CRANFIELD INSTITUTE OF TECHNOLOGY

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

PhD THESIS

ACADEMIC YEAR 1992-93

H. M. WANG

The Quality Management of New Product Design and Development

Supervisor: **J. H. ROGERSON**

April 1993

ABSTRACT

The quality management of a modern complex product from design to production is very complicated matter which involves the whole company as well as external bodies (customer and supplier etc).

In this thesis, based on customer-oriented principles, major management techniques, creating a time-phased quality management programme to approach the quality related design processes, combines with the development of a quantitative method to measure the quality achievement of each design activity, including each phase and the overall design stage, for their correctness and efficiency in terms of time, cost and performance.

A practical example is given for demonstrating the validation of the quantification.

Through proper tailoring, the time-phased quality management programme can be applied to different types of product, simple and complex, and to hardware and software, as well as to totally new design or partial design improvement.

A quality information system is also developed to enhance the efficiency and effectiveness of the design and development process and to obtain improved product performance.

Through a systematic analysis of the design process, it is shown that the majority of the steps taken are amenable to discipline and control and, therefore, design can realistically be included in a formal quality management system.

CONTENTS

Page No.

ABSTRACT

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 INTRODUCTION

1.1 Motivation 1-1

1.2 The difficulties of Design Control 1-2

1.3 Thesis Structure 1-3

CHAPTER 2 A SURVEY OF DESIGN CONTROL RELATED MANAGEMENT TECHNIQUES

2.1 Introduction 2-1

2.2 Total Quality Management (TQM)

2.2.1 Definition 2-2

2.2.2 Building up a TQM system 2-2

2.2.3 Applying TQM in product design and development 2-4

2.3 ISO 9000 Quality System

2.3.1 Definition 2-5

2.3.2 ISO 9001 2-5

2.3.3 Advantages of ISO 9001 2-6

2.3.4 Disadvantages of ISO 9001 2-7

2.4 Concurrent Engineering (CE)

2.4.1 Definition 2-8

2.4.2 Tools to support CE 2-8

2.4.3 The benefits of CE 2-10

		Page No.
	2.4.4 The relation between CE and TQM	2-11
2-5	System Engineering and System Management	
	2.5.1 Definition	2-13
	2.5.2 The application of system engineering and management in "Total Quality Control"	2-14
	2.5.3 Disadvantages	2-16
2.6	Analysis of System Effectiveness, Life Cycle Cost and Cost Effectiveness	
	2.6.1 System effectiveness	2-17
	2.6.2 Life cycle cost (LCC)	2-18
	2.6.3 Cost effectiveness	2-19
	2.6.4 The quantification of cost effectiveness	2-19
2.7	Configuration Management	
	2.7.1 Introduction	2-22
	2.7.2 Configuration management program	2-23
2.8	Quality Engineering (TAGUCHI Methods)	
	2.8.1 Definition	2-25
	2.8.2 Off-line quality control	2-27
	2.8.3 Advantages and disadvantages	2-28
2.9	The seven Fundamental Tools of Quality Control	2.29
2.10	Quality Function Development (QFD)	2-32
2.11	Failure Mode and Effect Analysis (FMEA)	2-34
2.12	JURAN'S "Design for Quality" Concept	2-35
2.13	FEIGENBAUM'S "Total Quality Control" and "New Design Control"	2-39
2.14	Conclusions	2-41

CHAPTER 3 ANALYSIS OF THE QUALITY RELATED DESIGN AND DEVELOPMENT PROCESS

		Page No.
3.1	Introduction	3-1
3.2	Development of a Time-Phased Quality Management System	3-3
3.3	Conceptual Phase	
3.3.1	Identifying customer needs	3-5
3.3.2	Mission profile and life cycle analysis	3-6
3.3.3	Feasibility study	3-7
3.3.4	Project group organisation	3-8
3.3.5	System requirement specification	3-9
3.3.6	Conceptual design review	3-10
3.4	Design Phase	
3.4.1	Functional allocation and production	3-12
3.4.2	Establishment of design criteria	3-15
3.4.3	Stress/strength analysis	3-15
3.4.4	FMEA	3-16
3.4.5	Material, parts selection and control	3-17
3.4.6	Integrated design analysis	3-18
3.4.7	Integrated test planning	3-24
3.4.8	Engineering data and documentation	3-25
3.4.9	Detailed design review	3-26
3.5	Development Phase	3-28
3.5.1	Environmental stress screening test	3-29
3.5.2	Prototype construction	3-30
3.5.3	Functional test	3-30
3.5.4	Environmental test	3-31
3.5.5	Reliability growth test	3-31
3.5.6	Fix product specification	3-32
3.5.7	Edit SOP, SIP and technical manuals	3-33
3.5.8	Critical design review	3-34

Page No.

3.6 Qualification Phase

3.6.1 Incoming material inspection and test 3-35

3.6.2 Tool planning 3-36

3.6.3 Pilot run 3-37

3.6.4 Reliability qualification test 3-38

3.6.5 Life test 3-39

3.6.6 Process capability analysis 3-40

3.6.7 Final design review 3-43

3.6.8 Design release 3-43

CHAPTER 4 QUALITY MEASUREMENT OF THE DESIGN AND DEVELOPMENT PROCESS

4.1 Introduction 4-1

4.2 Developing the Quality Measurement Theory

4.2.1 The evaluation factor 4-2

4.2.2 The complexity factor 4-5

4.3 Definition and Calculation of Quality Index at Various Quality Management Levels

4.3.1 Quality index at activity level 4-7

4.3.2 Quality index at phase level 4-7

4.3.3 Quality index at system level 4-9

CHAPTER 5 THE APPLICATION OF QUALITY MEASUREMENT MODEL TO THEORETICAL AND PRACTICAL EXAMPLES

5.1 Introduction 5-1

5.2 A Theoretical Example

5.2.1 Quality measurement to each Activity 5-3

5.2.2 Quality measurement to Conceptual Phase (Phase 1) 5-34

5.2.3 Quality measurement to Design Phase (Phase 2) 5-36

Page No.

5.2.4 Quality measurement to Development Phase (Phase 3) 5-37
5.2.5 Quality measurement to Qualification Phase (Phase 4) 5-38
5.2.6 Quality measurement for a Quality Management System during Design Stage 5-39
5.3 A Practical Example
5.3.1 Quality measurement to each Activity 5-42
5.3.2 Quality measurement to Conceptual Phase (Phase 1) 5-73
5.3.3 Quality measurement to Design Phase (Phase 2) 5-74
5.3.4 Quality measurement to Development Phase (Phase 3) 5-75
5.3.5 Quality measurement to Qualification Phase (Phase 4) 5-76
5.3.6 Quality measurement for a Quality Management System during Design Stage 5-77
5.3.7 Conclusion of study and areas for improvement 5-78
5.4 The Difficulties of Application on Quality Measurement Model During Design Stage 5-80

CHAPTER 6 THE ANALYSIS OF SOFTWARE DESIGN CONTROL AND DEVELOPING THE QUALITY INFORMATION SYSTEM OF PRODUCT DESIGN AND DEVELOPMENT

6.1 The Analysis of Software Design Control 6-1
6.1.1 Introduction 6-1
6.1.2 Definition 6-2
6.1.3 Time-phased quality management programme 6-4
6.1.4 Major sources of error during software design and development 6-7
6.1.5 Quality measurement for software design 6-8

Page No.

6.2 Developing the Quality Information System of Product Design and Development

6.2.1 Introduction 6-9

6.2.2 Definition of the information required 6-11

6.2.3 Developing information flows 6-12

6.2.4 Database design 6-13

6.2.5 Choosing a computer system 6-14

6.2.6 Managing and using the quality information system 6-15

CHAPTER 7 DISCUSSION, CONCLUSION AND RECOMMENDATION

7.1 Discussion 7-1

7.2 Conclusion 7-9

7.3 Recommendation 7-11

Page No.

REFERENCES R-1

APPENDIX I : PROBLEMS AT THE DESIGN AND DEVELOPMENT STAGE

APPENDIX II: DESIGN AND DEVELOPMENT CONTROL CHECKLIST

LIST OF TABLES

		Page No.
Table 2.1	The distinctions between traditional and modern products	2-43
Table 3.1	Stages of reliability prediction and measurement	3-45
Table 3.2	Reliability prediction data summary	3-46
Table 4.1	Evaluation factor -- rating scale	4-11
Table 4.2	Complexity factor -- rating scale	4-12
Table 4.3	Q_{Ai} -- ranges and corrective action	4-13
Table 4.4	The weighted evaluation value for phase p	4-14
Table 4.5	Q_p and H_p ranges, phase descriptive ratings and evaluation grades for phases of quality system	4-15
Table 4.6	Q_s and H_s ranges, system descriptive ratings and evaluation grades for the quality system	4-16

LIST OF FIGURES

		Page No.
Figure 2.1	Basic design control model from ISO 9001	2-44
Figure 2.2	The prime ingredients of cost-effectiveness	2-45
Figure 2.3	Off-line quality control	2-46
Figure 2.4	The seven fundamental tools of quality control	2-47
Figure 3.1	Time-phased quality management programme	3-47
Figure 3.2	Quality function deployment methodology	3-48
Figure 3.3	System engineering model	3-49
Figure 3.4	System functional indenture levels	3-50
Figure 3.5	Series of flow block diagram (evolutionary development)	3-51
Figure 3.6	Reliability block diagram	3-52
Figure 3.7	Various factors contributing to the stress and strength distribution	3-53
Figure 3.8	Reliability as a function of the stress and strength distribution	3-54
Figure 3.9	Reliability growth management model	3-55
Figure 4.1	H_p and Q_p transformation from numerical value to percentage value	4-17
Figure 6.1	The specification and documentation hierarchy of software	6-17
Figure 6.2	The identification of engineering design data	6-18
Figure 6.3	Information flows (during product design and development stage)	6-19
Figure 6.4	Single data base concept	6-20
Figure 7.1	New product development approach -- series and parallel	7-13

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

There is increasing evidence that many quality problems can be traced to the design of the product.

In a classic study of 850 field failures of relatively simple electronic equipment, 43% of failures were due to engineering design.

In a study of 7 space programmes, 35.2% of component failures were due to design or specification error.

During a typical 11-month period at a chemical plant, 42% of the rework cost was traced to research and development (cited by Juran & Gryna, 1988).

In a study of 'quality calamities' by the British Institute of Management, 36% of failures were due to the lack of proving new designs, materials or processes and 16% were due to lack of or wrong specifications (cited by Rogerson, 1986).

In one chemical company, a startling 50% of the product shipped was out of specification. A review concluded that many of the specifications were obsolete and had to be changed (cited by Juran & Gryna, 1988).

For mechanical and electronic products of at least moderate complexity, it is Juran and Gryna's opinion that errors during product development cause about 40% of the fitness-for-use (quality) problems.

Where product development is responsible for both creating and formulation (design) of the product and also responsible for developing the manufacturing process, as in chemicals, about 50% of the problems are due to development (cited by Juran & Gryna, 1988).

Therefore, how to improve 'quality' during product design and development stage becomes a very important issue.

Some critical design problems (information compiled by the Defense Science Board, USA in 1983) are listed in Appendix I.

1.2 THE DIFFICULTIES OF DESIGN CONTROL

i. It is often thought that design, being basically a creative activity, is not amenable to the standard quality management system. Thus, design control must be imposed, without putting restrictions and disciplines on the designer which may interfere with his creativity.

ii. Usually, design output is intangible. In most cases, design output is a set of instructions rather than hardware, which makes it difficult to quantify the adequacy and measurement of the performance of the design output.

iii. The errors at the design stage are so fundamental and have such far reaching effects, that their rectification is likely to be expensive and may not even be possible.

iv. The more complex the product, the more organisations (customer, supplier, design consultant, fabricator) will be involved. The interfaces between different bodies are difficult to control.

Despite the above mentioned difficulties, the designer (creator) still needs to communicate his design to other people. This can only be done through processes, procedures and measurements.

A basic design control model (see Fig. 2.1) illustrates that any design requires certain inputs, then through the design process to produce an output. A feedback loop is the key function to improve design quality. This simple 'design control model' will be the starting point for further study and will help to develop a more detailed design process relevant to quality management.

1.3 THESIS STRUCTURE

Chapter 2 presents a survey of major design control related management techniques. This will help to establish a generic time-phased quality management programme in Chapter 3. Based on the management programme, a quality measurement method will be developed in Chapter 4. This quantification model can measure the 'quality achievement' of each design activity and phase and overall design stage, for correctness and efficiency in terms of time, cost and performance.

In Chapter 5 an example is given to demonstrate the validation of the quantification model.

In Chapter 6, software design control is discussed and the theory developed in Chapters 3 and 4 is applied.

In the meantime, a quality information system is developed to enhance quality management during the design stage.

In Chapter 7, more applications of the time-phased quality management programme are discussed and the major conclusions arrived at is that design activities are measurable and amenable to quality management.

Finally, it is recommended that computer-aided tools are adopted to help implement design control activities.

CHAPTER 2

A SURVEY OF DESIGN CONTROL RELATED MANAGEMENT TECHNIQUES

2.1 INTRODUCTION

a. The scope of this survey will focus on major engineering and quality management techniques which contribute to product design and development.

This survey will not include professional design skills and pure engineering design technology.

b. The aim of this survey is to apply existing knowledge and 'received wisdom' to help create a generic quality management programme for new product design and development.

2.2 TOTAL QUALITY MANAGEMENT (TQM)

2.2.1 Definition

i. TQM is also known as Company-wide Quality Management (CWQM), which is a continuous improvement process that involves the whole company: every department, every activity, every single person at every level, not only in solving problems but also in preventing them.(Peters)

ii. The British Quality Association (BQA) has a long definition of TQM:

TQM is a corporate business management philosophy which recognises that customer needs and business goals are inseparable. It is applicable within both industry and commerce. It ensures maximum effectiveness and efficiency within a business and secures commercial leadership by putting in place processes and systems which will promote excellence, prevent errors and ensure that every aspect of the business is aligned to customer needs and the advancement of business goals, without duplication or waste of effort. (BQA, cited by Hand & Plowman, 1992)

2.2.2 Building up a TQM system

The aim of establishing a TQM system is to use the quality system as a formal measuring and feedback system to improve performance. The steps to be taken are as follows:

i. Establishing the 'Company vision'

This is the development and definition of the company's prime objective, thus providing the framework for management strategy.

ii. Defining strategy

This means defining the company quality levels and implementing the feedback loops.

iii. Defining detailed methods

Detailed quality policies need to be produced as well as responsibilities and objectives for individual departments, together with actual management procedures and instructions where appropriate.

It is at this detailed level that the important performance indicators need to be defined.

iv. Implementing the system in stages

Implementing a quality management system is the hardest part, as it is not immediately obvious to most staff why such a system is needed anyway, except perhaps in certain special and well-defined areas of direct-paying customer contact.

As a corollary, it is worth implementing a system gradually, starting with key areas or, perhaps, the straightforward areas and, as people see their worth and it is learned how to modify the system, then the implementation task becomes progressively easier. (Rogerson & Rooney 1990)

v. Modifying and improving the system

A quality management system should identify areas for improvement. There is, therefore, a need for regular and systematic analysis of the findings of the system and the operation of the system itself. This is the feedback loop which leads to quality improvement.

2.2.3 Applying TQM in product design and development

i. TQM only provides an ideal guide to establishing a management system for product design and development.

ii. A suitable design process, design goals and design criteria must be established for different products and companies, followed by monitoring of the design output.

iii. If a design output is not satisfactory, corrective action must be taken. **A feedback loop will lead to continuous improvement.**

2.3 ISO 9000 QUALITY SYSTEMS

2.3.1 Definition

A quality system is defined as the organisation structure, responsibilities, procedures, processes and resources for implementing quality management.

To promote the system management effort referred to in the definition, a universally applicable set of quality management quality system requirements was introduced in the form of an international standards, the ISO 9000 series of documents.

ISO 9000 is the general specification for quality systems and is designed **to cover the design/development and production of all types of products** and is, therefore, somewhat general in its requirements. It is also divided into three separate parts: 9001, 9002 and 9003, each of which defines a different level of quality system.

2.3.2 ISO 9001 (Identical to BS 5750, Part 1, 1987)

The major difference between ISO 9001 and 9002/3 is that 9001 includes **'design control'** requirements. Section 4.4 'Design Control' lists important topics which must be included in a design control system:

i. 4.4.1: General

The supplier shall establish and maintain procedures to control and verify the design of the product in order to ensure that the specified requirements are met.

ii. 4.4.2: Design and development planning.

iii. 4.4.2.1: Activity assignment.

iv. 4.4.2.2: Organisational and technical interfaces.

v. 4.4.3: Design input.

vi. 4.4.4: Design output.

vii. 4.4.5: Design verification.

viii. 4.4.6: Design changes.

The basic design control model is illustrated in Fig. 2.1.

Some other relevant sections such as 4.5: Document Control, 4,14: Corrective Action, 4.16: Quality Records, are of importance in so far as they deal with design documentation, action and records.

It also must be stressed that above mentioned 'design control requirements' relate to the management control activities, rahter than the specific technical or engineering of the design.

2.3.3 Advantages of ISO 9001

i. It is widely accepted by many countries and industries as the baseline for any quality management system.

ii. It can be considered as a formalised checklist. Corresponding to Sections 4,4, 4,5, 4,14 and 4,16, checklists are developed which can carry out a quick check for a design control system (see Appendix II).

2.3.4 Disadvantages of ISO 9001

i. 'Quality Cost' is an independent and useful system parameter, but it was not emphasised sufficiently in ISO 9001.

ii. Because of the general nature of ISO 9001 it does not give specific guidance, which makes working to the standard difficult.

iii. Some activities in Section 4.4 (such as design input/output identification) are difficult to classify, whether they should belong to 'Design Activities' or 'Quality System Activities'.

iv. Quantitative measurement for quality achievement index is not mentioned in ISO 9001.

v. Section 4.4: Design Control, does not include the modern design concept, e.g. simultaneous design, cost-effectiveness design etc, which will be discussed later.

vi. The overall ISO 9001 quality system only focuses on the traditional industry process control - that is the 'design, production and test' process. It does not consider covering the whole life-cycle of a product.

vii. ISO 9001 emphasises 'performance' control but does not pay attention on 'time and cost' control.

viii. From the above mentioned problems, it can be concluded that ISO 9001 is only applied in the narrow sense of design control.

2.4 CONCURRENT ENGINEERING (CE)

2.4.1 Definition

Concurrent Engineering is known as 'Simultaneous Design', 'Total Design', 'Systematic Design' or 'Integrated Design'.

Some generally accepted definitions of CE are:

i. "A systematic approach to the integration of design, production and related processes which considers all aspects of a product life cycle." (ICL Today, 1991).

ii. Total Design is defined as "The systematic activity necessary from market/user need through to selling in order to produce competitive products for world markets." as distinct from Engineering Design which forms a component part of Total Design. It embraces the product, process, people and organisation (Pugh, 1990).

iii. CE has been termed "a modern treatment of systems engineering in an integrated computing environment", (Schrage, 1989).

2.4.2 Tools to support CE

i. Building cross-functional design teams.

The principle tool for CE is team working. The theory of team working should show how to integrate people, tasks and settings so that groups perform effectively. In general, effective team working

involves a learning process that needs to be guided. Teams must understand why they are a team, what their objective is and what their deliverables are.

ii. Management techniques

a. Improved process: A concurrent process focuses on quality, cost and development time, emphasises customer satisfaction and competitive benchmarking.

b. Close co-operation: Integrated organisation, employee involvement and strategic relations with suppliers.

iii. Employment of quality engineering methods

Using Dr Taguchi's 'off-line quality control' concept and 'quality function deployment' method, achieves product and process optimisation.

iv. Computer application

An integrated computer-aided engineering environment, with simulation to prove out downstream design criteria prior to production and provide information for swift decision-making.

2.4.3 The Benefits of CE

i. Increased quality (customer satisfaction)

"47% of British companies acknowledge that they are unclear about the main type of customers in the market and what their needs are." (Witcher, 1990). This is because they have not had to concentrate on 'customer focus' and have not had to employ the services of marketing. Product development has been engineering rather than market driven.

The use of team working and 'quality function deployment' ensures that marketing and engineering are communicating in the same language.

ii. Reduction in development time

"Company lose 33% of after-tax profit when they ship products six months' late, as compared with a loss of 3.5% when they overspend by 50% on product development. (House, 1991).

The concept of CE is right first time. Whilst initial designs may take longer than with the traditional process, because input has to be received from all functions, designs are less likely to require extensive modification at a later stage. Manufacturing and marketing input at the concept stage of a development project ensures that designs take into account the ease of manufacture and assembly and customer requirements.

As fewer design modifications become the norm, it becomes easier to plan towards product launch dates. This makes the job of the project manager easier as target dates become more achievable.

iii. Reduced product costs

"By the time manufacturing get a look at a new product, around 90% of the design, and therefore most of the eventual product cost, are locked in." (Mortimer, 1991).

Without input from manufacturing most of the finer details of product design are entrenched at a very early stage. In many cases, the inappropriateness of these designs for manufacturability has meant increased unit costs of production. Early contributions from production means not only designs that are sympathetic to current manufacturing capability but also a simultaneous design of the manufacturing route.

2.4.4 The relation between CE and Total Quality Management

i. CE shares three primary objectives with TQM:

(1) Increased quality
(2) Reduction in development time
(3) Reduction in cost.

ii. If TQM is a philosophy for the whole company management, then CE is the definition of a successful implementation of the philosophy. (Meyer, 1990)

iii. The philosophy of TQM matches the CE philosophy but the strand of concentration in CE is in the new product delivery process. TQM considers the improvement of all business processes in summation and aims to make the entire corporation more systematic. Therefore TQM goes far beyond CE; CE can be thought of as the application of TQM to product development. (Don Clausing, 1990)

2.5 SYSTEM ENGINEERING AND SYSTEM MANAGEMENT

2.5.1 Definition

System engineering is the application of scientific engineering and management effort to:

i. Transform an operational need into a description of system performance parameters and a preferred system configuration through the use of an iterative process of functional analysis, synthesis, optimisation, definition, design, test and evaluation.

ii. Integrate related technical parameters and assure compatibility of all physical, functional and program interfaces in a manner that optimises the total system definition and design.

iii. Integrate reliability, maintainability, human factors, safety, security, structural integrity, producibility and other related specialities, into the total engineering effort.

The **system engineering process** in evolving of functional detail and design requirements, has as its goal the achievement of the proper balance among operational, (e.g. performance, effectiveness), economic and logistics factors. The process employs a sequential and iterative methodology to reach cost-effective solutions and the information developed through this process is used to plan and integrate the engineering effort for the system as a whole. (MIL-STD-499A, AMCP 706-196).

System engineering is not necessarily new, but is good engineering with the emphasis on a **'top-down'** approach, looking at the system as a whole. Further, emphasis is also placed on a 'life-cycle' approach and the 'interdisciplinary' or 'team' approach to design and development.

2.5.2 The application of system engineering and management in 'total quality control

Total quality control work requires effective ways of integrating the efforts of large numbers of people with large numbers of machines and huge quantities of information. Hence, it involves systems questions of significant proportions and a system approach is inherent in total quality control.

As applied to total quality control, the system engineering and system management may be defined as follows:

i. **System engineering is the technological process** of creating and structuring effective people/machine/information quality systems. This also includes the process of establishing audits to assure system maintenance, as well as the continuing work to upgrade the quality system, when needed, by matching the quality system requirements with the most up-to-date quality technology.

On the other hand, system engineering is likely to provide what might be thought of as the fundamental 'design technology' of the modern quality engineer.

ii. **System management (system engineering process) is the administrative process** of assuring effective operation of the quality system. This also includes administering the system so that its disciplines are, in fact, followed and enhancing the system, when needed, by carefully adding to its improvements as they are engineered.
Therefore, system management is likely to become a fundamental managerial guide for quality managers in their activities to guide and lead integrated quality activities throughout the organisation. (Feigenbaum, 1991).

iii. Systems economics, especially quality cost, is the measurement and control process for guiding the most effective resource allocation of the people/machine/information content of the quality system. The objective is that the lowest quality costs are achieved, consistent with full customer quality satisfaction, including guidance so that investments or other expenditures planned for the quality system will be based upon net economic improvements obtained throughout the system, rather than in only a self-contained portion of that system.

iv. System measurements, particularly with respect to system audits and customer quality determinations, are the process of the evaluation of the effectiveness with which the quality system meets its objectives and fulfils its goals.

System measurements are likely to provide key benchmarks for quality control personnel as well as for functional and general management.

2.5.3 Disadvantages

Despite the above advantages that can be obtained from adopting system engineering and management, for practical application it need a strong organisation and well-trained system engineers to tailor and implement the system engineering process.

2.6 ANALYSIS OF SYSTEM EFFECTIVENESS, LIFE CYCLE COST AND COST EFFECTIVENESS

Designers have long tried to achieve a balance between effectiveness and cost. This balance may involve increasing cost in one phase to reduce cost and increase effectiveness elsewhere, but can result in lower overall costs and greater effectiveness. This process of balancing cost and effect is known as trade-off analysis. The quantification provided by system effectiveness models and life cycle cost models can spearhead the trade-off analysis.

The prime ingredients of cost effectiveness are illustrated in Fig. 2.2 (Juran, 1980). The detailed descriptions are as follows:

2.6.1 System Effectiveness

System effectiveness is often expressed as one or more figures of merit representing the extent to which the system is able to perform the intended function. The figures of merit used may vary considerably depending on the type of system and its mission requirements and should consider the following:

i. System performance parameters such as the capacity of a power plant, the destructive capability of a weapon and the accuracy of a radar capability.

ii. Availability, or the measure of the degree a system is in the operable and committable state at the start of a mission when the mission is called for at an unknown random point in time. This is

often called 'operational readiness'. Availability is a function of operating time (reliability) and down-time (maintainability/supportability).

iii. Dependability, or the measure of the system operating condition at one or more points during the mission given the system condition at the start of the mission (i.e. availability). Dependability is a function of operating time (reliability) and down-time (maintainability/supportability).

A combination of the foregoing considerations (measures) represents the system effectiveness aspect of total cost effectiveness.

2.6.2 Life Cycle Cost (LCC)

LCC involves all costs associated with the system life cycle, including:

i. Design and development cost: the cost of feasibility studies, system analysis, detail design and development, fabrication, assembly and test of engineering models and associated documentation.

ii. Production and construction cost: the cost of fabrication, assembly and test of operational systems, operation and maintenance of production capability and associated initial logistic support requirements.

iii. Operation and maintenance cost: the cost of sustaining the operation, personnel and maintenance support, spare/report parts and

related inventories, test and support equipment, maintenance, transportation and handling, and so on.

iv. System retirement and phase-out cost: the cost of phasing the system out of the inventory due to obsolescence or wear-out and subsequent items of equipment recycling and reclamation as appropriate.

Life-cycle cost may be categorized many different ways, depending on the type of system and sensitivities desired in cost-effectiveness measurement.

2.6.3 Cost Effectiveness

The development of a system or product that is cost effective, with the constraints specified by operational and maintenance requirements, is a prime objective. Cost effectiveness relates to the measure of a system in terms of mission fulfilment (system effectiveness) and total life-cycle cost. Cost effectiveness, which is similar to the standard cost benefit analysis factor employed for decision making purposes in many industrial and business applications, can be expressed in various terms (i.e. one or more figures of merit), depending on the specific mission or system parameters that one wishes to measure.

2.6.4 The Quantification of Cost Effectiveness

The quantification of cost effectiveness involves the development of mathematical models for both cost and effectiveness (Juran, 1980):

$$\text{Cost effectiveness} = \text{Effectiveness} \ / \ \text{Total Cost}$$

A useful model for effectiveness define system effectiveness as:

$$P_{SE} = P_A \times P_R \times P_C$$

where

P_{SE} = Probability of overall system effectiveness.

P_A = Probability that the system will be available for use (i.e. availability).

P_R = Probability that the system will be reliable (i.e. reliability).

P_C = Probability that the system has the design capability to perform the function required.

Once such a model is developed it can be used to:

i. evaluate a design against user requirements;

ii. compare alternative designs;

iii. evaluate trade-offs among availability, reliability and capability.

Ordinarily, the cost parameter is defined as life cycle costs:

$$C_T = C_A + C_I + C_{OS} + C_D$$

where

C_T = Total life cycle cost.

C_A = Total acquisition cost.

C_I = Total investment cost.

C_{OS} = Total operation and support cost.

C_D = Total disposal cost.

Regardless of the type or origin of the model chosen, it should be capable of providing comparisons and evaluations for trade-off analyses of alternative options, identifying risks and establishing a baseline for sensitivity analyses throughout the acquisition process.

During the concept phase the quantity and quality of detailed design data are limited, so the bulk of information used for modelling must come from assumptions or estimates. As the design matures towards the end of full-scale development, the data should be much more accurate, making the LCC model results as precise as possible. (MIL-HDBK-25 contains a detailed explanation for estimating life cycle costs).

LCC models are extremely complex and require an enormous amount of input data from many different sources in order to produce a reasonable prediction. Therefore, all modelling should be done by computer.

2.7 CONFIGURATION MANAGEMENT

2.7.1 Introduction

The concept of a smooth transition from development to production requires that the design is frozen and documented at a point in time and from then on, that the 'configuration' is carefully controlled and documented. Only then can the final planning for production, installation, maintenance and logistics be completed. Configuration control must be maintained throughout the life cycle of the product (or system) to avoid degraded operational availability and higher support costs.

'Configuration' basically refers to the **functional and physical characteristics** of a product, including both **hardware** and **software.**

Ideally, a complex product is thoroughly evaluated and changes are made during design and development so that the design released to production is 'frozen'. Of course, this is often not the case and changes are made after production commences.

A change may result from the redesign of a prime product item, the revision of a production process, and will affect technical data, impact on the reliability of the product, and so on. Thus, what initially appears to be a simple system modification, often has a tremendous impact on the prime equipment, associated software, production capability and logistical support.

The collection of activities needed to accomplish these changes for complex products is called 'Configuration Management'. (Juran, 1988)

2.7.2 Configuration Management Program

The purpose of carrying out a configuration management program is to control and minimise the changes which occur on equipment hardware, software and manufacturing operations.

The program usually consists of three elements:

i. Configuration Identification

This is the process of defining and identifying every element of the product. A configuration established at a particular point in time is called a 'baseline'. Configuration identification consists of three levels of baseline documents:

(1) The **functional baseline** defines the general requirements of an entire product.

(2) The **allocated baseline** defines the general requirements for a major item in the overall production.

(3) The **product baseline** defines the detailed requirement of an item. This baseline is used as a basis of reference from which all future changes are controlled.

The baseline document include drawings, specifications, test procedures, standards and any other information which defines the physical and functional characteristics.(MIL-STD-483A, 1985)

ii. Configuration Control

This is the process of managing the design change from the time of the original proposal for change through the approval or disapproval of the changes. This involves the technical evaluation, costing and determination of the specific serial numbers which will have the change incorporated. As the decisions affect many functions, a Configuration Control Board is often set up to review all proposed changes.

iii. Configuration Accounting

This is the process of verifying that changes are made in the hardware and software, and documenting those changes. A formal accounting-type system is required because changes may continually be made. Every change made must be compatible with existing hardware from an engineering point of view.

2.8 QUALITY ENGINEERING (TAGUCHI METHODS)

Quality engineering can be viewed in two distinct categories (see Fig. 2.3):

i. Off-line Quality Control activities occur at the product and process design stages. They optimise product and process design using design of experiments. The design process includes system design, parameter design and tolerance design.

ii. On-line Quality Control activities occur at the actual production stage. They include process control systems, use of adjustment factors and inspection. 'Statistics Process Control' is one way to do On-line Quality Control.

The discussion will focus on **Off-line Quality Control.** (Taguchi, 1987 and Logothetis, 1989)

2.8.1 Definition

i. Quality Loss Function

Parabolic approximation of the quality loss which results when a quality characteristic deviates from its best (or target) value.

ii. Nominal the best characteristic

The name given to those quality characteristics that have an attainable target, or nominal value (e.g. length, voltage, etc).

iii. Noise

The undesirable and uncontrollable factors that cause a functional characteristic to deviate from its target value are called 'Noise' factors. There are three types:

(1) Outer noise: environmental conditions, such as temperature, humidity, etc.

(2) Inner noise: deterioration of parts, material, sub-components etc.

(3) Between product noise: piece-to-piece variation.

iv. Signal-to-Noise Ratio (SN)

SN is a metric used to project (from experimental results) field quality performance. SN is generally in decibels and depends on the type of characteristic being considered.

v. ANOVA

Analysis of Variance.

vi. Design of Experiments (DOE)

Dr Taguchi's DOE is different from classical DOE. Taguchi recommends the use of orthogonal arrays for constructing control and noise factor matrices in experimental design.

vi. Robust

A product/process that has limited or reduced functional variation, even in the presence of noise.

2.8.2 Off-line Quality Control

i. System Design

System design requires technical knowledge and extensive experience in engineering and science to initially 'design' or specify the product or process.

System design does not utilise design optimisation methods such as design of experiments.

ii. Parameter Design

Parameter design is the most important effective step in the process. It makes the system performance insensitive to the noise factors at low cost by selecting optimal level settings for the control factors.

Design of experiments is used extensively during the parameter design stage.

iii. Tolerance Design

Tolerance design can be used to reduce the variation by reducing the tolerances based upon the quality loss function if the parameter design cannot achieve the required performance variation.

