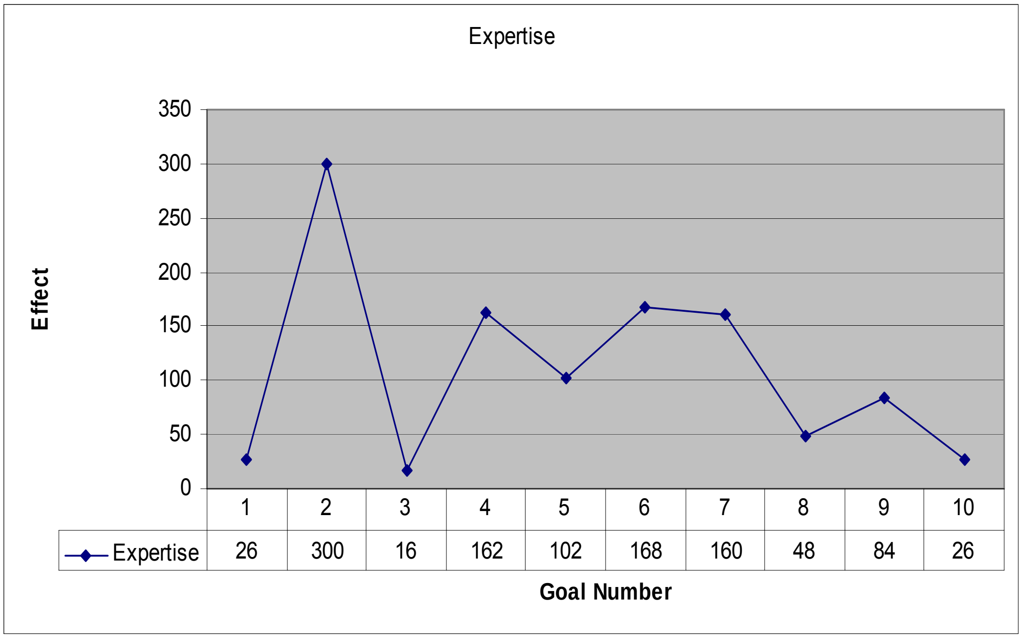


Figure 9.10 Effect of Expertise Resource Group on Individual Goals

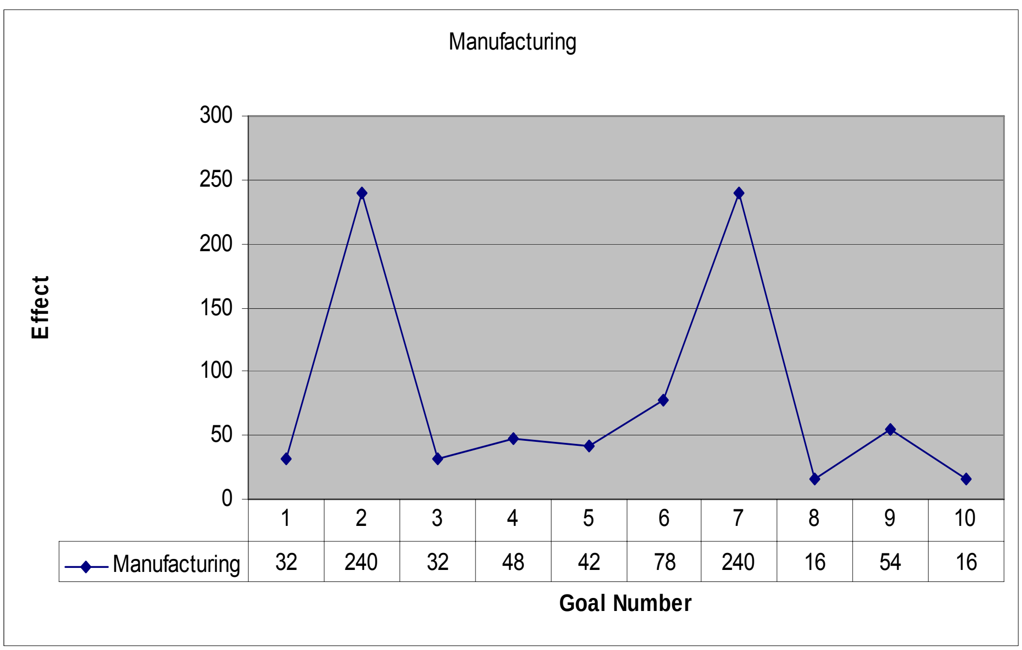


Figure 9.11 Effect of Manufacturing Resource Group on Individual Goals

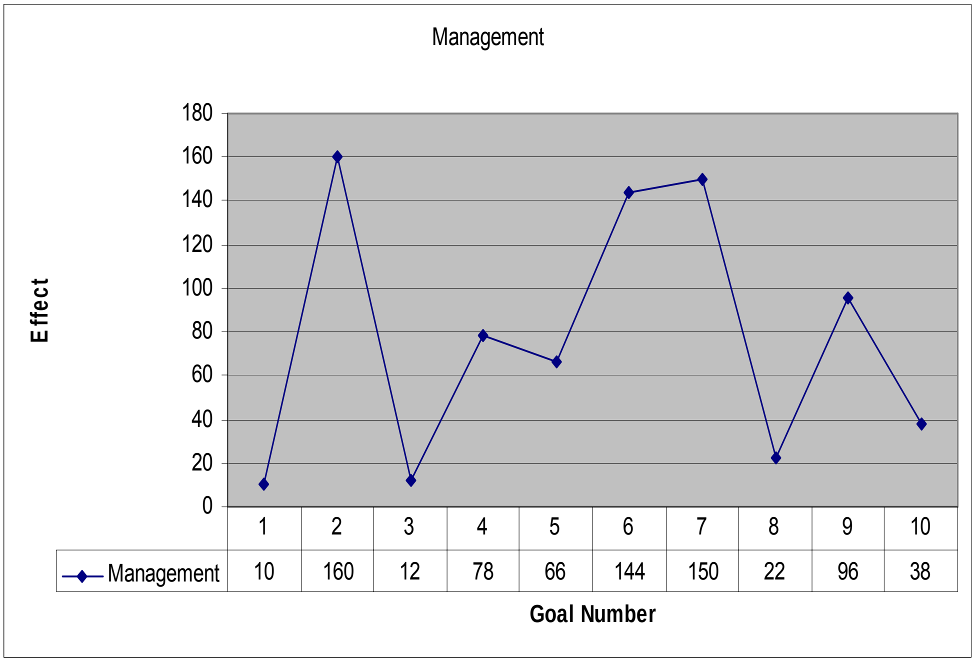


Figure 9.12 Effect of Management Resource Group on Individual Goals

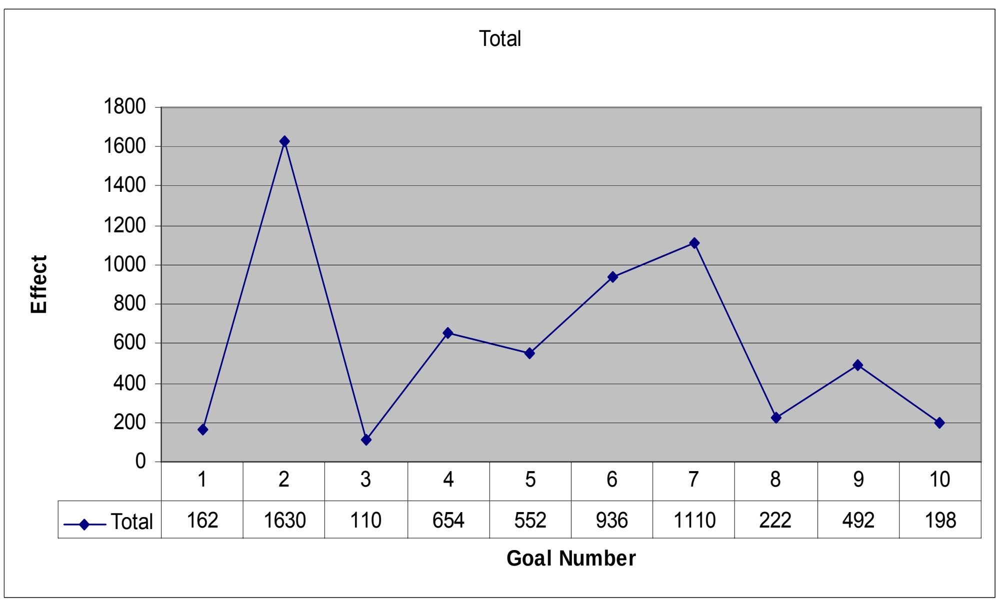


Figure 9.13 Effect of Total Resources on Individual Goals

The trends of Figs. 9.8 – 9.12 shows that the goal Technical Feasibility is the most affected aspect by each resource group. The management may consider revising the resource allocation through this measure so as to shift the overall impact of the resource groups to another goal. Fig. 9.13 supplements the fact that goal number 2 is the most affected by the overall resources by obtaining 1630 rating. Goal number 7 stands second by obtaining 1110 grade.

