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By

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FUZZY QUALITY FUNCTION DEPLOYMENT FOR AIRCRAFT MAINTENANCE ORGANIZATIONS

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GENERAL INTRODUCTION

General Introduction

At present, companies world-wide have adopted advanced quality management systems in order to help them to provide a quality service at a minimum reasonable cost. Such quality management systems are of major interest in aircraft maintenance organizations due to the complexity of the industry and also, above all, because safety is of paramount importance. In addition, the fierce competition in the aircraft and air transport industries and the pressures to reduce the costs of servicing, and the time taken for the servicing without reducing the quality of work is a current issue of strong concern. This study, therefore, aims to improve the methods used for quality management in aircraft maintenance organizations. This should help to treat in an optimal way complex issues involving aircraft servicing turn-round time, quality service and cost issues.
Quality Function Deployment is a general method whose aim is to improve, through analysis and planning, the performance of product and service organizations. Concern over the increase in sophistication of modern aircraft has highlighted the need for rigorous quality management in aircraft maintenance. Quality management evaluation is a key issue to ensure safety, reliability, risk awareness, and the assurance of quality. Moreover, the fields of quality and safety share a common requirement: both have to be everyone's concern in the organization. This is the basis for efficient implementation of quality and safety system in any aircraft maintenance organization. In addition, the aerospace environment is much regulated in that every maintenance task has to respect a very detailed process which in principle should ensure the safety of flight. To achieve this goal, the maintenance process is tied to very stringent rules and procedures which have been defined by the regulation authorities. The quality management system in aircraft maintenance needs to be a closed-loop system where mistakes and failures will not be allowed to happen. In addition, the evaluation of the system should cover all aspects of maintenance including quality management, safety management and risk awareness issues.
This thesis, based on these factors, addresses the problem of enhancing the classical Quality Function Deployment process when applied to aircraft maintenance organizations. Quality Function Deployment is used as a planning methodology for translating the customer needs with respect to maintenance, the customers' requirements, into service features or design requirements. Classical Quality Function Deployment analysis makes use of crisp values to describe and deal with qualitative opinions in order to reach for the final decision making. The Quality Function Deployment involves the construction of the House of Quality for aircraft maintenance organizations, including the use of Fuzzy Logic techniques and ranking analysis. The fuzzy set theory has been proven as a useful tool in modeling the vagueness and imprecision which has been applied in this case.
The main scenario considered in this study is relative to reducing through Quality Function Deployment applied to an aircraft maintenance organization, servicing time while limiting costs related with installations, equipments and processes. Other objectives are to increase fleet availability and to maintain aircraft reliability.
The proposed approach should be valuable for civil and military aircraft maintenance entities which will be enabled to increase their level of organizational quality management.

The thesis is structured and divided into eight chapters:

Chapter 1 is an introduction of the subject; setting the scene to the research by looking at problem definition, scope of the research, and the structure of the thesis.

Chapter 2 discusses the literature, by providing a review of the general industrial engineering quality concepts and methods. This covers quality and its evolution, the quality management principles and key features, the tools and techniques of quality, and the quality management implementation steps. The theoretical background of some of the main quality assessment principles and frameworks is also discussed in brief.

Chapter 3 provides a state of the art about quality practice in the field of aircraft maintenance. It describes aircraft maintenance management and the structure of engineering organizations and their functions. The chapter also deals with human factors in aircraft maintenance, covering some of the important aspects of this crucial issue. It also discusses the military aircraft maintenance and its quality aspects, and looks at the safety culture in aircraft maintenance. The chapter concludes with two examples, one being a case of civilian aircraft maintenance, and the other being the case of a military aircraft maintenance entity.

Chapter 4 introduces a detailed presentation and an analysis of Quality Function Deployment. This covers discussion on its first elements, a comparison between the traditional quality systems and Quality Function Deployment. The chapter also introduces the House of Quality, and covers the methods used in quality function deployment. It also, briefly covers recent applications and new developments of the quality function deployment.

Chapter 5 addresses the issue of enhanced organizations of aircraft maintenance through the use of Quality Function Deployment. It displays the current aircraft maintenance organizations processes, analysis the requirement for time and cost reduction in aircraft maintenance by using technical solutions analysis and ranking methods. The chapter covers the Quality Function Deployment stages and procedures, and most importantly the results provided by this methodology in order to have projects that are workable, measurable and capable of design enhancement.

Chapter 6 discusses fuzzy modeling and its link with Quality Function Deployment. It starts with an introductory to the elements of fuzzy logic, and also displays the fuzzy representation of linguistic variables as fuzzy logic is known to deal efficiently with linguistic, vague, and uncertain data. This chapter also handles the fuzzy weighted averages by looking at the fuzzy representation of knowledge about the process to be improved, and the technical importance of a design requirement. This is gained by considering customer attributes and design requirements. Further, the chapter makes computation of the membership function for the technical importance of the requirement, and fuzzy ranking. This chapter in general describes how fuzzy set theory can be adapted to describe and process approximate or imprecise information in the Quality Function Deployment framework.

In chapter 7, the application to aircraft maintenance organizations of the resulting fuzzy modeling and quality function deployment approach is handled. The findings from the analysis in chapters 5 and 6 are weighed & compared with the data obtained from the fuzzy logic analysis in this chapter. The chapter illustrates the usefulness of the proposed approach which is based on fuzzy decision making, to improve the quality function deployment process for the enhancement of aircraft maintenance organizations.

Chapter 8 includes recommendations and conclusions. It provides recommendations for successful implementation of the proposed quality management enhancement method for aircraft maintenance organizations. It also provides a number of propositions to further improve the Quality Function Deployment process, specially when applied to tightening the quality and safety management in aircraft maintenance organizations. The conclusion of the paper is closing thoughts on the whole research project.

CHAPTER 2

INDUSTRIAL ENGINEERING QUALITY CONCEPTS AND METHODS

2.1 Introduction

The aim of this chapter is to present the background to understand the notion of quality management, and its evolution over time as a philosophical approach in Industrial Engineering. The chapter also examines the definition of the concept of "quality", the development of quality management, the quality management principles and key features, and the tools and techniques of quality management. The chapter will cover the integration of quality management with statistical and other quantitative tools, and the quality management implementation steps. It will look at the main existing frameworks that establish the principles and requirements to assess and develop a quality management system: the International Organization for Standardization series, the quality award models, the performance measurement, the quality chain, and the service quality gaps model.

2.2 Understanding Quality and its Evolution

Review of the literature on quality reveals that there are various definitions of quality which have been cited from different perspectives by different authors and experts. The development of quality went through many steps and phases to get to where it is now. The concepts of quality and its development are outlined below in detail.

2.2.1 The Concept of Quality

Quality is a concept that is commonly applied to everything related to many of our needs either be it products or services. In discussing the definition of the term "quality", it was generally cited in the literature that "quality" is an imprecise term as it means different things to different people. Despite the lacking in its definition, it is not an inexplicable term. There had been many attempts to interpret the definition of quality from different perspectives. Here are some paragraphs which discuss these attempts.

Referring to the dictionary there are several meanings such as excellence, degree of excellence, attribute, character [The Oxford Colour Dictionary, 1995]. In a linguistic sense, [Dale and Cooper, 1992] stated that quality originates from the Latin word "quails" meaning "such a thing really it is". The British Standards Institute and the International Organization for Standardization (ISO) define quality as "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs" [BS. 4778: Part 1, 1987], [ISO 8402, 1986]; this term is more internationally widely agreed and used. Moreover, the experts in this domain only defined quality in the broad terms, and most of these definitions are product-based definitions since most of the experts addressed quality primarily on the basis of operation perspectives including the product and the design with conformance to specifications. For instance, [Crosby, 1984], stated that quality must be defined as "conformance to requirements" if it is to be managed and measured. This means that for a product to be of a high quality it has to conform to all its requirements. In table (2.1) definitions of quality are summarized from [Hunt, 1992].