2.8.3 Advantages and Disadvantages

i. Advantages

a. Identifying the interaction between control factors and noise factors in order to obtain 'Robustness'.

b. Parameter design is applicable to product design and product improvement as well as process design and improvements.

c. Improves quality without increase in cost.

ii. Disadvantages

During the system design stage, Taguchi's method did not provide a systematic process for initial design.

2.9 THE SEVEN FUNDAMENTAL TOOLS OF QUALITY CONTROL (QC)

These QC tools (see Fig. 2.4) are well-known as:

i. Cause and Effect diagram

This is also known as the 'fishbone' diagram or the Ishikawa diagram.

The 'effect' is the quality characteristic that is under investigation; the problem that needs to be solved, the effect that needs to be improved or controlled.

Improvements are made by removal or prevention of the factors that cause the effect.

ii. Checklists

Cause and effect diagrams answer the question "What do we already know, or think we know, about a problem?" Checklists are used to collect data to confirm (or deny) this thinking. They are also used to collect data to monitor a process or to monitor the changes that occur as a result of actions taken to remedy a problem.

iii. Stratification

Stratification means to separate or classify into distinct layers or levels.

For problem analysis, the more sub-sets used for data collection, the better.

Data from separate sources should be kept separate and discrete.

iv. Histograms

Histograms are a way of arranging and displaying data so that variation can easily be seen. This is exactly the same as the checklist but re-drawn with bars instead of tally marks. It shows the frequency of occurrence of one set of values compared with the frequency of another.

v. Pareto Diagrams

Pareto diagrams are bar charts, re-drawn with items of different frequency. The greatest frequency is put on the left.

vi. Scatter Diagrams

When data is collected to confirm or deny the thinking that has gone into constructing the cause and effect diagram, scatter diagrams can be used to check for any relationship between the effect and suspected cause.

vii. Control Charts

Control charts are used to monitor a process to rapidly identify when the process has gone out of control. On the other hand,

control charts can be used to estimate the capability of process. This would be very useful for process design.

The above mentioned tools and techniques are championed by Dr Kaoru Ishikawa and used in Japanese companies since the early 1950s. They are used by everyone in the organisation, at all levels and for all functions. (Hand & Plowman, 1992)

Data are collected and displayed in simple, visual formats; everyone speaks the same language and there are no misunderstandings. Use of the tools is not restricted to manufacturing problems; design, safety, cost efficiency etc. can all be tackled.

Usually, the seven tools are used to evaluate current performance, make improvements to it and then control it at the new level. The whole cycle is then repeated - continuous improvement.

The tools are used in the team work environment and everyone in the organisation must be trained in the use of the tools.

2.10 QUALITY FUNCTION DEPLOYMENT (QFD)

i. "Carrying the voice of the customer through to the factory floor" is the aim of QFD.

QFD is a customer-driven planning tool. The essence of QFD is a series of interlocking matrices that start with customer's needs and then deploy these down to the process control characteristics.

ii. The QFD spreadsheet (known as the 'house of quality') was first developed at the Kobe, Japan, shipyards in the early 1970s and was also used for specific applications by Toyota in the mid-1970s. The 'house of quality' spreadsheet allows for additional information to be added to the generic spreadsheet, including competitive technical data, customer survey data, and importance factors. For details on QFD matrices, see Hauser and Clausing (1988), Sullivan (1986) and Morrell (1987).

iii. The main advantage of QFD is for recognising and prioritising the desirable features that could be built into a new product and then making sure that they are delivered. It is an opportunity/development process rather than one of problem solving or problem prevention.

iv. Enhanced QFD has recently been formulated by Don Clausing and Stuart Pugh (1991). Basic QFD is adequate for simple, static products. However, for complex and/or dynamic products, basic QFD reveals a fundamental gap between the first matrix (house of quality) and the second matrix (design).

The output of the 'house of quality' is the corporate expectations at the total system level, which becomes the inputs (rows) to the Design matrix. The output from the Design matrix is detailed design decisions, e.g. the dimensions of piece parts. However, the direct jump from total system expectations to detailed design decisions can only be made for simple, static products.

Enhanced QFD provides for the multiple levels of complex systems and enables dynamic concept selection at each level. The dynamic concept selection is performed by using the Pugh concept selection process. Enhanced QFD also has an improved information acquisition and analysis phase that leads into the 'house of quality'.

2.11 FAILURE MODE AND EFFECT ANALYSIS (FMEA)

i. FMEA is used as a planning and a problem prevention technique. It can be used particularly in the design stage to enable the designer to diagnose the cause and effect of problems. It is also a team technique where the team is made up of people who can contribute critical knowledge and ideas for the analysis of a proposed new product or process.

ii. For most products, it is not economic to conduct the analysis of FMEA for each component. Instead, engineering judgement is used to single out those items which are critical to the operation of the product.

iii. FMEA analysis is also useful in planning for inspection, assembly, maintainability and safety.

2.12 JURAN'S 'DESIGNING FOR QUALITY' CONCEPT

Dr J.M. Juran, in his books, introduced a very useful concept - **designing for quality** (1. Quality planning and analysis, 2nd edition, 1980. 2. Quality Control Handbook, 4th edition, 1988).

Juran compared traditional products with modern products and concluded that the change from traditional to modern products is often gradual and can mask the need for new approaches in product development. (The distinctions between traditional and modern products are shown in Table 2.1).

All products, traditional and modern, have two types of requirements: "functional performance" and "fitness-for-use", such as reliability, maintainability and safety. For traditional products. The design work carried out to achieve performance requirements is usually sufficient to meet the other parameters. Modern products have more exacting needs that require additional managerial methods and technological tools.

To reach the aim of 'Design for Quality'. Juran suggested important concepts and procedures as follows:

i. <u>Cost-effectiveness concept</u>

For modern products, attainment of fitness for use involves a balance among competing parameters and costs. The aggregation of these parameters and costs, from, the inception of the design to the end of the operational life is called the 'cost-effectiveness concept'. The practical application in the design process will be discussed in Chapter 3.

ii. The phase concept of product development

In practice, the 'design/manufacture/use' classification is an over-simplification. For many products (traditional or modern) it is useful to visualise an evolution taking place through many phases. For simple products, some of these phases are brief, or even combined with other phases:

a. Concept and feasibility phase

In this phase the known or anticipated need for a product is studied in enough detail to determine if it is feasible to design and manufacture a product responsible to the need.

b. Detailed design phase

For complex products, the detailed design phase may consist of two major sub-phases:

(1) A more detailed exploration of several design concepts uncovered in the feasibility stage.

(2) Selection of a final design concept followed by fully detailed design and development.

c. Prototype phase

In this phase, the first essentially complete units of the product are built and tested.

d. Pre-production demonstration phase

In this phase, a 'production design' is prepared and evaluated for producibility and performance.

e. Early warning concept

The frequency and severity of problems caused by design has stimulated companies to develop more and better forms of early warning of impending troubles. These early warnings are available in a variety of forms such as design review, failure mode and effect analysis (FMEA) and various testing etc.

f. Design for high reliability and maintainability

For complex products, reliability and maintainability are important parameters of fitness-for-use.

To achieve high reliability, it is necessary to define the specific tasks required. This task definition is called the reliability program.

Usually, a reliability program is identical to a quality program aimed at fitness-for-use, but a reliability program puts more emphasis on the concept of 'design-in', which is using specific techniques such as redundancy, derating, stress analysis and part selection etc. to improve the reliability of products in the early design phase.

From Juran's 'Designing for Quality' concept, it is seen that the simplicity of traditional products permits product development to be carried out with a modest amount of effort. The complexity of modern products and the consequences of releasing deficient designs can mean that product development must be structured with phases to assure that the designs released are adequate. **The establishment of a formal product development process is a policy decision for management.**

2.13 FEIGENBAUM'S 'TOTAL QUALITY CONTROL' AND 'NEW DESIGN CONTROL'

Dr Armand V. Feigenbaum introduced the TQC concept in his book (Total Quality Control, 3rd edition, revised 1991). He gave the TQC definition as follows:

> Total Quality Control is an effective system for integrating the quality-development, quality-maintenance and quality-improvement efforts of the various groups in an organisation so as to enable marketing, engineering, production and service at the most economical levels which allow for full customer satisfaction.

This TQC definition is quite similar to TQM from the British Quality Association. Both of them are customer-oriented quality concepts.

Feigenbaum also defined 'New Design Control' as follows:

> New Design Control involves the establishment and specification of the necessary cost-quality, performance-quality, safety-quality and reliability-quality for the product required for the intended customer satisfaction, including the elimination or location of possible sources of quality troubles before the start of formal production.

He suggested a pattern for the new design control routine as follows:

i. <u>Establishment of the quality requirements for the products.</u>

   This involves analyses that culminate in customer-satisfaction-oriented specification and standards which incorporate performance, reliability,

maintainability and safety requirements and the cost-quality balance for the product. it also covers the pre-production evaluation and testing of the product.

ii. Design of a product which meets these requirements

This involves the establishment of detailed drawings for the product and the preparation of the related engineering instruction. It also includes product life and safety evaluations, prototype construction and various testing.

iii. Planning to assure maintenance of the required quality

This involves the control of purchased material, maintenance of quality during processing and production and the assurance of quality during field installation and product servicing.

iv. Pre-production review of the new design and its manufacturing facilities: formal release for active production

This involves process design, process capability analysis and a series of qualification tests.

These four elements are quite basic in new design control of plants. For practical application, procedures should be developed to suit product type and company policy.

i. Traditional design process was completed with 'instructions for manufacture'. In the same condition, traditional 'design control' techniques such as 'design review', 'document control', 'design verification' and 'design evaluation' only provide an after-the-fact analysis. Thus, it is **a narrow-sense and passive 'design control'**.

ii. For modern complex products, **a broad-sense and active quality management** programme which can participate the design process and prevent design problems in the early stages, will be necessary.

iii. The advantages learnt from, the above mentioned survey will help to create a generic quality management programme. The following advantages will be adopted:

a.	From TQM:	Team work
		Feedback loop
		Continuous improvement
b.	From ISO 9001:	Design input/output model
		Interface control
		Design review and verification
		Document control
		Corrective action
c.	From Concurrent Engineering:	Systematic and simultaneous design concept
		Closer co-operation (cross-functional organisation)

d.	From System Engineering:	Top-down design process System decomposition System effectiveness Configuration control Life cycle cost
e.	From Taguchi's Method:	Off-line quality control concept Experimental design Design and process optimisation Parameter and tolerance design
f.	From QFD:	Interpreting customer needs for design requirements
g.	From FMEA:	Problem prevention
h.	From Juran:	Cost effectiveness Phase concept of product development Design for reliability and maintainability Early warning concept
i.	From Feigenbaum:	Total quality control Customer-oriented design concept New design control programs
j.	From 7 fundamental tools of QC:	Cause and effect analysis

Traditional versus modern products

Aspects of products	Traditional	Modern
Simplicity	Simple, static	Complex, dynamic
Precision	Low	High
Need for interchangeability	Limited	Extensive
Consumables or durables	Mainly consumables	Mainly durables
Environment in which used	Natural	Unnatural
User understanding of product	High	Low
Importance to human health, safety, and continuity of life	Seldom important	Often important
Life-cycle cost to user	Similar to purchase price	Much greater than purchase price
Life of a new design	Long; decades, even centuries	Short; less than a decade
Scientific basis of design	Largely empirical	Largely scientific
Basis of reliability, maintainability, etc.	Vague: "best effort"	Quantified
Volume of production	Usually low	Often high
Usual cause of field failures	Manufacturing errors	Design weaknesses

Table 2.1 The distinctions between traditional and modern products

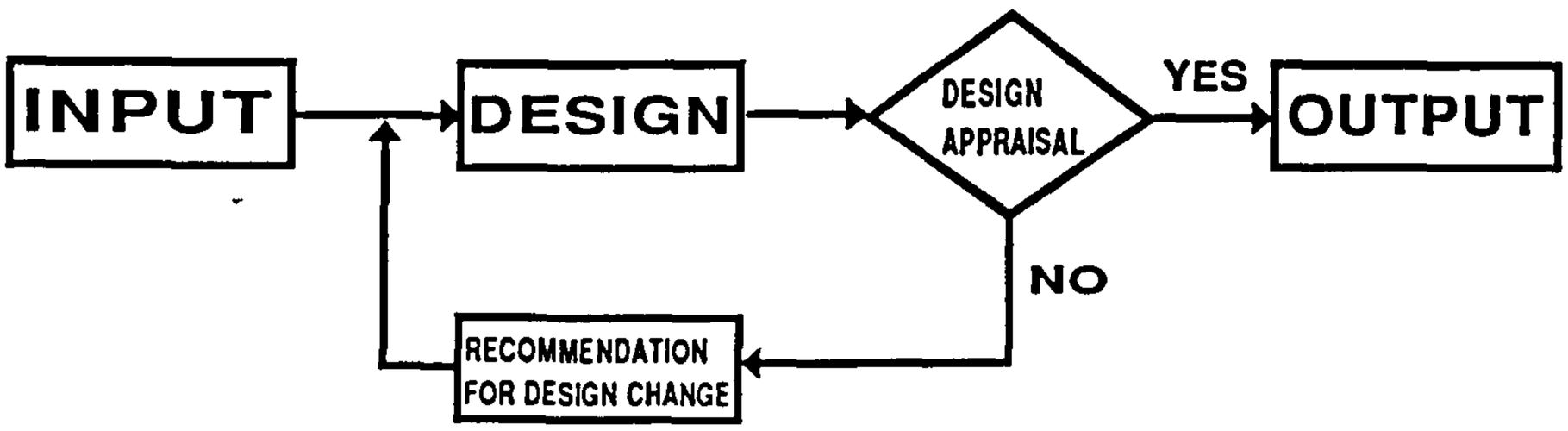
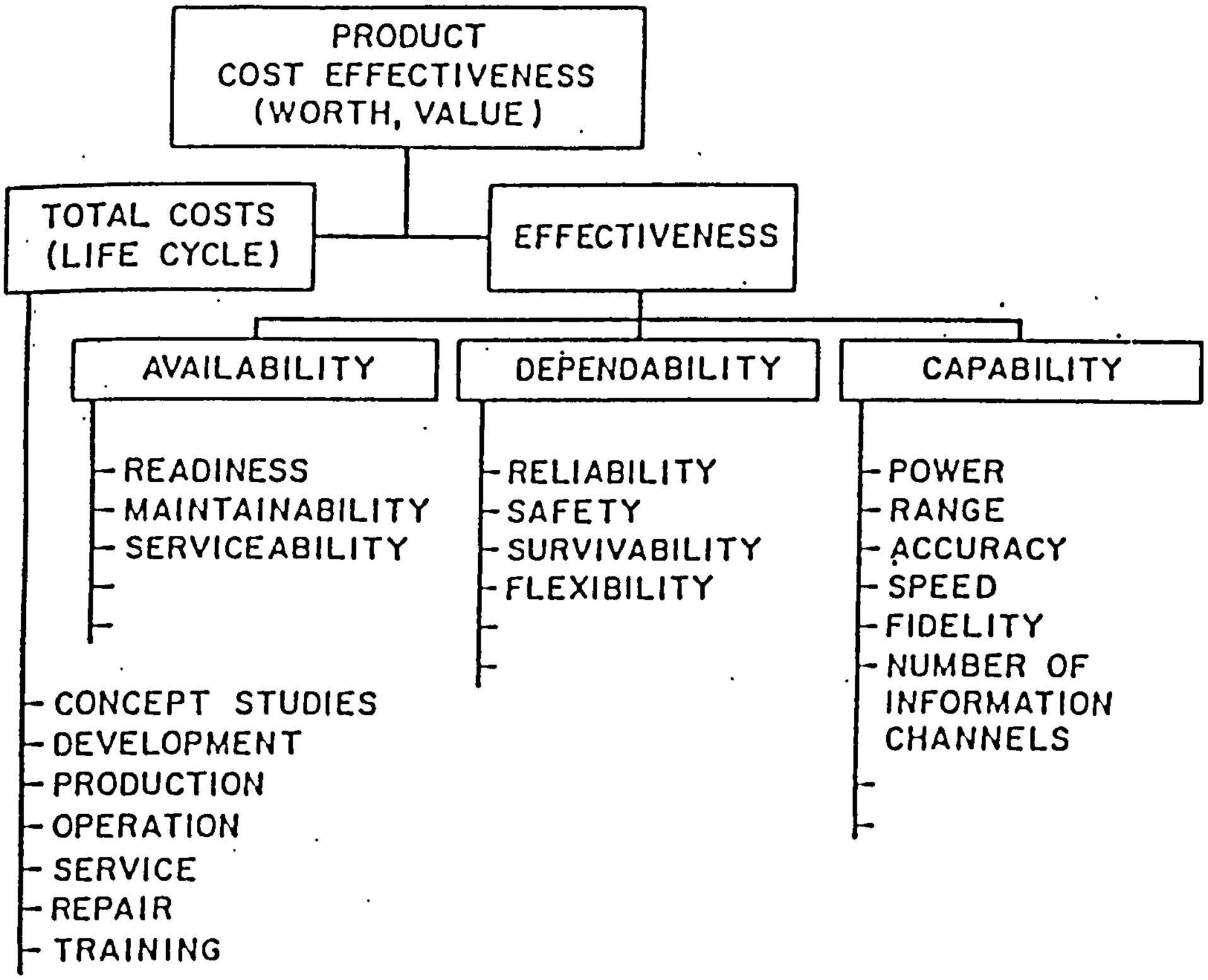


Figure 2.1 Basic design control model from ISO 9001



Elements of cost effectiveness.

Figure 2.2 The prime ingridiente of Cost-Effectiveness

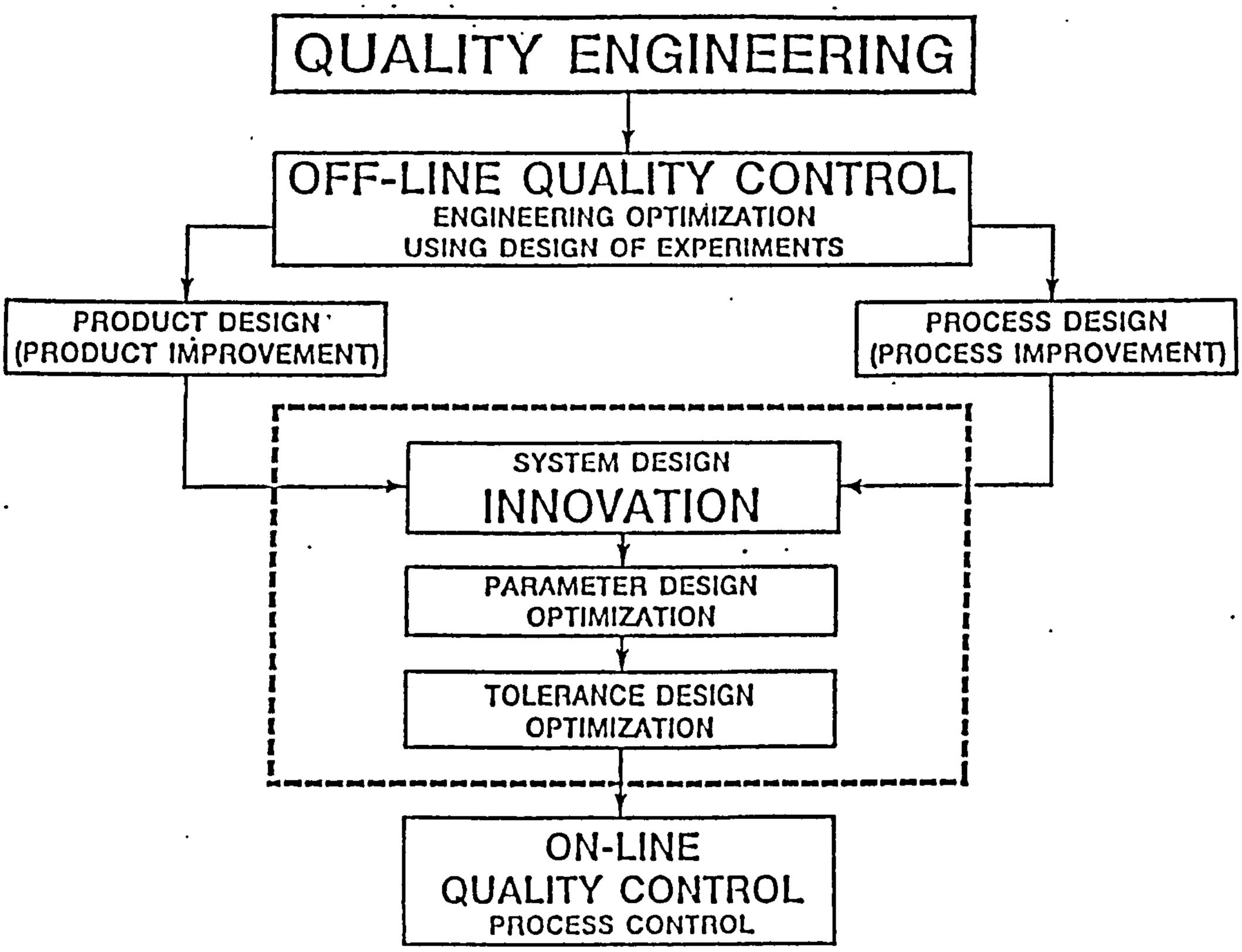
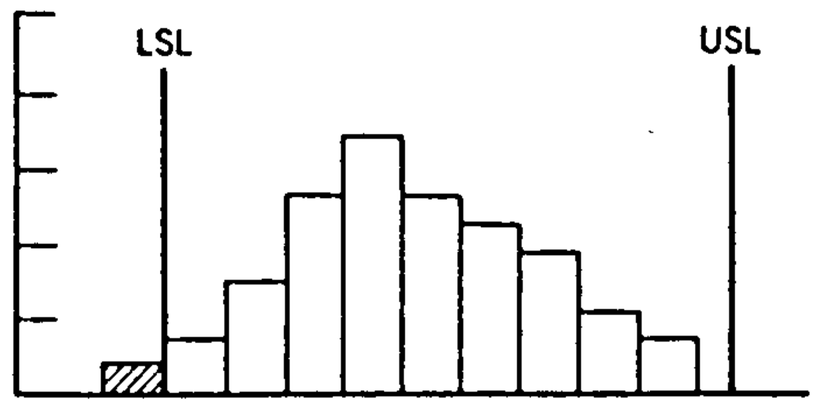


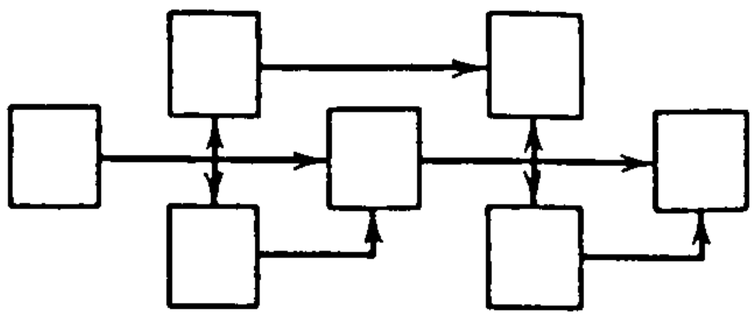
Figure 2.3 Off-Line Quality Control

Histogram



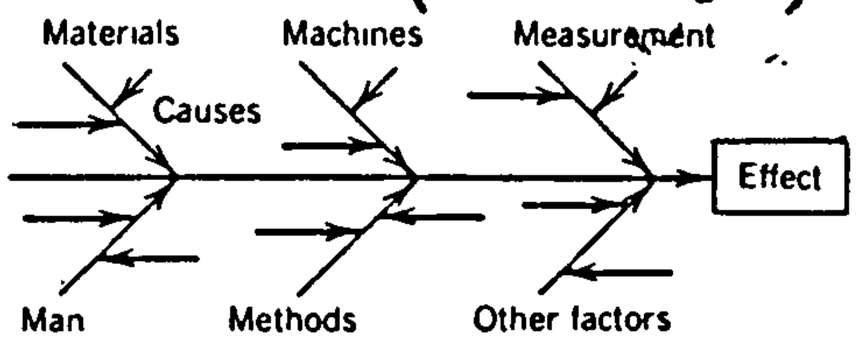
- The shape shows the nature of the distribution of the data
- The central tendency (average) and variability are easily seen
- Specification limits can be used to display the capability of the process

Process Flow Diagram



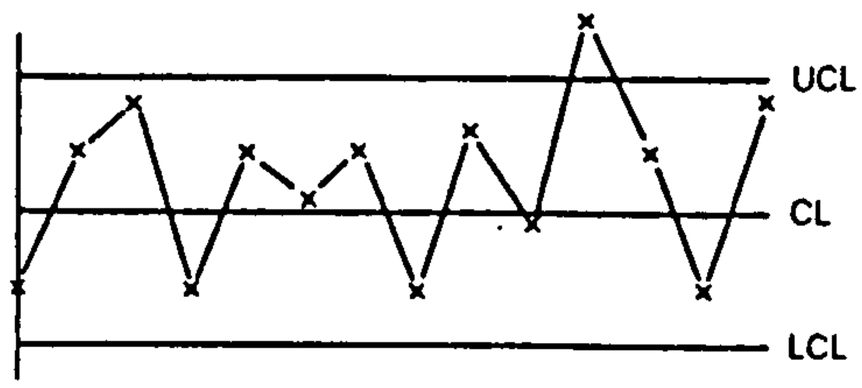
- Expresses detailed knowledge of the process
- Identifies process flow and interaction among the process steps
- Identifies potential control points

Cause and Effect (Fishbone Diagram)



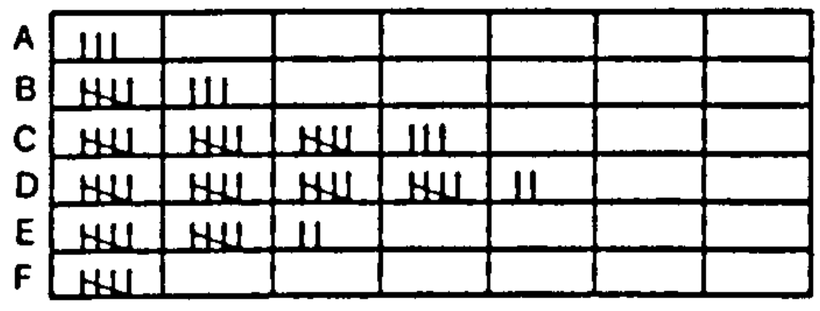
- All contributing factors and their relationship are displayed
- Identifies problem areas where data can be collected and analyzed

Control Chart



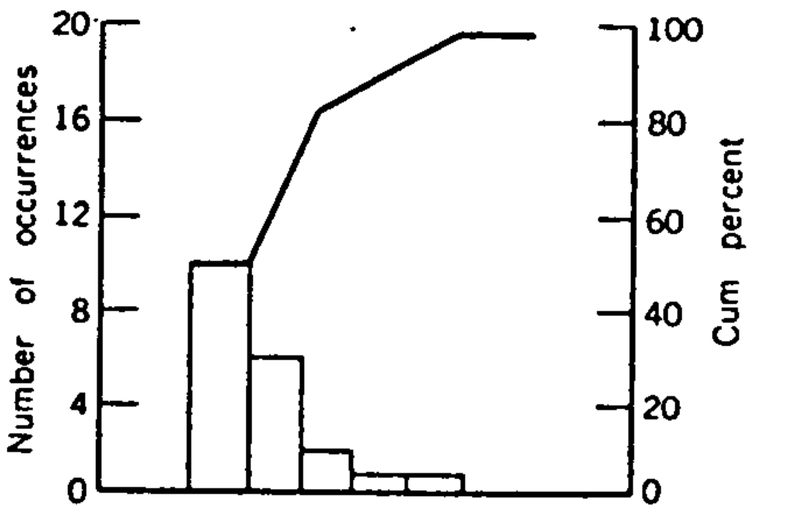
- Helps reduce variability
- Monitors performance over time
- Allows process corrections to prevent rejections
- Trends and out-of-control conditions are immediately detected

Checksheet



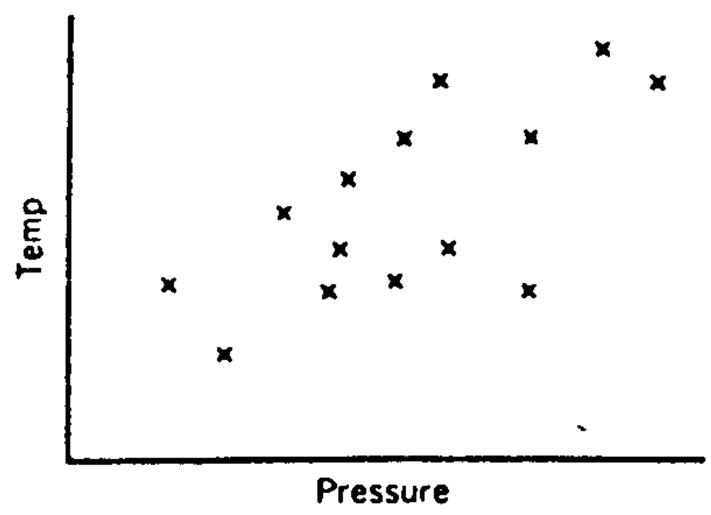
- Simplifies data collection and analysis
- Spots problem areas by frequency of location, type, or cause

Pareto Diagram



- Identifies most significant problems to be worked first
- Historically 80% of the problems are due to 20% of the factors
- Shows the vital few

Scatter Plot



- Identifies the relationship between two variables
- A positive, negative, or no relationship can be easily detected

Figure 2.4 The Seven Fundamental Tools of Quality Control

CHAPTER 3

ANALYSIS OF THE QUALITY RELATED DESIGN AND DEVELOPMENT PROCESS

3.1 INTRODUCTION

The purpose of planning a quality management programme during a new product design and development stage is to ensure that the design activities and outcomes can be assessed for **correctness**, suitability and **efficiency.**

The goals for every management activity should contribute to:

i. **satisfying the customer** (whether it is the internal manufacturer or the external end user).

ii. **shortening the time** from design to production;

iii. **minimising the cost** (to consider the whole life cycle, not just the design stage);

From past experience it can be said that most project managers and the hierarchy of management above them, do not understand or properly manage the technical process of new product design and development. This is because they measure success in terms of 'on time and within budget' rather than by performance in service.

The existing management system focuses on administrative issues: cost and scheduling. The milestone decision points are unrelated to the industrial processes and the transition between development and production in the factory.

In fact, a poorly designed product cannot be properly tested or produced. During the test programme there will be far more failures than would be expected. Manufacturing problems will overwhelm production schedules and costs. All this will cause needless, high re-design/re-work costs.

To avoid this, management should be held accountable for striking a balance between administrative and technical risk in every programme decision and a general understanding of the technical disciplines becomes an essential requirement.

It may cost more during the Design stage but the increased cost in design or test may be offset in production as a result of lower reject rates and reduced re-work, which will also shorten the time from design to production and also improve delivery schedules.

3.2 DEVELOPMENT OF A TIME-PHASED QUALITY SYSTEM

In order to meet the above mentioned goals (satisfactory performance, shorter time and minimum cost) and ensure the design outputs can be assessed for correctness and efficiency, the author applied multiple disciplines (motivated by literature review), creating a 'Time-phased Quality Activities' programme to describe Quality Management for the design and development of a new product.

A brief description of the features of the diagram (see Fig. 3.1) follows:

i. Using 'system engineering process' to divide the product life cycle into six phases (conceptual, design, development, qualification, production and field use phase) to form a **timescale.** It would then be easy to allocate time and other resources to each phase and evaluate the outcome of each phase.

ii. Each phase consists of a series of activities. These activities are the key tasks for most products. However, they can **be tailored** to suit different product types and different company policy, as well as different customer requirements. Thus their application would be very flexible.

iii. The complete diagram, each phase and each activity, is basically a **closed-loop.** One activity's output must satisfy the next (successive) activity's input requirement, otherwise that task will have to be redone.

In case the test results are not acceptable, some activities, and even a whole phase or more, will be re-worked. By strictly controlling the individual activity the possibility of re-work will be minimised. This closed-loop will keep a continuous improvement iteration.

iv. 'System engineering process' is used as a fundamental frame and then combines a conventional 'Engineering design process' with a more modern 'Integrated design process'.

v. A checkpoint (design review) is included at the end of each phase, which forms **an early warning system** and feedback route.

vi. All activities in the diagram are designed to support, enhance and monitor the design work, but **does not involve the pure professional design work or the designer's creativity.**

vii. The diagram function covers all conventional design control skills such as design review, design change control, interface control, documentation control and design verification, etc. (a detailed discussion is given later).

viii. The diagram forms **an active quality management system** to enable the quality engineer to join the design activities, not just to check the design results but also to work with the design engineer, manufacturing engineer and other related people.

ix. Many of the activities need to use 'Quality Function Deployment' and 'Experimental Design' skills to get the optimum solutions and to make trade-off decisions.

x. The 'Quality-related design and development process' **starts from 'Identify customer needs' and ends at 'Design Release'** and also provides a useful 'Quality Information System'.

3.3 CONCEPTUAL PHASE

a. The purpose of the conceptual phase is to fully define customer needs, develop a complete mission and a life-cycle profile for the new product/system.

b. When the need has been fully defined, the next step is to develop alternative technical approaches for fulfilling that need.