9.4.4 Measure 4: AM 3

This measure shows the effectiveness of the resource groups on the overall goal. The results of this calculation are shown in the form of a graph in Fig. 9.14. It can be easily seen that the resource group number 2 i.e. Expertise has the maximum affect on the overall goal. The expertise of the company has indeed put in the place where it stands today. The effectiveness of the expertise is far higher than any of the resource groups. The management can again pull the same resource group to obtain even more effectives or attention may be diverted to the resource groups presenting less outputs. This is the last measure of the AM group.

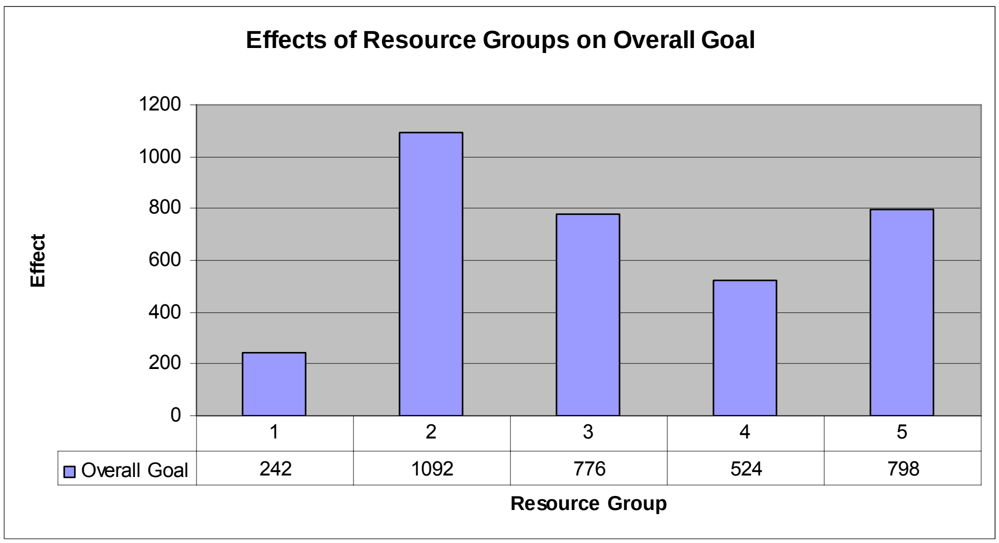
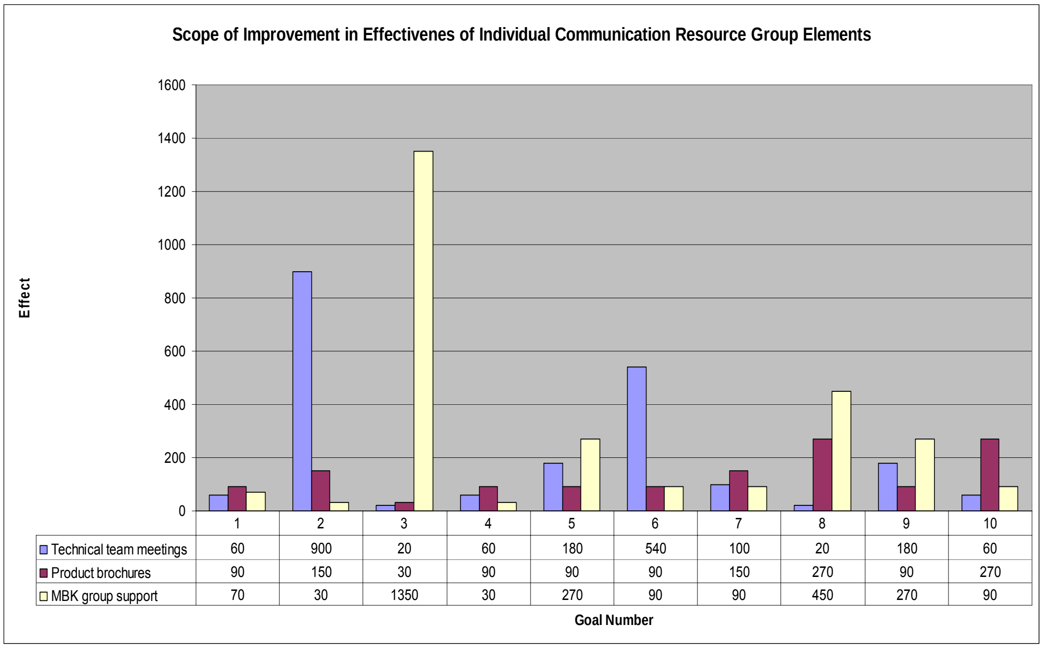


Figure 9.14 Effects of Resource Groups on Overall Goal

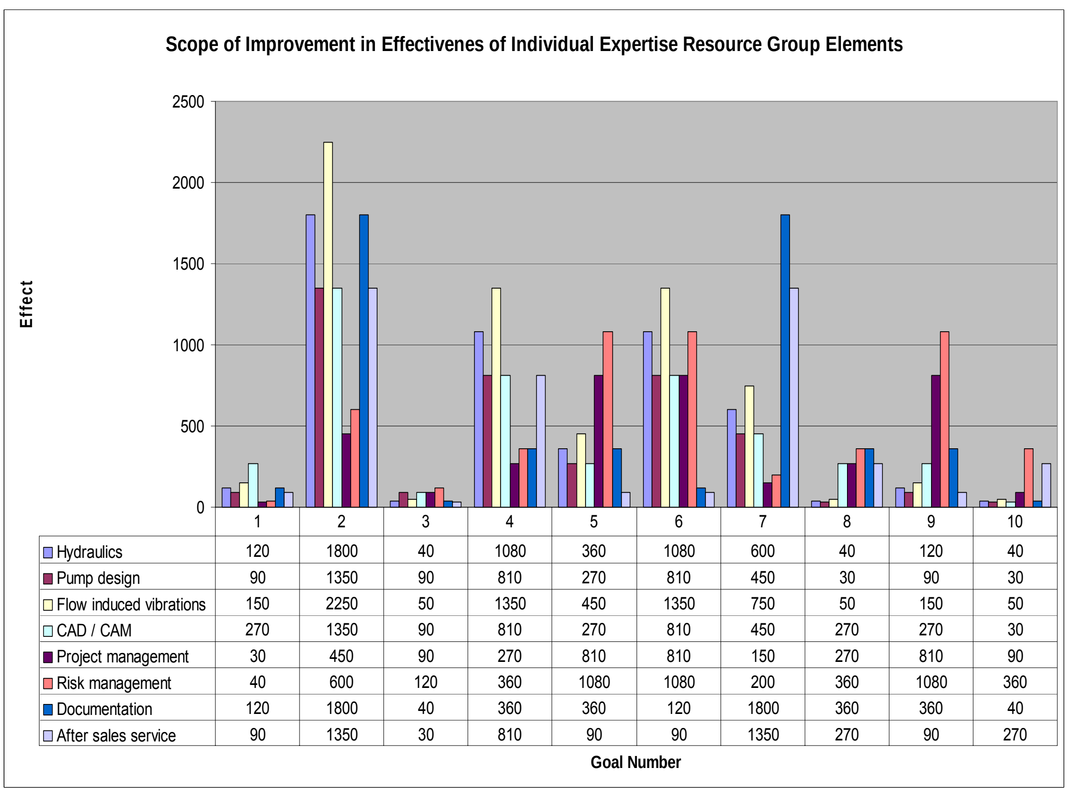
9.4.5 Measure 5: IM 1

This measure provides the difference between the actual and potential effectiveness to identify the room and impact of improvement after the exploitation of resources to the potential level and the resources when used in original (cost, manpower etc) to do so. The mentioned difference is calculated for each individual resource group for each goal. The results are shown in Figs. 9.15 – 9.19.



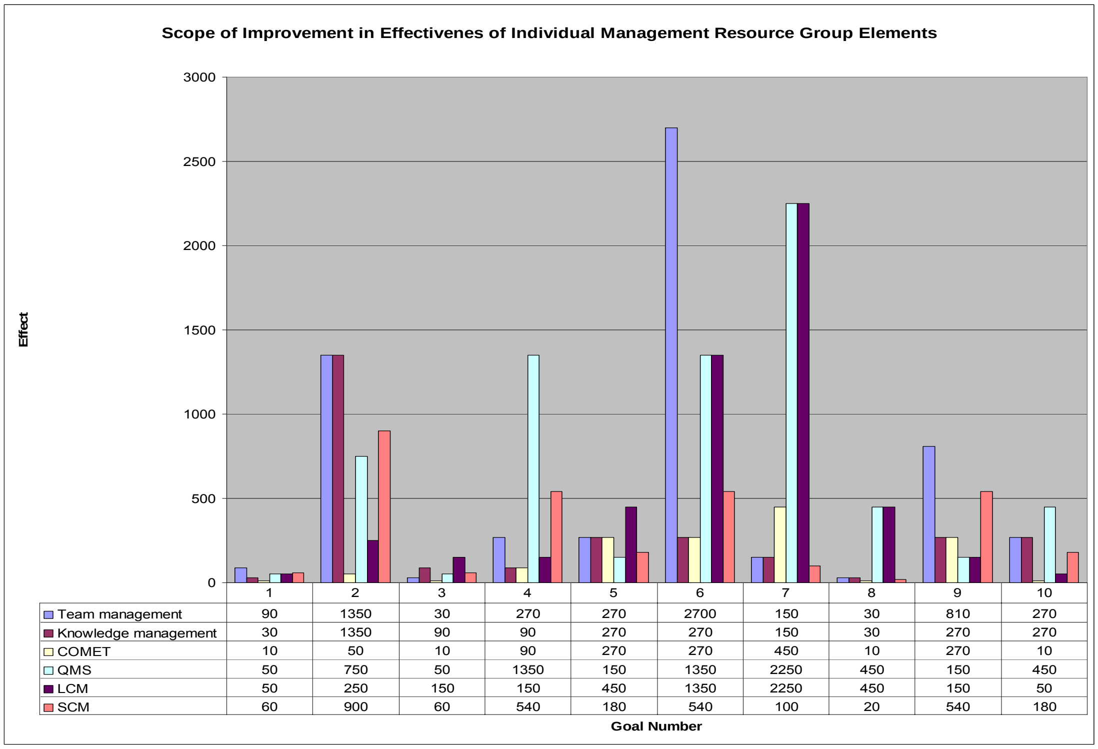
	1	2	3	4	5	6	7	8	9	10
Technical team meetings	60	900	20	60	180	540	100	20	180	60
Product brochures	90	150	30	90	90	90	150	270	90	270
MBK group support	70	30	1350	30	270	90	90	450	270	90