1. Customer-based	Fitness for use, meeting customer expectation.
2. Manufacturing-based	Conforming to design, specifications, or requirements. Having no defects.
3. Product-based	The product has something that other similar products do not that adds value.
4. Value-based	The product is the best combination of price and features.
5. Transcendent	It is not clear what it is, but it is something good.

Table 2.1: Definitions of Quality
Source: [Hunt, 1992]

2.2.2 The Development of Quality Management

Quality was originally viewed as "inspection", aimed at problem identification. Later, quality control principles began to emerge in the manufacturing sector, where statistical and mathematical techniques, sampling tables and process control charts were used to ensure quality of products. From the early 1950s to the late 1960s, quality control evolved into quality assurance, with emphasis on problem avoidance. From the 1970s to 1980s, the service sector has become a major concern of many organizations worldwide as a result of the increasing importance of the service sector in the economy. A number of service organizations, including both sectors; public and private, profit and non-profit organizations, have embraced the quality management approach as a strategy for improving their service, and enhancing their management processes. These organizations cover industries such as financial services, engineering maintenance, education and training, health-care, tourism, government, and transport services, where the focus of the business activity is on services rather than on products [Lewis, 1994]. [Tuckman, 1995] divided the evolution of quality management, during the 1970s and 1980s, into four phases, which are shown in table (2.2).

First phase	Late 1970s to early 1980s	Some experimentation with quality circles. Mostly affected firms' indirect competition with what Japan had concentrated on, e.g. electronics.
Second phase	The 1980s	Major companies, often affected by world recession, concerned with control of suppliers and sub-contractors.
Third phase	From mid-1980s	A growing concern with customer service, particularly in the service sector.
Fourth phase	From late 1980s	Penetration of concerns with 'customer service' in areas which previously had not recognized the existence of customers.

Table 2.2: The Evolution of Quality Management during the 1970s and 1980s
Source: [Tuckman, 1995]

[Dale et al., 1994] categorized the development of quality management into four stages as presented in Figure (2.1). These four key stages are: inspection, quality control, quality assurance, and Total Quality Management (TQM). The four key approaches are discussed below in detail.

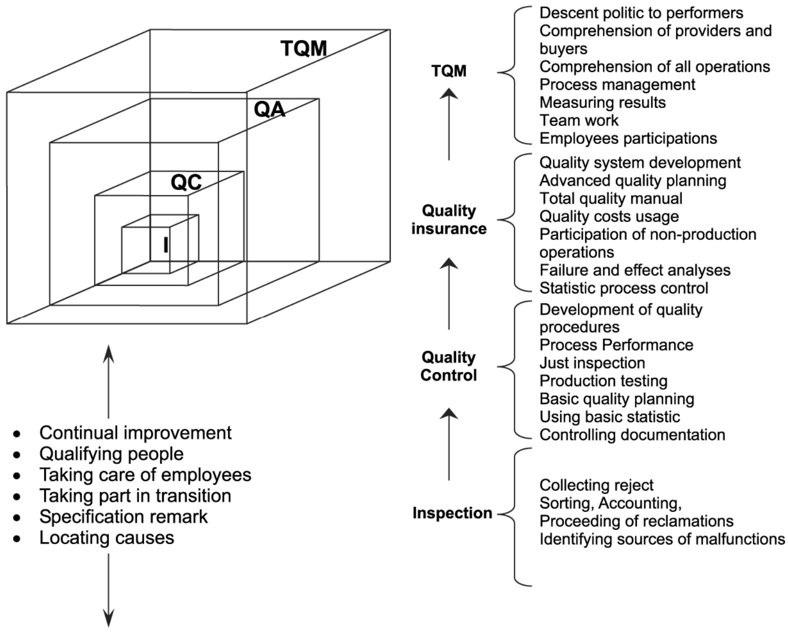


Figure 2.1: The Four levels in the Evolution of Quality Management
Source: [Dale et al., 1994]

2.2.2.1 Inspection

Inspection as defined in [ISO 4802, 1995] is "activity such as measuring, examining, and testing or gauging one or more characteristics of an entity and comparing the results with specified requirements in order to establish whether conformity is achieved for each characteristic". Inspection is applied in the industrial sector to examine and test the quality of products and services. [Seymour, 1992] pointed out that inspection, as a process existed in industry in the 1960s, when it was used to guarantee production uniformity, and was executed through gauging and measuring methods. From this definition the inspection process will be describing the product as good or bad by comparison of the results with standards held by the organization or by external bodies responsible for quality assurance. The term inspection is also widely used in the aircraft maintenance in that each organization will have laid down procedures for carrying out such inspections.

The traditional reason for inspecting things is because people suspect there maybe something wrong with such things. In other words, inspection is carried out to detect failure. There are many types of inspections, for example inspection by attributes where the five senses of the human are used, and inspection by variables where variables are measured and expressed numerically. When properly conducted, inspection may achieve some objectives for the organization for example reducing the risk of defective items, and also can provide a numerical indication of performance of the quality level. However, inspection is, in fact a very limited and restricted method of management that has become an inappropriate approach for managing complex systems, as it depends on testing and comparing products according to standard value. This fact was highlighted by [Aguayo, 1990] when commented regarding inspection by saying "inspection, if it is properly done can catch the defects and prevent them from reaching the customer. But is not improvement and does not guarantee quality. Inspection is a very limited tool, grossly overused and often misused".

2.2.2.2 Quality Control

The quality control is the second stage in the evolution of quality management, which involves the application of sampling procedures such as quality control charts or Statistical Process Control Charts, and periodic quality audits in the production process to ensure a product's specification and the efficiency of the producing equipment. It also involves co-operation between the different departments.

From the literature, many authors and experts have defined quality control as a concept. [Juran, 1989] stated that "quality control is a managerial process during which we":

- Evaluate actual quality performance
- Compare actual performance to quality goals
- Take action on the differences

Whereas, [Feigenbaum, 1991] defined quality control as "an effective system for integrating the quality-devolvement, quality-maintenance, and quality-improvement efforts of the various groups in an organization so as to enable marketing, engineering, production, and services at the most economical levels which allow for full customer satisfaction. In [International Standards Organization 8402, 1995] quality control is defined as "operational techniques and action that are used to fulfill requirements of quality". This means that managers, supervisors, and producers must employ appropriate techniques at every stage of the process, and that the final product or service meets its specifications. In this regard there are many operational techniques and activities applied in organizations, these include: planning, process control, inspection and test, documentation, material identification, control of non conforming materials, handling, storage, packing and delivery, and carrying out corrective actions.

2.2.2.3 Quality Assurance

This third step in the evolution towards quality management is quality assurance, which enables the system to monitor technical standards within the organization. It aims to prevent errors or when errors occur, to detect them promptly and prevent their repetition. This approach minimizes the cost of scrap and rework and ensures that the product or service is achieved at the most economical cost. In this regard, quality assurance involves management as well as employees, from all functional areas within the organization, and a commitment to the detection and prevention of quality problems.

In citing the literature, [ISO 8402, 1995] defines quality assurance as "all planned activities implemented within the quality system and demonstrated as needed, to provide adequate confidence that an entity will fulfill requirements for quality". [Seymour, 1992] stated that quality assurance was applied only to manufacturing between the 1950s and 1980s, and concentrated on the entire production chain, plus the contribution of all functional groups, to prevent quality failure, through the use of programs and systems. According to [Freeman, 1991], "quality assurance is an approach to identifying market needs and honing working methods to meet standards".