The result of the conceptual phase is the selection of the most feasible alternative for further study. If an alternative cannot be identified, then the cycle will be repeated for re-definition of the need.

c. Other output from the conceptual design phase usually includes the preparation of an 'A' specification (or functional baseline), definition of system operational requirement, the system maintenance concept, a preliminary system analysis and a top-level system functional flow diagram.

Reliability and maintainability requirements are included in the functional specification.

3.3.1 Activity 1-1: Identifying customer needs

i. The goal of quality management is to provide the product which satisfies the customer needs or requirements.
However, customer needs are not always clear enough. Therefore the designer needs to interpret them and carry out the necessary investigations to get useful information to support design tasks.

ii. Usually, the most common customer needs are economy, reliability, durability, easy of use, easy maintenance, safety and achieving a certain performance.

iii. If the customer is a manufacturer, he will ask for the design output to be easy to perform to enable further processing and the inspector will ask for it to be easily tested. Thus, each customer requirement will be quite different and the design engineers need to use some tools to translate 'customer needs' into engineering design requirements.

iv. Recently, the most efficient and accurate approach has been to use 'Quality Function Deployment' (QFD) methodology to identify the 'voice of the customer' and to translate this voice into actionable items in the design or process (see Fig.3.2).

3.3.2 Activity 1-2: Mission and Life Cycle Profile Analysis

i. When customer needs/requirements are properly translated into system design requirements, the engineers will identify the prime mission of the system. The mission may be defined through one, or a set of, scenarios or operational profiles. It is important that the 'dynamics' of the system operating characteristics are identified.

ii. For example, an aircraft's mission may consist of take-off, fly, land, communicate, use radar, etc. One mission may be composed of many different operations.

By studying mission operation requirement profiles, results are obtained from these which are useful for functional identification and design requirements

iii. The system life-cycle encompasses a number of programme phases to include advance planning and conceptual design, detail design and development, qualification, production, distribution, operation, sustaining maintenance and support and system requirement and disposal.

So, design and development must be addressed on a life-cycle basis and as an integral part of the overall system engineering process.

iv. In reviewing the experience associated with many of the systems in use today, it has been found that the resulting output is highly influenced by the planning and design decisions made during the early phases of the system life-cycle. (Blanchard, 1985)

3.3.3 Activity 1-3: Feasibility Study (Trade-off study)

i. A broad spectrum of feasibility study (or trade-off study) is initiated during the conceptual exploration phase. These feasibility studies continue into the development phase as a logical approach to selecting the best design once customer (or mission profile) and design requirements have been specified.

ii. Input data: customer, design and operational requirements, life cycle cost, system effectiveness.

iii. (1) Identify all possible alternatives that will fulfil the requirements.

(2) Identify a system configuration which is feasible within the constraints of available technology and resources (i.e. money, human resources, equipment, material, or a combination thereof).

(3) Screen and evaluate the most likely candidates in terms of performance, effectiveness, reliability and economic criteria, etc.

iv. Output: Justify the system and describe a recommended, preferred configuration and design approach. The final selection and design approach must consider such factors as producibility and operational suitability as well as **performance, cost and schedule.**

3.3.4 Activity 1-4: Project Group Organisation

Usually, a R & D project represents a broad spectrum of activity involving many organisations in a company.

In the past, these various R & D activities have operated somewhat independently, especially not matching the quality management system and the results have been less than effective. Design problems cannot be found in the early stage.

For large R & D projects and complex product design, a matrix organisation (cross functional), or a more flexible organisation, should be established (i.e. Project Manager, Failure Review Board, etc).

3.3.5 Activity 1-5: System Requirement Specification

In this activity, design and operational requirements and system specification must be decided upon.

i. The design requirements for full-scale development must be specifically defined to meet the mission profile, beginning with factory acceptance and extending throughout the life of the system. These requirements include a complete definition of the total range of environments to which the product system will be exposed, including storage conditions, maintenance, transportation and operational use.

ii. The system specification (top-level system specification) must state the technical and mission requirements for the system as an entity, allocates requirements to functional areas, documents design constraints and defines the interfaces amongst or between the functional areas. Normally, the initial version of a system specification is based on parameters developed during the Conceptual Exploration phase. This specification is used to establish the general nature of the system that is to be further defined and finalised during the Qualification phase.

iii. Operational requirements, from which design requirements are derived, are of no direct value to a system designer. It is the responsibility of the producer to specify the design requirements which will satisfy the operational requirement.

iv. Design requirements include a full and explicit statement of quantitative performance requirements. In addition to the more obvious requirements for system performance levels, this set of parameters include structural static and dynamic requirements, weight, reliability, maintainability and unit production cost.

v. Besides the more obvious performance and reliability requirements, there is the additional demand of producibility: it must be economically feasible to manufacture a quality product at a specified rate and to deliver the finished items capable of achieving the performance and reliability inherent in the design.

3.3.6 Activity 1-6: Conceptual Design Review (C.D.R.)

i. The C.D.R. may be scheduled during the early part of a programme when operational requirement and support concepts have been defined. Feasibility studies justifying preliminary design concepts should be reviewed. (MIL-STD-1521B, 1985)

ii. An example checklist for C.D.R. is:

a. Mission and requirements analysis.
b. Functional flow analysis.
c. Preliminary requirements allocations.
d. System/cost effectiveness analysis.
e. Trade-off studies.
f. Synthesis.
g. System interface studies.
h. Programme risk analysis.

i. Producibility analysis plans.

j. Technical performance measurement planning.

k. Engineering integration.

l. Data management plans.

m. Configuration management plans.

n. System safety.

o. Human factor analysis.

p. Life cycle cost analysis.

q. Manpower requirements/Personnel analysis.

r. Milestone schedules.

3.4 DESIGN PHASE

a. The basic principle for complex product design is to use a 'System Engineering Model' (Shubert, 1989) to identify the 'voice of the engineer' and translate that voice into actionable items in the design or process (see Fig. 3.3).

b. Usually, preliminary system design starts with the baseline configuration for the system identified through the functional specification in conceptual design and proceeds towards translating the established system-level requirements into detailed qualitative and quantitative design characteristics.

c. The detailed design phase begins with the concept and configuration derived through preliminary system design. That is, a configuration with performance, effectiveness, reliability and other requirements as has been described in the system specification.

The accomplishment of configuration definition in the form of 'B' and 'C' specifications (i.e. sub-system, equipment, software, material, process, procurement, etc.) will also be established.

d. The following activities from 2-1 and 2-8 are the key points of quality control in the design phase:

3.4.1 Activity 2-1: Functional Allocation and Prediction

i. Functional analysis is a logical and systematic approach to system design and development. It constitutes the process of translating

system operational and support requirements into specific qualitative and quantitative design requirements for each hierarchical level. (The indenture relationships of functions by level are illustrated in Fig. 3.4). (Blanchard, 1985)

ii. This process is iterative and is accomplished through the development of functional flow block diagrams.

Functional flow block diagrams are developed for the primary purpose of structuring the system requirements into functional terms. They are developed to indicate basic system organisation and to identify functional interfaces. Functional blocks are concerned with what is to be accomplished as against the realisation of how something should be done (flow block diagram example is shown in Fig. 3.5).

iii. The functional analysis provides a description of major system functions and translates them into specific system design requirements (or constraints). The next step involves the allocation of system top-level design requirements to the various sub-elements of the system. Such requirements can be reliability, maintainability, interchangeability, safety, testability, standardisation and even economic factors. (An example of reliability allocation is shown in Fig. 3.6). (Juran 1988)

iv. As engineering data becomes available, functional prediction is accomplished as a check on design in terms of system requirement and the factors specified through allocation. Here, 'reliability prediction' is taken as an example.

The predicted values of MTBF, or failure rate (λ) are compared against the requirement and areas of incompatibility are evaluated for possible design improvement.

Prediction is accomplished at different times in the system design process and will vary somewhat depending on the type of data available. Reliability block diagrams, models, and computer methods are employed to varying degrees depending on the problem at hand. (See Table 3.1, extracted from Juran 1980)

v. Basic reliability prediction techniques are summarised as follows:

a. Prediction based on the analysis of a similar product.

b. Prediction based on an estimate of an Active Element Group (AEG).

The AEG is the smallest functional building block that controls or converts energy.

c. Prediction may be accomplished from a system parts count. There are a variety of methods used that differ somewhat due to data source, number of part-type categories and assumed stress levels. Basically, a design parts list is used and parts are classified in certain designated categories. Failure rates are assigned and combined to provide a predicted MTBF at the system level. (An example is illustrated in Table 3.2, Data from MIL-HDBK-217D).

3.4.2 Activity 2-2: Establishment of Design Criteria

i. With the identification of operational functions and the accomplishment of requirements allocation, it is possible to generate detailed design criteria. Such criteria constitutes specific requirements in the areas of reliability, maintainability, standardisation, interchangeability, repair versus discarded levels, safety features, and so on.

These criteria may be stated qualitatively or quantitatively and are employed as guidelines for the design engineer.

ii. The established design criteria must be consistent with system operational requirements and other factors defined through allocation. During the early phases of system development, design progress is monitored in terms of compliance with these guidelines.

3.4.3 Activity 2-3: Stress/Strength Analysis

i. The basis of the concept of reliability is that a given component has a certain stress resisting capacity; if the stress induced by the operating conditions exceeds this capacity, then failure results.

ii. The conventional design approach, which is based on somewhat arbitrary multipliers such as safety factors and safety margins, gives little indication of the failure probability of the components. In reality, the failure probability may vary from low to an intolerably high value for the same safety factor.

Furthermore, the design variables and parameters are often random variables, a fact completely ignored by the conventional design approach.

iii. The conventional design is not adequate from a reliability view point. Another design methodology that does consider the probabilistic nature of the design is needed so that component reliability can be calculated at the design stage. Such a design methodology is called 'probabilistic design'. It identifies explicitly all the design variables and parameters which, in turn, determine both the stress and strength distributions (see Fig. 3.7) (Kapur & Lamberson 1977). Once these two distributions are determined, the component reliability can be easily calculated. That is, this approach expresses the component reliability as a function of the stress and strength distributions (see Fig. 3.8). (Juran, 1980)

iv. For an effective application of this methodology, the design engineer must have adequate information on the probabilistic strength, the strength degradation data for the material to be used and the design data on the statistical distribution of loads.

3.4.4 Activity 2-4: FMEA

i. FMEA (Failure Mode and Effect Analysis) provides a methodical way of examining a design for possible ways in which failure can occur. In the FMEA, a product (at the system and/or lower level) is examined for all the ways in which a failure may occur. For each potential failure, an estimate is made of its effect on the total system and of its seriousness.

In addition, a review is made of the action being taken (or planned) to minimise the probability of failure or to minimise the effect of failure. Note that the failure 'mode' is the symptom of the failure, which consists of the proved reasons for the existence of the symptoms.

ii. For most products, it is not economic to conduct the analysis of failure mode and failure effect for each component. Instead, engineering judgement is used to single out those items which are critical to the operation of the product.

Generally, FMEA on one item is helpful to designers of other items in the system. In addition, the analyses are useful in planning for inspection, assembly, maintainability and safety.

3.4.5 Activity 2-5: Material, Parts Selection and Control

i. It is a difficult exercise for a designer to choose a material/parts having regard to a manufacturing process and his own company's facilities.

ii. Each manufacturing company should have its own internal design policy laying down both company standards and national and international standards.

iii. Safety factors are sometimes specified by legal requirement or customer. Commonly used factors ranged from 1.25 - 4 depending on the uncertainties involved and can be applied to the yield stress for ductile materials, to the ultimate tensile strength for brittle

materials and to the fatigue strength for parts subjected to fatigue loadings. (Kapur & Lamberson 1977)

iv. Essential information can be obtained from previous history of parts used in similar products.

v. Any new application must be subjected to qualification tests, including overstress, to determine safety factors.

vi. Use de-rating to ensure that the stresses applied to the parts are lower than the stresses those parts can normally withstand.

vii. Supplier inspections and test records must be required.

viii. Parts standardisation and interchangeability must be considered.

3.4.6 Activity 2-6: Integrated Design Analysis

i. Basically, design analysis evaluates the ability of the design to meet performance specifications at low risk.

Those analyses oriented to the reduction of design risk include, but are not limited to, stress/strength, worst case tolerance, sneak circuit, failure modes and effects, and thermal analyses.

ii. Computer-Aided Design (CAD) and Computer-Integrated Manufacture (CIM) will greatly help design analysis.
To maximise the use of 'design analysis' will achieve significant cost savings from various tests.

iii. 'Integrated Design' has the same meaning as Total Design, Concurrent Engineering and Systematic Design. (Pugh, 1990)

The distinction between traditional engineering design (sequential approach) and integrated design (parallel approach) is that integrated design considers not only product design but also manufactured and supported problems, simultaneously.

iv. Normally, integrated design analysis includes design for reliability, producibility (manufacturability), testability and safety, etc.

Brief descriptions are as follows:

3.4.6.1 Design for Reliability

i. The objective of design for reliability is to design a system that will meet all operational requirements in an effective and efficient manner.

ii. In design, this is basically accomplished through the proper selection and application of components, application of de-rating methods as appropriate, specification of highly reliable processes, incorporation of redundancy provisions in critical areas, and so on.

iii. The following actions indicate major approaches to improving reliability during design:

a. Reliability functional analysis.

b. Reliability allocation and prediction.

c. Selection of component parts.

d. Use of redundancy to provide more than one means of accomplishing a given task in such a way that all the means must fail before the system fails.

e. Use de-rating to ensure that the stresses applied to the parts are lower than the stresses those parts can normally withstand.

f. Failure mode, effect and criticality analysis (FMECA).

g. Control of the operating environment to provide conditions that yield lower failure rates.

h. Specify replacement schedules to remove and replace low-reliability parts before they reach the wear-out stage.

3.4.6.2 Design for Manufacture (producibility)

i. The designer should be aware of the methods by which the product may be made.

Product performance depends not only on the design but also on the choice of material and the way in which it is manufactured.

ii. On the other hand, the economic manufacturing process must be considered. The Taguchi off-line quality control methodology is very useful for getting an optimised solution for the manufacturing process.

iii. Ensure that the design is, indeed, consistent with production processes and capabilities.

iv. Producibility is considered as part of the design criteria to be evaluated for cost-effectiveness and ease of manufacture versus the degrees of compliance with the functional requirements.

v. Producibility is identified as one of the items to be covered in a design review but is not to be regarded as one of the major cost drivers in the transition from development to production.

3.4.6.3 Design for Testing (Testability)

i. Past development projects have neglected to consider the need for, production and field test capabilities during the early design phase.

ii. Built-in Test and Production Testing are two major test areas that must be considered from the start of the design effort. Otherwise, these and other test considerations can negatively impact both manufacturing and life cycle costs.

3.4.6.4 Design for Safety

i. Safety has always been considered of paramount importance during all phases of the product life cycle, beginning with the design phase.

ii. The evaluation of modern reliability, maintainability and safety techniques has followed an identical pattern. The modern techniques for product safety attempt to treat safety in a more formal, quantitative way. With the increased complexity of many products, these techniques emphasise the effects of interactions of components on overall product performance.

iii. The terms 'hazard' and 'risk' are used extensively in the literature. A hazard is an attribute of a product that is capable of a harmful result. Risk is the probability of injury occurring due to a hazard when the product is being operated by the user.

iv. During the design phase, both qualitative and quantitative techniques can be helpful. These include fault tree analyses, fail-safe concepts, in-house and field testing, data analysis, designation of safety-oriented characteristics and components.

v. The general approach to safety analysis is as follows:

   a. Review historical data on safety of similar, previous products.
   b. Study the way in which the product has actually been used or misused.
   c. Assess the risk that damage will actually occur.
   d. Quantify the exposure (time, cycles, etc.) of the product and the users to hazardous conditions.
   e. Determine the severity of the effect of a hazard on the product or the user.

3.4.6.5 Design for Human Factors

i. Until fairly recently, human factors in design have received little priority in relation to performance, schedule, cost and even reliability and maintainability. However, it is now realised that for system design to be complete, the human element has also to be addressed and the interface between the human being and the machine.

ii. Optimum hardware (and software) design alone will not guarantee effective results. Consideration must be given to:

anthropometric factors, e.g. human physical dimensions,
human sensory factors, e.g. sight, hearing, feel,
human physiological factors, e.g. reaction to environment,
psychological factors. e.g. need, expectation, attitude, motivation and their interrelationships. (Cullum, 1988)

iii. The general approach to analysing the human element during design is summarised as follows (Swain ,1970, cited by Juran 1980):

a. Prepare a time-based flow chart showing the allocations of system functions between the human and the machine for the complete cycle from factory to end use.

b. List the likely operational uses and conditions of use for the system.

c. Estimate the personnel factors (skill, experience, training and motivation).

d. Analyse the behaviour process for potential sources of human error.

e. Identify specific error-likely situations and estimated error rates.

f. Estimate the likelihood that errors will be undetected or uncorrected.

g. Estimate the consequences of undetected errors.

h. Recommend changes to the system.

3.4.7 Activity 2-7: Integrated Test Planning

i. Because testing is a major cost and schedule driver, adequate planning is essential long before the start of any testing.

ii. Usually, mechanical, hydraulic, pneumatic and electrical products are subjected to three qualification tests: performance, environmental and endurance (durability). The integration of these separate tests into a more comprehensive reliability test program can avoid costly duplication and ensure that deficiencies are not overlooked, as they often are in the fragmented approach.

iii. A typical integrated test plan includes the following:

a. Performance (function) tests should be conducted as soon as items are fabricated. They should be brief and should provide the immediate basis for correction of any deficiencies they disclose.

b. Environmental tests should be considered an early portion of Reliability Growth Test. They must be conducted early in development and the corrections must be verified under stress.

c. Endurance (durability) testing usually consists of a normal test, an overload test and a mission profile cycling test, which duplicates or approximates the conditions expected in field use. An integrated test programme will combine reliability testing and durability testing. (MIL-STD-781C & 785D)

v. To gain the greatest benefit from failures encountered during the testing programme, a closed-loop Failure Reporting Analysis and Corrective Action system (FRACA) should be implemented and test results showing design strengths and weaknesses should be presented at design reviews.

3.4.8 Activity 2-8: Engineering Data and Documentation

i. Engineering data and documentation include all types of design data, analysis reports, calculations, specifications, material lists and various engineering drawings, standards etc. All of these should be documented and controlled. Documentation control is one of the most frequently found causes of quality system deficiency, not least in the design phase.

ii. Formal configuration control must be established prior to the beginning of production.

After configuration control is established, all changes to the design of the product must be approved by an authorised person.

iii. During the initial design phase, the drawings change almost daily due to engineering effort. The point where all documentation becomes subject to configuration control is called 'baseline'. At system baseline, the design is normally complete except for changes required as a result of testing and acceptance criteria. The basic system design is complete.

3.4.9 Activity 2-9: Detailed Design Review (DDR)

i. The DDR will be conducted to evaluate the optimisation, traceability, correlation, completeness and risk of allocated requirements, including corresponding test requirements in fulfilling the system requirements (the functional baseline).

ii. The review also includes a summary review of the system engineering management activities (e.g. functional analysis, requirement allocation, manufacturing methods/process selection, technical risk analysis, trade-off study, intra- and inter-system interface studies, integrated design analysis, integrated test planning and configuration management) which produced the above mentioned system definition products.

iii. An example checklist for DDR is:

a. Mission and requirements analysis.
b. Functional analysis.
c. Requirements allocation.
d. System/cost effectiveness.
e. Synthesis.
f. Reliability/maintainability/availability (R/M/A).
g. Electromagnetic compatibility.
h. Safety.
i. Human factors.
j. Standardisation.
k. Value engineering.
l. Technical risk analysis.
m. Technical performance measurement planning.
n. Producibility analysis and manufacturing.
o. Life cycle cost.
p. Environmental conditions.
q. Milestone schedules.
r. Software development procedures.
s. Configuration control.
t. Engineering data.

3.5 DEVELOPMENT PHASE

i. During the design phase a system engineering process is used decomposing the system configuration into sub-systems, components and parts. This is basically a top-down process but during the development this top-down process is changed to a bottom-up process (see Fig. 3.3).

ii. The tasks in the development phase are as follows:

a. Description of sub-systems, units, assemblies and lower-level components and parts.

b. Preparation of design documentation (e.g. specifications, trade-off study reports, technical manual, detailed drawings), describing all elements of the system.

c. Definition and development of computer software (as applicable).

d. Development of an engineering model, a service test model and a prototype model of the system and its elements for test and evaluation to verify design adequacy.

e. Integrated test and evaluation of the system model which has been developed.

f. Re-design and re-test of the system (e.g. a Test-Analyse-And-Fix methodology). (MIL-STD-1635)

3.5.1 Activity 3-1: Environmental Stress Screening (ESS) Test

i. The purpose of the ESS test is to find early failures which are due to weak parts, workmanship defects and other non-conformance anomalies, to ensure that parts/components/assembly presented for high-level testing are free of workmanship defects and other 'infant mortality' problems. (Juran,1988)

ii. The ESS detailed test plan includes the following:

a. Description of environmental stress types, levels, profiles and exposure times to be applied.
b. Identification of the level (parts, components, assembly) at which testing will be accomplished.
c. Identification of item performance and stress parameters to be monitored during ESS.
d. Proposed test duration (failure-free interval and maximum ESS test time per item).

iii. The results of ESS testing during development will be analysed (FMECA) and used as the basis for the ESS procedures to be specified for production.

3.5.2 Activity 3-2: Prototype Construction

i. The building and testing of prototypes are significant techniques for analysing product quality. When the detailed design stage is completed, it will have the necessary output (drawings, materials

list, manufacturing process, basic machine and tools, documentation, etc.) to support the building of prototypes.

ii. Prototype construction aids the subsequent quality planning. This indicates the characteristics which may cause difficulty from a quality control point of view and also help to establish the cause-and-effect relationship between process and product. Materials and components which represent extremes of tolerance can be represented in prototypes so that their effects on function can be studied.

iii. Care must be taken to analyse differences in performance between hand-made prototypes and tool-made products, or products from the actual production process.

3.5.3 Activity 3-3: Functional Test

i. Functional tests should be conducted as soon as prototypes are fabricated. They should be brief and should provide the immediate basis for correction of any deficiencies they disclose.

ii. The test programme for complex systems must be quite elaborate, including functional identification, testing requirements, standards, procedures, data collection, etc.

iii. The test report should describe test conditions, test data, the results of data analysis and corrective action (if results do not conform to system functional requirements).

iv. Test results are also used to develop design trade-offs.

3.5.4 Activity 3-4: Environmental Test

i. Sufficient environmental testing should be conducted to provide confidence that the product (system) will operate satisfactorily in the environment for which it is intended.

ii. Testing should include exposure to both individual environments and combinations of environments. This normally consists of a sequence of testing, analysis of all failures, incorporation of corrective actions and re-testing, with the sequence repeated until the required capability has been demonstrated.

iii. A series of environmental test should be carried out covering temperature cycling, shock, vibration, sand and dust, salt-spray, fungus, humidity, acoustic noise, and so on.

iv. For detailed testing procedures, conditions and levels, see MIL-STD-810D.

3.5.5 Activity 3-5: Reliability Growth Test (RGT)

i. The RGT is a planned Test-Analysis-And-Fix (TAAF) process in which development items are tested under actual or simulated mission profile environments to disclose design deficiencies and to provide engineering information on failure modes and mechanisms.

ii. The purpose of RGT is to provide a basis for early incorporation of corrective actions and verification of their effectiveness in improving the reliability of the product/system.

iii. RGT emphasises reliability growth rather than being a numerical measurement.

iv. Reliability growth during RGT is the result of an iterative design process (see Fig. 3.9). RDT, using the TAAF process, is a key requirement to achieving acceptable system reliability.

v. Reliability Growth model and test data analysis.

3.5.6 Activity 3-6: Fix Product Specification

i. The system engineering process is used to translate the customer needs into a Type A specification (system specification), as well as deriving a Type B specification (item development specifications) from Type A specification.

ii. Design engineering is the process used to derive Type C specification (system manufacturing specifications) from Type B specifications.

iii. Process engineering is the process used to drive manufacturing drawings, process instructions and other applicable documents from Type C specifications.

iv. At the end of the development phase, some different types of specifications will be established, as follows:

Type B: a. Prime Item Development Specification.

b. Critical Item Development Specification.

c. Software Development Specification (if necessary).

Type C: a. Prime Item Product Function Specification.

b. Prime Item Product Fabrication Specification.

c. Software Product Specification.

Type D: Process Specification.

Type E: Material Specification.

3.5.7 Activity 3-7: Edit SOP, SIP and Technical Manuals

i. As a standard must be followed, the Standard Operation Procedure (SOP) is to give the correct work procedure in the manufacturing process. Standard Inspection Procedure (SIP) is to give the correct inspection procedure for the workpiece during the manufacturing process.

ii. The purpose of a Technical Manual (TM) is to provide users or maintenance personnel with all the information and instructions required to operate and maintain the system/equipment.

iii. Technical Manuals contain a detailed narrative and pictorial descriptions of operation and maintenance procedures, necessary support and test equipment, reference information and identification of spare and repair parts. It can be divided into three groups: Operator Manual, Maintenance Manual and Parts Manual.

3.5.8 Activity 3-8: Critical Design Review (CDR)

i. The purpose of CDR is to analyse the results of hardware construction and integrated tests to ascertain design deficiencies.

ii. The design process at the development phase has identified specific design constraints, additional or new requirements and major problem areas. Such a review is conducted prior to proceeding with finalisation of the detailed design.

iii. An example of a checklist is:

a. Hardware Configuration Items (HWCI): Adequacy of the detailed design reflected in the prototype specification in satisfying the requirements of the HWCI Development Specification for the item being reviewed.

b. Electrical and mechanical design.

c. Environmental control.

d. Electromagnetic compatibility.

e. Reliability/maintainability/availability.

f. System safety engineering.

g. Producibility and manufacturing.

h. Standardisation.

i. Interface control.

j. Documentation control.

k. Human factor.

l. Life cycle cost.

3.6 QUALIFICATION PHASE

i. The objectives of this phase are:

a. System qualification.

b. Design qualification.

c. Process qualification.

ii. Qualification is defined as, 'An item or a system is qualified when objective evidence exists that the item or the system fully complies with all the requirements of the relevant specification.'

iii. Qualification is through a series of activities, starting from Parts Inspection, then Pilot Run, various tests and, finally, Final Design Review

When every deficiency has been corrected, the pre-production tasks are completed, which leads to the important terminative activity - Design Release.

3.6.1 Activity 4-1: Incoming-Material Inspection and Test

i. The technique of incoming-material inspection and test is applied to the acceptance of materials, parts, components, and sub-assemblies that qualify as meeting quality standards.

ii. Analytical techniques applied to the physical and chemical properties of materials permit measuring the degree to which the materials conform to the quality/program plan.

iii. Normally, test equipment includes hardness tester, tensile test machines, radiation tester, moisture testers, ultrasonic testers, spectrophotometer and other state-of-the-art and non-destructive evaluation techniques.

iv. In ISO 9001 the requirements which might be anticipated are less precisely defined and do not give a great deal of practical guidance. The relevant clauses of ISO 9001 are:

4.6 Control of purchased material.
4.7 Purchaser supplied material.
4.13 Control of non-conforming material.

v. Various other operations must be prepared, such as SIP, calibration, purchase contracts, specification, test standards, non-conforming material control, etc.

3.6.2 Activity 4-2: Tool Planning

i. Since tooling includes those devices such as, fixtures, aids, etc. which are required to form, shape, fabricate, assemble, hold or handle the prime equipment, or any part of it, it is obvious that tooling has a great impact on cost, quality and rate.

ii. A tool plan should be developed and proven before product design is frozen.

iii. Tool designers, product designers and manufacturing engineers should co-operate during the conceptual phase. This means that tool

planning, design, review and demonstration must be consistent with the product design and development phases.

iv. An established routine for maintenance and periodic calibration is also necessary to ensure and maintain tool serviceability.

3.6.3 Activity 4-3: Pilot Run

i. A pilot run is a trial production run using regular production tooling and production compounds - electronic, mechanical, chemical and others.

ii. The first manufactured units are subjected to qualification tests to see if they meet performance requirements.

iii. Besides analysis of data resulting from testing the pilot run product, a comprehensive analysis of the pilot run itself should be made to discover any inadequate manufacturing/assembly processes, or to find that some special tools have not been considered. The pilot run will also influence design producibility and, furthermore, provide valuable data for process capability analysis.

iv. It is important to point up quality trouble spots, so correction to the process or product design can be made prior to the start of production. An evaluation of the effectiveness of the corrective action should also be made.

3.6.4 Activity 4-4: Reliability Qualification Test (RQT)

i. The purpose of RQT is to determine that specified reliability requirements (MTBF/MTBM) have been achieved.

ii. RQT must be carried out before the production phase.

iii. RQT is carried out on at least two or more sample items representative of the approved production configuration.

iv. RQT differs from Reliability Growth Test (RGT) in two ways:

- It is intended to prove the product design, not make it fail.

- It is normally performed by an independent testing agency.

v. RQT test conditions, procedures and methods of data analysis are pre-planned on the basis of engineering requirements and statistical considerations. Statistical considerations pertain to the desired accuracy of the test results and of the confidence limits assigned.

Engineering requirements relate to the duty cycles, environmental stress levels, application and performance values and their limits which define the define the basis for success or failure of the item being tested. A clear definition of what constitutes successful system operation is necessary. On the other hand, a failure must be recognised when it occurs.

3.6.5 Activity 4-5: Life Test

i. The purpose of a life test is as follows:

a. To ensure that the design will not fail prematurely due to metal fatigue, component aging or other problems caused by long-term use or environmental effects.

b. To make maintenance and support plans more accurate.

c. To establish life characteristics.

d. To allow the implementation of design changes prior to final design release.

ii. Test Conditions

a. The test environments must be based on expected mission environments/profiles.

b. The test should be scheduled for completion during the full-scale development phase.

c. Aging failure data must be collected and analysed to help identify design risk and estimated product life.

iii. Accelerated Life Test

a. The life test can be time consuming and costly. A commonly used technique, to provide the designer with early life test results, is accelerated life testing. When this type of test is carried out, great care should be taken in choosing the verified acceleration factors and environmental stresses.

3.6.6 Activity 4-6: Process Capability Analysis

i. Before design drawings are frozen and full-scale production entered into, it must be ensured that the manufacturing processes will be able to hold the tolerances that are expected.

ii. Process capability is a measure of the inherent uniformity of the process.

Usually, the process is measured indirectly by measuring the product uniformity, as it is not feasible to determine this process capability by direct measurement of the process under operating conditions.

iii. Measuring the product can discover two types of variability, one is the natural or inherent variability of the process and the other is the time-to-time variability. Both of these can be quantified in statistical terms.

iv. According to Juran, (Quality Planning and Analysis, 1980) there are multiple purposes for which these capabilities can be put to use:

a. To predict the extent to which the process will be able to hold tolerances.

b. To plan the interrelation of sequential processes.

c. To assign machines to classes of work for which they are best suited.

d. To test theories of causes of defects during quality improvement programmes.

e. To provide a quantified basis for establishing a schedule of periodic process control checks and readjustments.

v. <u>The methods of process capability analysis</u>

a. <u>Statistical approaches</u>

The following statistical techniques can be used to analyse Capability:

- Frequency distribution
- Probability paper
- Control charts
- Advanced techniques

Usually, the index of capability ratio is:

$$\text{Capability ratio} = \frac{6\sigma \text{ variation}}{\text{Total tolerance}}$$

b. Graphic Approach

This is a structured approach to analysis. As the process becomes complex, the analysis to measure process capability also becomes complex. The product lots are, in reality, composed of multiple streams, each of which can exhibit time-to-time drift and other changes [SPAN 1956].

c. Design of experiment and analysis of variance

This is a generalised approach, with flexibility to fit any combination of variables. For each such combination, there is a prepared, tailor-made design for collecting the data, which will permit resolution of the composite variation into its components. (Juran, 1988)

vi. Prior to data collection, the following steps should be taken:

a. Choose the machine(s) to be used to establish capability.
b. Define the process conditions.
c. Select a representative productive operator.
d. Provide sufficient raw material for uninterrupted study.
e. Provide adequate gauging and define measurement method.
f. Make provision for keeping track of the order in which the units are made.

3.6.7 Activity 4-7: Final design Review

i. The final design review is scheduled after detail design has been completed but prior to the release of firm design data to production. Such a review is conducted to verify the adequacy and producibility of the design.

The design is essentially frozen at this point and manufacturing methods, schedules and costs are re-evaluated for final approval.

ii. Data requirements for final design review include manufacturing drawings and material lists, production management plan, final reliability, maintainability predictions, engineering test reports and a formal logistic support plan, etc.

3.6.8 Activity 4-8: Design Release

i. Designs may be released which are incomplete, inaccurate or premature. When this happens, it obviously causes problems downstream for all activities involved with the hardware or the design documentation.

ii. 'Design Release' does not mean just various engineering drawings but includes related software, reports, test records, technical manuals, design reviews, configuration audit, manufacturing processes, etc. Therefore, design release is really quite a huge and very important activity.

iii. To ensure that transition from development to production will be smooth, it is necessary for the project group to carry out transition planning in order to control the schedule and costs and to identify the transitive items.