Figure 9.15 Scope of Improvement in Effectiveness of Individual Communications Resource Group Elements



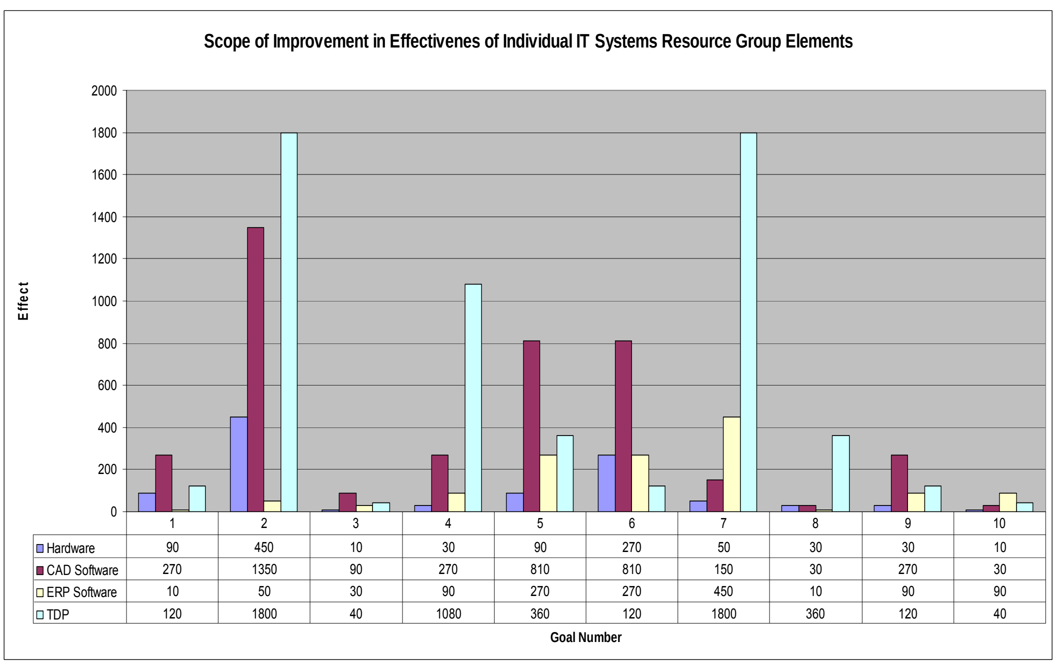
	1	2	3	4	5	6	7	8	9	10
Hydraulics	120	1800	40	1080	360	1080	600	40	120	40
Pump design	90	1350	90	810	270	810	450	30	90	30
Flow induced vibrations	150	2250	50	1350	450	1350	750	50	150	50
CAD / CAM	270	1350	90	810	270	810	450	270	270	30
Project management	30	450	90	270	810	810	150	270	810	90
Risk management	40	600	120	360	1080	1080	200	360	1080	360
Documentation	120	1800	40	360	360	120	1800	360	360	40
After sales service	90	1350	30	810	90	90	1350	270	90	270

Figure 9.16 Scope of Improvement in Effectiveness of Individual Expertise Resource Group Elements



	1	2	3	4	5	6	7	8	9	10
Team management	90	1350	30	270	270	2700	150	30	810	270
Knowledge management	30	1350	90	90	270	270	150	30	270	270
COMET	10	50	10	90	270	270	450	10	270	10
QMS	50	750	50	1350	150	1350	2250	450	150	450
LCM	50	250	150	150	450	1350	2250	450	150	50
SCM	60	900	60	540	180	540	100	20	540	180

Figure 9.17 Scope of Improvement in Effectiveness of Individual Management Resource Group Elements



	1	2	3	4	5	6	7	8	9	10
Hardware	90	450	10	30	90	270	50	30	30	10
CAD Software	270	1350	90	270	810	810	150	30	270	30
ERP Software	10	50	30	90	270	270	450	10	90	90
TDP	120	1800	40	1080	360	120	1800	360	120	40

Figure 9.18 Scope of Improvement in Effectiveness of Individual IT Systems Resource Group Elements

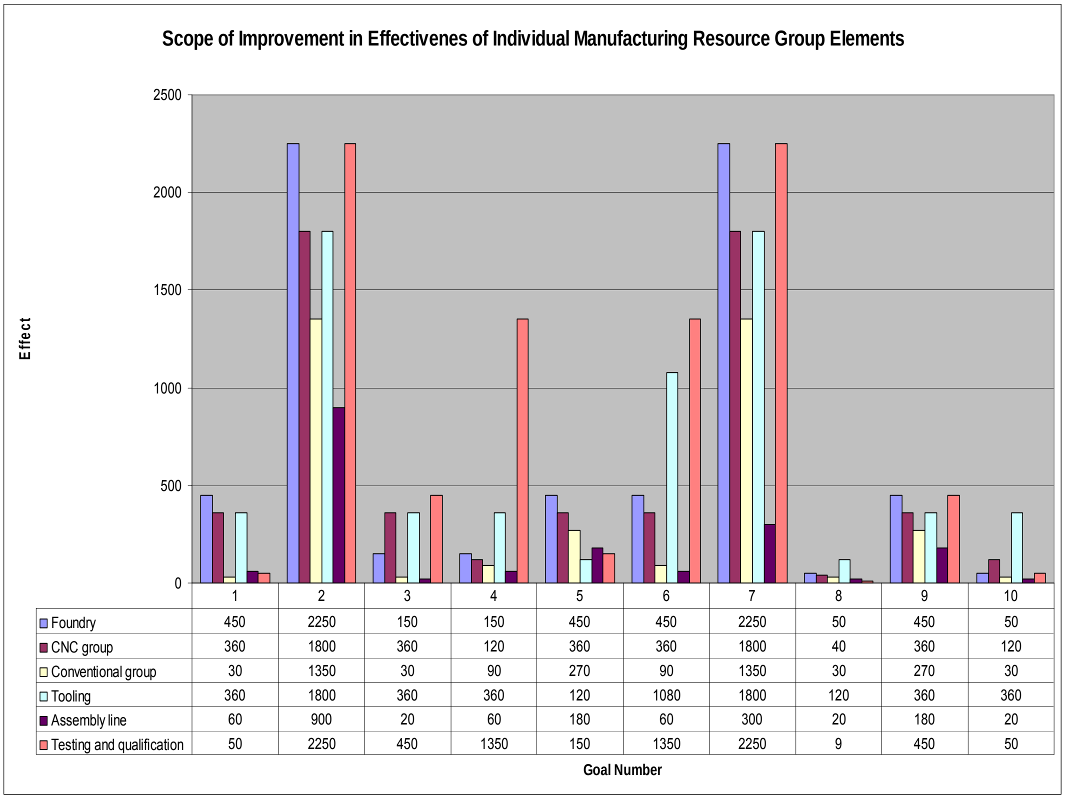


Figure 9.19 Scope of Improvement in Effectiveness of Individual Manufacturing Resource Group Elements

The results of this measure are summarized in Table 9.4. It can be seen that although the Expertise and Manufacturing groups contributed highest towards the overall goal as per AMs, most room of improvement is present in them. Flow induced vibrations, Foundry and Testing & qualification have the highest value for improvement, with respect to goals 2 & 7.

S. No.	Resource Group Name	Individual Resource Name	With respect to Goal Number	Value
1.	Communications	MbK	3	1350
2.	Expertise	Flow induced vibrations	2	2250
3.	Management	Team management	6	2700
4.	IT Systems	TDP	2 & 7	1800
5.	Manufacturing	Foundry and Testing & qualification	2 & 7	2250

Table 9.4 Room for Improvement in Individual Resources With Respect to Individual Goals

9.4.6 Measure 6: IM 2

This measure presents the difference between the potential and actual effectiveness and identifies the room for improvement with reference to a specific resource in relation to a higher level goal and hence cost of improvement can be calculated. This is a very useful measure as it gives the overall picture of the process to the enterprise. The results of this calculation are shown in Fig. 9.20. It can be seen that the highest room for improvement is in the resource number 27 i.e. Testing and qualification, the value being 8800. This also shows the strongest potential area for improvement i.e., resource number 18. Management gets a clear view of the room of improvement for each resource in this graph. Optimization is again suggested if it is desired to improve more than one resource.