From the above it can be summarized that activities connected with quality are arranged so that:

- Performance meets requirement
- Customers are satisfied
- Errors are prevented so there should be no need to do things more than once

2.2.2.4 Total Quality Management

Total Quality Management has become the last management approach. It, however, involves all functional areas at all levels to achieve continuous improvement, teamwork, customer (external as well as internal) satisfaction, and improved productivity with reduced costs. In the 1980s Total Quality Management became a popular approach in the manufacturing industry. It was subsequently implemented in 1990s in almost across all the industry sectors. [British Standards EN ISO, 1995], [Cited in Dale and Bunney, 1994] states that Total Quality Management is "a management approach of an organization, centered in quality, based on the participation of all its members and aiming at long-term success through customer satisfaction, and benefits to all members of the organization and society". Whereas [ISO 8402, 1995] defines quality as "The totality of features and characteristics of an entity that bear upon its ability to satisfy stated or implied needs".

In discussing the theory and concepts of quality in the literature, there is no single theoretical formalization of Total Quality Management. In this, the quality experts (refer to Annex A) constructed and provided a set of core assumptions and specific principles of management which can be synthesized into a coherent framework [Hill, 1995]. In the Total Quality Management literature, Deming is regarded as the pathfinder of modern quality management concepts. [Feigenbaum, 1991], defined quality as "the total composite product or services characteristics of marketing, engineering, manufacturing, and maintenance; through which the product and service in use will meet the expectation of the customer". It worth noting that Juran's message is that "quality cannot happen by chance". In "Juran's Trilogy", the three managerial processes are: quality planning, quality control, and quality improvement [Juran, 1989].

The implementation of the principles of quality management need to be founded on a strategic evaluation of company's quality performance compared to its own mission statement and the performance of its competitors. Leadership is required to set direction and specific goals for the program. Management then interprets strategy into specific plans for people, resources, and processes. Clear procedures are set with the aim of consistent, reliable service to the customer.

2.3 Quality Management Principles and Key Features

Quality management as a philosophical approach emphasizes that quality is the responsibility of everyone in an organization by involving commitment to continues improvement, and that all managers and workers should be trained and educated to use quality tools and techniques for solving problems, and decision-making. On other words, quality management should work in the basis of having a totally integrated efforts towards improving performance at every level.

Moreover, quality management may be distinguished from other organizational improvement approaches, such as the Business Process Re-engineering, Just-In-Time, Kaizen, and Six Sigma, despite some similarities between their objectives and those of quality management. In the literature, [Hammer and Stanton, 1995] differentiated between quality management and Business Process Re-engineering by stating that "Total Quality Management stresses incremental improvement through structural problem solving, whereas, Business Process Re-engineering is about radical improvement through total process redesign". Distinguishing Just In Time from quality management was tackled by a research carried out by [Flynn et al., 1995] by describing Total Quality Management as an approach for improving the quality for products and services that is characterized by the goals of continuous improvement of all processes customer-driven quality, production without defects, a focus on improvement of processes than rather on a criticism of people, and data-based decision making. On the other hand, Just In Time is based on the notion of eliminating waste through the implications of manufacturing processes, which includes the elimination of excess inventories and overly large lot sizes that cause unnecessarily long customer cycle times.

2.4 The Tools and Techniques of Quality Management

As was said before, quality management is a philosophy that is committed to continuous improvement in the management processes. Hence this continuous quality improvement process requires tools and techniques to identify and solve quality problems within an organization. The production and delivery of products and services in an organization needs a sound framework to give direction, a scale to measure quality improvement, and a follow-up process in order to gain feedback on products and services quality. Therefore, the management of the organization has to select specific tools and techniques to achieve the improvement on their organization.

There exist many tools for the improvement of process quality, which have been discussed by several authors and experts. For example, [Bergman, and Klefsjo, 1994] agreed on similar tools, specifically the Pareto, the scatter diagram, the cause and effect, and the control chart. [Juran, 1989] has proposed seven quality control tools: the control chart, the scatter diagram, Pareto analysis diagram, the control chart, the scatter diagram, and graphs. These tools all come under the basis of Statistical Process Control diagrams.

2.4.1 Statistical Process Control Tools

Statistical process control is a management approach that is intended to improve an organization's product or service quality by reducing variation in the work process [Houston et al., 1986]. Statistical process control can be applied to both industrial and non industrial processes, and in its practical application can help the organization realize continuous improvement. Statistical process control techniques provide accountability and are essential ingredient in this quality effort. Statistical process control is an analytical decision-making tool in order to see when a process is working correctly or when it is not. Variation is present in any process, deciding when the variation is natural and when it needs correction is the key to quality control. The preparatory phases of Statistical Process Control involve several steps using a number of different tools. In total, there are eight tools and techniques for continuous quality improvement, these are: the cause and effect chart, the check sheet, the scatter diagram, the flow chart, Pareto chart, the histogram, the control chart, and benchmarking. For an organization to implement these tools correctly, their application and involvement should be fully understood by the entire work team. Each technique has an overall objective to meet as described and outlined briefly in the paragraphs below:

A. Cause and effect charts: The more famous is known as the 'fishbone chart', and in some cases referred to as 'Ishikawa diagram'. "Aims to list all the factors which affect the quality of a process and then to map the interrelationships between them" as was stated by [Sallis, 1994], whereas [Mears, 1995], and [Dale and Bunney, 1994] stated that this diagram illustrates relationships between activities and helpful in generating ideas for improvement. The person or team that is trying to discover the root cause of a problem has to construct the cause and effect diagram by first listing the undesirable effect. Then, continues by listing the major cause categories and the minor cause categories, which are then connected to the undesirable effect [Besterfield, 1994]. Once all the minor and major causes are identified, solutions are developed to correct the most likely causes in an effort to eliminate the undesirable effect [Besterfield, 1994].

B. **Check sheets:** accurate data collection is a fundamental to Statistical Process Control. Check sheets are a simple tool for recording information. [Mears, 1995] pointed out that check sheets are used to ensure that the data is gathered in a systematic manner. According to [Arcaro, 1995] check mark shows that the job is completed or the item is safe. The exact form of the check sheet is tailored to each situation.

C. **Scatter diagrams:** they how the pattern of relationship between two variables that are to be treated. [Bergman, and Klefsjo, 1994] mentioned that a scatter diagram can be used to show how the process or product varies owing to an explanatory variable. [Mears, 1995] stated that scatter diagrams are used to visually measure how the change in one variable affects another.

D. **Flow charts:** according to [Arcaro, 1995] a flow chart is a diagram of the steps in a process. Using flow charts prevents the team from leap-fogging over activities which are a natural sequence in the process. By showing how the process works, the team can identify the potential problem areas and create a new or improved process.

E. Pareto chart: used to show the distribution of items and arrange them from the most frequent to the least frequent. [Arcaro, 1995] stated that the "Pareto chart helps to centre efforts on the problems that offer the greatest capacity for improvement". Pareto diagram differ from histogram in that the horizontal axis of a Pareto diagram is categorical (e.g, subsystem number) whereas the horizontal axis of a histogram is numerical. The Pareto diagram can be used to quickly identify which category along the horizontal axis is the most frequently occurring. However, the Pareto diagram does not automatically identify the most important occurring [Montgomery, 2001]. For example a Pareto chart might be constructed to show which aircraft subsystem fails the most frequently. However, if the user of the chart is interested in which subsystem is creating the largest drain on the maintenance budget; then the Pareto diagram would not be displaying the most important information. On other words, frequency does not always have a direct correlation with importance.

F. **Histograms:** They are a graphical representation of the distribution of data. [Hind, 1994] stated that histograms are broadly used for drawing grouped data. Grouped data are put into categories, or bands, in order to make the information easy to handle. The histogram is an effective tool for showing the general shape, location, or central tendency, and spread or variation in a given population [Montgomery, 2001]. It can also show if there are any gaps in the data [Besterfield, 1994].