Stages of reliability prediction and measurement*

	1 Start of design	2 During detailed design	3 At final design	4 From system tests	5 From customer usage
Basis	Prediction based on approximate part counts and part failure rates from previous product usage; little knowledge of stress levels, redundancy, etc.	Prediction based on quantities and types of parts, redundancies, stress levels, etc.	Prediction based on types and quantities of part failure rates for expected stress levels, redundancies, external environments, special maintenance practices, special effects of system complexity, cycling effects, etc.	Measurement based on the results of tests of the complete system; appropriate reliability indices are calculated from the number of failures and operating time	Same as step 4 except calculations are based on customer usage data
Primary uses	1. Evaluate feasibility of meeting a proposed numerical requirement 2. Help in establishing a reliability goal for design	1. Evaluate overall reliability 2. Define problem areas	1. Evaluate overall reliability 2. Define problem areas	1. Evaluate overall reliability 2. Define problem areas	1. Measure achieved reliability 2. Define problem areas 3. Obtain data for future designs

*System tests in steps 4 and/or 5 may reveal problems that result in a revision of the "final" design. Such changes can be evaluated by repeating steps 3, 4, 5.

Table 3.1 Stages of Reliability Prediction and Measurement

RELIABILITY PREDICTION DATA SUMMARY

Component Part	*λ/Part (%/ 1000 Hours)*	*Quantity of Parts*	*(λ/Part) (Quantity)*
Part *A*	0.161	10	1.610
Part *B*	0.102	130	13.260
Part *C*	0.021	72	1.512
Part *D*	0.084	91	7.644
Part *E*	0.452	53	23.956
Part *F*	0.191	3	0.573
Part *G*	0.022	20	0.440
Failure rate (λ) = 48.995%/1000 hours MTBF = $\frac{1000}{0.48995}$ = 2041 hours			Σ = 48.995%

Source: Data from MIL-HDBK-217, *Military Standardization Handbook, Reliability and Failure Rate Data for Electronic Equipment.*

Table 3.2 Reliability Prediction Data Summary

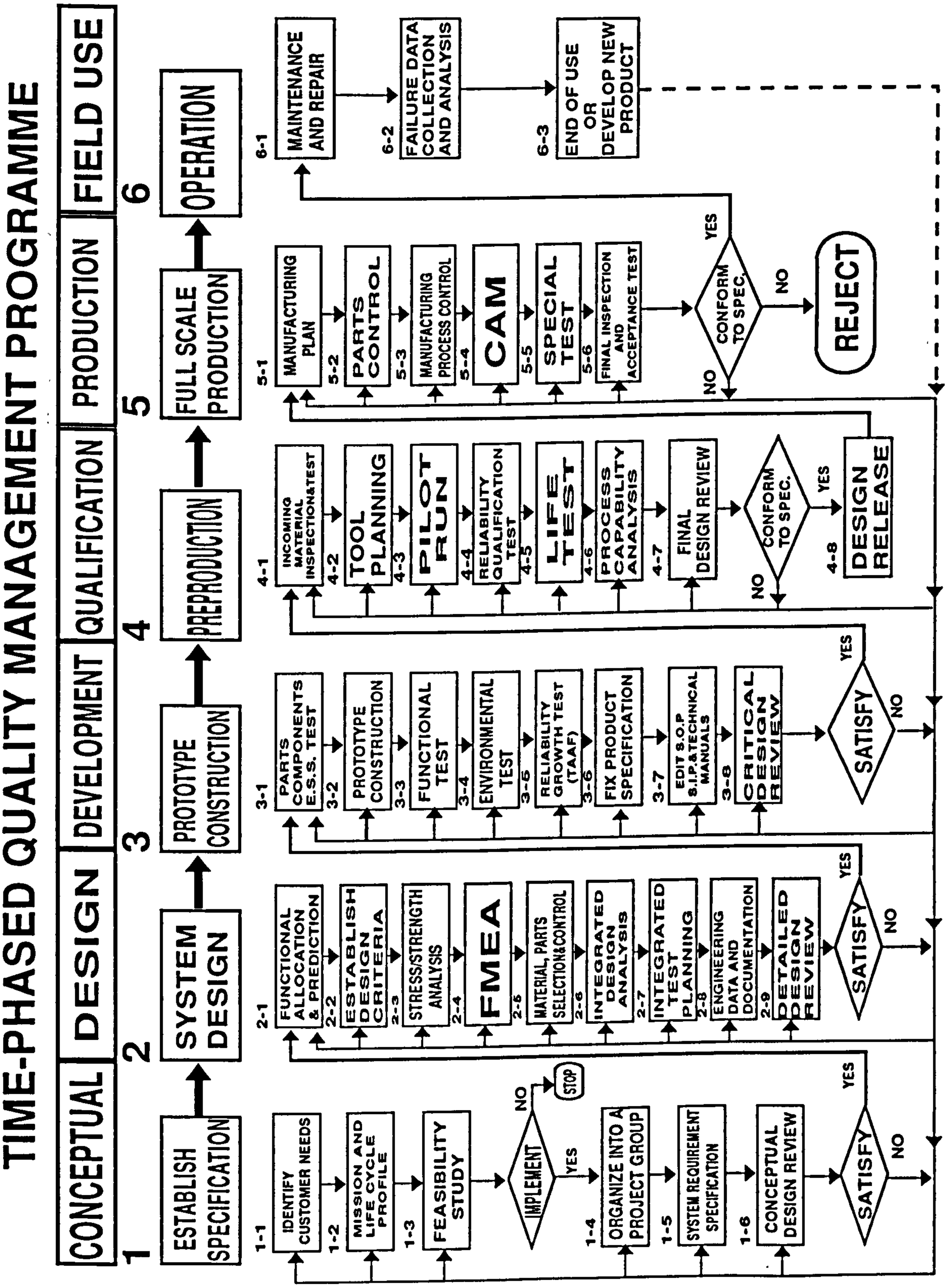


Figure 3.1 Time-phased Quality Management Programme

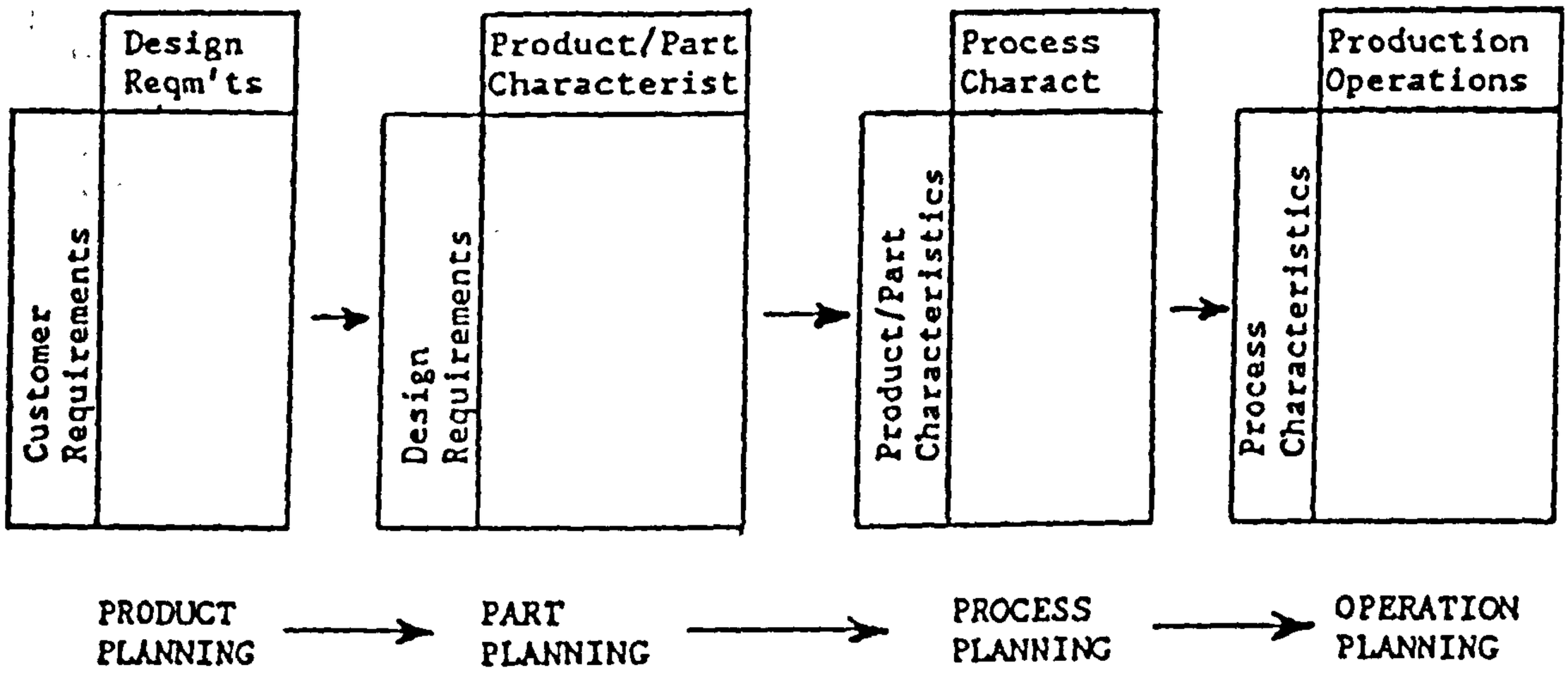
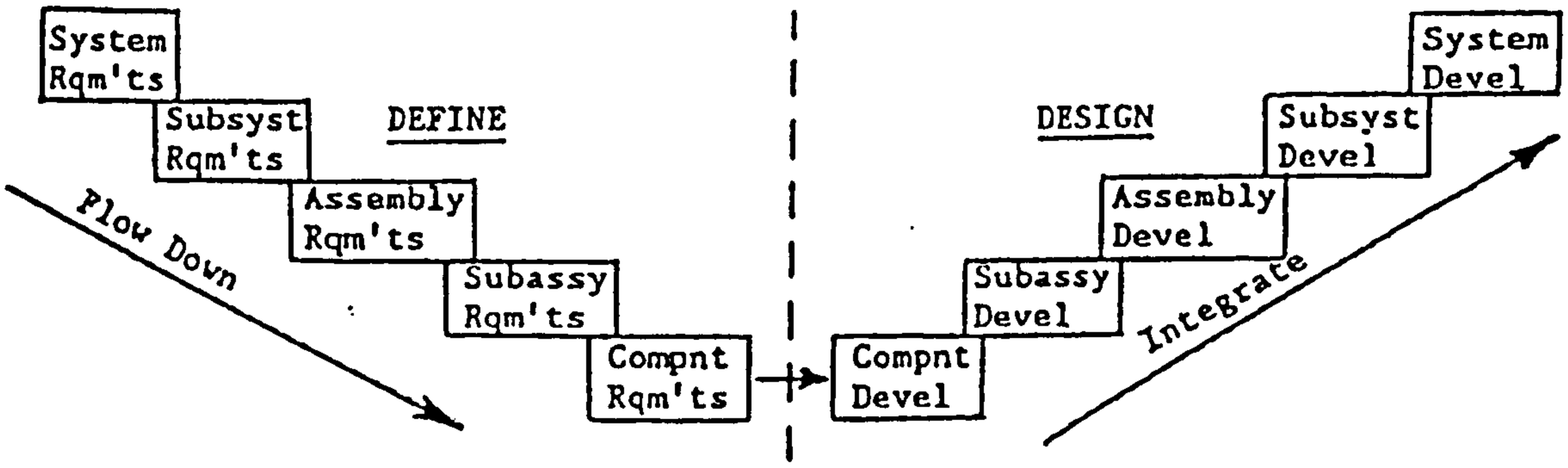


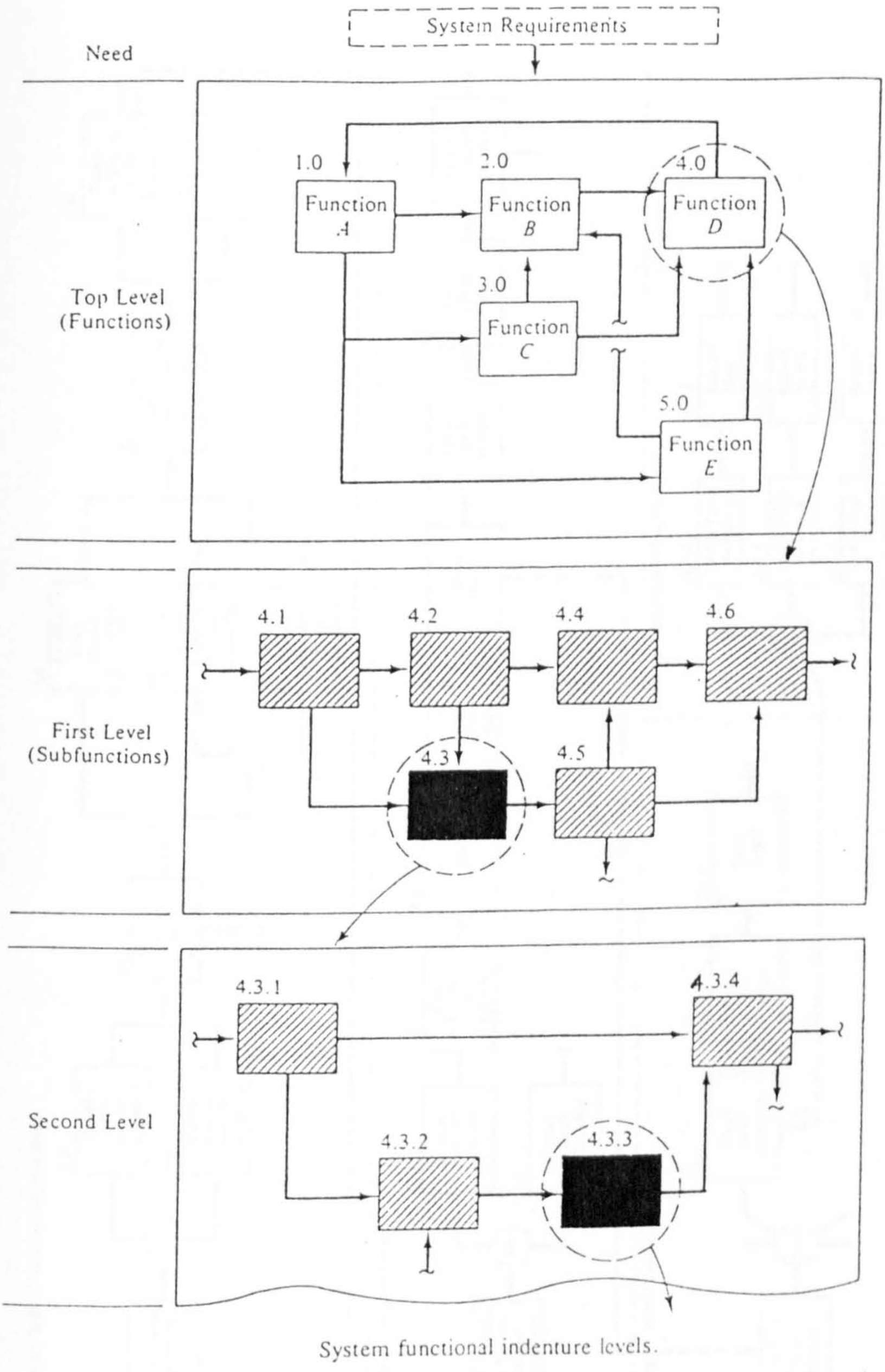
Figure 3.2 Quality Function Deployment Methodology



SYSTEMS ENGINEERING

MODEL

Figure 3.3 System Engineering Model



System functional indenture levels.

Figure 3.4 System Function Indenture Levels

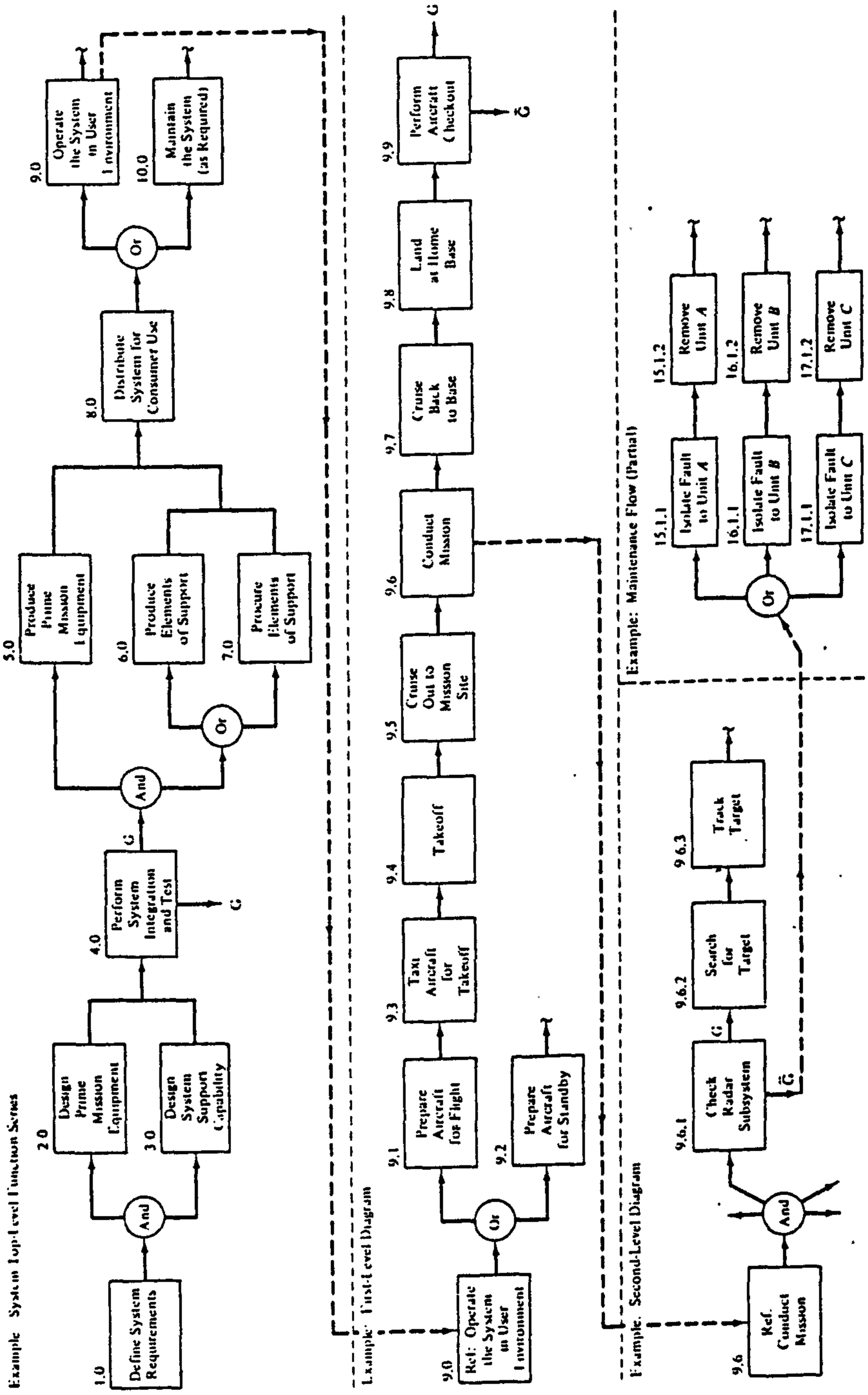


Figure 3.5 Series of Flow Block Diagram (evolution) Development

Reliability block diagram.

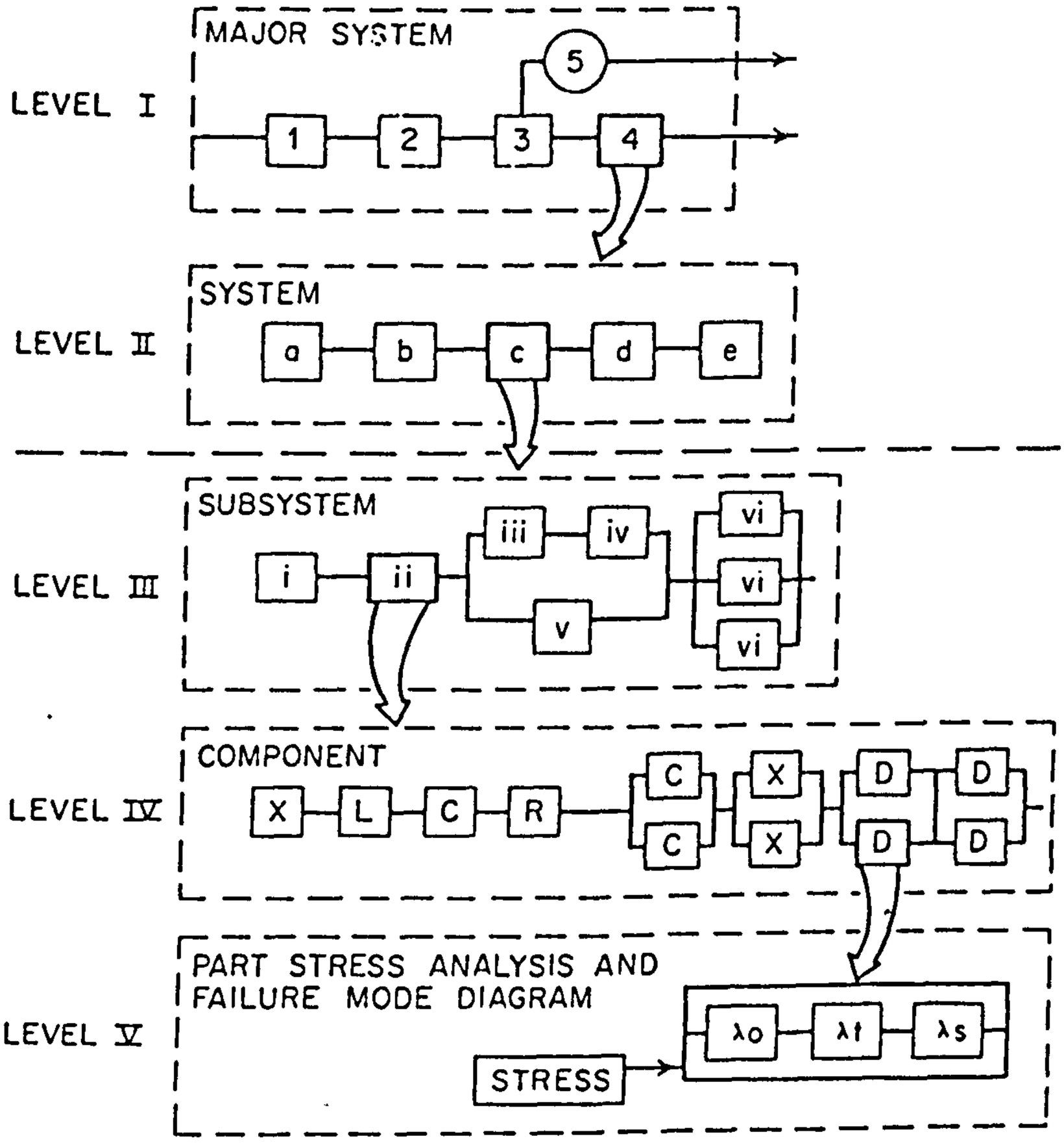


Figure 3.6 Reliability Block Diagram Approach

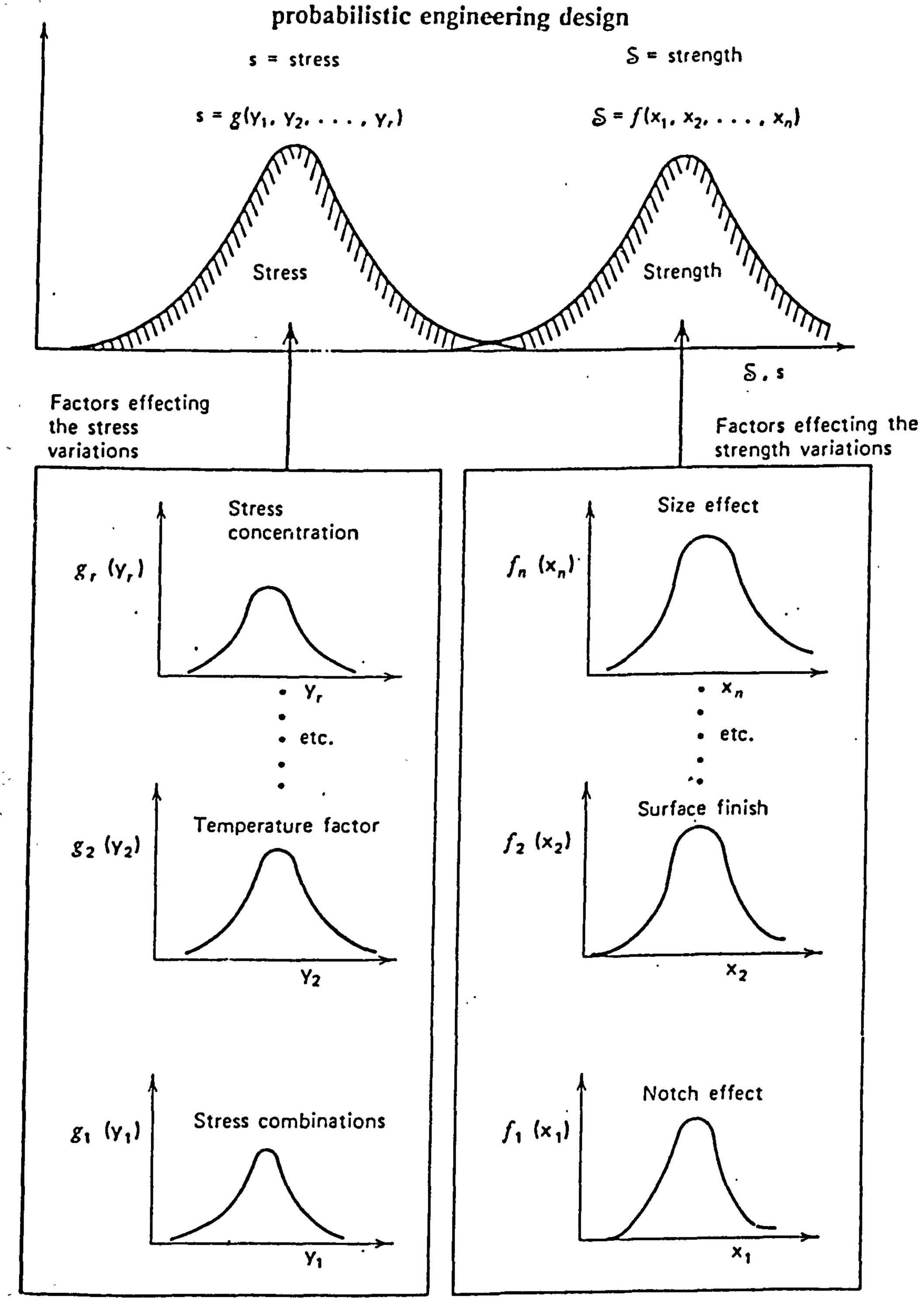
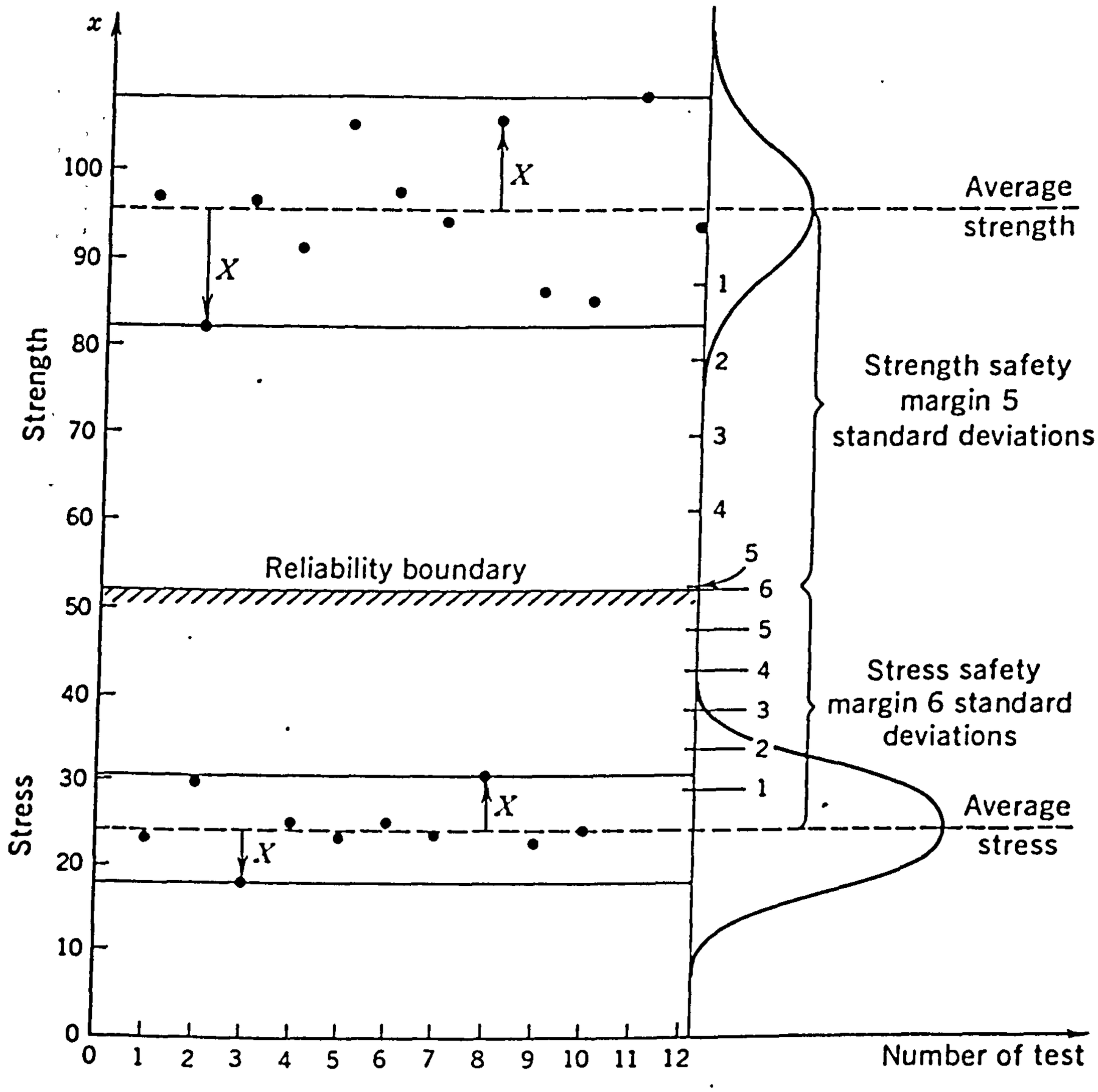
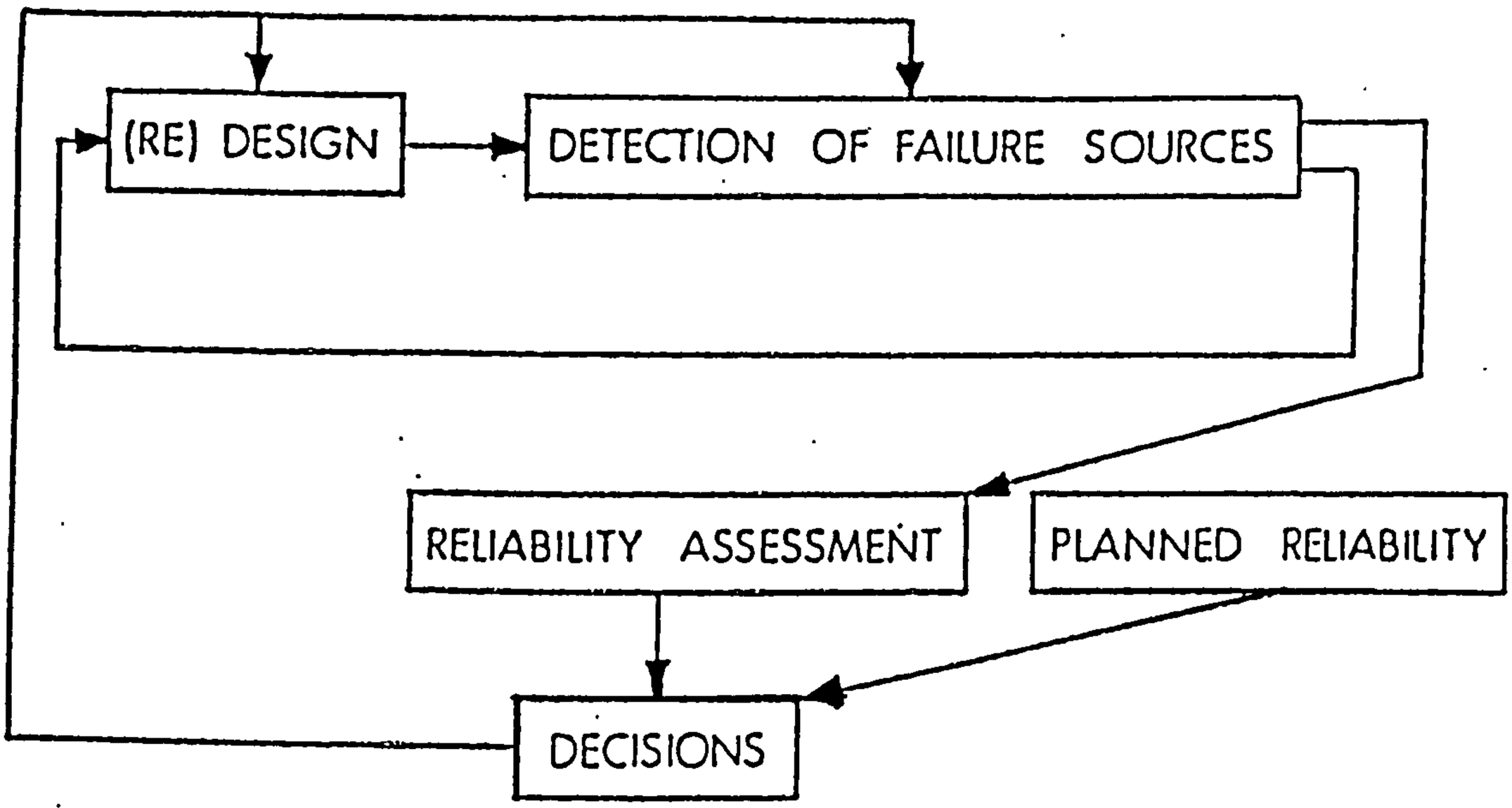


Figure 3.7 Various Factors Contributing to the Stress and Strength Distribution



Illustrating how scatterbands of stresses and strengths should be separated by a reliability boundary.