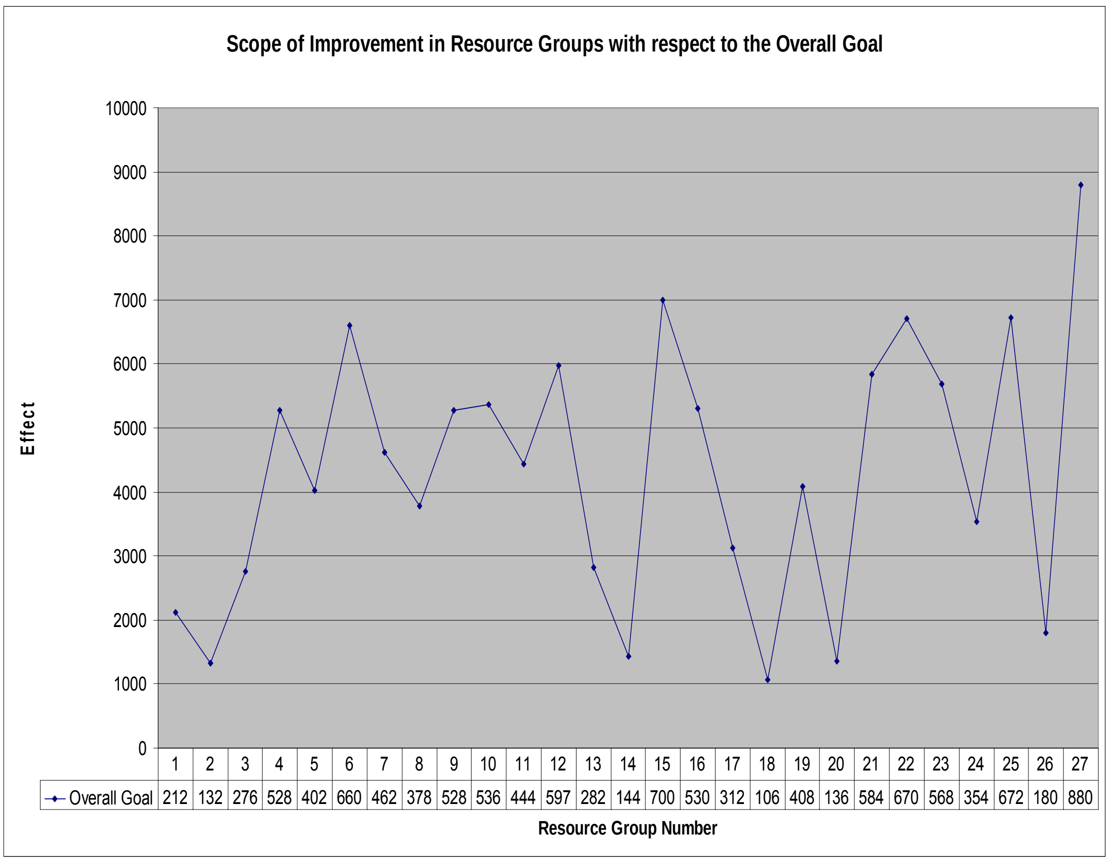
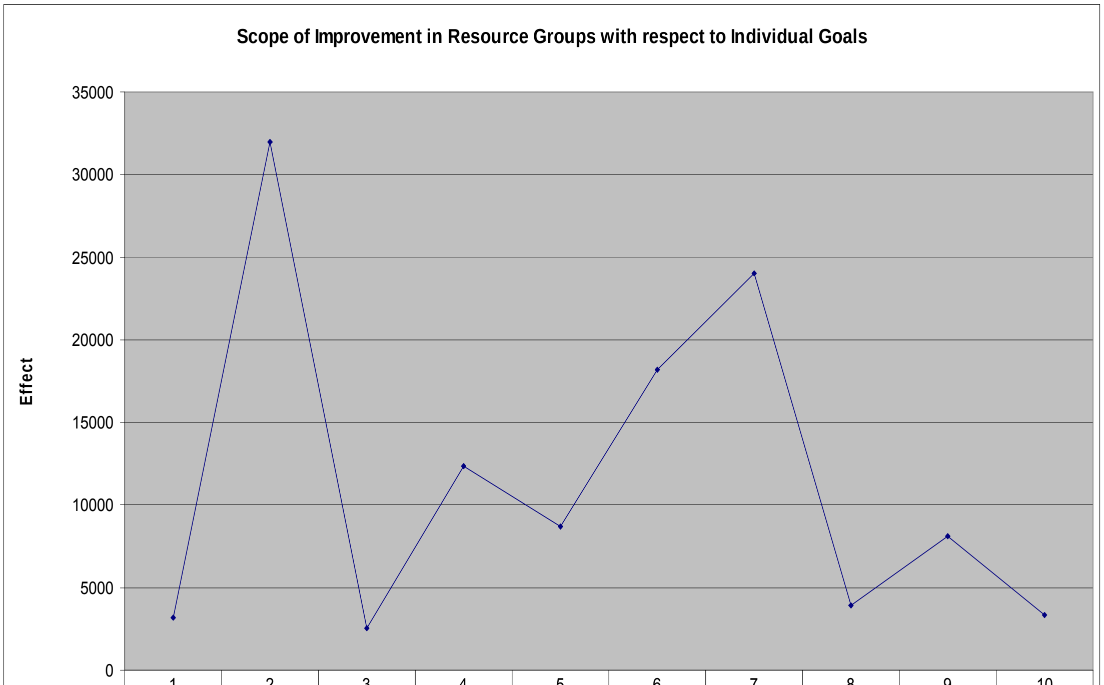


Figure 9.20 Scope of Improvement in Resource Groups with respect to the Overall Goal

9.4.7 Measure 7: IM 3

This measure provides the difference between the potential and actual effectiveness and identifies room for improvement with reference to a resource group in relation to a specific goal and hence cost of improvement can be calculated. The results of this calculation are depicted in Fig. 9.21. The graph shows that the highest scope of improvement is present in resource group number 2 i.e. Expertise. Measure 8 is omitted in the following text as the results provided by it are also integrated in this graph for the sake of simplicity.



	1	2	3	4	5	6	7	8	9	10
Series1	3180	32000	2560	12360	8700	18210	24000	3899	8100	3360

Figure 9.21 Scope of Improvement in Overall Resource Groups with respect to Individual Goals

9.4.8 Measure 9: RoI

This final measure provides RoI which is targeted to provide an indication of the return (in terms of increased effectiveness) from the investment of resources (time, money, people etc.) to further exploit a resource. The measure is defined only for higher level goals as resources target to accomplish many goals at a single time. The results of this calculation are shown in Figs. 9.22 – 9.26.