G. **Control charts:** of all the tools offered by Statistical Process Control, the control chart is the most technically sophisticated [Montgomery, 2001]. According to [Arcaro, 1995], and [Gunther, and Hawkins, 1999] a control chart graphically displays the variations in an organization's work process. For example, it can maybe used to show the relative performance of two groups of people. [Bergman, and Klefsjo, 1994] mentioned that in their opinion the control chart is an important tool in finding assignable causes and for supervising a process. There are two basic types of control charts: those for variable data and those for attribute data [Montgomery, 2001]. Variable control charts are used when the quality characteristics can be expressed in terms of a continuous numerical scale. Examples of variable data include product weight, volume, dimensions, etc. When the quality characteristic is not a numerical variable, then it is expressed as an attribute such as conforming/non-conforming, or non-defective/defective.

H. **Benchmarking:** it is a process that entails comparing the activities of an organization with other excellent organization to develop and achieve the best performance. [Liston, 1999] describes benchmarking as "a tool to improve products, services, or management processes by analyzing the best practices of other companies or organizations to determine standards or performance, and how to achieve them in order to increase customer (client, stakeholder) satisfaction".

Statistical process control has been successfully implemented in both service and manufacturing industries [Montgomery, 2001]. In the service industries, Statistical Process Control techniques are applied by treating process errors similarly to the way they are treated in a manufacturing setting [Montgomery, 2001]. For example errors on billing statement, documentation errors on loan application paperwork, errors in computer software, etc can all be considered as defects.

2.4.2 Integrating Quality Management with Statistical and Other Quantitative Technique

Quality management involves the integration of both the qualitative and quantitative techniques. Some of the techniques have been briefly discussed above. Emphasis by managers and experts has been primarily on the qualitative aspects. However, companies will not realize the full benefits of quality management until they integrate the quantitative techniques into their company's processes. As was stated by [Heinrich G., 1994], a generic approach is to stress the qualitative aspects initially and form quality-improvement teams using relatively simple statistical tools. As teams mature and operations improve, the teams will have to progress to more sophisticated statistical tools to continue the necessary improvement. Figure (2.2) [Heinrich G., 1994], shows that the management and cultural changes required to achieve quality management are as listed in the triangle at the top. The foundation of this figure shows the qualitative and quantitative efforts that need to be integrated. The integration can be best accomplished through the use of team tools as shown in the centre of the foundation.

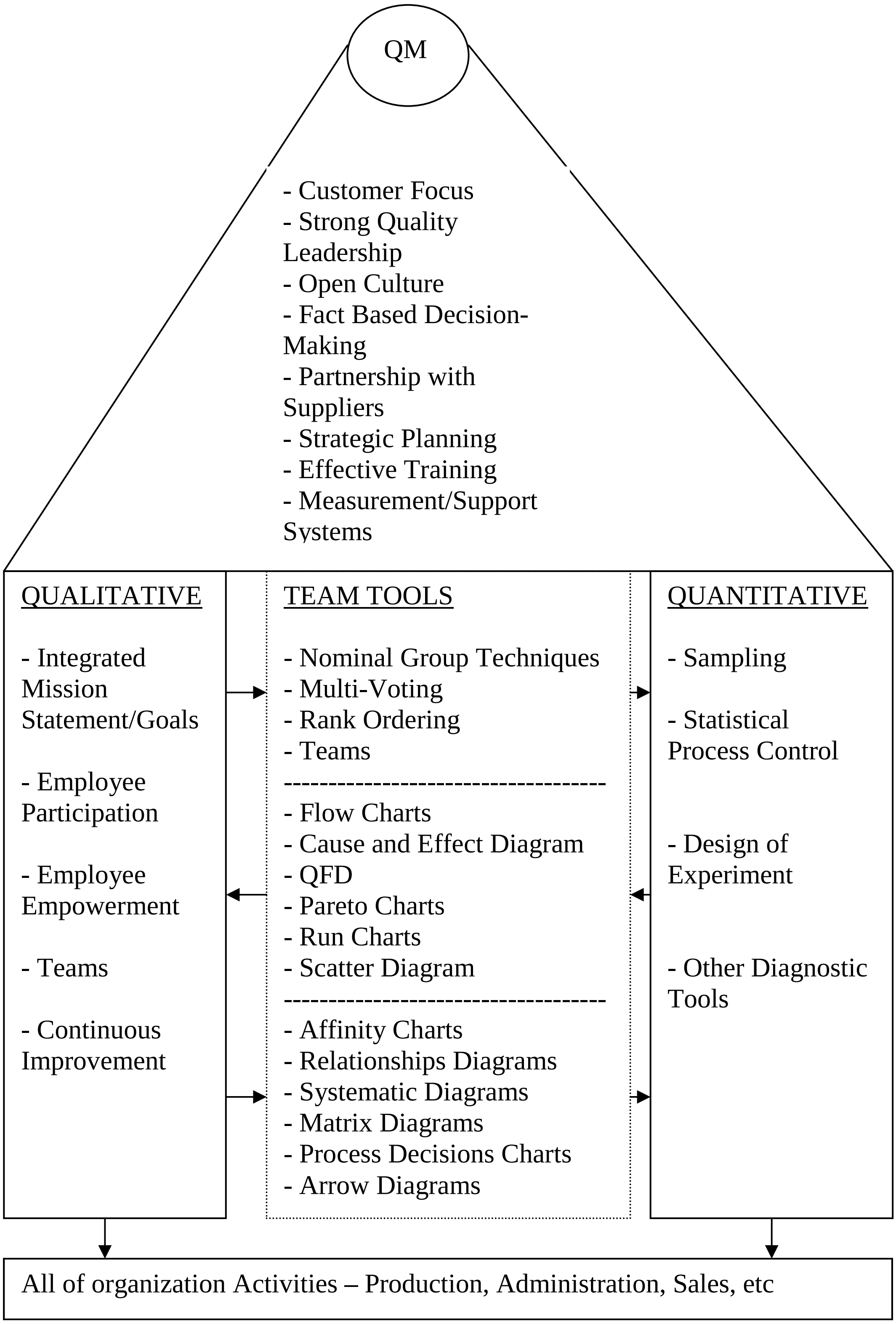


Figure 2.2: Integration of Cultural Attributes Qualitative and Quantitative Techniques and Team Tools
Source: [Heinrich George, 1994]

On the other side, [Ograjensek, 1998], stated that empirical evidence on Slovene companies regarding their inclination towards the integration of statistical quality control into a quality management system, three types of companies with ISO-certified quality management systems exist: **"enlightened"** – those actually using the methods; **"self-satisfied"** – those being aware of the importance of the statistical quality control's integration into a system, but at present not using the methods because, due to their favorable competitive position, they do not have to, and **"careless**" – those presently not using the methods and not planning to use them in the future either. For each group of companies, appropriate activities and measures for integration of statistical quality control into a quality management system can be identified. The following points should be emphasized in each individual group [Ograjensek, 1998]:

- ⇒ In the group of **"enlightened companies":** regular audits of the correctness of statistical quality control methods use on the one, and introduction of new statistical methods which help companies reduce costs on the other hand.
- ⇒ In the group of **"self-satisfied companies":** intensive employee training with the emphasis on the use of modern statistical software tools.
- ⇒ In the group of **"careless companies":** emphasis on both motivating top managers and training middle managers for the use of statistical quality control methods.

2.5 Quality Management Implementation Steps

There exist many of the quality management implementation models which belong to various sponsoring consultant firms. An adaptation of a very practical and simple model was presented in [Heinrich George, 1994], which was quoted from (Total Quality Management Guide, a Department of Defense publication). This model as depicted in figure (2.3) clearly emphasizes the need for top management commitment and the establishment of a new culture, with steps 2 through 5 are clearly team efforts.