Figure 3.8 Reliability as a Function of the Stress and Strength Distribution



Reliability Growth Management Model

Figure 3.9 Reliability Growth Management Model

CHAPTER 4

QUALITY MEASUREMENT OF THE DESIGN AND DEVELOPMENT PROCESS

4.1 INTRODUCTION

The aim is to develop a quality measurement algorithm to assess the output of individual activities, phases and the overall quality system for correctness and efficiency.

Normally, output means performance (for example, qualitative analysis or quantitative data). The performance must satisfy the customer and be accepted by him (whether it is for internal successive activities or the external end user). Therefore the performance is measured by its correctness.

For assessing efficiency, the time and cost of carrying out the design and development process needs to be measured.

Thus, for developing the Quality Measurement model, three objectives need to be assessed: Performance, Time and Cost. Interpreting these three objectives to some measurable factors and then using the factors to calculate, estimates the Quality Achievement.

Each activity, phase and the overall quality system will have a unique index to represent its Quality Achievement.

4.2 DEVELOPING THE QUALITY MEASUREMENT THEORY

As was discussed at the beginning of Chapter 3, most managers measure success in terms of 'on time and within budget' rather than by performance. On the other hand, most design engineers emphasise performance more than time and cost.

Here, the author creates one '**co-factor**' concept which can assess the 'engineering output' (performance) as well as management considerations (time and cost) simultaneously during the product design and development stage.

This concept is motivated by the concurrent engineering management philosophy for simultaneous co-ordination of both the engineering and management aspects of the design and development process.

To assess individual activities, phases and, finally, the unique quality system, two independent factors are needed:

i. **Evaluation Factor**

ii. **Complexity Factor**

Detailed descriptions are as follows:

4.2.1 The Evaluation Factor

The **Evaluation Factor** is used to assess the design/development activities' output for **correctness** and **efficiency** involved in **performance, time and cost.**

The following discussion describes the Co-factor concept (including performance, time and cost) and combines 'qualitative check' with 'quantitative measurement' to form a comprehensive Evaluation Factor.

i. Evaluating Correctness

For each activity, it is most important to ensure that output performance is correct.

Correct output means that it conforms to certain criteria, standard or specification and would be accepted and approved by successive activities. If there is any argument between the two activities, a special committee will make a judgement (see Chapter 3, 3.3.4. Project Organisation).

The 'Time-phased Quality Activities' diagram (see Fig. 3.1) is designed to be a closed-loop for each activity (see Fig. 2.1) phase and overall quality system.If any activity's performance is not correct, we are not permitted to proceed to the next activity. This will prevent the incorrect output from entering the successive activities, can avoid much re-design/re-work and can save Time and Cost as well.

ii. Evaluating Efficiency

It should be kept in mind that the 'currently' correct output does not mean it is always correct. Through design reviews, various testing and customer feedback data, the original design may have to be changed, in which case, re-design will occur.

Applying the concept of 'design change control', the amount of redesign/rework for each activity can be found.

In the meantime, at the beginning of a certain design and development project, the total time will be decided and then a limited amount allocated to each phase or activity. Using the allocated time and counting the redesign number, we can establish a rating scale for the Evaluation Factor (see Table 4.1). Two positive (excellent, good) and two negative (poor, very bad) rating terms are used to measure the degree of efficiency. (The idea of giving a rating to the factor, come from CSA Z299, cited by Rogerson, 1986)

Here, the Cost Factor can be eliminated/ignored, the reasons being:

a. The increased cost in design or test may be offset in production or field use as a result of lower reject rates, reduced rework and reduced customer complaints.

b. To count each activity's expense, preferably the product Life-Cycle Cost would be considered (refer to Activity 1-3, Feasibility Study).

c. The cost of some creativity and creative activities are not easy to measure.

Therefore, assessing efficiency by cost during the design and development stage, has no significant meaning.

In fact, correct performance and efficient design task (measured by amount of design change and allocated time) already minimises the redesign/rework cost.

However, if it is necessary, a given budget can be allocated to each activity, thus managing the cost.

In conclusion, to assess a certain activity's Correctness and Efficiency, both 'qualitative check' and 'quantitative measurement' are used to get the **'quality achievement'** index (see Table 4.1, Evaluation Factor). The index is time-related, whenever a 'design change' takes place, it will be updated.

4.2.2 The Complexity Factor

The Complexity Factor is determined independently from the Evaluation Factor and **acts as a weighting factor.**

The degree of complexity will depend on having:

i. sufficient and necessary input data to support a certain design/development task;

ii. an approved procedure and relevant knowledge to implement the design task;

iii. design experience on a similar product;

iv. the use of new technology or methodology to implement the design task.

According to the above mentioned conditions, a rating scale can be established for the Complexity Factor (see Table 4.2).

The reason that 'Importance Factor' is not chosen is because every activity and phase in a chain-loop is assumed to be of equal importance. It may be thought that an activity in the early phase may be more important than one

in a later phase but, in fact, at the end of each phase, a 'check point' (design review) is placed and the output from each individual activity will be double-checked by an 'activity correctness check' and 'design review' check. Therefore, the possibility of having incorrect output from each activity is the same.

However, if 'root cause' cannot be detected from upstream, this will cause more downstream activity's redesign/rework. This influence could be evaluated by 'design change', which has been discussed previously in 'Evaluation Factor'.

4.3 DEFINITION AND CALCULATION OF QUALITY INDEXES AT VARIOUS QUALITY MANAGERIAL LEVELS

4.3.1 Quality Index at Activity level

Let: Q_{Ai} = Quality Index for Activity i.

E_i = Evaluation Factor for Activity i.

C_i = Complexity Factor for Activity i.

then: $Q_{Ai} = E_i \times C_i$

Compare each individual value Q_{Ai} with the criteria in Table 4.3 to make a decision as to the implementation of corrective action or not. In the meantime, we can rate the grade of 'Efficiency'.

4.3.2 Quality Index at Phase level

Calculating steps:

i. Summation over the individual activity quality indexes:

$$\Sigma Q_{Ai} = \Sigma(E_i \times C_i) = A_p$$

(See Table 4.4)

ii. Summation over the individual activity complexity weighting factors:

$$\Sigma C_i = B_p$$

(See Table 4.4)

iii. The weighted evaluation value for Phase p:

$$H_p = \frac{\sum EC_I}{\sum C_I} = \frac{A_p}{B_p}$$

The parameter H_p could be a fractional value such as 2.65 which places the weighted evaluation status of the 'Phase' somewhere between Excellent and Good (see Table 4.1).

This is an unacceptable method of describing the evaluation status of a specific Phase. Therefore we need to transform the value H_p to a percentage and couple the percentages to specific ranges and evaluation grades.

iv. The weighted evaluation value H_p is transformed into a percentage value by the following equation:

$$Q_p = \left[\left(1 - \frac{H_p - 1}{4 - 1}\right) x\ 100\right]\%$$

This percentage value (Q_p) will be used as a quality index for the specific phase.

The phase quality index Q_p can also be defined in terms of evaluation grade according to Table 4.5. The table further contains Phase descriptive ratings coupled to indicated H_p and Q_p ranges.

The transformation of H_p to Q_p is shown in Fig. 4.1.

4.3.3 Quality Index at the System level

i. If the individual phase quality indexes are Q_{p1}, Q_{p2}, ... Q_{pn} and a weighting factor W_i is introduced to cater for differences in complexity between each phase (e.g. Conceptual, Design, Development and Qualification Phase), then the system quality index Q_s defined as:

$$Q_s = \frac{\sum W_i Q_{pi}}{\sum W_i} = \frac{\sum [W_i \times (1 - \frac{H_{pi} - 1}{4 - 1})] \times 100}{\sum W_i} \%$$

The weighting factor W_i can assume the discrete value 1, 2, 3, or 4. For definition of the descriptive meaning of W_i values can be the same as Table 4.2

ii. An alternative calculation method for Q_s would be that for each phase of a quality system a weighted evaluation value is determined by H_{p1}, H_{p2}, ... H_{pn}.

Assume that for each phase a specific weighting factor has been prescribed by W_1, W_2, ...W_n.

Then a weighted evaluation value for the quality system (H_s) can be calculated by using the formula:

$$H_s = \frac{\sum W_i H_{pi}}{\sum W_i}$$

The above calculated value H_s can also be used to calculate the quality system index Q_s:

$$Q_s = \left[\left(1 - \frac{H_s - 1}{4 - 1}\right) x\ 100\right]\%$$

The value Q_s (a percentage value) is entered into Table 4.6 to determine the system descriptive rating, the system evaluation grade and the weighted evaluation value H_s.

TABLE 4.1

EVALUATION FACTOR

RATING SCALE

Description	Rating Value	Rating Term
A. Getting correct output at the first time and within the allocated time.	1	Excellent
B. Getting correct output by several times re-design but within the allocated time.	2	Good
C. Getting correct output at the first time but over the allocated time.	3	Poor/Fair
D. Getting correct output by several times re-design and over the allocated time.	4	Very bad

TABLE 4.2

COMPLEXITY FACTOR

RATING SCALE

Description	Rating Value	Rating Term
A. 1. Having sufficient input data to support design task. 2. Having approved procedure to implement design task. 3. Having design experience on similar product. 4. Do not need to use new technology or methodology.	1	Normal (Not complex)
B. Having any three conditions mentioned in (A).	2	Slightly complex
C. Having any two conditions mentioned in (A).	3	Complex (Difficult)
D. Having only one condition mentioned in (A), or not at all.	4	Very complex (Very difficult)

TABLE 4.3

Q_{Ai} - RANGES AND CORRECTIVE ACTION

DECISION CRITERIA

Q_{Ai} - Ranges (E_i x C_i)	Corrective Action Required	Grade
A. $1 \leq Q_{Ai} \leq 4$	No	Very efficient (Good)
B. $4 < Q_{Ai} \leq 9$	Routine action	Efficient (Average)
C. $9 < Q_{Ai} \leq 16$	Urgent action	Inefficient (Poor)

TABLE 4.4

Activity Number	Complexity Factor	Evaluation Factor	Activity Quality Index
	C_i	E_i	Q_{Ai}
1	C_1	E_1	$E_1 C_1$
2	C_2	E_2	$E_2 C_2$
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
n	C_n	E_n	$E_n C_n$
	---		---
	-		-
	$B_p = \Sigma C_i$		$A_p = \Sigma E_i C_i$

The weighted evaluation value for Phase p:

$$H_p = \frac{\sum E_I C_I}{\sum C_I} = \frac{A_p}{B_p}$$

TABLE 4.5

Q_p AND H_p RANGES, PHASE DESCRIPTIVE RATINGS AND EVALUATION GRADES FOR PHASES OF A QUALITY SYSTEM

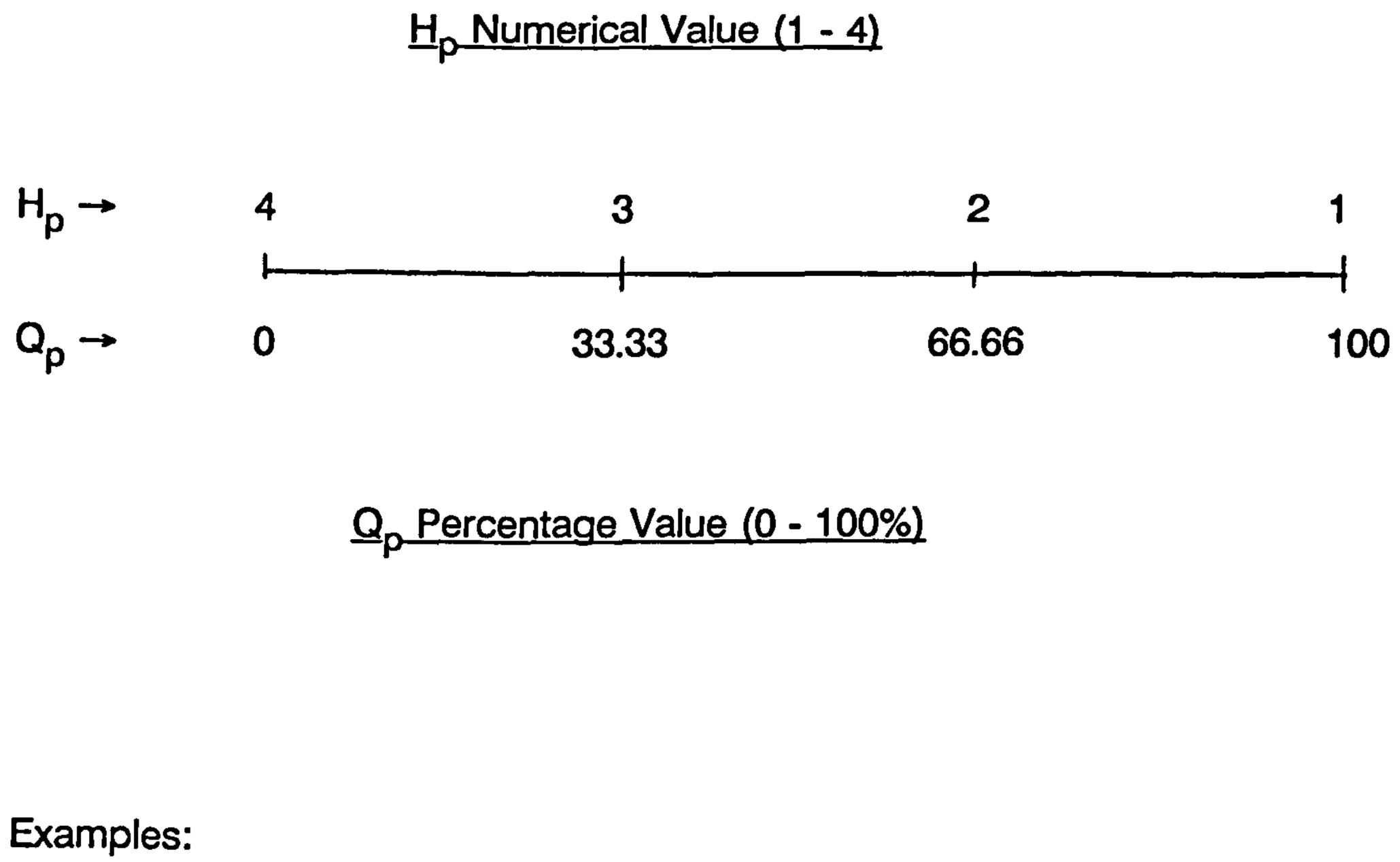
Q_p Ranges (Percentages)	H_p Ranges (Value 1-4)	Phase Descriptive Rating	Evaluation Grades
A. 66.66 ~ 100	1 ~ 2	Exceeds requirements	Very efficient (Good)
B. 33.33 ~ 66.65	2.01 ~ 3	Meets requirement	Efficient (Average/ Marginal)
C. 0 ~ 33.32	3.01 ~ 4	Provisionally meets requirements	Inefficient (Poor)

TABLE 4.6

Q_s AND H_s RANGES, SYSTEM DESCRIPTIVE RATINGS AND EVALUATION GRADES FOR THE QUALITY SYSTEM

Q_s Range (Percentages)	H_s Range (Values 1 ~ 4)	System Descriptive Rating	Evaluation Grade
A. 66.66 ~ 100	1 ~ 2	Performance exceeds requirements. Within time limits.	Very efficient (Excellent)
B. 33.33 ~ 66.65	2.01 ~ 3	Performance meets requirements. On time.	Efficient (Good)
C. 0 ~ 33.32	3.01 ~ 4	Performance provisionally meets requirements, or over time limits. (Needs redesign/rework)	Inefficient (Poor) .

FIG. 4.1


H_p Numerical Value (1 - 4)
$H_p \rightarrow$
4
3
2
1
$Q_p \rightarrow$
0
33.33
66.66
100
Q_p Percentage Value (0 - 100%)
Examples:
$H_p = 2.34$
$H_p = 1.65$
$H_p =$
4
3
2
1
0
33.33
66.66
100
$Q_p = 55.33\%$
$Q_p = 78.33\%$

CHAPTER 5

THE APPLICATION OF QUALITY MEASUREMENT MODEL TO THEORETICAL EXAMPLE AND PRACTICAL EXAMPLE

5.1 INTRODUCTION

Before to demonstrating the measurement model developed in Chapter 4, some conditions must be fulfilled:

i. Scope

The application will include conceptual, design, development and qualification phases, starting from Activity 1-1 'Identifying customer needs' and ending with Activity 4-8 'Design release'. (refer to Fig. 3.1).

ii. Responsibility

A cross-function organisation will be authorised to monitor all design/ development activities, measurements and to approve the design output, measurement outcomes etc. All existing documents (criteria, standard, specification) are also controlled.

iii. Schedule

All activities will have an allocated time. If this needs adjustment, approval should be by the authorised organisation or person.

iv. Information format

The author will design a standard form to carry out measurements for individual activity (see section 5.2). The form will include such information as design input/output data, design task, evaluation factor, complexity factor, design change times, checklist and calculations etc.

v. Final output

It is assumed that the output of each activity and phase has been currently frozen.

5.2 THEORETICAL EXAMPLE

5.2.1 Quality Measurement to each Activity

Activity 1-1: Identifying Customer Needs

INPUT	TASKS	OUTPUT
Customer needs: A certain performance Reliable Ease of use Economy Safety Similar product Marketing data Experience data	1. Identify customer needs and related data. 2. Using Quality Function Deployment tool, to translate input data into actionable items	System requirement Reliability requirement Environmental constraints Cost estimation Design requirement Safety study Updated reports

CHECKLIST	
Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

CALCULATION OF QUALITY INDEX	COMMENT
1. Evaluation Factor Value: $E_{1-1} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{1-1} = 1$	2. Very efficient
3. Quality Index: $Q_{1-1} = E_{1-1} \times C_{1-1} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 1-2: Mission and Life Cycle Profile Analysis

INPUT	TASKS	OUTPUT
System requirement. System operating characteristic. Prime mission of the system. System engineering process. System life cycle. Experience on similar system.	1. Identify input data. 2. Define the prime mission of the system through one or a set of scenarios, or operational profiles. 3. Using system engineering process to define a life-cycle for a system.	Mission/operation requirements. Identification of life cycle. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	Yes

CALCULATION OF QUALITY INDEX	COMMENT
1. Evaluation Factor Value: $E_{1\text{-}2} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{1\text{-}2} = 2$	2. Very efficient.
3. Quality Index: $Q_{1\text{-}2} = E_{1\text{-}2} \times C_{1\text{-}2} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 1-3: Feasibility Study

INPUT	TASKS	OUTPUT
Identified: Customer requirements. Design requirements. Operational requirements. Experience data. Cost-Effectiveness Analysis	1. Identify all possible alternatives. 2. Identify a system configuration that is feasible to carry out within existing constraints. 3. Screen and evaluate the most likely candidates.	Justify the system configuration and design approach. Identification of the final selection.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	Yes

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{1\text{-}3} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{1\text{-}3} = 2$	2. Very efficient.
3. Quality Index: $Q_{1\text{-}3} = E_{1\text{-}3} \times C_{1\text{-}3} = 2 \times 2 = 4$	3. To implement the final selection of system configuration.

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 1-4: Project Group Organisation

INPUT	TASKS	OUTPUT
Company quality policy. Quality management system. Personnel resource. Company organisation. Technical Requirements.	1. Organise a cross-functional organisation. 2. Define responsibility of organisation.	Project group. Failure Review Board.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{1-4} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{1-4} = 2$	2. Very efficient.
3. Quality Index: $Q_{1-4} = E_{1-4} \times C_{1-4} = 2 \times 2 = 4$	

Designer:_____ Date: _____
Approved by:_____ Date: _____

Activity 1-5: System Requirement Specification

INPUT	TASKS	OUTPUT
Design requirements. Operational requirements. System life-cycle. Mission profile. Environmental constraints. Experience of establishing specification.	1. Identify input data. 2. Define technical and mission requirements. 3. Define the interfaces between functional areas. 4. Define system parameters and performance requirements.	System specification (top level system specification). Updated data.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index

1. Evaluation Factor Value: $E_{1\text{-}5} = 2$
2. Complexity Factor Value: $C_{1\text{-}5} = 1$
3. Quality Index: $Q_{1\text{-}5} = E_{1\text{-}5} \times C_{1\text{-}5} = 2 \times 1 = 2$

Comment

1. No corrective action required.
2. Very efficient.

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 1-6: Conceptual Design Review

INPUT	TASKS	OUTPUT
Output from: Activity 1-1, 1-2, 1-3, 1-4 and 1-5. Feedback data.	1. Identify input data. 2. Develop a checklist to check input data. 3. Plan design review schedule, procedure.	Design review report. Follow-up plan. Updated data.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{1\text{-}6} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{1\text{-}6} = 2$	2. Very efficient.
3. Quality Index: $Q_{1\text{-}6} = E_{1\text{-}6} \times C_{1\text{-}6} = 2 \times 2 = 4$	3. Go to the next phase.

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-1: Functional Allocation and Prediction

INPUT	TASKS	OUTPUT
System requirements specification. Other required data.	1. Develop functional flow block diagrams. 2. Identify functional interfaces. 3. Analyse functional requirements. 4. Allocate system top-level requirements to lower level. 5. Predict functional requirement.	Functional design requirement. Functional Analysis. Functional prediction. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No.

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}1} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{2\text{-}1} = 1$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}1} = E_{2\text{-}1} \times C_{2\text{-}1} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-2: Establish Design Criteria

INPUT	TASKS	OUTPUT
System: Operational requirements. Functional allocation. Reliability. Standardisation. Interchangeability. Safety. Etc.	1. Identify various system requirements and design requirements. 2. Establish qualitative and quantitative design criteria.	Identification: Design Criteria, standard, specification and documents.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	• Comment
1. Evaluation Factor Value: $E_{2\text{-}2} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{2\text{-}2} = 1$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}2} = E_{2\text{-}2} \times C_{2\text{-}2} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-3: Stress/Strength Analysis

INPUT	TASKS	OUTPUT
Design variables and parameters. Material strength. Statistical distribution of stress and strength. Requirements of data.	1. Identify stress and strength statistical distributions. 2. Using 'probabilistic design' methodology to decide safety factor.	Material selections. Safety factors. Stress/strength analysis. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}3} = 2$	1. No correction action required.
2. Complexity Factor Value: $C_{2\text{-}3} = 2$	2. Very efficient.
3. Quality Index: $Q_{\text{-}2\text{-}3} = E_{2\text{-}3} \times C_{2\text{-}3} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-4: FMEA

INPUT	TASKS	OUTPUT
Stress/strength analysis. Functional diagrams. Design criteria. Previous failure data. Critical items (by Engineering Judgement).	1. Identify failure mode. 2. Estimate potential failure and its effect. 3. Define failure mode and effect. 4. Engineering judgement.	Failure mode and effect analysis. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	No
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}4} = 2$	1. Need corrective action.
2. Complexity Factor Value: $C_{2\text{-}4} = 3$	2. Efficient.
3. Quality Index: $Q_{2\text{-}4} = E_{2\text{-}4} \times C_{2\text{-}4} = 2 \times 3 = 6$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-5: Material, Parts, Selection and Control.

INPUT	TASKS	OUTPUT
Design policy. Company standards. National standards. International standards. Safety factors. Previous history. Supplier inspection data. Other required data.	1. Identify input data. 2. Check design requirement. 3. Use derating method to choose suitable material and parts.	Parts standardisation and interchangeability studies. Materials and parts lists. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}5} = 4$	1. Needs corrective action.
2. Complexity Factor Value: $C_{2\text{-}5} = 2$	2. Efficient.
3. Quality Index: $Q_{2\text{-}5} = E_{2\text{-}5} \times C_{2\text{-}5} = 4 \times 2 = 8$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-6: Integrated Design Analysis

INPUT	TASKS	OUTPUT
Performance requirement for: Reliability Manufacturing Testing Safety Human factors Other related data. FMEA. Stress/strength analysis. Functional allocation.	1. Identify input data. 2. Use CAD, CAM. 3. Use concurrent engineering and system engineering methodology to analyse.	Design for: Reliability Producibility Testability Safety Human factors. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	No
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}6} = 2$	1. Needs corrective action.
2. Complexity Factor Value: $E_{2\text{-}6} = 3$	2. Efficient.
3. Quality Index: $Q_{2\text{-}6} = E_{2\text{-}6} \times C_{2\text{-}6} = 2 \times 3 = 6$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-7: Integrated Test Planning

INPUT	TASKS	OUTPUT
Test conditions/levels. Test duration data. Test objective data. Test facilities data. Reject/Accept criteria. Design criteria.	1. Identify input data 2. Define test purpose. 3. Determine test sequence, procedure. 4. Test data collection analysis methods. 5. Test schedule.	Integrated test planning: Functional test plan. Environmental test plan. Reliability growth test plan. Reliability qualification test plan. Life test plan. Failure reporting analysis and corrective action system (FRACA).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}7} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{2\text{-}7} = 2$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}7} = E_{2\text{-}7} \times C_{2\text{-}7} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-8: Engineering Data and Documentation

INPUT	TASKS	OUTPUT
Design data: Analysis reports. Calculations. Specification. Material list. Engineering drawing. Standard.	1. Identify input data. 2. Establish configuration control. 3. Establish design change control. 4. Establish document control.	Documented and under control. Engineering data and documentation.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}8} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{2\text{-}8} = 2$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}8} = E_{2\text{-}8} \times C_{2\text{-}8} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-9: Detailed Design Review

INPUT	TASKS	OUTPUT
Output from: Activities: 2-1, 2-2, 2-3, 2-4, 2-5, 2-6, 2-7., 2-8. Feedback data.	1. Identify input data. 2. Develop a checklist for input data. 3. Plan design review schedule, procedure.	Design review report. Follow-up plan. Updated data.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	Yes
If not, how many attempts (including first time and re-design)?	
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}9} = 1$	1. No corrective action required.
2. Complexity Factor Value: $C_{2\text{-}9} = 1$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}9} = E_{2\text{-}9} \times C_{2\text{-}9} = 1 \times 1 = 1$	3. Go to next phase.

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-1: Parts Components Environmental Stress Screen Test

INPUT	TASKS	OUTPUT
Environmental stress: types, levels, profiles and exposure times. Identification of parts, components level. Identification of parts, components performance and stress parameters. Test duration. Other required data.	1. Identify input data. 2. Carry out E.S.S. test. 3. Collect test data.	Failure mode effect and correction action. Test records, analysis. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}1} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{3\text{-}1} = 1$	2. Very efficient.
3. Quality Index: $Q_{3\text{-}1} = C_{3\text{-}1} \times E_{3\text{-}1} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-2: Prototype Construction

INPUT	TASKS	OUTPUT
Engineering drawings. Material list. Manufacturing process. Machine and tool. Documentation.	1. Identify input data. 2. Prototype construction.	Prototype. Manufacturing tolerance. Cause-and-effect relationships between process and product.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	No
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3-2} = 2$	1. Needs corrective action.
2. Complexity Factor Value: $C_{3-2} = 3$	2. Efficient.
3. Quality Index: $Q_{3-2} = E_{3-2} \times C_{3-2} = 2 \times 3 = 6$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-3: Functional Test

INPUT	TASKS	OUTPUT
Test program. Functional identification. Testing standards, procedures, conditions.	1. Identify input data. 2. Carry out test. 3. Control test procedure. 4. Collect test data.	Test records. Corrective action. Data analysis. Design trade-off.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3-3} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{3-3} = 2$	2. Very efficient.
3. Quality Index: $Q_{3-3} = E_{3-3} \times C_{3-3} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-4: Environmental Test

INPUT	TASKS	OUTPUT
Mission profile. Individual and combination environmental conditions. Test plans: Procedures, conditions and levels. Related documents.	1. Identify input data. 2. Carry out a sequence test. 3. Analyse all failures. 4. Incorporate corrective action. 5. Re-test.	Test record. Data analysis. Updated records.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}4} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{3\text{-}4} = 1$	2. very efficient.
3. Quality Index: $Q_{3\text{-}4} = E_{3\text{-}4} \times C_{3\text{-}4} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-5: Reliability Growth Test

INPUT	TASKS	OUTPUT
Functional requirement. Reliability target. Test plans, procedures. Reliability growth model. Related documents.	1. Identify input data. 2. Use Test-Analyse-and-Fix process. 3. Re-test.	Test records. Data analysis. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	No
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}5} = 4$	1. Needs corrective action.
2. Complexity Factor Value: $C_{3\text{-}5} = 2$	2. Efficient.
3. Quality Index: $Q_{3\text{-}5} = E_{3\text{-}5} \times C_{3\text{-}5} = 4 \times 2 = 8$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-6: Fix Product Specification

INPUT	TASKS	OUTPUT
System specification ('A' specification). Related design criteria, standards. Data requirements.	1. Identify input data. 2. Use system engineering process to derive a Type 'B' spec. from a Type 'A' spec. 3. Use design engineering to derive Type 'C' spec. from, Type 'B' spec. 4. Use process engineering to derive Type 'D' spec. from Type 'C' spec.	Type 'B' spec.: Prime item and critical item development spec. Software development spec. Type 'C' spec.: Prime item product function spec. Prime item product fabrication spec. Type 'D' spec.: Process spec. Type 'E' spec.: Material spec.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}6} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{3\text{-}6} = 1$	2. Very efficient.
3. Quality Index: $Q_{3\text{-}6} = E_{3\text{-}6} \times C_{3\text{-}6} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-7: Edit S.O.P., S.I.P. and Technical Manuals

INPUT	TASKS	OUTPUT
Manufacturing process. Inspection procedure. Maintenance requirement. Operational requirement. Test equipment. Spare parts requirement.	1. Identify input data. 2. Edit S.O.P., S.I.P. and technical manuals.	Standard operational procedure. Standard inspection procedure. Technical manual. Updated data.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3-7} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{3-7} = 2$	2. Very efficient.
3. Quality Index: $Q_{3-7} = E_{3-7} \times C_{3-7} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-8: Critical Design Review

INPUT	TASKS	OUTPUT
Output from Activities: 3-1, 3-2, 3-3, 3-4, 3-5, 3-6, 3-7. Feedback data.	1. Identify input data. 2. Develop a checklist for input data. 3. Plan design review schedule, procedure.	Design review report. Follow-up plan. Updated data.

CHECKLIST	
Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	Yes
If not, how many attempts (including first time and re-design)?	
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}8} = 1$	1. No corrective action required.
2. Complexity Factor Value: $C_{3\text{-}8} = 1$	2. Very efficient.
3. Quality Index: $Q_{3\text{-}8} = E_{3\text{-}8} \times {}_{3\text{-}8} = 1 \times 1 = 1$	3. Go to next phase.