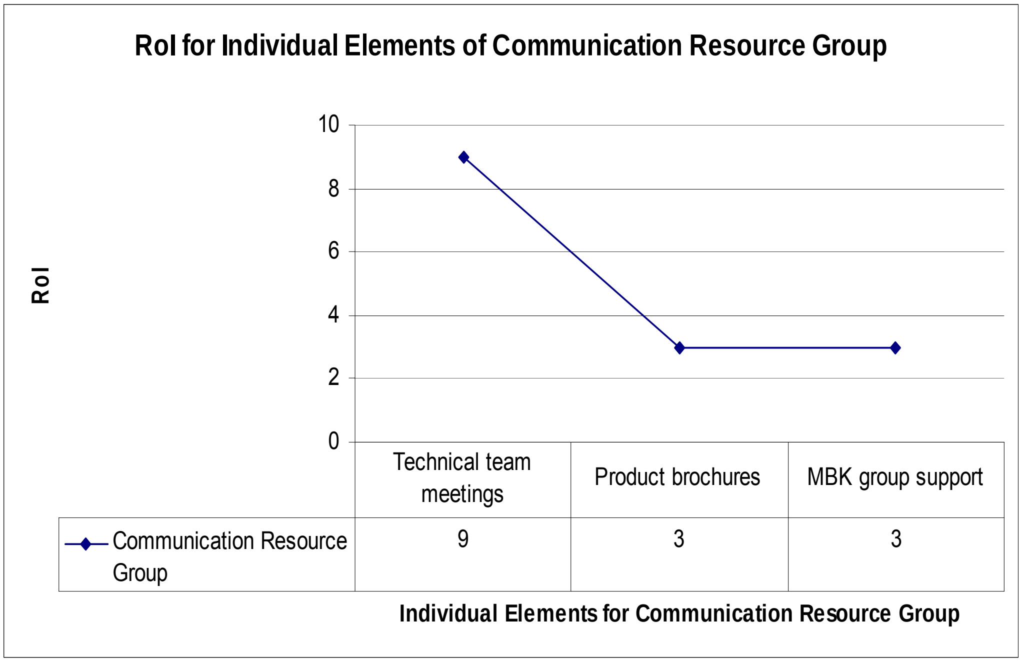


Figure 9.22 RoI for Individual Elements of Communication Resource Group

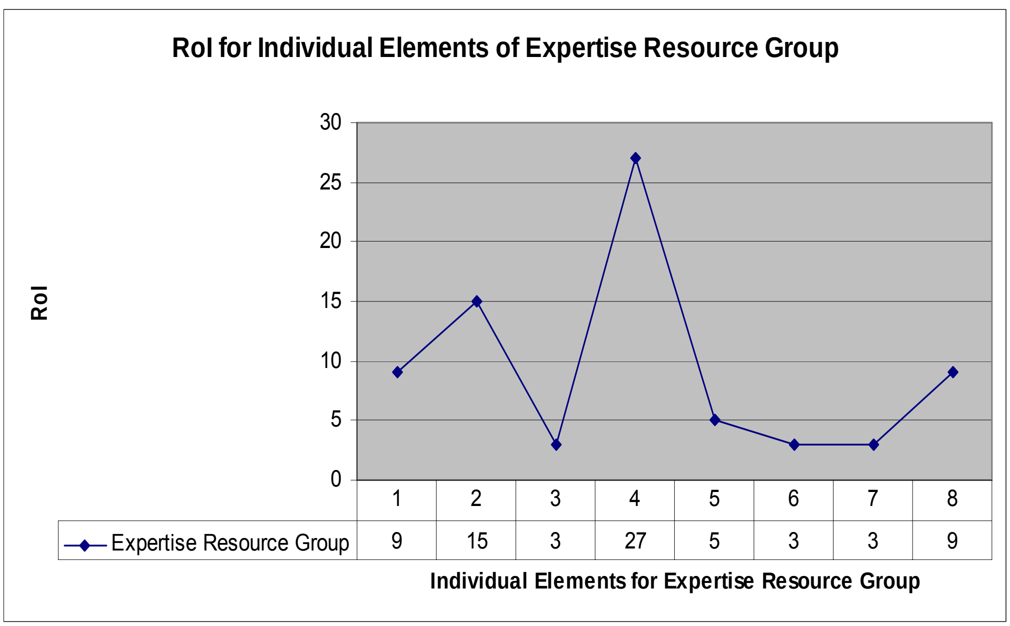


Figure 9.23 RoI for Individual Elements of Expertise Resource Group

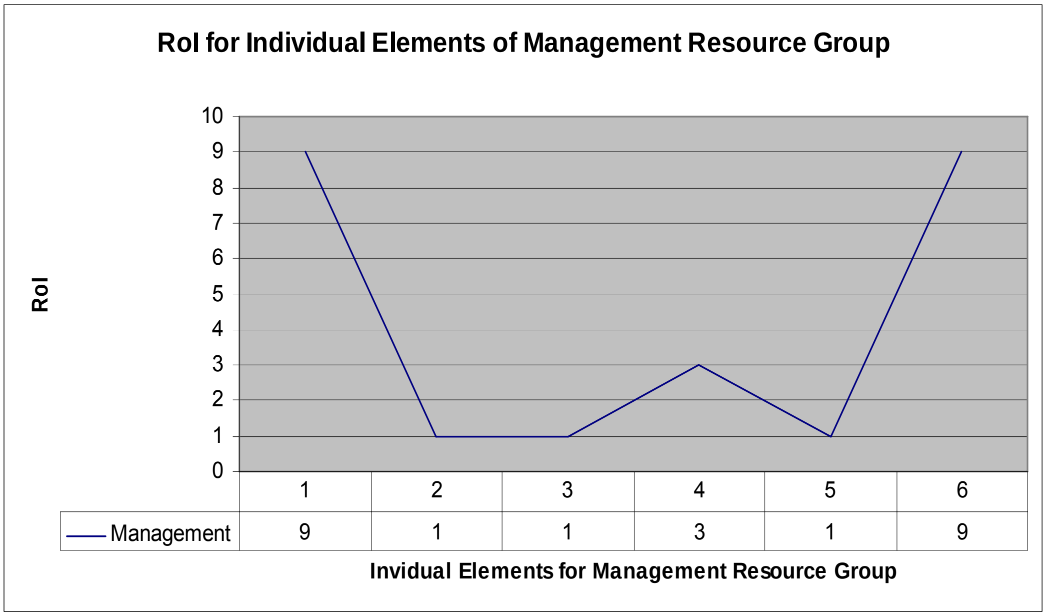


Figure 9.24 RoI for Individual Elements of Management Resource Group

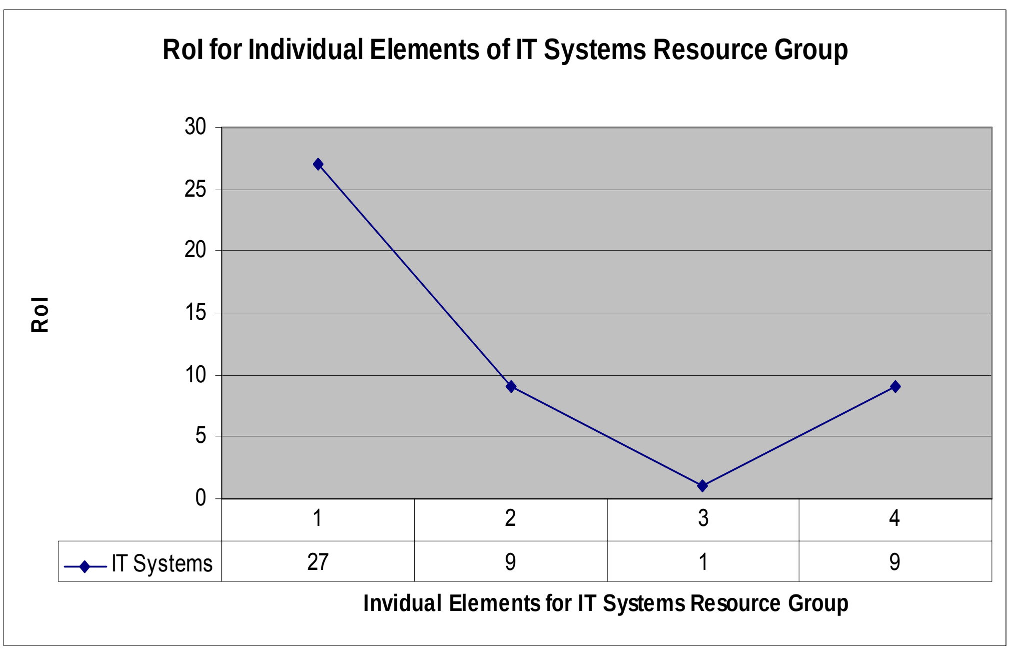


Figure 9.25 RoI for Individual Elements of IT Systems Resource Group

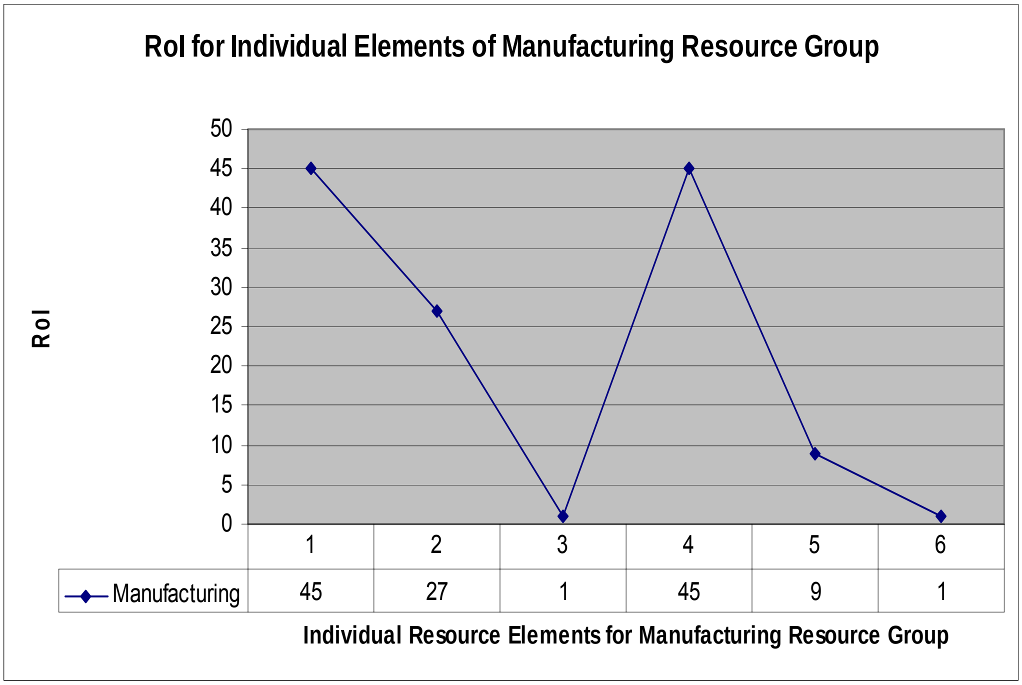


Figure 9.26 RoI for Individual Elements of Manufacturing Resource Group

The results indicate that the highest RoI will be delivered through the improvement of resource elements both from manufacturing resource group, namely, Foundry and Tooling. The management can introduce new technologies and practices in the reference areas for gaining the maximum RoI in these two fields.