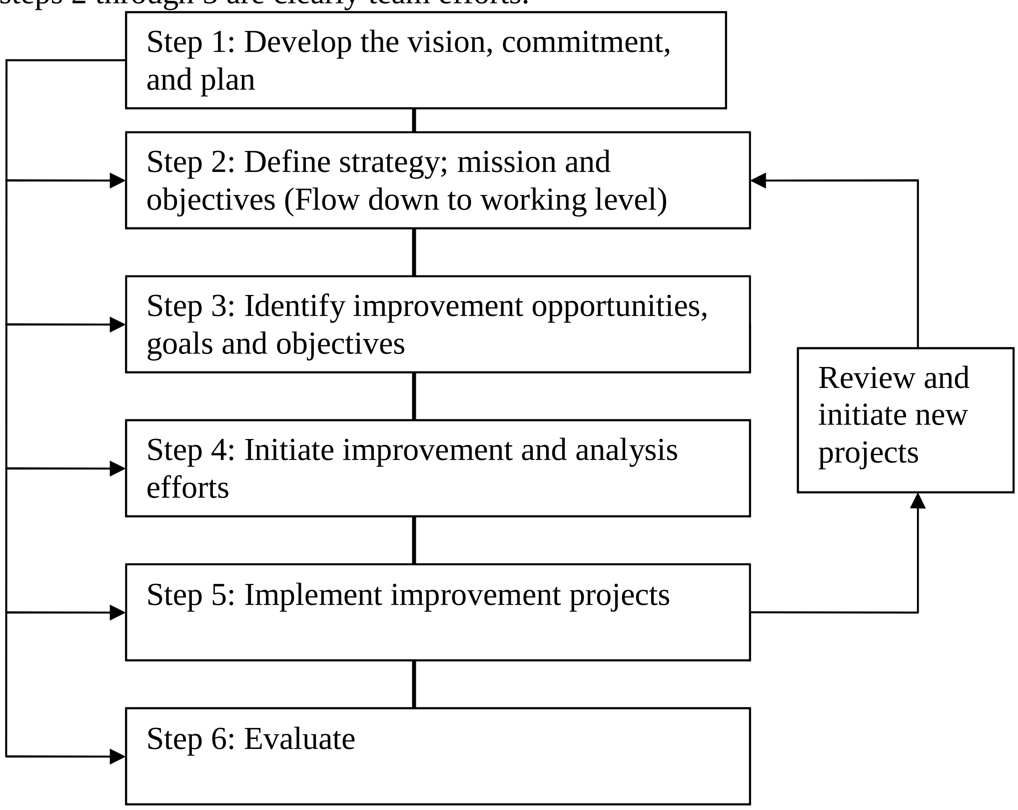


Figure 2.3: Quality Management Implementation Model
Source: [Heinrich George, 1994], Quoted in TQM Guide, Department of Defense publication.

The actions and activities needed in each of the steps stated in figure (2.3) above are described below [Heinrich George, 1994], which was quoted in (Total Quality Management Guide, a Department of Defense publication);

Step 1: Develop the vision, commitment, and plan:

⇒ Prepare a concise vision statement that can be translated to top-level goals and objectives.
⇒ Agree to long-term commitment, including provision of support systems and necessary training budget.
⇒ Commit to changes in personnel involvement.
⇒ Develop a top-level disciplined approach to continue improvement.

Step 2: Define strategy; mission and objectives (Flow down to working level):

⇒ Identify internal and external actors.
⇒ Develop a mission statement and objectives for your organization/team.
⇒ Identify customers' requirements.

Step 3: Identify improvement opportunities, goals and objectives:

⇒ Determine how to maximize value to customers
⇒ Develop organization/team goals that are consistent with organizational top-level goals and objectives.
⇒ Pursue deeper understanding of processes to ensure that goals are realistic. However, goals should "stretch".

Step 4: Initiate improvement and analysis efforts:

⇒ Focus on critical processes in which capability indices need improvement.
⇒ Select projects with high value-added potential for customers.
⇒ Develop improvement plans and matrices to measure progress.
⇒ Apply a structured performance improvement methodology.

Step 5: Implement improvement projects:

⇒ Analyze process data.
⇒ Remove assignable (special) causes of variation.
⇒ Eliminate non-value-added steps and simplify.
⇒ Review other improvement opportunities.

Step 6: Evaluate:

⇒ Evaluate projects and project teams. These evaluations are essential elements of the continuous improvement cycle.
⇒ Include behavioral change in the evaluation to ensure that there is no backsliding or fading of the quality management program.

2.6 Quality Management Systems

A Quality management system can be defined as a set of policies, processes, and procedures required for planning and execution (product/development/service) in their core business areas of an organization. Quality management system integrates the various internal processes within the organization and intends to provide a process approach for project execution.

It also enables organizations to identify, measure, control, and improve the various core business processes that will ultimately lead to improved business performance. A quality management system is one that includes quality management as an integral part of an organization's management approach. As defined by [ISO 8402, 1995] a "quality system is made up of the organizational structure, responsibilities, procedures, processes, and resources for implementing quality management". Some organizations refer to quality management as Total Quality Management. In aircraft maintenance organizations, the quality management system manages all components of the quality process, including quality assurance, quality control, quality improvement and quality auditing and assessment.

The aim of a good quality management system is to provide the operators of the process with consistency in terms of methods, materials, procedures, information, etc. Feedback from the customer of the process and from the process itself (through measurement) is essential to monitor and improve performance. It is a fundamental of Total Quality Management to have a good quality management system in place, whether the system is home-made, or certified to an international standard, subject to third party audit. It is the basic control mechanism for consistent delivery from business processes [Borley, 1994].

The objectives of the quality management systems are to: increase reliability, increase efficiency, reduce cost and optimize safety. So, therefore, an organization's functional systems and management procedures play a critical role in implementing quality management. If the management systems of the organization are not prepared and capable of meeting the requirements demanded by Total Quality Management, then it would be difficult to start a quality management program.

For effective system implementation, the quality management system needs to be implemented from the top; therefore, the top management commitment is needed in order to ensure that such system continues effectively. As [Calavera and Aparicio, 1990] pointed out, "the responsibility for the quality of work carried out obviously falls on those responsible for its execution". In addition, a Quality Management System can not function effectively unless everybody in the organization knows what it is. Therefore, to make sure that everyone has a common understanding, the system needs to be documented; the documents that should be available but not limited to, in any organization, are: quality plan, quality manual, procedure description, work instructions, method statements, inspection and test plan.

2.7 The Main Quality Assessment Principles and Frameworks

Measuring quality is not an easy task. Many techniques are available at a detailed level, but few measure the success of a quality management program as a whole. Historically, quality has been measured by the percentage of failures. Then, as prevention and quality assurance became more prevalent, Statistical Process Control, and audits provided key measures. In the 1980s with cultural change encouraged for continuous improvement, employee surveys became popular. However, the historic nature of quality management in the 1990s requires that customer, shareholder, and competitor reactions are also important to assess quality management success. In this regard, quality audits, performance measurement, the quality chain analysis, and the service gap model will be discussed in detail.

2.7.1 Quality Assessment/Audit

As with any system, feedback is required to ensure that the individual elements of the maintenance system are functioning as intended. Continuing high standards of quality in many industrial and service organizations, such as aircraft maintenance organizations, imply regular monitoring of all activities. Therefore, quality assessment is a vital component of maintaining and improving the quality of service or product provided by an aircraft maintenance organization. Assessments can be carried out in different ways such as assessment by supervisors, peers either from the same department or different department within the same organization, or by independent external raters, or self-assessment. The discussion on this paper will concentrate on the assessment when carried out by a group of experience people from the different departments within the same organization, and on assessments carried out by independent external body. Assessments when carried out correctly can reflect the performance of the organization in light of its strength and weaknesses in order to identify the proper corrective action. There are a number of factors that need to be embedded throughout the organization before any assessment begins.

It is a requirement that quality audits should be carried out by personnel independent of those having direct responsibility for the activity being audited. This is the author's vision in this paper to have assessments done by external auditors, or teams from the different departments in the organization, not including any personnel from the department being audited and assessed. Furthermore, he doesn't fully believe on self-assessments as there is a tendency for vagueness in this regard.