Designer:_____ Date: _____
Approved by:_____ Date: _____

Activity: 4-1 Incoming Material Inspection and Test

INPUT	TASKS	OUTPUT
Company standards. National standards. International standards. Material list. Physical and chemical test procedure. Test equipment and calibration Purchase contracts. Historical data.	1. Identify input data. 2. Carry out inspection and test. 3. Non-conforming material control.	Inspection and test records. Updated data.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4\text{-}1} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{4\text{-}1} = 1$	2. Very efficient.
3. Quality Index: $Q_{4\text{-}1} = E_{4\text{-}1} \times C_{4\text{-}1} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity: 4-2 Tool Planning

INPUT	TASKS	OUTPUT
Manufacturing process. S.O.P., S.I.P. Tool requirements. Tool design. Data requirements. Experience data.	1. Identify input data. 2. Tool planning.	Tool plans. Tool calibration and maintenance plan. Updated data.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4-2} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{4-2} = 1$	2. Very efficient.
3. Quality Index: $Q_{4-2} = E_{4-2} \times C_{4-2} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity: 4-3 Pilot Run

INPUT	TASKS	OUTPUT
Performance requirement. Tool plans. Production process. Material List. Incoming materials parts. Data requirements. S.O.P., S.I.P.	1. Identify input data. 2. Use regular production tooling and production process. 3. Analyse test data from pilot-run product.	Process capability analysis. Discover inadequate manufacturing/assembly process. Suggest special tools. Improved producibility. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	No
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4\text{-}3} = 4$	1. Need urgent corrective action.
2. Complexity Factor Value: $C_{4\text{-}3} = 3$	2. Inefficient.
3. Quality Index: $Q_{4\text{-}3} = E_{4\text{-}3} \times C_{4\text{-}3} = 4 \times 3 = 12$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity: 4-4 Reliability Qualification Test

INPUT	TASKS	OUTPUT
Reliability requirements. Samples for testing. Test conditions. Test procedures. Mission profile. Environmental stress level.	1. Identify input data. 2. Carry out test. 3. Collect and analyse data. 4. Define the basis for success or failure of item being tested. 5. Corrective action.	Test record. Analysis reports. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4\text{-}4} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{4\text{-}4} = 1$	2. Very efficient.
3. Quality Index: $Q_{4\text{-}4} = E_{4\text{-}4} \times C_{4\text{-}4} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity: 4-5 Life Test

INPUT	TASKS	OUTPUT
Mission profile. Environmental constraints. Test plan. Test condition, procedure, level. Performance requirements. Experience.	1. Identify input data. 2. Use accelerated life test technique. 3. Collect and analyse test data. 4. Corrective action.	Product life data. Suggestions for support plans and maintenance. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4\text{-}5} = 2$	1. No Corrective action required.
2. Complexity Factor Value: $C_{4\text{-}5} = 1$	2. Very efficient.
3. Quality Index: $Q_{4\text{-}5} = E_{4\text{-}5} \times C_{4\text{-}5} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-6: Process Capability Analysis

INPUT	TASKS	OUTPUT
Engineering drawings. Manufacturing Process. Tolerances. Pilot-run inspection data. Historical data.	1. Identify input data. 2. Measure the product uniformity. 3. Collect and analyse process data.	Variability of process. Process capability analysis. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4\text{-}6} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{4\text{-}6} = 2$	2. Very efficient.
3. Quality Index: $Q_{4\text{-}6} = E_{4\text{-}6} \times C_{4\text{-}6} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-7: Final Design Review

INPUT	TASKS	OUTPUT
Manufacturing drawings. Material lists. Production plan. Final reliability prediction. Engineering test reports. Output data from Activities 4-1, 4-2, 4-3, 4-4, 4-5, 4-6. Feedback data.	1. Identify input data. 2. Develop a checklist. 3. Corrective action.	Design review reports. Updated reports.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4\text{-}7} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{4\text{-}7} = 1$	2. Very efficient.
3. Quality Index: $Q_{4\text{-}7} = E_{4\text{-}7} \times C_{4\text{-}7} = 2 \times 1 = 2$	3. Go to 'Design Release'.

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-8: Design Release

INPUT	TASKS	OUTPUT
Engineering drawings. Software. Test records. Analysis records. Technical manuals. Design review. Configuration audit. Manufacturing process. Cost-Effectiveness.	1. Identify all input data. 2. Freeze all design data. 3. Ensure that transition from development to production will be smooth.	Identification of all input data.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comments
1. Evaluation Factor Value: $E_{4\text{-}8} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{4\text{-}8} = 1$	2. Very efficient.
3. Quality Index: $Q_{4\text{-}8} = E_{4\text{-}8} \times C_{4\text{-}8} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

5.2.2 Quality Measurement to Conceptual Phase (Phase 1):

Calculating steps:

i. Summation over the individual activity quality indices:

$$\Sigma Q_{Ai} = \Sigma(E_i \times C_i)$$

$$= Q_{1\text{-}1} + Q_{1\text{-}2} + Q_{1\text{-}3} + Q_{1\text{-}4} + Q_{1\text{-}5} + Q_{1\text{-}6}$$

$$= 2 + 4 + 4 + 4 + 2 + 4$$

$$= 20$$

ii. Summation over the individual complexity factor:

$$\Sigma C_i = 1 + 2 + 2 + 2 + 1 + 2$$

$$= 10$$

iii. The weighted evaluation value for Phase 1:

$$H_{p1} = \frac{\sum EC_i}{\sum C_i} = \frac{20}{10} = 2$$

iv.

$$Q_{p1} = \left[\left(1 - \frac{H_{p1} - 1}{4 - 1}\right) x\ 100\right]\% = \left[\left(1 - \frac{2 - 1}{4 - 1}\right) x\ 100\right]\% = 66.66\%$$

Since $H_{p1} = 2$ and $Q_{p1} = 66.66\%$, then the conclusion is that the conceptual phase was implemented in a 'very efficient' and 'correct' manner (see Table 4.5).

5.2.3 Quality Measurement to Design Phase (Phase 2):

Calculating steps:

i. Summation over the individual activity quality indices:

$$\Sigma Q_{Ai} = \Sigma(E_i \times C_i)$$
$$= Q_{2\text{-}1} + Q_{2\text{-}2} + Q_{2\text{-}3}\ \ Q_{2\text{-}4} + Q_{2\text{-}5} + Q_{2\text{-}6} + Q_{2\text{-}7} + Q_{2\text{-}8} + Q_{2\text{-}9}$$
$$= 2 + 2 + 4 + 6 + 8 + 6 + 4 + 4 + 1$$
$$= 37$$

ii. Summation over the individual complexity factor:

$$\Sigma C_i = 1 + 1 + 2 + 3 + 2 + 3 + 2 + 2 + 1$$
$$= 17$$

iii. The weighted evaluation value for Phase 2:

$$H_{p2} = \frac{\sum E_i C_i}{\sum C_i} = \frac{37}{17} = 2.18$$

iv.

$$Q_{p2} = \left[\left(1 - \frac{H_{p2} - 1}{4 - 1}\right) x\ 100\right]\% = \left[\left(1 - \frac{2.18 - 1}{4 - 1}\right) x\ 100\right]\% = 60.67\%$$

According to Table 4.5, the conclusion is that the Design phase was implemented in an 'efficient' and 'correct' manner.

5.2.4 Qualitu Measurement to Development Phase (Phase 3):

Calculating steps:

i. Summation over the individual activity quality indices:

$$\begin{aligned}\Sigma Q_{Ai} &= \Sigma(E_i \times C_i) \\ &= Q_{3\text{-}1} + Q_{3\text{-}2} + Q_{3\text{-}3}\ \ Q_{3\text{-}4} + Q_{3\text{-}5} + Q_{3\text{-}6} + Q_{3\text{-}7} + Q_{3\text{-}8} \\ &= 2 + 6 + 4 + 2 + 8 + 2 + 4 + 1 \\ &= 29\end{aligned}$$

ii. Summation over the individual complexity factor:

$$\begin{aligned}\Sigma C_i &= 1 + 3 + 2 + 1 + 2 + 1 + 2 + 1 \\ &= 13\end{aligned}$$

iii. The weighted evaluation value for Phase 3:

$$H_{p3} = \frac{\sum E_i C_i}{\sum C_i} = \frac{29}{13} = 2.23$$

iv.

$$Q_{p3} = \left[\left(1 - \frac{H_{p3} - 1}{4 - 1}\right) x\ 100\right]\% = \left[\left(1 - \frac{2.23 - 1}{4 - 1}\right) x\ 100\right]\% = 41\%$$

According to Table 4.5, the conclusion is that the development phase was implemented in an 'efficient' and 'correct' manner.

5.2.5 Quality Measurement to Qualification Phase (Phase 4):

Calculating steps:

i. Summation over the individual activity quality indices:

$$\Sigma Q_{Ai} = \Sigma(E_i \times C_i)$$
$$= Q_{4\text{-}1} + Q_{4\text{-}2} + Q_{4\text{-}3}\ \ Q_{4\text{-}4} + Q_{4\text{-}5} + Q_{4\text{-}6} + Q_{4\text{-}7} + Q_{4\text{-}8}$$
$$= 2 + 2 + 12 + 2 + 2 + 4 + 2 + 2$$
$$= 28$$

ii. Summation over the individual complexity factor:

$$\Sigma C_i = 1 + 1 + 3 + 1 + 1 + 2 + 1 + 1$$
$$= 11$$

iii. The weighted evaluation value for Phase 4:

$$H_{p4} = \frac{\sum E_i C_i}{\sum C_i} = \frac{28}{11} = 2.54$$

vi.

$$Q_{p4} = \left[\left(1 - \frac{H_{p4} - 1}{4 - 1}\right) x\ 100\right]\% = \left[\left(1 - \frac{2.54 - 1}{4 - 1}\right) x\ 100\right]\% = 48.67\%$$

According to Table 4.5, the conclusion is that the qualification phase was implemented in an 'efficient' and 'correct' manner.

5.2.6 Quality Measurement for a Quality Management System during Design Stage:

Calculating steps:

i. For each phase of the quality system, the weighted evaluation value has been determined by H_{p1}, H_{p2}, H_{p3} and H_{p4}.

Assume that for each phase a specific weighting factor has been prescribed by:

$$W_{p1} = 1,\ W_{p2} = 2,\ W_{p3} = 3,\ W_{p4} = 2$$

(W_{pf} value from 1 ~ 4, see Table 4.2)

Then, a weighted evaluation value for the quality system (H_s) can be calculated by:

$$H_s = \frac{\sum W_{pi} H_{pi}}{\sum W_{pi}} = \frac{W_{p1}H_{p1} + W_{p2}H_{p2} + W_{p3}H_{p3} + W_{p4}H_{p4}}{W_{p1} + W_{p2} + W_{p3} + W_{p4}}$$

$$= \frac{1 \times 2 + 2 \times 2.18 + 3 \times 2.23 + 2 \times 2.54}{1 + 2 + 3 + 2} = 2.27$$

ii. Therefore, quality system index (Q_s) will be:

$$Q_s = \left[\left(1 - \frac{H_s - 1}{4 - 1}\right) x\ 100\right]\%$$

$$Q_s = \left[\left(1 - \frac{2.27 - 1}{4 - 1}\right) x\ 100\right]\% = 57.67\%$$

According to Table 4.6, the conclusion is that the quality system was implemented in an **'efficient'** and **'correct'** manner.

5.3 A PRACTICAL EXAMPLE

One industrial defence company obtained a contract from the Government to design and develop a new rifle for the Army.

The contract was required to finish within 24 months and then to deliver 500 rifles (first article), together with all design, test and engineering data, to demonstrate and guarantee the smooth transition from design to mass-production.

The company already had design and production experience on Type X1, 7.62 mm rifle, and some other small calibre arms.

The general requirements for the new rifle (Type X2) are as follows:

Calibre: 5.56 mm, compatible with the existing M197 ammunition.

Lightweight.

Reliable.

Ease of maintenance.

Safety.

All major performance (firing rate, effective range, accuracy) must be equivalent to M16AI rifle, or even better.

5.3.1 Quality measurements for each activity

Activity 1-1: Identifying Customer Needs

INPUT	TASKS	OUTPUT
Customer needs: A 5.56mm rifle. Lightweight. Reliable. Ease of maintenance. Safety. Automatic and semi-auto fire. Similar product: M16A1 rifle data. AR18 rifle data. AK47 rifle data. Experienced data: Type X1 rifle.	1. Identify customer needs and related data. 2. Investigate current files data. 3. Using QFD tool, to translate customer voice into actionable items.	System requirements: Calibre: 5.56mm Weight: Less than 3.18 Kg. Gas operated. Air-cooled. Effective range: 460m. Reliability requirement: Class I MRBF = 1000 rounds. Class II MRBF = 2000 rounds. Class III MRBF = 6000 rounds. Environmental constraints: Temperature, humidity, dust, mud, icing, etc. Cost Estimation: Less than £150. Updated reports: (OPS-X2-11).

CHECKLIST	
Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	Yes

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{1-1} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{1-1} = 2$	2. Very efficient.
3. Quality Index: $Q_{1-1} = E_{1-1} \times C_{1-1} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 1-2: Mission and Life Cycle Profile Analysis

INPUT	TASKS	OUTPUT
System requirement: Activity 1-1 output. Operating characteristics: Preparation for firing. Loading. Precautions in firing ammunition. Firing. Unloading. Life Cycle: Design, development, qualification, production, distribution, maintenance, disposal. Experience on similar products.	1. Identify input data. 2. Define the prime mission of rifle, through operational profiles. 3. Using system engineering process to define a life cycle for a system.	Mission/operation requirements: Single shot fire. Semi-automatic fire. Three short burst. Operation under usual/unusual conditions. Infantry combat mission. Identification of life cycle. Updated reports: (OPS-X2-12)

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comments
1. Evaluation Factor Value: $E_{1\text{-}2} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{1\text{-}2} = 1$	2. Very efficient.
3. Quality Index: $Q_{1\text{-}2} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 1-3: Feasibility Study

INPUT	TASKS	OUTPUT
From Activity 1-1: Customer requirement. System requirement. From Activity 1-2: Operational requirements. Experience data: M16A1 rifle. AR18 rifle. AK47 rifle. X1 rifle. Cost Effectiveness data: (not available)	1. Identify all possible alternatives. 2. Identify a system configuration that is feasible to carry out within existing constraints. 3. Screen and evaluate the most likely candidates.	Identification of the final selection. Make a decision to develop a new rifle (Type X2) which will have all the advantages within present rifles. Analysis reports (OPS-X2-13). Producibility analysis plans. Human factor analysis. Milestone schedules. Programme risk analysis.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{1-3} = 4$	1. Need corrective action.
2. Complexity Factor Value: $C_{1-3} = 2$	2. Efficient.
3. Quality Index: $Q_{1-3} = 4 \times 2 = 8$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 1-4: Project Group Organisation

INPUT	TASKS	OUTPUT
Technical requirements: Rifle design. Ammunition design. Ballistics calculation. Manufacturing process. Test. Personnel resources. Company organisation. Quality Management System.	1. Organise a cross-functional organisation. 2. Define responsibility of organisation.	Project group. Failure Review Board. Updated reports: (OPS-X2-14).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	Yes
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{1-4} = 1$	1. No corrective action required.
2. Complexity Factor Value: $C_{1-4} = 1$	2. Very efficient.
3. Quality Index: $Q_{1-4} = 1 \times 1 = 1$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 1-5: System Requirement Specification

INPUT	TASKS	OUTPUT
From Activity 1-1: System requirement. Environmental constraints. From Activity 1-2: Operational requirements. Life Cycle. Mission profile. Document of establishing specification (MIL-S_83490). Experience.	1. Identify input data. 2. Define technical and mission requirements. 3. Define the interfaces between functional areas. 4. Define system parameters and performance requirements.	System specification (top level spec.): Objective: Type X2 rifle.d Scope. Reference. Required equipment. Performance requirements. Quality Assurance provisions. Test items. Updated reports:(OPS-X2-15).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{1-5} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{1-5} = 1$	2. Very efficient.
3. Quality Index: $Q_{1-5} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 1-6: Conceptual Design Review

INPUT	TASKS	OUTPUT
Updated reports and output from: Activities 1-1, 1-2, 1-3, 1-4, 1-5. Feedback information: New design. New material. New technology.	1. Identify input data. 2. Develop a checklist for input data. 3. Plan design review schedule, procedure.	Design review checklist: Mission and requirement analysis. Preliminary requirement allocations. Trade-off studies. Engineering integration. Configuration management plans. System safety. Follow-up plan: Use new material and design. Reduce the weight of rifle and improve the performance. Updated records: (OPS-X2-16).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{1\text{-}6} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{1\text{-}6} = 2$	2. Very efficient.
3. Quality Index: $Q_{1\text{-}6} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-1: Functional Allocation and Prediction

INPUT	TASKS	OUTPUT
System requirement specification (Activity 1-5 output): Weight: 3.10 Kg. Calibre: 5.56 mm. Ammunition: M197. Method of feeding: Magazine. Method of operating: Gas. Mechanical features: Rifling, R.H 6 grooves. Max. rate of fire: 200 rds/m. Effective range: 460 m. Fundamental processes of firing a projectile.	1. Develop functional block diagram. 2. Identify functional interfaces. 3. Analyse functional requirements. 4. Allocate system requirement to lower level. 5. Predict reliability requirement.	Functional design requirements: Upper/lower receiver groups. Barrel assembly. Bolt carrier assembly. Hammer assembly. Automatic sear assembly. Buffer assembly. Rear sight assembly. Trigger assembly. Reliability requirements: Class I MRBF: 1000 rounds. Class II MRBF: 2000 rounds. Class III MRBF: 6000 rounds. Updated reports: (OPS-X2-21). Updated Drawings: (OPS-X2-21-10).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	5
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}1} = 4$	1. No corrective action required.
2. Complexity Factor Value: $C_{2\text{-}1} = 1$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}1} = 4 \times 1 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-2: Establish Design Criteria

INPUT	TASKS	OUTPUT
Design requirement (from Activity 2-1) Operational requirement (from Activity 1-2) Reliability requirements (from Activities 1-1, 2-1) Safety requirement (from Activity 1-1) Standardisation (from MIL-STD) Interchangeability (MIL-STD-280A). Handbook on rifle design.	1. Identify various system requirements and design requirements. 2. Establish qualitative and quantitative design criteria.	Identification: Design criteria, standard, specification and documents and drawings. Head space: Not less than 1.4647 inches. Not more than 1.4705 inches. Trigger Pull: Within 5.5 - 9.5 pounds. High pressure resistance: Conforming to MIL-C-46936. Targeting and accuracy endurance: 6000 rounds. Interchangeability. Updated reports: (OPS-X2-22).

CHECKLIST	
Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}2} = 4$	1. Needs corrective action.
2. Complexity Factor Value: $C_{2\text{-}2} = 2$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}2} = 4 \times 2 = 8$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-3: Stress/Strength Analysis

INPUT	TASKS	OUTPUT
Design parameters: Gun propellant. Max. pressure: 55,000 psi. Internal ballistics. External ballistics. Intermediate ballistics. Gun mechanic. Recoil. Forces on the entire gun. Material strength: AISI 8620, 4140. 4150, 1020. Aluminium alloy 7075. Synthetic material. Material handbook. Engineering drawings.	1. Identify stress/strength statistical distribution. 2. Using probabilistic design methodology to decide safety factor. 3. Using finite element model to analyse stress.	Material analysis (OPS-X2-23-1) Safety factors = 3.5 Stress/strength analysis for critical parts = Bolt. Gun barrel. Receiver. Firing pin. Updated reports: (OPS-X2-23-2).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}3} = 4$	1. No corrective action required.
2. Complexity Factor Value: $C_{2\text{-}3} = 1$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}3} = 4 \times 1 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-4: Failure Mode and Effect Analysis

INPUT	TASKS	OUTPUT
Functional diagrams (Activity 2-1 output). Design criteria (Activity 2-2 output). Stress/strength analysis (Activity 2-3 output). Critical parts (Activity 2-3 output). Previous failure data.	1. Identify failure mode. 2. Estimate potential failure and its effect. 3. Define failure mode and effect. 4. Engineering judgement.	FMEA analysis: Failure to fire. Failure to unlock. Failure to cock. Failure to feed. Failure to extract. Failure to eject. Short recoil. Updated reports: (OPS-X2-24)

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2-4} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{2-4} = 1$	2. Very efficient.
3. Quality Index: $Q_{2-4} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-5: Material, Parts, Selection and Control

INPUT	TASKS	OUTPUT
Design policy. National standards. International standards. Military standards. Safety factors. Previous history. Supplier inspection data. Material handbook. Parts selection handbooks. Engineering drawings.	1. Identify input data. 2. Check design requirements. 3. Use derating method to choose suitable material and parts. 4. Plan material and parts inspection procedure.	Material and parts list (OPS-X2-25-1). Material and parts inspection procedure (OPS-X2-25-2). Standardisation study (OPS-X2-25-3). Interchangeability study (OPS-X2-25-4).

CHECKLIST	
Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	6
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	Yes

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}5} = 4$	1. Needs urgent corrective action.
2. Complexity Factor Value: $C_{2\text{-}5} = 3$	2. Inefficient.
3. Quality Index: $Q_{2\text{-}5} = 4 \times 3 = 12$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-6: Integrated Design Analysis

INPUT	TASKS	OUTPUT
Functional requirement (Activity 2-1 output). Reliability requirement (Activity 2-1 output). Human factors, safety (Activity 1-3 output). Producibility, Testability (Activity 1-3 output). FMEA (Activity 2-4 output). Stress/strength analysis (Activity 2-3 output).	1. Identify input data. 2. Use CAD/CAM. 3. Use concurrent engineering and system engineering methodology to analyse. 4. Plan an integrated test to demonstrate. 5. Parts and manufacturing process design.	Human factors evaluation items: Observations of the compatibility of the man and the rifle. Reliability and maintenance evaluation items: MRBF: Mean round between failure. MRBM: Mean round between maintenance. Producibility evaluation. Test evaluation. Updated reports: (OPS-X2-26).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}6} = 4$	1. Needs corrective action.
2. Complexity Factor Value: $C_{2\text{-}6} = 2$	2. Efficient.
3. Quality Index: $Q_{2\text{-}6} = 4 \times 2 = 8$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-7: Integrated Test Planning

INPUT	TASKS	OUTPUT
Test objective: Functional test. Environmental test. Reliability test. Life test. Test conditions/Levels. Test duration data. Test Facilities data. Reject/Accept criteria. Hand and shoulder weapons test procedure (MTP-3-2-059). Reliability design qualification and production acceptance tests (MIL-STD-781C).	1. Identify input data. 2. Define test purpose. 3. Determine test sequence, sample size and procedure. 4. Planning of integrated test. 5. Test data analysis methods. 6. Test schedule.	Integrated test plan (OPS-X2-27-1): Functional test plan. Environmental test plan. Reliability test plan. Life test plan. Failure Reporting Analysis and Corrective Action System (FRACA) (OPS-X2-27-2).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}7} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{2\text{-}7} = 2$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}7} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-8: Engineering Data and Documentation

INPUT	TASKS	OUTPUT
Output data from Activities 1-1 to 1-6 Activities 2-1 to 2-7. Standard. Specification. Creature. Calculation. Material list. Engineering drawing. Analysis reports. Etc.	1. Identify input data. 2. Establish configuration control. 3. Establish design change control. 4. Establish document control.	Engineering data and documentation are under control: OPS-X2-11 OPS-X2-12 ⋮ OPS-X2-27

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}8} = 4$	1. Needs corrective action.
2. Complexity Factor Value: $C_{2\text{-}8} = 2$	2. Efficient.
3. Quality Index: $Q_{2\text{-}8} = 4 \times 2 = 8$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 2-9: Detailed Design Review

INPUT	TASKS	OUTPUT
Output from Activities 2-1 to 2-8.	1. Identify input data. 2. Develop a checklist for design review. 3. Plan design review schedule, procedure.	Design review checklist: Functional allocation. Reliability analysis. Human factors. Standardisation. Producibility analysis. Environmental conditions. Configuration control. Engineering data. Etc. Follow-up plan: Need to establish technical performance measurement plan. Updated records: (OPS-X2-29).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{2\text{-}9} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{2\text{-}9} = 2$	2. Very efficient.
3. Quality Index: $Q_{2\text{-}9} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-1: Incoming Material and Parts Inspection

INPUT	TASKS	OUTPUT
Purchase contract. Material List. Parts List. Engineering Drawing. Supplier inspection. Metal inspection procedure (OPS-I-100). Parts inspection procedure (OPS-I-200). Gun barrel inspection (MIL-S-11595). Synthetic material inspection procedure (OPS-I-110).	1. Identify input data. 2. Carry out inspection and tests. 3. Record test data.	Test records: Physical test. Chemical test. Macrostructure. Impact resistance. Hardenability. Forging practice. Non-metallic inclusion. Inspection records. Rejected items and corrective action. Updated reports: (OPS-X2-31).

CHECKLIST	
Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}1} = 4$	1. Needs corrective action.
2. Complexity Factor Value: $_{3\text{-}1} = 2$	2. Efficient.
3. Quality Index: $Q_{3\text{-}1} = 4 \times 2 = 8$	

Designer:_____ Date: _____
Approved by:_____ Date: _____

Activity 3-2: Prototype Construction

INPUT	TASKS	OUTPUT
Engineering drawings. Manufacturing process. Machine and tool Inspection procedure. S.O.P. (not available). S.I.P. (not available). Special tool and machine (not available). Production line and machine layout (not available).	1. Identify input data. 2. Prototype construction.	20 rifles (prototype). Manufacturing tolerance study. Process and product study. Correction action: Gun barrel forging process improvement. Gun barrel rifling process improvement. Receiver design change. Updated reports (OPS-X2-32).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	Yes

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3-2} = 4$	1. Needs urgent corrective action.
2. Complexity Factor Value: $C_{3-2} = 3$	2. Inefficient.
3. Quality Index: $Q_{3-2} = 4 \times 3 = 12$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-3: Functional Test'

INPUT	TASKS	OUTPUT
Functional test plan (from Activity 2-7). Sample size: 4 rifles. Test procedures (MTP-3-2-059).	1. Identify input data. 2. Preparation for test. 3. Test conduct. 4. Collect test data.	Recording of malfunctions. Records (under normal conditions): Accuracy. Cook-off. Endurance. Unlubricated. Flash. Noise. Automatic and semi-auto. Safety evaluation. Human factor evaluation. Maintenance evaluation. Corrective action. Updated reports: (OPS-X2-33).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3-3} = 4$	1. No corrective action required.
2. Complexity Factor Value: $C_{3-3} = 1$	2. Very efficient.
3. Quality Index: $Q_{3-3} = 4 \times 1 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-4: Environmental Test

INPUT	TASKS	OUTPUT
Mission profile (Activity 1-2 output). Climatic extremes for military equipment (MIL-STD-210). Environmental test methods (MIL-STD-810D). Test plans: (Activity 2-7 output). Temperature: ± 50°C. Humidity: 90%. Salt water immersion. Sand and dust. Mud. Drop test: 12 ft.	1. Identify input data. 2. Carry out a sequence test. 3. Analyse all failures. 4. Incorporate a corrective action. 5. Re-test.	Test records. Data analysis. Updated reports: (OPS-X2-34).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}4} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{3\text{-}4} = 1$	2. Very efficient.
3. Quality Index: $Q_{3\text{-}4} = 2 \times 1 = 2$	

Designer:_____ Date: _____
Approved by:_____ Date: _____

Activity 3-5 Reliability Growth Test

INPUT	TASKS	OUTPUT
Functional requirement (from Activity 2-1) Reliability Report: Class I MRBF: 1000 rounds Class II MRBF: 2000 rounds Class III MRBF: 6000 rounds. Test plans, procedures (AD/A-007-093). Reliability growth model: Test-Find-Test. Reliability growth management (MIL-STD-189). Reliability growth testing (MIL-STD-1635).	1. Identify input data. 2. Use Test-Analyse-And-Fix (TAAF) process. 3. Re-test.	Test records. Data analysis. Updated reports: (OPS-X2-35).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}5} = 4$	1. No corrective action required.
2. Complexity Factor Value: $C_{3\text{-}5} = 1$	2. Very efficient.
3. Quality Index: $Q_{3\text{-}5} = 4 \times 1 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-6: Fix Product Specification

INPUT	TASKS	OUTPUT
System specification (Activity 1-5 output). Design creature (Activity 2-2 output). Related standards: MIL-S-83490. MIL-S-280A. OPS-I-100. OPS-I-200. OPS-I-110.	1. Identify input data. 2. Use system engineering process to derive a Type "B" spec. from a Type "A" spec. 3. Use design engineering to drive Type "C" spec. from Type "B" spec. 4. Use process engineering to derive Type "D" spec. from Type "C" spec.	Type "B" Spec: X2 rifle prime item and critical item development spec. (OPS-X2-36-20). Type "C" Spec: X2 rifle prime item product function spec. (OPS-X2-36-30). X2 rifle prime item product fabrication spec. (OPS-X2-36-40). Type "D" Spec: X2 rifle parts manufacturing process spec. (OPS-X2-36-50).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}6} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{3\text{-}6} = 2$	2. Very efficient.
3. Quality Index: $Q_{3\text{-}6} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-7: Edit S.O.P., S.I.P. and Technical Manuals.

INPUT	TASKS	OUTPUT
X2 rifle parts and assembly inspection procedure. X2 rifle parts manufacturing process. X2 rifle operational requirement. X2 rifle maintenance requirement. Test and Inspection equipment. X2 rifle spare parts requirement.	1. Identify input data. 2. Edit S.O.P. 3. Edit S.I.P. 4. Edit Technical Manual.	X2 rifle standard operational procedure. (OPS-X2-37-10) X2 rifle standard inspection procedures. (OPS-X2-37-20) X2 rifle Technical Manual (OPS-X2-37-30)

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3.7} = 4$	1. Needs corrective action.
2. Complexity Factor Value: $C_{3.7} = 2$	2. Efficient.
3. Quality Index: $Q_{3.7} = 4 \times 2 = 8$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 3-8: Critical Design Review

INPUT	TASKS	OUTPUT
Output data from Activities 3-1 to 3-7.	1. Identify input data. 2. Develop a checklist for design review. 3. Plan design review schedule and procedure.	Design review checklist: Hardware configuration item. Mechanical design. Environmental control. Producibility. Interface control. Documentation control. Follow-up plan: Accuracy improvement. Recoil improvement. Design change control. Updated reports: (OPS-X2-38).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{3\text{-}8} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{3\text{-}8} = 2$	2. Very efficient.
3. Quality Index: $Q_{3\text{-}8} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-1: Incoming and Material and Parts Inspection

INPUT	TASKS	OUTPUT
Purchase contract. Material list (OPS-X2-25-1). Military standard. International standard. Test equipment and calibration. Physical and chemical test procedures: OPS-I-100. OPS-I-200. OPS-I-110. Supplier inspection. Historical data (not available).	1. Identify input data. 2. Carry out inspection and test. 3. Non-conforming material control. 4. Record test data.	Inspection and test records. Non-conforming material approach. Corrective action: Change supplier. Improve test procedure. Correct sample size. Updated reports: (OPS-X2-41).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	Yes

Calculation of Quality Index

1. Evaluation Factor Value: $E_{4\text{-}1} = 2$
2. Complexity Factor Value: $C_{4\text{-}1} = 2$
3. Quality Index: $Q_{4\text{-}1} = 2 \times 2 = 4$

Comment

1. No corrective action required.
2. Very inefficient.

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-2: Tool Planning

INPUT	TASKS	OUTPUT
Manufacturing process (Activities 2-6, 3-2, 3-6). S.O.P. and S.I.P. (Activity 3-7). Tool requirement. Tool design. Tool purchase plan. Special tools (not available). Experience data.	1. Identify input data. 2. Tool planning.	Tool plans (OPS-X2-42-10). Tool calibration and maintenance plan (OPXS-X2-42-20). Updated reports: (OPS-X2-42).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	Yes

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4-2} = 4$	1. Needs urgent corrective action.
2. Complexity Factor Value: $C_{4-2} = 3$	2. Inefficient.
3. Quality Index: $Q_{4-2} = 4 \times 3 = 12$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-3: Pilot plan

INPUT	TASKS	OUTPUT
Engineering drawing. Manufacturing process. Material list (OPS-X2-25-1). Tool and machine. S.O.P. S.I.P. Performance requirement. Process capability data (not available). Tolerance calculation (not available). Experience data.	1. Identify input data. 2. Use regular production tooling and producing process. 3. Analyse test data from pilot-run product.	Pilot run size: 500 X2 rifles. Discover inadequacies: Assembly process incorrect. Heat treatment unsatisfactory. Needs special tool for rifling "Ejector spring" under high failure rate. Process capability analysis. Corrective action. Updated reports: (OPS-X2-43).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	3
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	Yes

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4\text{-}3} = 4$	1. Needs urgent corrective action.
2. Complexity Factor Value: $C_{4\text{-}3} = 3$	2. Inefficient.
3. Quality Index: $Q_{4\text{-}3} = 4 \times 3 = 12$	

Designer:_____ Date: _____
Approved by:_____ Date: _____

Activity 4-4: Reliability Qualification Test

INPUT	TASKS	OUTPUT
Reliability requirement (Activities 1-1 and 2-1). Sample size: 3 rifles. Reliability test procedure for prototype small calibre arms (AD/A-007-093) Hand and shoulder weapons test procedures (MTP-3-2-059) Test conditions: Includes all rates of fire and use bipod. Ammunition: M197.	1. Identify input data. 2. Define the basis for success or failure of item being tested. 3. Carry out test. 4. Collect and analyse data. 5. Corrective action.	Test record (OPS-X2-44-10) Analysis reports (OPS-X2-44-20) Updated reports: (OPS-X2-44)

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4-4} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{4-4} = 1$	2. Very efficient.
3. Quality Index: $Q_{4-4} = 2 \times 1 = 2$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-5: Life Test

INPUT	TASKS	OUTPUT
Sample size: 3 rifles, each firing 25,000 rounds. Test type: replacement. Operation mode: automatic. Test Plan: (OPS-X2-45-10). Experience.	1. Identify input data. 2. Carry out test. 3. Collect and analyse test data. 4. Record failure time (round). 5. Replace or repair any failure during the test.	Product and parts life data. Suggestions for support plans and maintenance. Updated reports: (OPS-X2-45)

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt? If not, how many attempts (including first time and re-design)?	Yes
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	Yes
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	Yes

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4-5} = 1$	1. No corrective action required.
2. Complexity Factor Value: $C_{4-5} = 1$	2. Very efficient.
3. Quality Index: $Q_{4-5} = 1 \times 1 = 1$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-6: Process Capability Analysis

INPUT	TASKS	OUTPUT
Engineering drawings (Activities 2-1 to 2-7). Manufacturing process (Activities 2-6, 3-2, 3-6). Machine tolerances. Pilot-run inspection data (Activity 4-3). Historical data.	1. Identify input data. 2. Measure product uniformity. 3. Collect and analyse process data.	Variability of process. Process capability analysis (OPS-X2-46-10). Updated reports: (OPS-X2-46).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4\text{-}6} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{4\text{-}6} = 2$	2. Very efficient.
3. Quality Index: $Q_{4\text{-}6} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-7: Final Design Review

INPUT	TASKS	OUTPUT
Engineering drawings (Activities 2-1 to 2-7). Material list (Activity 2-5). All test reports. Final reliability data. Output data (Activities 4-1 to 4-6). Feedback data. Production Plan.	1. Identify input data. 2. Develop final design review checklist. 3. Plan design review schedule and procedure.	Final design review reports (OPS-X2-47-10). Corrective action: Improve parts design. Improve production process. Design change control. etc. Updated reports: (OPS-X2-47).