9.5 Recommendations

The management was asked to observe the trends of the graphs and values and come up to a consensus about the parameters which they want to improve. It was decided that at least one resource from each resource group will be selected for further improvement. Following recommendations were finally concluded based upon the results presented in the previous section.

a. *Measure 1:* This measure shows that the resources of the company are primarily contributing towards two goals namely Technical Feasibility and Quality Standards (MbK). When these two goals are considered, there are some resources that contribute towards both of them. These resources are as under.
    i. Documentation
    ii. After Sales Service
    iii. Technical Data Pack
    iv. Foundry

   v. CNC Group
   vi. Tooling, and
   vii. Testing and Qualification

   It was therefore decided that these resources will be further utilized and explored to gain further competitive advantage towards the respective two goals. It was further observed that documentation and manufacturing were two major contributing resources.

b. *Measure 2:* According to this measure, again the Testing and Qualification of the products has gained the highest ranking and Tooling has gained the second highest ranking. This measure supplements the fact that measure 1 has pointed out. Moreover this measure has also pointed out that these two resources, while contributing to the goals as pointed out above, also contribute toward the overall goal. So the management was agreed to put further attention to these two resources.
   i. Tooling, and
   ii. Testing and Qualification
c. *Measure 3:* This measure also supplements the fact that the company's prime goals are the same as pointed out by measure 1, namely, Technical Feasibility and Quality Standards (MbK). That is why the resources utilized by the company, as pointed out by this measure; contribute mainly to these two goals thereby gaining the two highest rankings 1630 and 1110. It was decided that while maintaining these two goals important, the goal of Forming Relation will also be addressed in the context of customer satisfaction and reputation.
d. *Measure 4:* This measure shows that the resource group two i.e. Expertise has the highest ranking in contributing towards the overall goal. The Manufacturing resource group has the second rating. It was decided that while maintaining these two resource groups, the Communications resource group will be improved, being the lowest.
e. *Measure 5:* This measure shows that the highest room for improvement with respect to individual goals is present in Team Management with respect to the goal Meet Performance Targets. It is also noted that the highest ranking room for improvement is present in the manufacturing resource group, thereby complementing the result pointed out by measure 1. It was therefore decided that TDP, Foundry and Testing and Qualification, being also selected by measures defined before, will be addressed for further exploitation.
f. *Measure 6:* This measure again identifies the greatest room for improvement in the resource Testing and Qualification for the overall goal. This again supplements the identification provided by measure 5. It was thus decided that major focus will be on Testing and Qualification for further improvement.
g. *Measure 7:* Expertise is identified as the resource group which has the greatest room for improvement. It was therefore decided that Expertise will be taken as a whole for further exploitation and improvement.

h. *Measure 9:* The greatest RoI can be obtained through investment in Foundry and Tooling. Foundry was also identified by measure 5. It was thus decided that maximum investment will be provided in Foundry and in Tooling on second number.

It can be observed that in the above session many similarities are found throughout. This further certifies the authenticity of the analysis presented by the approach.

REFERENCES

1. Rumbaugh J., Blaha M., Premerlani W., Eddy F. and Lorensen W., "*Object Oriented Modeling and Design*", Engle-wood Cliffs, New Jersy, Prentice Hall, 1991
2. U.S. Department of the Treasury, "*Treasury IT Performance Measures Guide*", Office of the Chief Information Officer (OCIO), Enterprise Architecture Program (2007), May 2007
3. UN Office of Personnel Management, "*A Handbook for Measuring Employee Performance*", Performance Management and Incentive Awards Division, PMD–013, September 2001
4. *The Oxford Dictionary*, 2008
5. Pahl G. and Beitz W., "*Engineering Design: A System Approach*", Ken Wallace (Editor), Springer-Verlag London Ltd., 1986
6. Rehman A., Duffy A. H. B. and Yan X., "*Design Management and Prediction*", Northwestern Polytechnical University Press, China, 2008
7. Neely A. D., "*Measuring Business Performance*", Economist Books, London, 1998
8. *The American Heritage® Dictionary of the English Language*, Fourth Edition copyright ©2000 by Houghton Mifflin Company. Updated in 2009. Published by Houghton Mifflin Company
9. Elzinga D. J., Horak T., Lee C. and Bruner C., "*Business Process Management: Survey and Methodology*", IEEE Transactions on Engineering Management, 1995. 42(2)
10. Leifer R. and W. J. Bruke, "*Organizational Activity Analysis: A Methodology for Analyzing and Improving Technical Organizations*", IEEE Transactions on Engineering Management, 1994. 41(3)
11. Araujo C. S. and A. H. B. Duffy, "*Assessment and Selection of Product Development Tools*" in *International Conference on Engineering Design*, 1997, Tampere Finland
12. Neely A., M. Gregory and K. Platts, "*Performance Measurement System Design: A Literature Review and Research Agenda*", International Journal of Production and Operations Management, 1995. 15(4)
13. Donnell F. J. O. and A. H. B. Duffy, "*Design Performance*", Springer, 2005
14. Martyrer, E., "*Der Ingenieur unddas Konstruieren*", Konstruktion 12 (1960) 1-4
15. French M. J., "*Conceptual Design for Engineers*", Design Council, London, 1985
16. Dixon J. R., "*Design Engineering: Inventiveness, Analysis and Decision Making*", New York, McGraw Hill, 1966
17. Penny R. K., "*Principles of Engineering Design*", Postgraduate 46, 1970
18. Pahl G., "*Entwurfsingenieur und Konstruktionslehre unterstutzen die modern Konstruktionsarbiet*", Konstruktion 19, 1967

19. Groger B., "*Ein System zur rechnerunterstutzten und wissensbasierten Bearbeitung des Konstrucktionspronzesses*", Konstuktion 42, 1990
20. Groger B., "*Die Einbeziehung der Wissensverarbeitung in den rechnerunterstutzten Konstruktionsproze*", Diss Tu Berlin 1991
21. VDI: "*Simultaneous Engineering-heue Wege des Projektmanagements, VDI-Tagung Frankfurt*", Tagungsband, Duesseldorf, VDI-Verlag, 1989
22. Cross N., "*Engineering Design Methods: Strategies for Product Design*", Third Edition, Wiley, 2006
23. Jolly A., "*Innovation: Harnessing Creativity for Business Growth*", Design Council, Kogan Page, 2003
24. Brown, T. E., "*Innovation, Entrepreneurship and Culture: The Interaction between Technology, Progress and Culture",* Edward Elgar Publishing, 2004
25. Dorner D., "*Problemlosen als Informationsverarbeitung*", 2. Aufl. Stutgart: Kohlhammer 1979.
26. Müller J., "*Arbeitsmethoden der Technikwissenschaften*", Berlin, Springer, 1990
27. Andersen M. M., Duffy A. H. B., Maccallum K. J., Bowen J., Storm T., "*The Design Co-ordination Framework – Key Elements for Effective Product Development*", Proceedings of 1st International Engineering Design Debate, Glasgow (UK), 1996
28. Roozenburg, N.F.M. and J. Eekels, "*Product Design: Fundamentals and Methods",* Product Development – Planning, Designing, Engineering, ed. N. Cross and N. Roozenburg. 1995: John Wiley & Sons Ltd., Chichester Po19 1UD, United Kingdom.
29. Hollins, W.J. and S. Pugh*, "Successful Product Design - What to do and When"*, 1990, London: Butterworth.
30. Andreasen, M.M. and L. Hein, "*Integrated Product Development"*, IFS (Publications) Ltd and Springer-Verlag London UK, 1987.
31. Edwards, S. and P. Lewis, "*The Product Introduction Process.* 1991, Birmingham: Lucas Engineering & Systems Ltd.
32. Reinders, H., "*From Abstract Idea until Production",* 1989, CTB Report 23/89EN, Centre for Manufacturing Technology, Philips Bedrijven BV: Eindhoven.
33. Sheldon, D.F., "*Designing for Whole Life Costs at the Concept Stage",* Journal of Engineering Design, 1990. 1(2).
34. Syan, C.S. and U. Menon, (Ed.) *"Concurrent Engineering - Concepts, Implementation and Practice"*, Chapman& Hall Ltd.: London, 1994
35. Clausing, D. and S. Pugh, *"Enhanced Quality Function Deployment*" In *Int. Conf. on Design and Productivity,* Honolulu, Hawai, USA, 1991
36. Pugh, S., "*Total Design: Integrated Methods for Successful Product Engineering"*, Addison-Wesley Ltd., 1990
37. Dym, C. L. and Little P., "*Engineering Design: A Project-Based Introduction"*, New York, John Wiley and Sons, 2000
38. *The Economist*, April 14, 1990
39. Andreasen M. M. and Hein L., *Integrated Product Development*, Technical University of Denmark, 1987
40. Degarmo E. P., Black J. T. and Kohser R. A., *Materials and Processes in Manufacturing*, 9th Edition, John Wiley and Sons, 2003