2.7.2 Performance Measurement

Performance measurement is extensively used by the business units and industries to assess the progress against the set goals and objectives in a quantifiable way for its effectiveness and efficiency. Performance measurement provides the required information to the management for effective decision making. Performance can not be managed without measurement, as measurement can only indicate the present status of performance. Research results demonstrate that companies using integrated balanced performance systems perform better than those who do not manage measurements [Kennerly and Neely, 2003], [Lingle and Schiemann, 1996]. Each organization spends considerable resources and time for measuring the performance and to assess the success of the organization. Performance measurement literatures emphasize the importance of maintaining relevant measures that continue to reflect the issues of importance to the business [Lynch and Cross, 1991]. However, most of the organizations pay little or no attention to integrate the performance measurement system with their organizational hierarchical levels and the different measurement criteria linked to the external and internal stakeholders as well as the operational process. Besides, enough importance is not given to the external and internal effectiveness, to achieve the total maintenance effectiveness for the organization. A summarized list of some of the currently existing performance frameworks and performance measures found in [Parida A., 2006] is shown at Annex B. In general, there are seven fundamental elements of performance measurement, which every manager in an organization should be aware of. Every manager in an organization monitors, evaluates, and controls at least one of these seven elements, which are: effectiveness, efficiency, quality, productivity, quality of work life, budget-ability (profitability), and innovation (product and process). Each one of these factors of performance measurement describes a unique aspect of the performance of an organization or activity.

Also, Performance Measurement Indicators are used for measurement of maintenance impact on the process performance [Wireman, 1998], [Parida et al., 2003]. Performance Measurement Indicators need to be linked to down time, costs and wastes, capacity utilization, productivity, quality, health and safety [Parida and Kumar, 2004] to compare actual performance with a specific set of reference conditions (requirements) [EEA, 1999]. Under challenges of increasingly technological changes, implementing an appropriate performance measurement system in an organization ensure that actions are aligned to strategies and objectives [Lynch and Cross, 1991]. In fact, performance cannot be managed, if it cannot be measured. The development and implementation process for indicators has been studied by [Andersen and Fagerhaug 2002] and [Engelkemeyer and Voss 2000]. The development and identification of Performance Measurement Indicators for an organization is undertaken from the vision, objectives and strategy points of view and on the basis of the requirements of both the external and the internal stakeholders [Kumar and Ellingsen, 2000], [Liyanage, and Kumar, 2003] as presented in figure (2.4). The Performance Measurement Indicators are required to be considered from the perspective of the multi-hierarchical levels of the organization. The first hierarchical level could correspond to the corporate or strategic level, second to the tactical or managerial level, and the third to the functional/operational level, depending on the organizational structure, the hierarchical levels could be more than three [Parida A., 2006].

Figure 2.4: Developing Performance Measurement Indicators from Vision, Objectives and Strategy
Source: [Parida A., 2006]

The effectiveness of any performance measurement system is meant to meet the needs of the operations and maintenance processes. The critical strategic areas vary from company to company, and from sector to sector, but generally include areas such as financial or cost-related issues, health safety and environment related issues, processes-related issues, maintenance task related issues, and learning growth and innovation related issues, while at the same time comprising the internal and external aspects of the company. It is important to link and integrate the overall objectives and strategy of the company. The linkage between visions, objectives and strategy and measures of performance such as return on investments and health, safety and environment indicators are considered to be the most important factors. In our case, in the aircraft maintenance, most organizations are giving their upmost consideration to this issue in order to contribute to the overall objective of the organization and its business units.

2.7.3 International Quality Organizations

There exist many international quality organizations (refer to Annex C). The European Foundation for Quality Management (EFQM) Model is widely used by United Kingdom and European organizations, in both public and private sectors as a means of reviewing performance against internationally recognized best practice. It is structured of nine criteria items, and 32 sub-criteria, against which organizations can assess their activities. The model is based on the principle that the five enablers of excellence are about leadership, policy and strategy, people, partnerships and resources, and processes. These activities enable excellent performance, as demonstrated by people results, customer results, society results, and ultimately, key performance results. Key performance results are the indicators of progress towards the organization's aims and objectives. The Malcolm Baldrige National Quality Award identifies and recognizes top-quality United States of America companies. The Program entails self-assessment and action planning. The ISO describes standards for a quality management system addressing the process surrounding the design, development, and delivery of a general product or service. Organizations can participate in a continuing certification process to demonstrate their compliance with the standard. The alliance for performance excellence is a network of states, local, and international organizations that use the Malcolm Baldrige National Quality Award criteria and model to improve their performance and economies.

2.7.4 The Quality Chain

Measuring quality of service should be regarded as part of a whole quality system which works in a continuous cycle, and should lead to a system of continuous improvement. The "Quality Chain" which is composed of the elements as can be seen in figure (2.5). These elements are:

- Evaluation of customer needs and expectations: this step is prior to implementing a service, the service supplier needs to know what customers require or expect. This step can be achieved through marketing studies, surveys, comment cards and analysis of complaints.
- Implementation of adequate service: The analysis of customer needs and expectations leads to the design and implementation of the service to be delivered, which should be as close as possible to expectations. This requires the mobilization of all the necessary resources, trained personnel, material, finance and processes, in order to make the service available.
- Achieve the service: When the service is ready to function it has to enter into operation. Quality of service is perceived by the customer at this point in time.
- Measure Quality of Service: In order to verify that the desired quality of service has been achieved, quality of service has to be measured and evaluated.

Measuring the quality of service in an aviation maintenance organization can be done in different ways at different times, such as: assessments carried out by the Quality Assurance Coordinators at the working place, another carried out by Quality and Standards Monitors in that organization, or and by specialized Quality and Standards team normally six monthly or yearly. This can vary depending on the size of the organization and its management philosophy. [Airports Council International, 1st edition -2000].