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	2
3. Has it been gained within the allocated time (including on time)?	No
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4-7} = 4$	1. Needs corrective action.
2. Complexity Factor Value: $C_{4-7} = 2$	2. Efficient.
3. Quality Index: $Q_{4-7} = 4 \times 2 = 8$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

Activity 4-8: Design Release

INPUT	TASKS	OUTPUT
All engineering drawings. All test records. All analysis reports. All documents: Standards. Specifications. Technical Manuals. Configuration audit (not available).	1. Identify all input data. 2. Freeze all design data. 3. Ensure that transition from development to production will be smooth.	Identification of all input data. Design release package.

CHECKLIST

Output:	
1. Has it been approved for correctness?	Yes
2. Has the currently correct output been gained at the first attempt?	
If not, how many attempts (including first time and re-design)?	4
3. Has it been gained within the allocated time (including on time)?	Yes
Task:	
4. Does it have the necessary and sufficient input data?	No
5. Does it have an approved procedure and knowledge to implement tasks?	Yes
6. Does it have experience of similar product design?	Yes
7. Does it need new technology and methodology?	No

Calculation of Quality Index	Comment
1. Evaluation Factor Value: $E_{4\text{-}8} = 2$	1. No corrective action required.
2. Complexity Factor Value: $C_{4\text{-}8} = 2$	2. Very efficient.
3. Quality Index: $Q_{4\text{-}8} = 2 \times 2 = 4$	

Designer:_____ Date: _____

Approved by:_____ Date: _____

5.3.2 Quality measurement to Conceptual phase (Phase 1)

i. Summation over the individual activity quality indices:

$$\sum Q_{AI} = \sum (E_I \times C_I) = 4 + 2 + 8 + 1 + 2 + 4 = 1$$

ii. Summation over the individual Complexity Factor:

$$\sum C_I = 2 + 1 + 2 + 1 + 1 + 2 = 9$$

iii. The weighted Evaluation value for Phase 1:

$$H_{P1} = \frac{\sum E_I C_I}{\sum C_I} = \frac{21}{9} = 2.33$$

iv. The Quality Index for Phase 1:

$$Q_{P1} = \left[\left(1 - \frac{H_{P1} - 1}{4 - 1}\right) x\ 100\right] \% = \left[\left(1 - \frac{2.33 - 1}{4 - 1}\right) x\ 100\right] \% = 55.67\%$$

Since $H_{P1} = 2.33$ and $Q_{P1} = 55.67\%$, then the conclusion is that the Conceptual Phase was implemented in an 'Efficient' and 'Meets requirements' manner (see Table 4.5).

5.3.3 Quality measurement to Design phase (Phase 2)

i. Summation over the individual activity quality indices:

$$\sum Q_{AI} = \sum (E_I \times C_I)\ 4 + 8 + 4 + 2 + 12 + 8 + 4 + 8 + 4 = 54$$

ii. Summation over the individual Complexity Factor:

$$\sum C_I = 1 + 2 + 1 + 1 + 3 + 2 + 2 + 2 = 16$$

ii. The weighted evaluation value for Phase 2:

$$H_{P2} = \frac{\sum E_I C_I}{\sum C_I} = \frac{54}{16} = 3.38$$

iv. The Quality Index for Phase 2:

$$Q_{P2} = \left[\left(1 - \frac{H_{P2} - 1}{4 - 1}\right) \times 100\right] \% = \left[\left(1 - \frac{3.38 - 1}{4 - 1}\right) \times 100\right] \% = 20.67\%$$

According to Table 4.5, the conclusion is that the Design Phase was implemented in an 'Inefficient' and 'Provisionally meets requirements' manner.

5.3.4 Quality measurement to Development phase (Phase 3)

i. Summation over the individual activity quality indices:

$$\sum Q_{AI} = \sum (E_I \times C_I) = 8 + 12 + 4 + 2 + 4 + 4 + 8 + 4 = 46$$

ii. Summation over the individual Complexity Factor:

$$\sum C_I = 2 + 3 + 1 + 1 + 1 + 2 + 2 + 2 = 14$$

iii. The weighted evaluation value for Phase 3:

$$H_{P3} = \frac{\sum EfC_I}{\sum C_I} = \frac{46}{14} = 3.286$$

iv. The Quality Index for Phase 3:

$$Q_{P3} = \left[\left(1 - \frac{H_{P3} - 1}{4 - 1}\right) x\ 100\right]\% = \left[\left(1 - \frac{3.286 - 1}{4 - 1}\right) x\ 100\right]\% = 23.80\%$$

According to Table 4.5, the conclusion is that the Development Phase was implemented in an 'Inefficient' and 'Provisionally meets requirements' manner.

5.3.5 Quality measurement to Qualification phase (Phase 4)

i. Summation over the individual activity quality indices:

$$\sum Q_{AI} = \sum (E_I \times C_I) = 4 + 12 + 12 + 2 + 1 + 4 + 8 + 4 = 47$$

ii. Summation over the individual Complexity Factor:

$$\sum C_I = 2 + 3 + 3 + 1 + 1 + 2 + 2 + 2 = 16$$

iii. The weighted evaluation value for Phase 4:

$$H_{P4} = \frac{\sum EC_I}{\sum C_I} = \frac{47}{16} = 2.938$$

iv. The Quality Index for Phase 4:

$$Q_{P4} = \left[\left(1 - \frac{H_{P4} - 1}{4 - 1}\right) x\ 100\right] \% = \left[\left(1 - \frac{2.938 - 1}{4 - 1}\right) x\ 100\right] \% = 35.42\%$$

According to Table 4.5, the conclusion is that the Qualification Phase was implemented in an 'Inefficient' and 'Provisionally meets requirements' manner.

5.3.6 Quality measurement for a Quality Management System during Design Stage

i. For each phase of the quality system, the weighted evaluation has been determined by H_{P1}, H_{P2}, H_{P3} and H_{P4}.

Assume that for each phase, a specific weighting factor has been prescribed by:

$W_{P1} = 2,\ W_{P2} = 2,\ W_{P3} = 3,\ W_{P4} = 2.$

(W_P = value from 1 ~ 4, see Table 4.2).

Thus a weighted evaluation value for the quality system (H_S) can be calculated by:

$$H_S = \frac{\sum W_P H_P}{\sum W_P} = \frac{W_{P1}H_{P1} + W_{P2}H_{P2} + W_{P3}H_{P3} + W_{P4}H_{P4}}{W_{P1} + W_{P2} + W_{P3} + W_{P4}}$$

$$= \frac{2 \times 2.33 + 2 \times 3.38 + 3 \times 3.286 + 2 \times 2.938}{2 + 2 + 3 + 2} = 3.017$$

ii. Therefore, Quality System Index (Q_s) will be:

$$Q_S = \left[\left(1 - \frac{H_S - 1}{4 - 1}\right) \times 100\right] \% = \left[\left(1 - \frac{3{,}017 - 1}{4 - 1}\right) \times 100\right] \% = 32.77\%$$

According to Table 4.6, the conclusion is that the Quality System was implemented in an 'Inefficient' and 'Performance provisionally meets requirements' or 'over time limits' manner.

5.3.7 Conclusion of study and areas for improvement

i. Conclusion of Study

According to Table 4.3, when the 'Quality Index' of any individual activity equals 12, corrective action is needed. When it is equal to 8, then routine corrective action is needed. Therefore, Activities 2-5, 3-2, 4-2, 4-3 need urgent corrective action and Activities 1-3, 2-2, 2-6, 2-8, 3-1, 3-7, 4-7 need routine corrective action.

The causes are due to:

1. The activity had insufficient input data to implement the design tasks, i.e. lack of handbooks, plans, procedures or experience data.

2. The design output did not conform with the specification or requirement. Therefore re-design/re-work is needed, i.e. lack of professional knowledge or influenced by previous design changes.

3. The design tasks cannot be completed within the allocated time, i.e. the estimated time did not take into account all design variables or uncertain 'out-of-control' factors.

4. Technical or technological problems such as:

   a. The use of a lightweight aluminium alloy receiver provides durability while reducing the overall weight of the rifle, although there was no manufacturing experience on 7075 aluminium alloy.

b. Substituting 'cold forging' for 'hot forging' to improve the macrostructure of the gun barrel, although there were problems in the manufacturing process.

c. Using 'pushing' instead of 'pulling' for the rifling process to improve accuracy but in this case special tools need to be designed, which causes delay.

5. Management problems such as:

a. Inaccurate time allocations and time adjustments which are inflexible - some activities can be implemented early.

b. 'Process capability' is not investigated enough, therefore the machine tolerance does not match the design tolerance and so more re-design/re-work is needed.

c. Some previous design changes did not notice subsequent design activities, which caused more re-design tasks and time delay.

ii. <u>Areas for improvement</u>

1. For design information enhancement: collection, investigation, management and distribution would provide sufficient design input data.

2. To consider about technological challenge and other possible uncertain factors: make the estimated time (allocated time) closer to realistic time.

3. Establish an on-line information system to improve design change control, configuration control, documentation control and decrease re-design times.

4. In general, better planning of the design operation would have prevented many of these inefficiencies.

5.4 THE DIFFICULTIES OF APPLICATION ON QUALITY MEASUREMENT MODEL DURING DESIGN STAGE.

i. The 'time criteria' is very important in the application of a Quality Measurement Model but 'time allocation' is not so easy: it is very dependent on design and engineering experience. The job of 'time allocation' is beyond the Quality Assurance engineer's responsibility.

Usually, the Project Manager and the consultant team are responsible for allocating the time for each activity. To overcome the time limitation, a 'parallel' approach must be used to approach product design and development. Some other management techniques, such as PeRT (Program Evaluation and Review Technique) and CPM (Critical Path Method) are also useful for 'time allocation'.

ii. Most design and development problems are cross-organisationally bounded. The key to solving such problems is teamwork. This will need the company to have adopted TQM, or already have established a quality system based on ISO 9001. The company must also educate and train employees to understand and use quality management techniques, after which the 'Quality Measurement Model' can be applied properly.

iii. To apply the 'Quality Measurement Model' updated design data and 'design change' records need to be kept. A Quality Information System will need to be established to implement efficient and effective measurement (see Chapter 6 for more discussion on QIS).

CHAPTER 6

THE ANALYSIS OF SOFTWARE DESIGN CONTROL AND DEVELOPING THE QUALITY INFORMATION SYSTEM OF PRODUCT DESIGN AND DEVELOPMENT

6.1 THE ANALYSIS OF SOFTWARE DESIGN CONTROL

6.1.1 Introduction

Modern complex products/systems have become increasingly dependent upon software for their operation. Thus, the software development activities must closely parallel hardware (physical product) development.

There is now general recognition of the seriousness of the software problem and about 60% of all software errors are introduced during the requirements definition and design phases. It is, therefore, necessary to develop a quality management programme to detect and prevent software errors. (Howley, 1978)

6.1.2 Definition

Before discussing "software design control", some definition are given as followings (C.I.T., 1985 and Jones, 1987):

i. Software

Software covers all instructions and data which are input to a computer to cause it to function. This includes operating systems, compilers and test routines, as well as applications programs. The definition embraces the documents used to define and describe the program (including flowcharts, network diagrams and program listings) and also covers any associated specifications, test data, test results and user instructions.

ii. Computer Software Configuration Item (CSCI)

CSCI is a functionally oriented or logically distinct segment of software that is controlled by configuration management in the same way as an item of hardware.

iii. Computer Software Component (CSC)

CSC is a functional or logical segment of CSCI. It may be at any level of the software structure and a typical software hierarchical structure may include the sub-system, module and individual unit. Units are the smallest logical segment of software.

iv Computer Software Documentation (CSD)

CSD is the technical documentation that describes the capabilities and limitations of a CSCI, or provides operating or maintenance instructions for the software. (The specification and documentation hierarchy are illustrated in Fig. 6.1).

v. Code

Instructions in a format suitable for reading by a computer (Source Code refers to that particular list of statements in the language used, which are given to the computer for decoding).

vi Listing

Printed list of the program instruction.

vii. Media

Physical items containing the program, for example disks, tapes, memory chips.

viii. Specification

A statement of requirements.

6.1.3 Time-phased Quality Management Programme

Here, 'Time-phased Quality Management Programme' will be used as a basic frame to describe the major activities of software design control:

i. Conceptual Phase

(1) In the conceptual phase, the design must focus on user requirements, which should be the starting point in a top-down design approach.

The user requirements specification should describe the functions required of the system.

(2) The initial analysis of system software requirements is accomplished to define the complete functional performance, interface and qualification requirements of each CSCI in the system. The results of this analysis form the functional baseline for system software, which is used to determine the overall hierarchy of the software, to plan further software effort and establish design criteria, standards and constraints to be followed during subsequent software development.

(3) After establishment of the functional baseline, a software requirement analysis is conducted to identify the CSCI's and CSC's that will be needed to meet the software requirements of the procurement specification. This analysis will be used to develop segments of the software structure and document the detailed requirements of each segment. The result of this

effort is the allocated baseline. The allocated baseline defines each CSC, describes the functions that each must perform and delineates the interface between each CSC.

ii. Design Phase

(1) The preliminary design activity consists of the development of detailed requirements for each CSCI and CSC. Using the allocated baseline, software engineers begin to develop the requirements for sub-systems and start detailed documentation of required software functions. This development includes applicable inputs and outputs of each sub-system, timing, interruptions, sequencing and interface among sub-systems.

(2) The results of the preliminary design are used during the detailed design stage to develop specific functional requirements for each CSC down to each module and unit of the software architecture. The results of the detailed design are a 'road map' of the functions that will be performed by each CSC, inputs, outputs and interface requirements.

The final software design can then be translated into computer-readable code for operation.

iii. Development Phase

(1) Actual translation of the detailed software design of each CSC into computer-readable code is a critical activity of the

overall software engineering process, because here is where the commands for computer computations and functions are translated from human to computer-usable form.

(2) The software code for each unit/module is tested thoroughly to ensure that the proper coding has been accomplished. Reliability, safety and human engineering disciplines have a vested interest in this phase of software development. The proper coding of software determines how reliably the total system will operate in the field. Safety is concerned with the operation of the system in a hazard-free manner and software performance can either increase or reduce hazards, depending on how the coding is accomplished. Proper software coding that minimises the occurrence of human-induced error increases overall system performance.

(3) The coded software developed during the previous activity is combined and tested in integrated segments. The purpose of this activity is to allow an orderly process to build the total software package. It is easier to find errors that occur as the individual units are combined, rather than trying to put it all together at one time and then having to find errors at the system level.

iv. Qualification Phase

(1) The final activity in software development is CSCI testing. CSCI testing is accomplished by actual loading of the

software onto the system and testing as part of the overall system acceptance test effort. This activity produces and validates the final software product baseline.

(2) After product baseline, the software is combined with the production hardware to produce the total system. The system is then subjected to various tests (ESS, qualification, acceptance, etc.) to demonstrate that it meets the requirements of the procurement specification. Software errors identified during these tests must be corrected prior to delivery to the customer.

6.1.4 Major Sources of Error during Software Design and Development

The aim of carrying out a time-phased quality management programme is to detect and prevent errors during the design stage.

The major sources of error during design are as follows (C.I.T., 1985):

Sources of error in the requirement specification

- Incorrect requirements
- Inconsistent or incompatible requirements
- Requirements are unclear or illogical.
- The requirement is left out of the specification (e.g. handling of invalid inputs).

Sources of Design errors

- Unstructured approach to the design breakdown.
- Use of unstandardised languages.
- Lack of change control.
- Misunderstanding of specification.

Types of Coding Faults

- Syntax errors involving incorrect use of statements.
- Logical errors in translating the algorithm into code.
- Detailed typographical errors may be detected by sophisticated compilers.
- Compilers are complex packages and can therefore introduce errors.

6.1.5 Quality Measurement for Software Design

In Chapter 4 we applied two independent factors - Evaluation Factor and Complexity Factor, to measure each design activity's quality achievement.

The measurement theory and algorithm developed in Chapter 4 is still suitable to use:

Evaluation Factor (E_i)

- To evaluate the software design output for its correctness (verification) and consistency (validation).
- To count the number of design changes.

Complexity Factor (C_i)

The complexity rating can be described in terms of language levels, the program length on the basis of the number of source code lines, or something of a comparable nature.

Quality Index for Individual Activity (Q_A)

$$Q_A = E_i \times C_i$$

Quality Index for each phase (Q_p) and overall design stage (Q_s) They will apply the same equations as used in Chapter 4.

6.2 DEVELOPING THE QUALITY INFORMATION SYSTEM OF PRODUCT DESIGN AND DEVELOPMENT

6.2.1 Introduction

1. The purpose of establishing a quality information system during the design stage is to provide project managers and engineers with the data they need to determine quality achievement. If provided in a timely manner, this information can be used for effective planning, review and control of actions related to product quality.

2. The benefits of a computer-based quality information system are as follows:

i. The inherent capabilities of computer technology to save time and cost through efficient data collection, analysis, recording, distribution and updating.

ii. The timely availability of data provided by computers allows engineers to spend their time conducting analyses and providing inputs to the design process based on real-time information.

iii. To provide an input to the design process which enhances the supportability of the product being designed as against after-the-fact analysis of what should have been done.

iv. Maintains consistency and traceability in fast changing designs.

v. Facilitates communication of design information between members of the product development team.

vi. Promotes re-use of existing design knowledge through a knowledge-based database.

vii. The exchange of information with other support information systems or databases. (If an incompatibility exists, an additional data-handling software package will be required).

3. The key points in establishing a computer-based quality information system are as follows:

i. Define information requirements.

ii. Develop information flows.

iii. Design the database.

iv. Choose a computer system.

v. Use and manage the information system.

6.2.2 Definition of the Information Required

This will be a detailed analysis of the type of information generated at each design activity in terms of:

i. What is needed.

ii. How it is generated.

iii. How it is measured.

iv. What is its volume.

v. To where does it need to be transmitted.

In Chapters 3 and 4 a clear illustration is given for each activity's input and output, as well as the quality achievement measured by quality indices Q_A, Q_p and Q_s.

Here, strict procedures are established to identify each activity's output data. These identification procedures, including correction action and design change control, are shown in Fig. 6.2.

The volume of information and the method of data transmission will be considered when choosing a computer system.

6.2.3 Developing Information Flows

The scope of the information system for the design stage will be limited in conceptual, design, development and qualification phases.

Two information flows will be considered:

i. Tracking from conceptual phase to design phase, development phase and then qualification phase (e.g. starting from Activity 1-1, Customer Needs, and ending with Activity 4-8, Design Release). This information flow is to help manage and control the overall design activities.

ii. Tracking from the qualification phase to development phase, design phase and then conceptual phase. This information flow is actually a feedback system for design change control and to update data. (Simplified versions of these two information flows are shown in Fig. 6.3).

These two information flows produce the means of real-time quality management. Once a design change occurs, the upstream or downstream activities' records will be updated immediately, thus it can be seen as an iterative process which is refined as the project progresses.

6.2.4 Database Design

The database is an essential component of an information system. It includes application programs, user interfaces and other types of software packages.

To minimise interface problems and to simplify input/output formats, a single database for all source data and analyses is suggested. Such a database, although not now in existence, would combine all pertinent data into one database that could serve all design application and quality management requirements (see Fig. 6.4).

The necessary requirements for a single database design are as follows:

i. Information in the database must be organised in a systematic manner so that it is uniquely addressable and readily accessible.

ii. A Database Management System (DBMS) needs to be established for managing a database, particularly for storing, manipulating and retrieving data on a computer system.

iii. Calculation and query programs, in which all the mathematics and query algorithms are specified, need to be designed.

iv. A centralised distribution database needs to be designed which will form an open system architecture to allow the exchange of information between designer, manufacturer, quality engineer and manager.

v. Inputs to the single database could be obtained from compatible CAD, CAM, CAE data systems or other knowledge-based application packages. If an incompatibility exists, an additional data-handling package will be required.

6.2.5 Choosing a Computer System

A quality information system consists of a database, a set of computer programs and computer hardware.

When choosing the correct computer system for quality management applications, many variables must be considered, including hardware, software, data, methods of transmission, volume and cost effectiveness. A company might be buying an initial computer system for quality management applications, or adding to an existing system to include quality management capabilities.

Another point to consider is whether quality management will be using the system as a stand-alone operation that is separate from other uses, or if the system will be used on a time-share basis with other users.

Planning for what type of system to install should be based on a logical evaluation of the requirements the users intend to meet. A general planning process is as follows:

i. The first point to consider is what output is required, how the output is to be provided to users or other organisations and the anticipated volume of the output and the data to be stored.

ii. The next step is to identify the software requirements necessary to provide the output required to process the volume of data in a timely manner.

iii. The final step is selecting the hardware configuration necessary to support the required software packages.

6.2.6 Managing and Using the Quality Inforamation System

To manage a quality information system requires the creation of procedures, instructions and forms for reporting, handling and monitoring various data. It also requires computer programs for efficiently processing the data into formats suitable for quality management. The use of a single unified database simplifies the problems of file searching, report generation and adding new data.

The information needed for different purposes are as follows:

i. For Design Engineers

They need historical data applicable to the design and development of new products having a similar nature and function.

ii. For Manufacturing Engineers

They need to know manufacturing processes, tool planning, process capabilities etc.

iii. <u>For Quality Engineers</u>

They need to know the quality achievement index, test data, design change reports, corrective actions, etc.

iv. <u>For Managers</u>

They need to know the project progress, cost and time control, the quality index and design review reports etc.