41. Day, G., *The Product Life Cycle: Analysis and Applications Issues*, Journal of Marketing, vol. 45, Autumn 1981.
42. Ullman, David G., *The Mechanical Design Process*, Mc Graw-Hill, 4th edition, 2008
43. Ulrich K. T. and Eppinger, S. D., *Product Design and Development*, 3rd Edition, McGraw-Hill, New York, 2004
44. Kim, J. and Wilemon, D., *Sources and Assessment of Complexity in NPD Projects*, R&D Management, 33 (1), 2002
45. Cooper, R. G. *Predevelopment activities determine new product success*, in: Industrial Marketing Management,Vol.17, No 2, pp. 237-248, 1998
46. Cooper R.G., Edgett, S.J., *Maximizing Productivity in Product Innovation*, in: *Research Technology Management*, March, 2008
47. Khurana, A., and Rosenthal, S.R., *Towards Holistic "Front Ends" in New Product Developmen*t, Journal of Product Innovation Management, 15(1), 1998
48. Kahn, K. B. (Ed.), *The PDMA Handbook of New Product Development*, Second Edition, Hoboken, NJ, John Wiley & Sons, 2005
49. Neely, A., *The Performance Revolution: Why Now and What Next?*, International Journal of Operations and Production Management, 19(2): p. 205-228, 1999
50. Bourne, M., M. Franco., and Wilkes, J., *Corporate Performance Management*, Measuring Business Excellence 2003, 7, 3; p. 15.
51. Harrington, H. J., *Business Process Improvement*, McGraw Hill, New York, 1991
52. Hammer, M. and Champy J., *Reengineering the Corporation: A Manifesto for Business Revolution*, Harper, New York, 1993
53. Rockart J. F., "*Chief Executive Define Their Own Data Needs*", Harvard Bus. Rev., vol 57, no. 2, pp. 81-92, Mar./Apr. 1979.
54. Daniel D.D., "*Management Information Crisis*", Harvard Bus. Rev., vol. 39, no. 5, pp. 111-121, Sept./Oct. 1961.
55. Geller A. N., "*Tracking the Critical Success Factors for Hotel Companies (Part-I)*", Cornell Hotel & Restaurant Admin. Quart. vol. 25, no. 4, pp. 76-81, 1985.
56. Hanks, G. F., "*Rx for Better Management: Critical Success Factors*", Manage Account, vol. 70, no. 4, pp. 45-49, 1988.
57. Isakson H. R. and Sircar S. "*The Critical Success Factors Approach to Corporate Real Asset Management*", Real Estate Issues, vol. 15, no. 1, pp. 26-31, Spring/Summer 1990.
58. Liang T. P. "*Critical Success Factors of Decision Support Systems: An Experimental Study*", Data Base, pp. 3-15, Winter 1986.
59. Camp R. C., *"Benchmarking"*. Milwaukee, WI: ASQC, 1989.
60. Borden J. P. "*Review of Literature on Activity-Based Costing",* Journal of Cost Management for the Manufacturing Industries., vol. 4, no. 1, pp. 5-12, 1990.
61. Pritchard R.D., "*Measuring and Improving Organizational Productivity: A Practical Guide*", New York: Prager Publishers, 1990
62. Cordero R., "*The measurement of Innovation Performance in the Firm: An Overview. Research Policy*", 19:p. 185-192. 1989.
63. Dwight R., "*Searching for Real Maintenance Performance Measures. Journal of Quality in Maintenance Engineering"*, 5(3): p. 258-275 1999.

64. Neely A., et al., *Getting the Measure of Your Business. 1996, Horton Kirby: Findlay Publications*.
65. Rolstadas A., "*Enterprise Performance Measurement. International Journal of Operations and Production Management*",. 18(9/10): p. 989-999, 1998.
66. Clark K.B. and T. Fujimoto*,* "*Product Development Performance: Strategy, Organization and Management in the World Auto Industry"*. Harvard Business School Press, 1991.
67. Doz Y., "*New Product Development Effectiveness: A Triadic Comparison in the Information-Technology Industry, in Managing Product Development*", T. Nishiguchi, Editor, Oxford University Press, Inc. p. 13-33, 1996.
68. Emmanuelides P.A., "*Towards an Integrative Framework of Performance in Product Development Projects. Journal of Engineering and Technology Management*", 10: p. 363-392, 1993.
69. Moseng B. and H. Bredrup, "*A Methodology for Industrial Studies of Productivity Performance*", Production Planning and Control, 4(3) 1993.
70. Meyer M.W. and V. Gupta, "*The Performance Paradox. Research in Organizational Behaviour*", 19: p. 309-369, 1994.
71. Drongelen C.K.-V., and Cook A., "*Design Principles for the Development of Measurement Systems for Research and Development Processes*". R&D Management, 27(4): p. 345-357, 1997.
72. Sinclair D. and Zairi M., "*Effective Process Management through Performance Measurement: Part 3 – in integrated model of total quality-based performance measurement*". Business Process Re-engineering and Management Journal, 1(3):p. 50-65, 1995.
73. Griffin A. and Page A. L., "*An Interim Report on Measuring Product Development Success and Failure*". Journal of Product Innovation Management, 10: p. 291-308, 1993.
74. Duffy A. H. B., "*Design Productivity*", in *The Design Productivity Debate*, A.H.B. Duffy, Editor, Springer-Verlag Publications, 1998.
75. Goldschmidt G., "*The Designer as a Team of One, in Analysing Design Activity*", N. Cross H. Christiaans, and K. Dorst, Editors. John Wiley and Sons, 1996.
76. Kaplan R.S. and D.P. Norton, "*Using the Balanced Scorecard as a Strategic Management System*", Harvard Business Review, January-February, 1996
77. Mehra S., *"Perpetual Analysis and Continuous Improvements: A Must for Organizational Competitiveness"*, Managerial Finance, 24(1), 1998
78. Kald M. and Nilsson F., "*Performance Measurement at Nordic Companies".* European Management Journal, 118(1)p. 113-127, 2000.
79. Rolstadas A. (Ed.), "*Benchmarking – Theory and Practice"*, Chapman and Hall, 1995.
80. Kaplan R.S. and D.P. Norton, "*The Balanced Scorecard – Measures That Drive Performance*", Harvard Business Review, 70(1):p. 71-79, 1992.
81. Bititici U.S., "*Measuring Your Way to Profit",* Management Decision, 32(6):p. 16-24, 1994.
82. Chissea V., Coughlan P., and Voss C.A., "*Development of a Technical Innovation Audit*". Journal of Product Innovation Management, 13(2):p. 105-136, 1996.

83. Dixon J.R., Nanni A.J., and Vollman T.E., "*The New Performance Challenge – Measuring Operations for World Class Competition"*. Homewood, IL: Dow Jones-Irwin, 1990.
84. De Hass M. and Kleingled A., "*Multilevel Design of Performance Measurement Systems: Enhancing Strategic Dialogue Throughout the Organization*", Management Accounting Research, 10:p. 233-261, 1999.
85. Tsang A., Jardine A., and Kolodny H., "*Measuring Maintenance Performance: A Holistic Approach*", International Journal of Operations and Production Management, 19(7):p. 691-715, 1999.
86. David Parmenter, "*Key Performance Indicators"*, John Wiley & Sons, 2007.
87. Graham K. K. and Dunk A. S., "*The Utility of Performance Measures: Production Manager's Perceptions",* IEEE Transactions on Engineering Management, Vol: 36 (1), 1989.
88. Mahoney T. A., "*Managerial Perceptions of Organizational Effectiveness",* Management Science, Vol. 14, pp. B76-B97, 1967.
89. Gary L. L. and Yoon E., "*Determinants of New Industrial Product Performance: A Strategic Re-examination of the Empirical Literature",* IEEE Transactions on Engineering Management, Vol: 36 (1), 1989.
90. Rothwell R., Freeman C., Horsley A., Jervis V. T. P., Robertson A. B., and Townsend J., "*SAPPHO updated – Project SAPPHO, Phase II",* Research Policy, Vol. 3, pp. 258-291, 1974.
91. Utterback J. M., Allen T. J., Hollomon H., and Sirbu M. H., *"The Process of Innovation in Five Industries in Europe and Japan",* IEEE Translation Engineering Management, Vol. 1, pp. 3-9, 1976.
92. Cooper R. G., "*The Dimensions of Industrial New Product Success and Failure",* Journal of Marketing, Vol. 45, pp. 48-80, 1981.
93. Calantone R., and Cooper G. "*New Product Scenarios: Prospects for Success"*, Journal of Marketing, Vol. 43, pp. 93-103, 1979.
94. Maidique M. A., and Zirger B. J., "*A Study of Success and Failure in Product Innovation: The Case of the US Electronics Industry",* IEEE Translation Engineering Management, Vol. 31, pp. 192-203, 1984.
95. Cooper R. G., "How New Product Strategies Impact on Performance", Journal of Product Innovation Management, Vol. 1, pp. 5-18, 1984.
96. Yoon E., and Lilien G. L., "*A New Product Launch time Decision Model",* in AMA Educators Proc., Series no. 52, pp. 400-405, 1986.
97. Gaker R., Green G., and Bean S., "*Why R&D Projects Succeed or Fail",* Research Management, Vol. 29, pp. 29-34, 1986.
98. Smithers T., et al., "*Design as Intelligent Behavior: An AI in Design Research Programme*", Artificial Intelligence in Engineering, 5(2), 1990.
99. Ullman D. G., Dietterich T. G., and S. L. A, "*A Model of the Mechanical Design Process Based Empirical Data*", AI EDAM, 2(1):p.33-52, 1988.
100. Hubka V., "Principles of Engineering Design". WDK. Zurich: Springer – Verlag, 1980.
101. Zhang Y., "Computer-based Modeling and Management for Current Working Knowledge Evolution Support", in Department of Design, Manufacture and Engineering Management, University of Strathclyde: Glasgow, 1998.