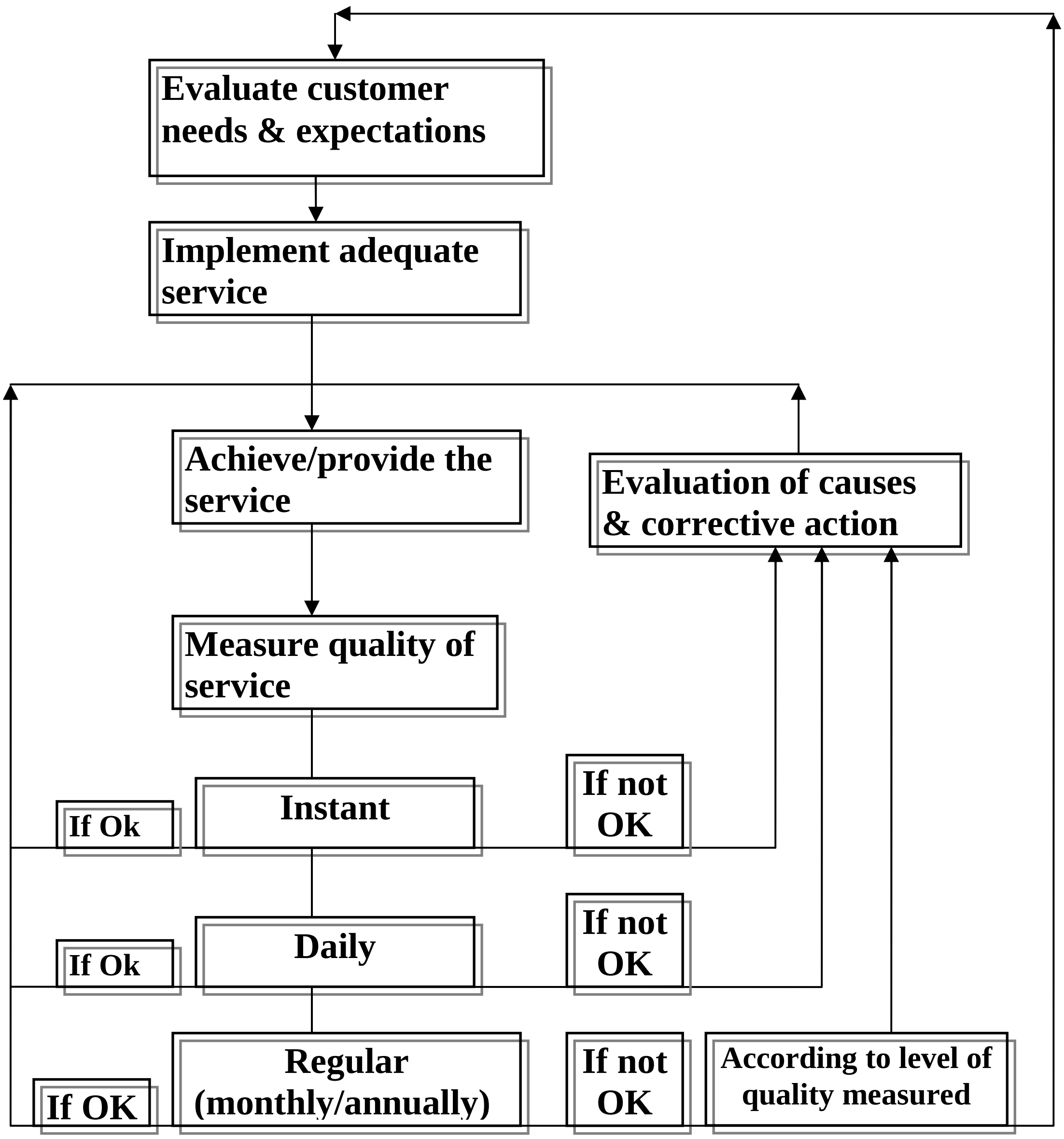


Figure 2.5: The Quality Chain
Source: [Airports Council International, First edition-2000]

2.7.5 Service Quality Gaps Model

As quality in goods and products had a great attention by researchers, quality in services remains largely undefined and un-researched. However, from the literature, it can be confirmed that service quality involves a comparison of expectations with performance. [Lewis and Booms, 1983] stated that "service quality is a measure of how well the service level delivered matches customer expectations. Delivering quality service means conforming to customer expectations on a consistent basis".

The "Gaps Model" (SERVQUAL) by [Zeithaml, Parasuraman, and Berry, 1988] as presented in figure (2.6) is a technique that is used for performing a gap analysis of an organization's service quality performance against customer service quality needs. It may be used by a services organization to improve service quality. The method involves the development of an understanding of the perceived service needs of target customers. The measured perceptions of service quality for the organization in question are then benchmarked against an organization that is excellent. The resulting gap analysis may then be used as a driver for service quality improvement. The gap analysis takes into account the perceptions of customers of the relative importance of service attributes. This is really good for organizations as it allows them to prioritize, and to utilize their resources in order to improve their most critical service attributes. The tool has been developed from four different service sectors; retail, banking, credit cards, securities brokerage, and product repair and maintenance.

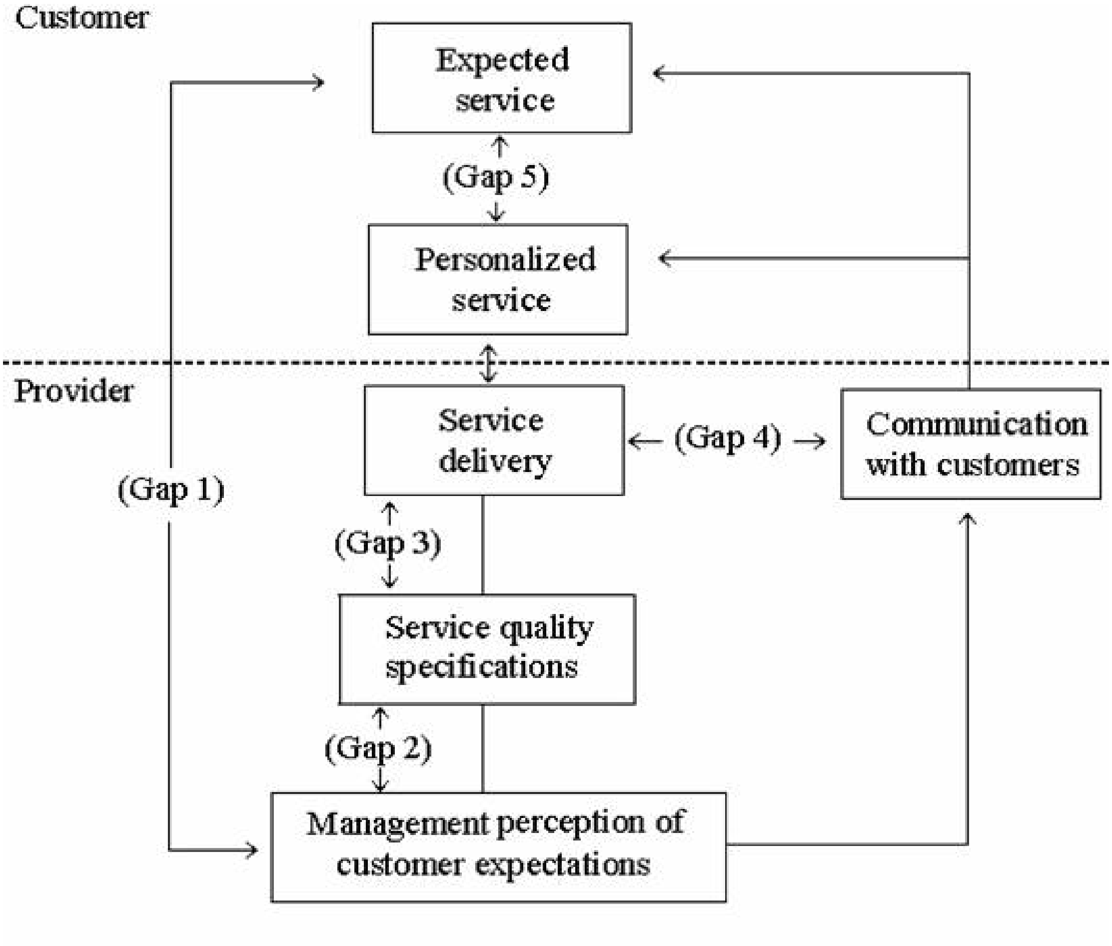


Figure 2.6: Service Quality Model
Source: [Zeithaml, et al., 1988]

2.8 Conclusion

The review of literature on quality revealed that there is no one universally accepted definition of quality. Each expert defines quality depending on the quality concept that they want to use in their domain. What is clear from the literature is that quality is a customer driven so that it can be judged and defined according to customer/client satisfaction. It was cited from the literature that while quality in goods and products had a great attention by researchers, quality in services remains largely undefined and un-researched. [Lewis and Booms, 1983] stated that "service quality is a measure of how well the service level delivered matches customer expectations. Delivering quality service means conforming to customer expectations on a consistent basis".

There are many tools and techniques to measure quality, but few measure the success of a whole quality management system. In this regard, each organization has to adapt the assessment tool that suits its particular requirement and needs.

Safety has always been the overriding consideration in all aviation activities. This can further be enhanced when linking quality with safety. Quality and safety share a common requirement; both have to be everyone's concern. This is the basis for efficient implementation of quality and safety system. On the other hand, there is an increasing need for enhanced security for aircraft operations. The use of technology and the new security products should help in building up an effective security measures. Therefore, for any aircraft operator's policy should always underline how importance to create and share a common quality, safety, and security culture for aircraft operations.

The next step is to see how these quality concepts can be successfully utilized in aircraft maintenance organizations, as this industry has a risky environment, and that mistakes should not be allowed to happen, as it cost lives and money.