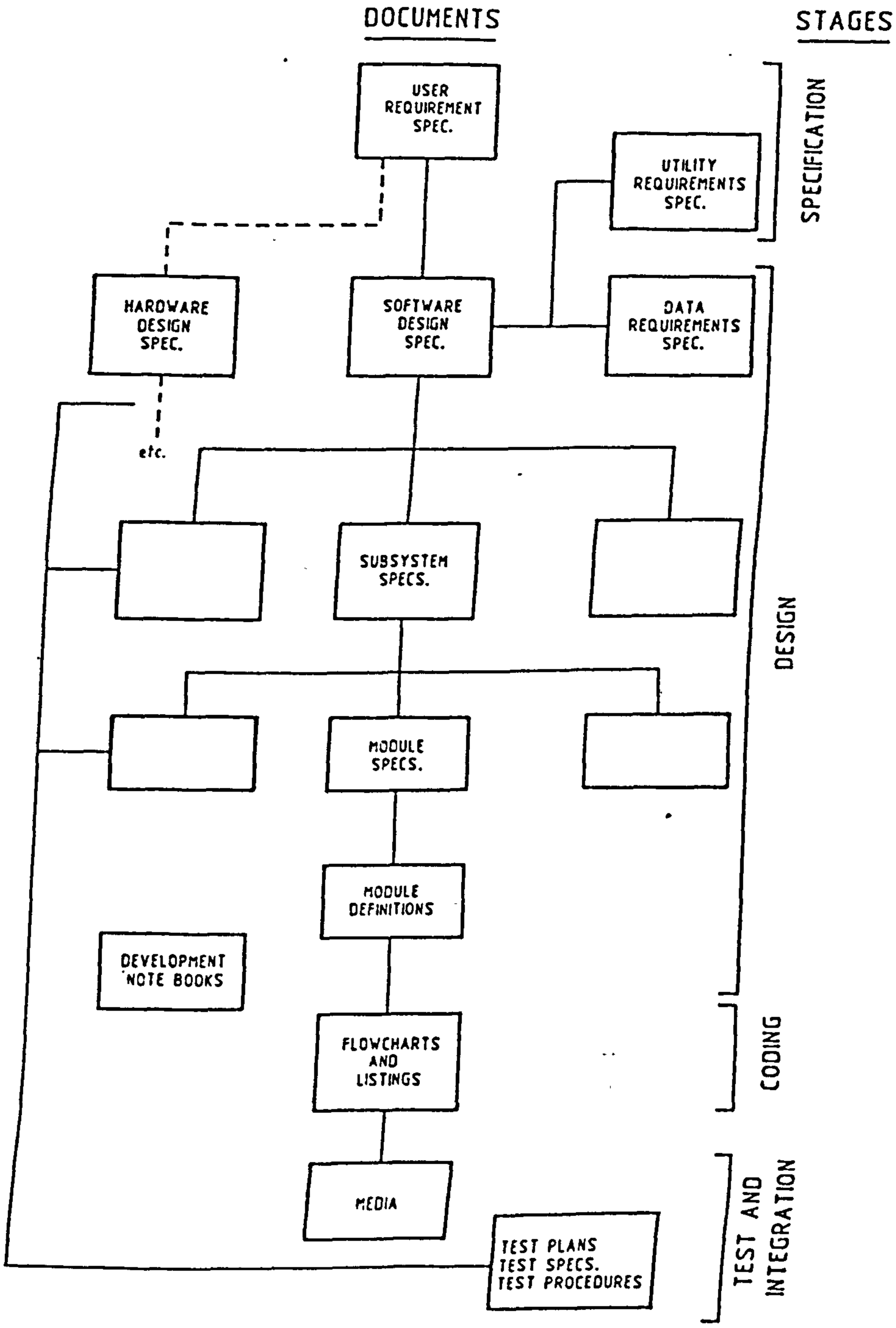


Figure 6.1 The Specification and Documentation Hierarchy of Software

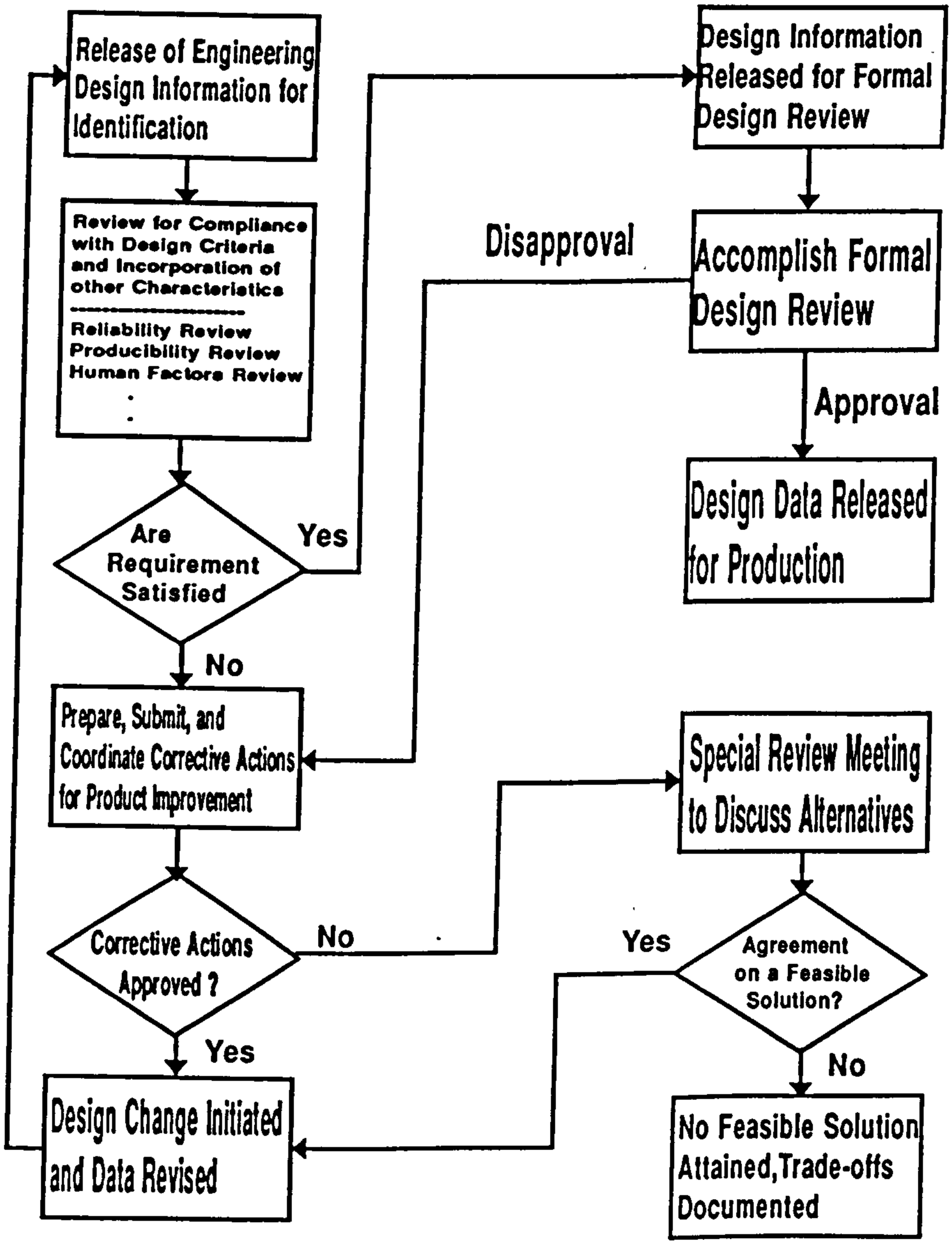


Figure 6.2 The Identification of Engineering Design Data

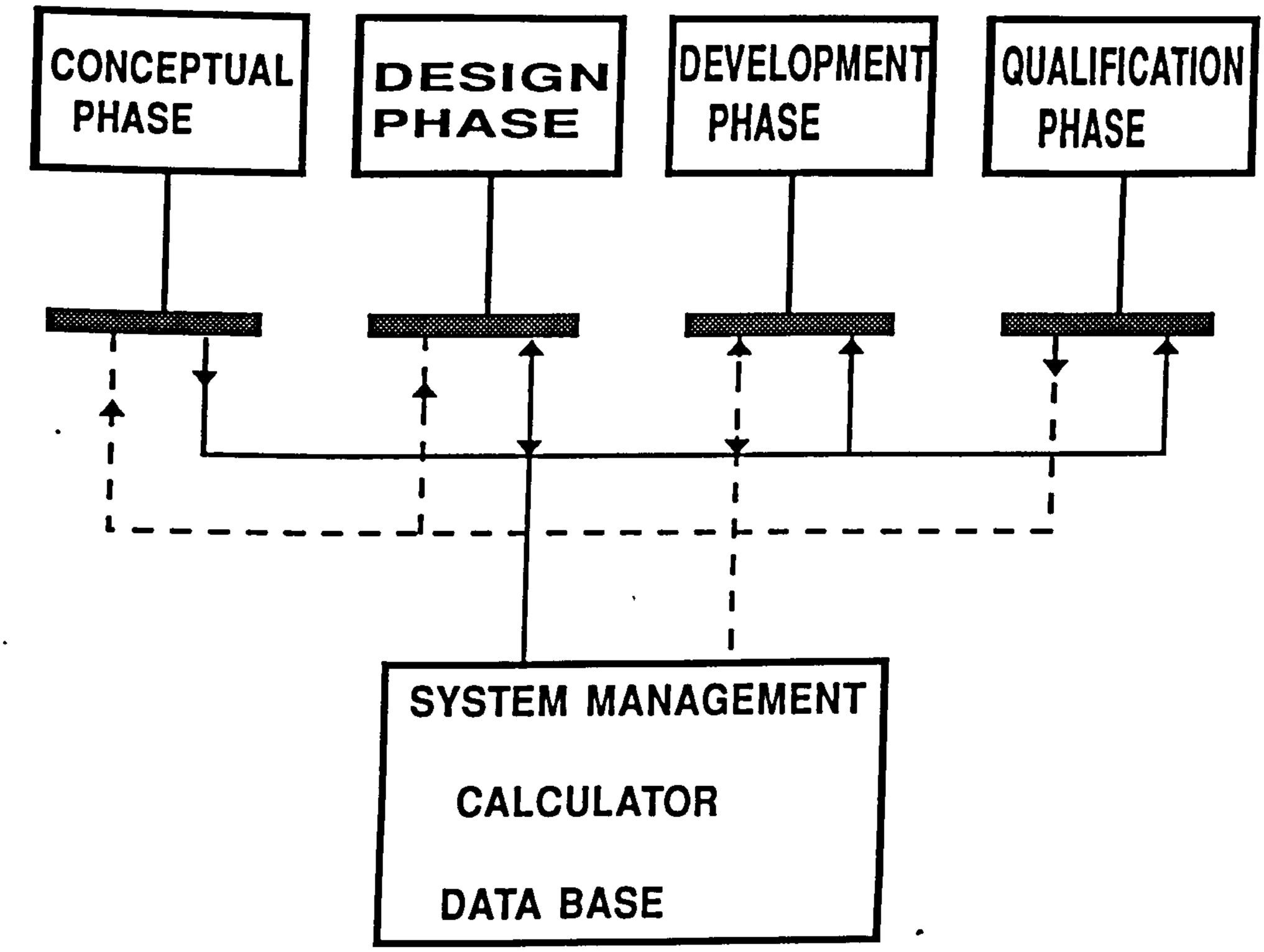
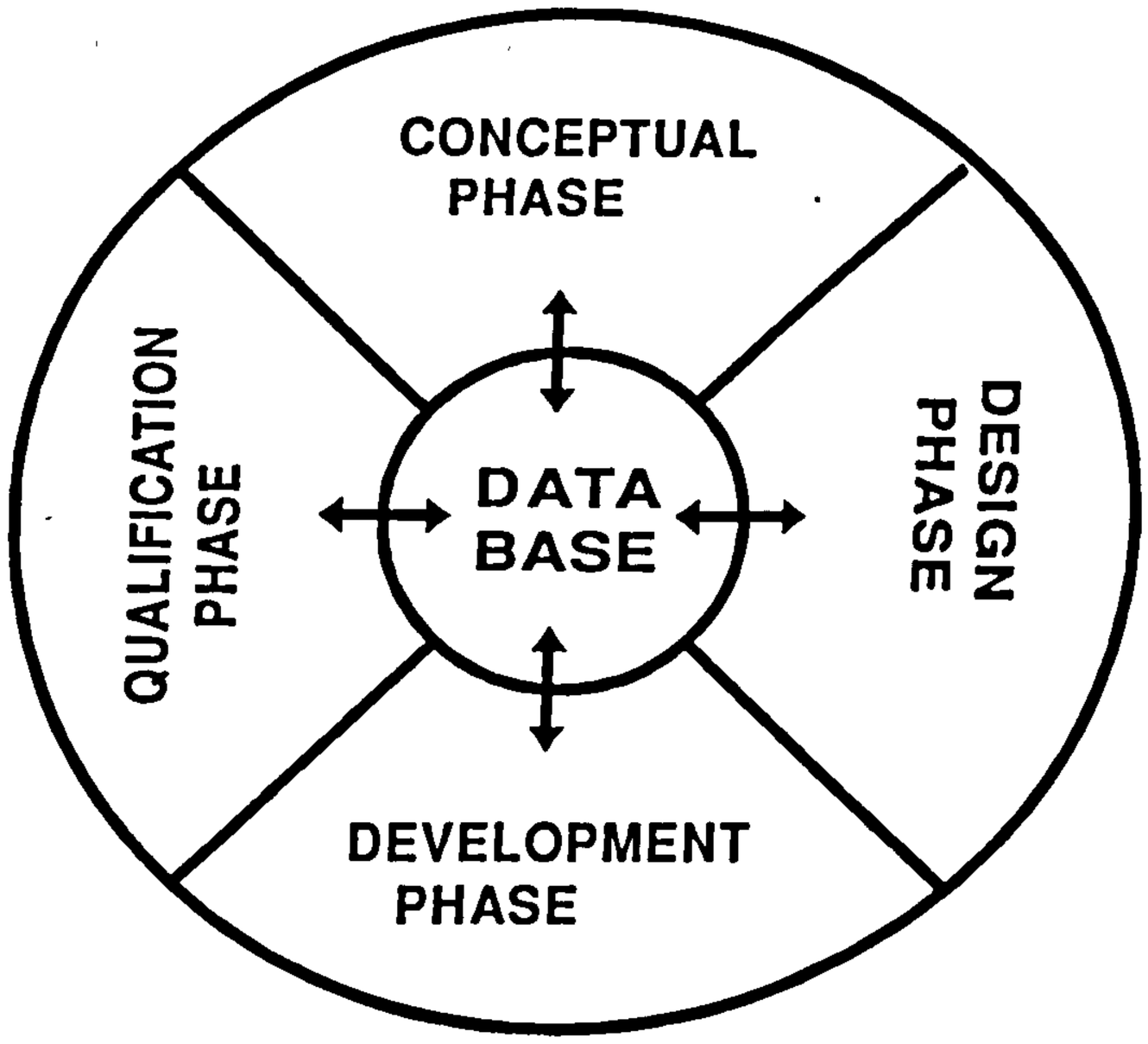
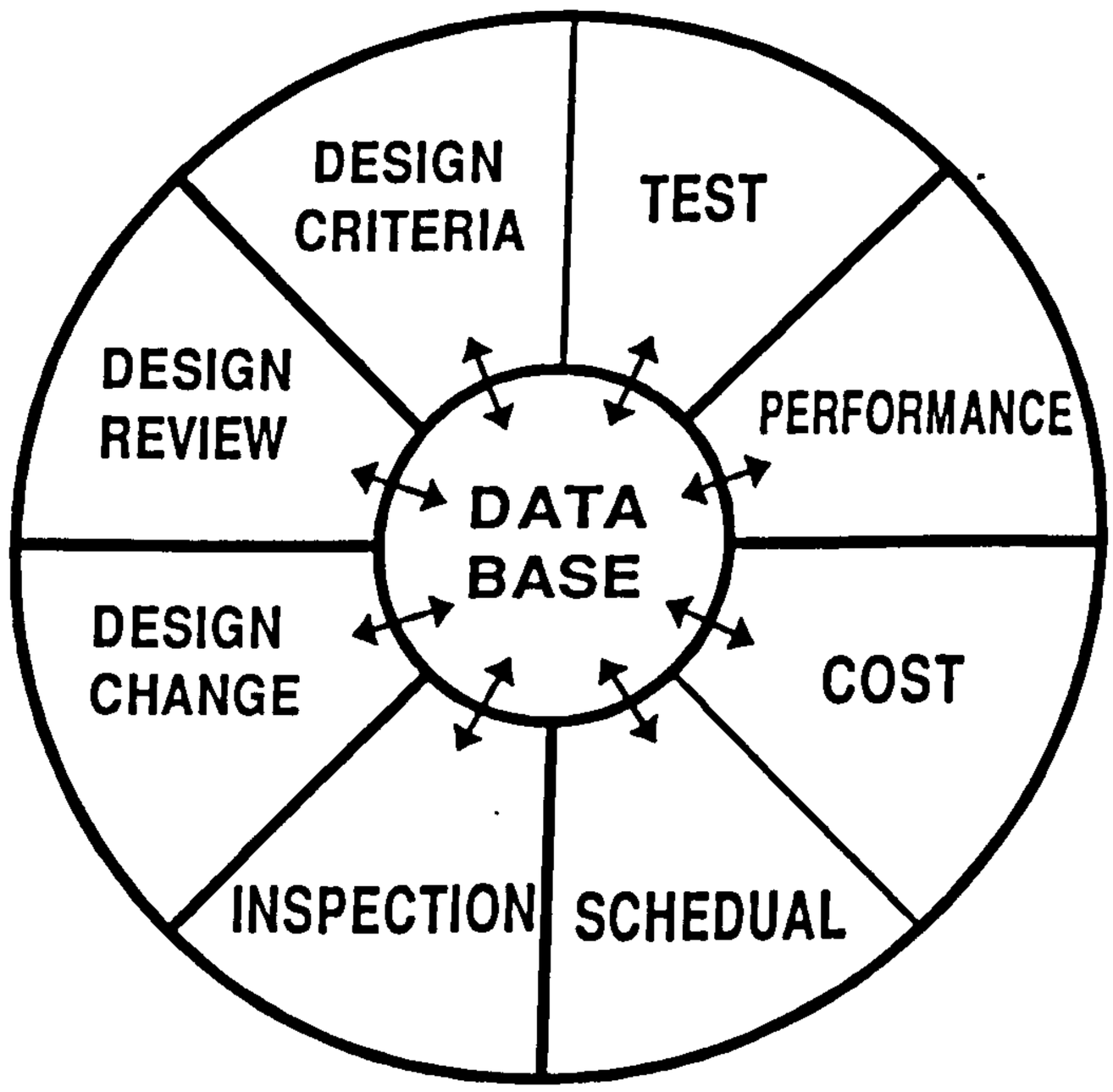


Figure 6.3 Information Flows (During Product Design and Development Stage)



TIME-PHASED INFORMATION STRUCTURE



FUNCTIONAL INFORMATION STRUCTURE

Figure 6.4 Single Data Base Concept

CHAPTER 7

DISCUSSION, CONCLUSION AND RECOMMENDATION

7.1 DISCUSSION

The 'Time-phased Quality Management Programme' which has been developed in Chapter 3 is a generic programme. It is not only suitable for physical products design control, but can also be applied to software design control (as discussed in Chapter 6). It also provides a basic framework for 'quality measurement' and 'information systems' (as discussed in Chapters 4 and 6). However, in practical application, it must be tailored to meet the specific requirements of a particular design or need.

The significant areas that should be considered when tailoring a programme are as follows:

i. **Time and resources available:** Resources include budget, personnel, technical ability, support facilities.

ii. **Type of product:** Mechanical, electric, electronic, electro-mechanical, aerospace, chemicals, nuclear and energy equipment, etc.

iii. **Complexity of product:** For some simple product designs, it is only necessary for a few activities to be carried out.

iv. **Size of production:** For large batch production, more attention must be paid to tool planning, process design and process capability analysis.

v. **Amount of design freedom:** The more constraints, the less freedom. The common constraints are as follows:

- Standards
- Requirements
- Safety Regulations
- Compatibility with other existing systems.

vi. **Work already done:** Work already done should not be repeated just for the sake of accomplishing a design activity or process.

vii. **Past experience and historical data:** This should indicate the most appropriate activities for a specific programme.

More applications are discussed, as follows:

7.1.1 The application of a time-limited development project

Basically, a time-phased management programme is a **sequential** system of operation. Today, major product/development programs often do not allow enough time to complete all activities in one-after-the-other style (see Fig. 7.1).

To overcome the time limitation, a **'parallel'** approach must be used to approach product development. But still we need **to use the time-phased programme as a baseline** to consider which activities need to be started as soon as possible. A general definition of a parallel approach is given as:

> **Design and development begins and carries forward while prototypes are being made and tested; as prototypes are being tested, unit production is begun.** (Feigenbaum, 1991)

A parallel approach will demand stricter quality management to assure development success. If any design change occurs, this will cause more rework and considerable cost. Some other management techniques, such as PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) are also useful for the parallel approach.

7.1.2 Different application for mass-production and job-shop type production

For mass-produced items, during the design stage more attention must be given to:

- material and parts selection
- standardisation and exchangeability
- tool planning
- pilot runs
- process optimisation
- process capability analysis.

Usually, high-tech products such as satellites and aircraft are job-shop production types. The design control activities rely on design criteria, design analysis and reliability design. New-design control is particularly of great importance to a company quality programme under job-shop conditions. When only one or a few units are to be produced, 'make it right the first time' becomes more than a slogan - it becomes a necessity.

On the other hand, in a research and development oriented company, the design control activities may make extensive use of such techniques as environmental testing and reliability analysis.

7.1.3 Different applications for mechanical and electronic products

For mechanical products, design control will stress

- producibility
- manufacturing process design
- stress/strength analysis.

For electronic products, design control will stress

- environmental stress screen test
- assembly design
- worst-case analysis
- sneak circuit analysis.

7.1.4 Applications for product improvement

For existing product improvement, design control will be easier than totally new product design.

Some design and development phases can be brief or even combined with other phases (or activities).

Past experience, historical data and lessons learned from field use could indicate the necessary 'design control activities' for a specific programme.

7.1.5 Using a time-phased quality management programme to support configuration management

By actually tailoring a time-phased quality management programme, configuration control can be achieved as follows:

i. Conceptual Phase

After system requirements are completed, a Functional baseline can be set up. In the meantime, a Configuration Control Board can be included in the project organisation.

ii. Design Phase

During the design phase, the Allocated baseline can be set up and the Configuration Item (hardware and software) defined. In the meantime, design data and design change records will be documented.

iii. Development Phase

All design improvements, test data, corrective actions and technical data (including drawings, specifications, reports etc.) will be documented.

'Interface control' between functional and physical characteristics, hardware and software will be implemented.

iv. Qualification Phase

The Product baseline will be set up. Functional Configuration Audit and Physical Configuration Audit must be implemented.

On the other hand, the Quality Information System which we have developed in Chapter 5 will support Configuration Accounting Reporting Systems.

7.1.6 The extended meaning of 'Satisfy' and 'Conform to Specification'

A check-point has been set up at the end of each phase in terms of 'satisfy' or 'conform to specification'. 'Satisfy' means that every output in the phase fulfils or exceeds the expected requirements. But the meaning of 'conform to specification' does not just mean that the output within the specification limits will be satisfied because the customer takes the risk to accept marginal products at specification limits, that may not work as expected, or last as long as they should in the field. Instead, reducing variability around the target value should be emphasized.

7.1.7 A comprehensive early-warning system

The quality indices (Q_A, Q_P, Q_S) we have developed in Chapter 4 will form a string early-warning system which can monitor each activity and phase and the overall design and development performance, as well as force corrective action to be taken.

Therefore, the design reviews and check-points at the end of each phase, as well as various tests, predictions, FMEA and so on, all form a comprehensive early-warning system.

The early-warning system also makes the time-phased quality programme an 'active' management system, not just to detect current incorrect output but also to prevent more serious influences on later activities.

7.1.8 More precise 'Quality Achievement Measurement'

The rating value used for the **Evaluation Factor and the Complexity Factor** is 1 - 4 (see Chapter 4). The evaluation grade used for the quality indices (Q_A, Q_P, Q_S) is categorised into three intervals - very efficient, efficient and inefficient.

For more precise measurements, a rating value of 1 - 5 (or even 1 - 6) is given and the evaluation grade is divided into four (or even five) intervals.

7.1.9 Applying Quality Indices to 'Development Risk Control'

Originally, the quality indices developed in Chapter 4 are used to measure the 'correctness' of the design output and the 'efficiency' of the design process in terms of time, cost and performance.

These quality indices can also be applied to indicate the following three types of development risk:

i. **Schedule risk:** This type of risk covers technical success within development costs but serious delays in the schedule.

ii. **Cost risk:** This type of risk is that technical success will be achieved within schedule but at a development cost far in excess of that which was predicted at the beginning of the development.

iii **Technical risk:** This type of risk covers failure to achieve one or more the vital system performance characteristics. Usually, development and manufacturing test results are good technical risk indicators.

7.1.10 Extending the Time-phased Quality Management Programme to the full life-cycle of the product

So far, discussion has been limited to the design stage (i.e. conceptual design, development and qualification phase): it can extend the management programme to production and 'field' use, to form a life-cycle management system. This quality management system also forms a closed feedback loop to carry out continuous improvement actions.

7.2 CONCLUSIONS

7.2.1 Design activities are amenable to quality management and are measurable

A systematic analysis of the design process (illustrated in Chapters 2 and 3) show that all activities carried out are amenable to discipline and control and, therefore, design can realistically be included in a formal quality management system.

On the other hand, any complex design tasks can be decomposed to some activity. Each design activity requires particular input and then follows a certain process to obtain an output. Thus, input, process and output are achieved (illustrated in Chapter 5).

Hence, we can develop a quantification model to measure the design activity for correctness and efficiency (see Chapters 4 and 5).

7.2.2 The time-phase quality management system is essentially successful design and development (or innovation)

In the past, quality was not a mainline activity in development and engineering. Innovation was thought of as the basic drumbeat for technology and quality work a much less challenging task.

In today's market, quality excellence is a total-value demand which includes not only expectations for good, intrinsic product function, but also for good, extrinsic product-support and service features co-ordinated for the customer from all these parts of the company.

Carrying out a quality management programme during the design and development stage, at least, can achieve the following benefits:

i. Emphasises high quality product design and process matching upstream - not after manufacturing planning has already frozen the alternatives.

ii. Accelerates new product introduction - not deceleration, a primary measure of the effectiveness of a company's quality programme.

iii. Reduces both the aforementioned upstream costs and their impact on creating much high downstream manufacturing costs.

iv. Makes quality a full and equal partner with innovation from inception of product development.

7.2.3 A time-phased quality management system can provide a smooth transition from development to production.

Management of a complex product from development to production requires the effective administration and co-ordination of a multitude of activities. Transitional planning must be considered throughout all phases of the acquisition process, including design, test and initial production.

Thus, the time-phased quality management system developed in Chapter 3 will contribute to the smooth transition from development to production.

7.2.4 Through appropriate tailoring, a generic time-phased quality programme can be a baseline to suit different types of products, totally new or partially revised design, hardware and software, simple or complex products.

7.2.5 A time-phased quality management system can greatly assist in obtaining high quality product and process design by having the following:

i. an early-warning system to detect incorrect design.

ii. corrective action (feedback loop) to solve problems.

iii. a systematic design process to prevent incorrect design.

iv. an information system to enhance the efficiency of the quality management programme.

7.3 RECOMMENDATIONS

To implement a time-phased quality management programme involves many different management techniques, personnel communication and data processing.

Therefore, to guarantee successful implementation, some pre-required conditions are needed, as follows:

i. The company should already have adopted Total Quality Management, or already have established a quality system based on ISO 9001. The company will have provided a good environment to implement the time-phased quality management programme.

Most design and development problems are cross-organisationally bounded. The key to solve such problems is teamwork - working together across functional boundaries to understand each other's needs.

ii. The company must educate and train the employee to understand and use quality management techniques.

iii. The purpose of implementing a time-phased quality management programme is to help the designer communicate his creation to other people, whilst at the same time not interfering with his creativity.

iv. Using integrated computer-aided tools (e.g. CAD, CAM, CIM) from the start of the design stage can enhance the efficiency and effectiveness of the product and process design and obtain improved product performance.

It must be borne in mind, however, that the quality-related design process and the management system must be defined and implemented in the first place. Then, computer-aided tools can help operate them out better and faster. Attempts to implement computers without a clear understanding of design process and the quality management system have failed.

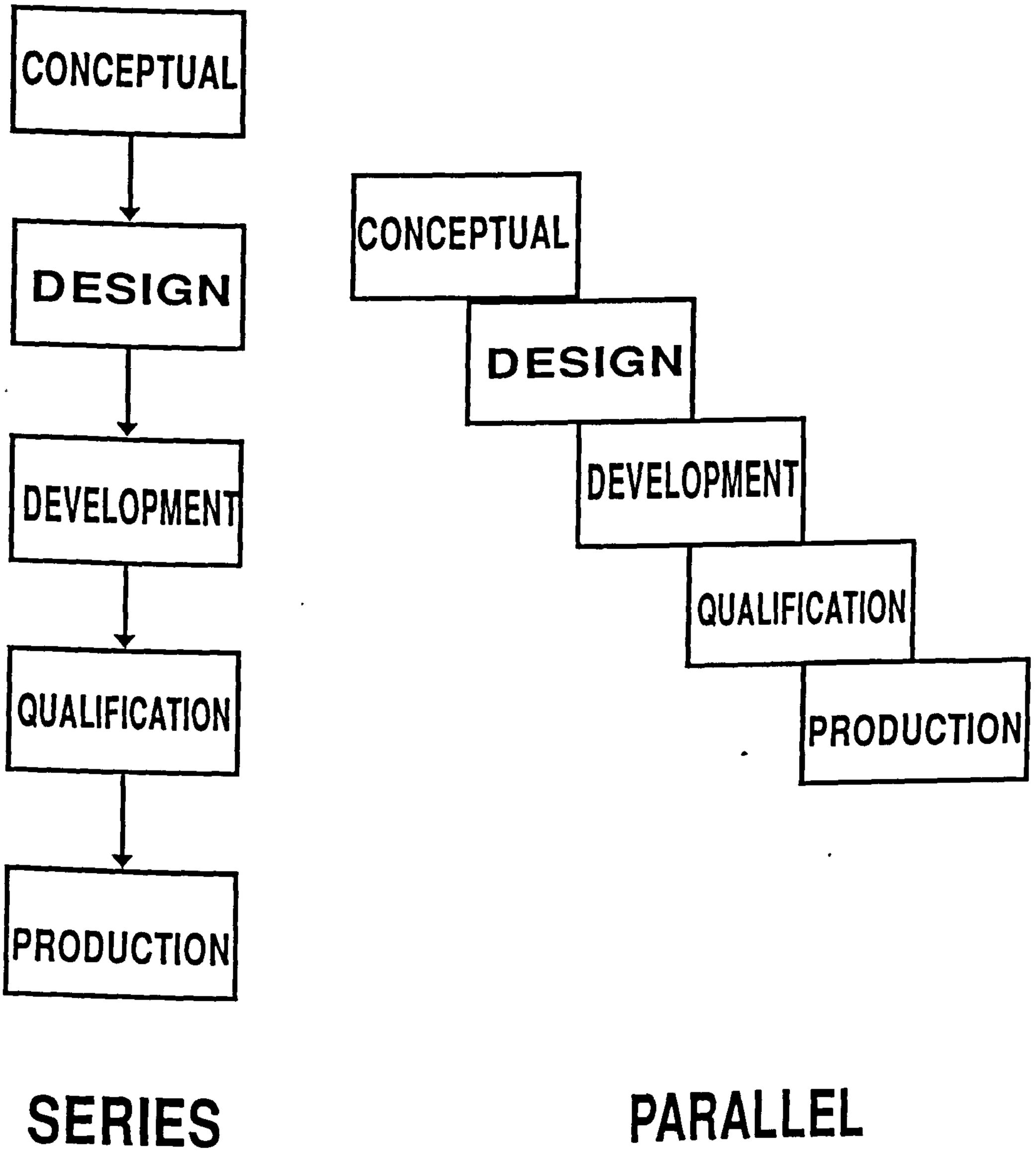


Figure 7.1 New Product Development Approach: Series and Parallel

REFERENCES

AMCP 706-196 — Engineering Design Handbook, U.S. Army Materiel Command

BLANCHARD, B.S. — Logistics Engineering and Management, 3rd. ed., Prentice - Hall Inc., 1985, P.87

BQA — British Quality Association, Total Quality Management Executive Committee

CULLUM, R.D. — Handbook of Engineering Design, Butterworths Co. Ltd., 1988, PP 6-9

DOD 4245.7-M — Transition from Development to Production Department of Defense, Washington D.C., 1985

DON CLAUSING — Systematic Design Method : Application in U.S. Industry, International Integrated Design Management Conference, London, 1990

DON CLAUSING & STUART PUGH — Quality Function Deployment, SAE International Congress, Detroit, 1987

FEIGENBAUM, A.V. — Total Quality Control, 3rd ed., McGRAW-Hill International Edition, 1991, PP14-15

HAND, M. & PLOWMAN, B. — Quality Management Handbook, CIMA, B.H. Ltd., 1st ed., 1992, PP61-70

HAUSER, J.R. & DON CLAUSING — The House of Quality, Harvard Business Review, May-June, 1988

HOUSE, C.H. — The Return Map : Tracking New Product Teams, Harvard Business Review, Jan. - Feb., 1991, PP92-100

HOWLEY, P.P. — Software Quality Assurance for Reliable Software, Proceeding, Annual Reliability and Maintainability Symposium, 1978, P73

ICL TODAY — Concept to Delivery with Concurrent Engineering, IDG Communications publications, 1991, PP19-20

ISO 9000 SERIES — International Organisation for STANDARD Standardization, 1987

JONES, J.V. — Integrated Logistics Support Handbook, T.A.B. Books Inc., 1987, PP362-386

JURAN, J.M. & GRYNA, F.M. — Quality Control Handbook, 4th ed., McGRAW-Hill Co., 1988

JURAN, J.M. & GRYNA, F.M. — Quality Planning and Analysis, 2nd ed., McGRAW-Hill, 1980, P169

KAPUR, K.C. & LAMBERSON, L.R. — Reliability in Engineering Design, John Wiley & Sons, Inc., 1977, PP73-94

Morrell, N.E. — Quality Function Deployment, SAE International Congress, Detroit, 1987

LOGOTHETIS, N. & WYNN, H.P. — Quality through Design - Experimental Design, Off-line Q.C. and Taguchi Contribution, Clarendon Press, Oxford, 1989

MEYER, S.A. — Integrated Design Environmental - Aircraft, A.H.S. Annual Forum, Washington D.C., Proceeding Vol. I, 1990

MIL-STD-1521B — Technical Reviews and Audits for Systems, Equipments and Computer Software, U.S.A.F., 1985

MIL-HDBK-217D — Reliability Prediction of Electronic Equipment, DOD, Washington D.C., 1982

MIL-STD-781C — Reliability Design Qualification and Production Acceptance Tests, 1981

MIL-STD-785B — Reliability Program for System and Equipment Development and Production, 1986

MIL-STD-1635 — Reliability Growth Testing

MIL-STD-189 — Reliability Growth Management, 1981

MIL-STD-810D — Environmental Test

MIL-STD-499A — Engineering Management U.S.A.F.

MIL-STD-483A — Configuration Management, U.S.A.F., 1985

PETERS, G.A. — Quality Progress, Vol. 11, 8, PP34-36

PUGH, STUART — Total Design - Systematic Design, International Integrated Design Management Conference, London, 1990, PP1-2

ROGERSON, J.H. — Quality Assurance in Process Plant Manufacture, Elsevier Applied Science Publishers, 1986

ROGERSON, J.H & ROONEY, E.M. — Total Quality Management Training Course, Cranfield Institute of Technology, 1990

SCHUBER, M.A. — Quality Function Deployment, CH2759-9 IEEE, 1989

SHARPE, C. — Fresh Approach Reduce Time-to-Market, Design Engineering, 1991, PP26-28

S.Q.A. — Software Quality Assurance, Cranfield Institute of Technology, Training Course, 1985

SULLIVAN, L.P. — Quality Function Deployment, Quality Progress, June, 1986

TAGUCHI, G. — Quality Engineering (Taguchi Methods), American Supplier Institute, 1987

WITCHER, B.J. — Total Marketing - Total Quality and the Marketing Concept, Quarterly Review of Marketing, Winter 1990, PP1-6

APPENDIX I

PROBLEMS AT THE DESIGN AND DEVELOPMENT STAGE

1. **User requirements and mission profiles** are often inadequately defined in design engineering terms. As a result, the design product is not compatible with all life-cycle use conditions:

   i. Incorrect specification environments are used.

   ii. The design engineer interprets system performance requirements.

   iii. Operational requirements do not define full functional and environmental profiles (ignores transportation, storage, training, maintenance etc).

2. **Design requirements:**

   i. Operational requirements are stated as design requirements.

   ii. Latest technical developments are used as a basis for design requirements.

   iii. Detailed design requirements evolve with design effort (design engineers confused as to what the requirements are).

3. Trade-off studies:

i. Conducted as a single event on performance requirements.

ii. New technology is used without trade-off studies being conducted.

iii. Trade-off studies are not completed prior to Critical Design Review.

iv. Alternative manufacturing processes are not considered.

4. Design policy:

i. No corporate design policy exists, or policy is not implemented below management level (MIL-STDs and MIL-SPECs used in lieu of corporate design policy).

ii. Low cost design policy is implemented (superficial design analysis and trade-off studies are dictated by cost).

iii. Lessons learned relative to design policies or practices on past projects are not documented.

5. Process design:

i. Producibility issues are not identified during Critical Design Review.

ii. Manufacturing processes are proven during low rate production (unanticipated tooling redesign is required for rate production).

iii. The design is dictated by design engineering (should collocate design and manufacturing engineering during product development).

6. Design analysis:

i. Design analyses are conducted when problems occur. Design problems (detectable by analysis) occur during prototype testing.

ii. Analysis recommendations are not implemented in the design.

iii. Achievement of design maturity is planned through the use of extensive testing.

7. Parts and Materials selection:

i. Lack of standardisation is indicated by design reviews.

ii. Engineers use their own derating criteria.

iii. Thermal design is verified by early performance tests. (Numerous design deficiencies are revealed during testing.)

8. Software design:

i. Hardware/software interfaces are not defined clearly.

ii. Programming is conducted in parallel with product design. (Programming should start at customer acceptance of product design specification).

iii. Software progress reviews are a part of the periodic project reviews.

9. Computer-Aided Design (CAD):

i. CAD implementation is not supported by formal plans.

ii. CAD is used as an interactive graphics tool. (Adequate CAD facilities and databases should be available to the designer).

iii. CAD is considered an individual program, requirement, a corporate database is not established or used.

iv. Design release and configuration control are not implemented in a CAD system.

10. Design for testing:

Past development projects have neglected to consider the need for production and field test capabilities during the early design phase.

i. Production test requirements are defined after design release.

ii. Specification should contain operational test and maintenance requirements. (Product is designed for performance testing and not for production acceptance and maintenance testing).

iii. Design efforts are concentrated on the prime system. Automatic Test Equipment (ATE) design is not considered.

11. Built-in Test (BIT)

i. BIT requirements/constraints are not integrated into detailed design effort.

ii. Integration of BIT with production test needs is considered at the start of the production phase (too late!).

iii. Trade-offs are not done for total test requirements.

12. Configuration Control:

i. Requirements are not tailored.

ii. Sub-contractors are left alone.

iii. Configuration control is ended with delivery.

iv. Improvement changes are expedited.

13. Design Reviews:

The reviews themselves often become a forum for providing an overview of the overall hardware design, rather than an in-depth technical assessment of design maturity.

i. Review is staffed with management people and conducted in accordance with a master schedule.

ii. Review is success-oriented, not a technical evaluation. Risk is not identified or assessed.

iii. Review is focused on the design. Analysis, assumptions and processes are not reviewed.

iv. Design reviews are held informally.

v. Some typically forgotten review topics are:

Product safety,

Component applications,

Materials,

Design requirements analysis,

Manufacturing and inspection processes and plan,

Tooling and test equipment,

High risk technology to manufacture and use,

Reliability and maintainability,

Built-in test,

Production and inspection,

Sub-contractor design,

Design margin analysis results,

Production readiness,

Software design walk-through.

14. Design release.

i. Design release points are pre-established.

ii. Pre-release drawings are used.

iii. Releases are not compatible with purchasing and manufacturing requirements.

iv. Drawings are approved for release only by design engineering.

APPENDIX II

DESIGN AND DEVELOPMENT CONTROL CHECKLIST

(Based on ISO 9001, Section 4.4)

1.	4.4.1	Has a system been established, documented and authorised to provide for design and development control?
2.		Has this system been implemented and maintained? *(Ref. 1* above).
3.	4.4.2	Are the accountabilities, responsibilities and authorities for design and development activities defined and documented?
4.	4.4.2.1	Are design, development and verification activities planned and assigned to competent and adequately equipped staff?
5.	4.4.2.2	Are the technical interfaces between groups involved in design, development and verification defined and documented?
6.	4.4.3	Are design and development input requirements identified and documented and their selection reviewed for adequacy?
7.	4.4.4	Is the design output documented and expressed in terms of drawings, specifications, calculations and analysis?

8.		Is the development output documented and expressed in terms of drawings, specifications, calculations and analysis?
9.	4.4.4	Is the development output controlled to ensure that it meets the design input requirements and that acceptance criteria are referenced?
10.	4.4.4	Is the design and development input controlled to ensure that regulatory or statutory requirements have been stated and complied with?
11.	4.4.4	Does the design and development output clearly identify characteristics of safety as well as critical major or minor features?
12.	4.4.5	Is the design verification process established, documented and authorised?
13.		Is this system implemented and maintained? (Ref. 12 above).
14.	4.4.5	Are design reviews, qualification tests, comparisons to similar designs, demonstrations and alternative calculations identified, performed, recorded and verified?
15.	4.4.6	Has a system been established, documented and authorised to provide for the identification, review and authorisation of changes and modifications?

16. Has this system been implemented and maintained? (Ref. 15 above).

DOCUMENT CONTROL CHECKLIST

(Based on ISO 9001, Section 4.5)

1.		Has a system been established, documented and authorised to provide for document control?
2.		Has this system been implemented and maintained? (Ref. 1 above).
3.	4.5.1	Are documents reviewed and approved by authorised staff?
4.		Are all documents that need controlling identified?
5.	4.5.1	Are the pertinent issues of appropriated documentation available at all locations where operations are performed?
6.	4.5.1	Does the system ensure prompt removal of obsolete documents?
7.	4.5.2	Are changes to documents reviewed and approved by the same functions/organisations that performed the original review and approval?
8.	4.5.2	Is the nature of the change identified on the document or appropriate attachments?
9.	4.5.2	Does the designated authorisation organisation have access to pertinent background information upon which to base their review and approval?

10.	4.5.2	Has a procedure for a master list (or equivalent document such as an MRI) been established to identify document status?

CORRECTIVE ACTION CHECKLIST

(Based on ISO 9001, Section 4.14)

1.		Has a system been established, documented and authorised to provide for corrective action?
2.		Has this system been implemented and maintained? (Ref. 1 above).
3.		Does the system provide for immediate withdrawal and rectification of non-conforming design output or products?
4.	4.14	Are non-conformances formally analysed and investigated to prevent recurrence?
5.	4.14	Is the effectiveness of all corrective actions evaluated and recorded?
6.	4.14	Are the changes is procedures and methods that flow from corrective actions documented?
7.		Are all records analysed to detect and eliminate potential non-conformances?

QUALITY RECORDS CHECKLIST
(Based on ISO 9001, Section 4.16)

1.		Has a system been established, documented and authorised to provide for the identification, collection, analysis, indexing, filing, storage, maintenance and disposition of quality records?
2.		Has this system been implemented and maintained? (Ref. 1 above).
3.	4.16	Do the records demonstrate achievement of the required quality?
4.		Are periodic managerial reports compiled and action initiated?
5.	4.16	Are all records legible and identifiable to the product involved?
6.	4.16	Are quality records stored and maintained in a way that enhances ready retrieval?
7.	4.16	Are quality records stored and maintained in facilities providing an environment that minimises deterioration or damage and prevents loss?

8. Have all records which have to be stored been identified and have retention times been established?