102. Brookes N.J. and Backhouse C. J., "*Measuring the Performance of Product Introduction*", Journal of Engineering Manufacture, 212(1): p. 1-11, 1998.
103. Hales C., "*Managing Engineering Design*", Longman Scientific and Technical, 1993.
104. Cooper, R.G., "*New Products: The Factors that Drive Success. International Marketing Review*", 11(1): p. 60-76, 1994.
105. Change Z. Y. and Young K. C., "*Dimensions and Indices for Performance Evaluation of a Product Development Project*". International Journal of Technology Management, 6(1/2): p. 166-167, 1991.
106. McGrath M.E., "*The R&D Effectiveness Index: Metric for Product Development Performance*". Journal of Product Innovation Management, 11: p. 201-202, 1994.
107. Eccles R.G., "*The Performance Measurement Manifesto*", Harvard Business Review, 69 January - February, 1991.
108. Johson H. T. and Kaplan R. S., "*Relevance Lost – the Rise and Fall of Management Accounting*", Boston, MA: Harvard Business School Press, 1987.
109. Finger S. and Dixon J.R., "*A Review of Research in Mechanical Engineering Design. Part 1: Descriptive, Prescriptive, and Computer-Based Models of Design Processes*", Research in Engineering Design, 1:p.51-67, 1989.
110. Blessing L. T. M., "*A Process-Based Approach to Computer-Supported Engineering Design*", University of Twente: Enschuguyg, The Neetherlands, 1994.
111. Pugh S., "*Design Activity Models: Worldwide Emergence and Convergence*". Design Studies, 7(3): p. 167-173, 1986.
112. Skinner W., "*The Anachronistic Factory",* Harvard Business Review, January – February, p. 61-70, 1971.
113. Bitici U., "*Modelling of Performance Measurement Systems in Manufacturing Enterprises*", International Journal of Production Economics, 42: p. 137-147, 1995.
114. Lockamy III A. and Spencer M. S., "*Performance Measurement in a Theory of Constraints Environment*", International Journal of Production Research, 36(8): p. 2045-2060, 1998.
115. Martin R., "*Do we practice quality principles in the performance measurement of critical success factors?*" Total Quality Management, 8(6): p. 429-444, 1997.
116. Kaplan, Robert S. and Bruns, W., "*Accounting and Management: A Field Study Perspective"* Harvard Business School Press, 1987.
117. Galloway, D. and Waldron, D., "*Through-Put Accounting Part 1 - The Need for A New Language for Manufacturing"*, Management Accounting, November, pp. 34-5, 1988.
118. Galloway, D. and Waldron, D., "*Throughput Accounting Part 2 - Ranking Products Profitability"*, Management Accounting, December, pp. 34-5, 1988.
119. Galloway D. and Waldron D., "*Through-Put Accounting Part 3 - A Better Way to Control Labour Costs"*, Management Accounting, January, pp. 32-3, 1989.
120. Galloway, D. and Waldron, D., "*Through-Put Accounting Part 4 -Moving On to Complex Products*", Management Accounting, February, pp. 40-41, 1989.
121. Ambler. T. and Kokkinaki. F. "*Marketing Performance Measurement: Which Way Is Up?*" in Neely, A.D. and Waggoner, D.B. (Ed.), "*Performance Measurement:*

Theory and Practice", Centre for Business Performance, University of Cambridge, pp. 31-8, 1998.

122. Rappaport, A., "*Creating Shareholder Value: The New Standard for Business Performance*", Free Press, New York, NY, 1998.
123. Stewart, G. B., "*The Quest for Value: The EVA Management Guide*", Harper – Business, New York, NY, 1991.
124. Mavrinac S. and Siesfeld, T, "*Measures That Matter: An Exploratory Investigation Of Investors' Information Needs And Value Priorities"*, Richard Ivey School of Business Working Paper, 1997.
125. McKinnon S. and Bruns W. "*The Information Mosaic"*, Harvard Business School Press, Boston, MA, 1992.
126. Keegan, D.P., Eiler, R.G. and Jones, C.R., "*Are your Performance Measures Obsolete?"*, Management Accounting, June, pp. 45-50, 1989.
127. Fitzgerald L., Johnston, R., Brignall, S., Silvestro, R. and Voss, C. "*Performance Measurement in Service Business",* CIMA, London, 1991.
128. Azzone, G., Masella, C. and Bertele, U., *"Design of Performance Measures for Time-Based Companies",* International Journal of Operations & Production Management, Vol. 11, No. 3, pp. 77-85, 1991.
129. Institute of Chartered Accountants, "*Measurement – The Total Picture",* The Institute of Chartered Accounts of Scotland, 1993.
130. Chandler, A.D., "*The Visible Hand – Managerial Revolution in American Business",* Harvard University Press, Boston, MA, 1977.
131. Brown, M., *"Keeping Score: Using the Right Metrics to Drive World Class Performance",* Quality Resources, New York, NY, 1996
132. Lynch, R.L. and Cross, K.F, "*Measure Up-the Essential Guide to Measuring Business Performance",* Mandarin, London, 1991.
133. Bitici U., "*Modeling of Performance Measurement Systems in Manufacturing Enterprises*", International Journal of Production Economics, 42: p. 137-147, 1995.
134. Keegan, D.P., Eiler, R.G. and Jones, C.R., "*Are your Performance Measures Obsolete?"* Management Accounting, pp. 45-50, June 1989.
135. Wisner, J.D. and Fawcett, S.E., "*Link Firm Strategy to Operating Decisions Through Performance Measurement",* Production and Inventory Management Journal, Third Quarter, pp. 5-11, 1991.
136. APQC, "*Corporate Performance Measurement Benchmarking Study Report",* American Productivity and Quality Centre: Houston, 1996.
137. Globerson, S. *"Isses in Developing a Performance Criteria System for an Organization",* International Journal of Production rResearch, Vol. 23, No. 4, pp. 639-46, 1985
138. Maskell, B., *"Performance measures for would class manufacturing",* Management Accounting, May, pp.32-3, 1989.
139. Loch C., Stein L., and Terwiesch C., "*Measuring Development Performance in the Electronics Industry*", Journal of Product Innovation Management, 13(2-20), 1996.

140. Griffin A., "*The Impact of Engineering Design Tools on New Product Development Efficiency and Effectiveness*" Institute for the Study of Business Markets, The Pennsylvania State University, 1996.
141. Cooper R.G., "*The Strategy-Performance Link in Product Innovation*", R&D Management, 14(4): p. 247 – 259, 1984.
142. Cohen L., "*Quality Function Deployment: How to make QFD work for you*", Engineering Process Improvement Series, Addison-Westly Publisher Ltd, 1995
143. Griffin A., "*Evaluating QFD's Use in US Firms as a Process for Developing New Products*", Journal of Product Innovation Management, 9: p. 171-187, 1992
144. Besterfield D. H., et al., "*Total Quality Management*", 3rd Edition, Pearson Education, Singapore, 2005.
145. Zeleny M., "*Multiple Criteria Decision Making*", McGraw-Hill Series in Quantitative Methods for Management, ed. M.K. Starr, New York: McGraw-Hill Book Company, 1982.
146. Pugh S., "*Concept Selection – a Method that Works*", in proceedings of the International Conference on Engineering Design, Rome, Italy 1981.
147. KSB AG, "*KSB: Makes Your World Flow*", Company Introduction Brochure, Germany, 2004
148. *COMET:* ERP System, KSB Pakistan, 2005
149. *AQAS*: KSB Pakistan's Yearly Magazines, 2000 – 2005
150. *The Karachi Stock Exchange*, Company History, 2000 – 2005
151. *Quality Management System Manual*, KSB(P)/Q/M – 001 G, Revision 6R, KSB Pakistan, Karachi, Pakistan
152. *KSB Pakistan Product Portfolio*, KSB Pakistan, Lahore, Pakistan, 2001
153. *Forum*, The Magazine for KSB Group Employees, Ed. Leiner, A., KSB AG, FT, Germany, 2003 – 2006
154. *Pumps Hand Book*, KSB AG, FT, Germany, 2004
155. Holzenberger, K. and Jung K., "*Centrifugal Pump Lexicon*", KSB AG, FT, Germany, 1990
156. *Centrifugal Pump Design*, KSB AG, FT, Germany, 1995
157. *Selecting Centrifugal Pumps*, KSB AG, Media Production V 51, FT, Germany, 2005