CHAPTER 3

AIRCRAFT MAINTENANCE ORGANIZATIONS

AND

QUALITY

3.1 Introduction

Maintenance may be seen as a kind of creation, science, and even an art. Throughout the years, the importance of maintenance functions and therefore of maintenance management has grown. This aspect has also entailed the growth on the quality management functions as well. Quality Management in aircraft maintenance requires another two important elements; safety and risk management to complete the quality management cycle. Quality, safety, and risk awareness share a common goal and requirements; all have to be everyone’s concern. This is the basis for the efficient implementation of the quality management system in aircraft maintenance. This fundamental link between quality, safety, and risk awareness is the pivot in the whole process for establishing a healthy "Quality Culture" within aircraft maintenance organizations quality management systems.

The maintenance cost represents 15% to 20% of aircraft direct operating costs [www.airbus.com]. Airlines cannot act on categories of costs such as depreciation, financing, insurance, fuel and fees. On the contrary, there are possibilities for the airlines to optimize flight crew costs and maintenance costs. This led airlines to outsource their maintenance activities to maintenance providers rather than to do it themselves. However, outsourcing maintenance and engineering activities did not reduce the cost by a great margin, and even sometimes increased them. In addition maintenance costs have a strong influence on the choice of an aircraft during the purchase process. Buying an aircraft with least direct maintenance cost is in every airlines purchase agenda. According to Airbus [www.airbus.com] a reduction of 10% in direct maintenance costs leads to an increase of 20-30% of profit margins of the airlines. However, this should not jeopardize aircraft safety.

This chapter describes aircraft maintenance organization, covering its management, and a state of the art about the quality practices in this field. The chapter also examines two case studies, one on an airline and the other will cover a military maintenance entity.

3.2 Aircraft Maintenance and Engineering Organization

Aerospace environment is much regulated in that every maintenance task has to respect very detailed process that ensures safety of flight. To achieve this goal, the maintenance process is tied to very stringent rules, which have been defined by regulation authorities. Maintenance is split into different categories according to time and required facilities (line maintenance, scheduled maintenance, or checks) or split by components (structure, components, powerplants). A lot of literature is available from various resources in the field of maintenance management. [Dekker, and Scarf, 1998] have presented various classification of maintenance optimization models by analyzing (112) papers. In addition, prior to airline deregulation in (1978), airlines performed most of their own maintenance; however, since that time the practice of outsourcing maintenance has become widespread. Nowadays, it is common for airlines to perform line and light maintenance in-house to preserve flexibility in responding to simple maintenance needs and to outsource heavy maintenance and overhauls that require more specialized and costly equipment and training. Various approaches for measuring maintenance performance have also been reviewed [Tsang et al., 1999]. Therefore, the concepts and functions of aircraft maintenance covering both the in-house maintenance and the outsourced maintenance, and the structure of engineering organization will all be discussed below in detail.

3.2.1 The Concepts and Functions of Aircraft Maintenance

There are many types of maintenance, such as Preventive Maintenance, Predictive Maintenance, Proactive Maintenance, Corrective Maintenance, Condition Based Maintenance, Reliability Centered Maintenance, and others. Maintenance is defined by airline's Technical Policies and Procedures Manual (TPPM) as "those actions required for restoring or maintaining an item in a serviceable condition, including servicing, repair, modification, overhaul, inspection, and determination of condition". John Moubray, an industrial consultant in the U.K in his book [Moubray J., 1997], defines maintenance as, maintenance is "ensuring that physical assets continue to do what their users want them to do". This definition is really rather wide open. In the Federal Aviation Regulations (FAR), part 1, maintenance is defined as "inspection, overhaul, repair, preservation, and replacement of parts". This describes what maintenance people do but it is not a definitive description of what maintenance is intended to accomplish. From the literature, it was found that there were many different definitions to the term maintenance looking at it in different angles. One of the more agreed definition has been written by Harry Kinnison in his Aviation Maintenance Management book, [Kinnison, 2004], that says "maintenance is the process of ensuring that a system continually performs its intended function at its designed level of reliability and safety".

On the other hand, to allow in-service failures to occur without adversely affecting safety and operation, a reliability program is usually employed for those components or systems whose failure rates are not predictable, and for those that have no scheduling maintenance tasks. The aviation industry is the most heavily regulated of all the transportation modes. In the aviation industry, there is a considerable amount of regulation, from the design of the vehicles through the manufacturing efforts to the operation and maintenance of the vehicles. Especially in maintenance, this is done to ensure that there is a stringent maintenance policies and procedures in place in order to take account for any system coming malfunction when the vehicles are on the sky. To this end, and under the Federal Aviation Administration (FAA), an air carrier or operator is responsible for all maintenance and alteration on that airline's aircraft. Also, the airline must have operations specifications for each model aircraft flown and must adhere to the FAA approved maintenance programs. The nature of maintenance is that it should be proactive, and should be based on providing resources to ensure that long term solutions are implemented.

3.2.2 In-House Maintenance

Aircraft maintenance encompasses a broad set of activities that must be performed so that an aircraft remains in a condition of airworthiness. These activities are either done in-house by the airline or military unit itself or outsourced to commonly refer to as maintenance, repair, and overhaul organizations. The activities include a complex blend of preventive scheduled and unscheduled work, as well as major refurbishments that return aircrafts and aircraft subsystems as closely as possible to their original condition. The management of the whole fleet of aircraft maintenance either done in-house or outsourced is a complex task, comprising technical, financial, operations and administrative functions. Consequently, such organizations need corresponding skills and resources. These skills and resources have to meet the following in-house functions of maintenance and engineering management:

- **Manage configuration of fleet maintenance:** the fleet of airlines/military is composed of aircraft from different manufacturers. Each configuration of this aircraft is unique, according to its type, and its age.

- **Manage schedule maintenance tasks:** according to airlines/military needs and operations requirements. The maintenance needs can differ, for example seasonal airlines will prefer to perform their maintenance during slack season, while airlines with regular flights will try to smoother the maintenance of their fleet during the year to maintain an acceptable level of aircraft flying.
- **Manage unscheduled events (trouble shooting + maintenance tasks):** when aircraft encounters some failures during its flight, such cases upset the maintenance planning and could divert the maintenance to be re-scheduled either before or later than the forecasted planned servicing.
- **The management of resources, facilities, and parts on a multi-site configuration:** airlines fly aircraft on a network routes, and maintenance may be needed at each node of the network. This will involve the management of different components at each airport and will include the management of many facilities such as hangers, shops or offices, spare parts, maintenance workers, and many other things.
- **Manage stocks and logistics**
- **Manage Partners and third party vs. in-house tasks:** most aircraft maintenance organizations out-source some other parts repair to other agencies.
- **Monitor performance (operational reliability, maintenance and engineering costs)**.

3.2.3 Outsourced Maintenance

While some airlines continue to perform major maintenance tasks in-house, the third-party outsourcing maintenance industry is growing. Contracting maintenance is especially attractive to smaller startup airlines, for which keeping a fully-equipped, fully-staffed maintenance department is often inefficient or even infeasible. Moreover, there is a growing trend within the airline industry is to outsource maintenance tasks to vendors who, through economies of scale and gains achieved through specialization in fleet types and maintenance procedures, can benefit in cost and expertise. The global outsourcing market is estimated to be worth between $25 billion [Gallacher, 1999] and $30 billion a year [Phillips, 1999]. Inventory in the airline industry's supply chain is valued in excess of $50 billion [Ebbs, 1997]. Maintenance and spares together are often viewed as potential areas for cost-savings for airlines, as repair stations offering to efficiently manage maintenance and spares needs. Therefore, outsourcing is an attractive option either for airlines or military for a number of reasons. For example, an operator may not have an efficient number of aircraft in a particular fleet type to justify the expense of trained personnel, facilities, tooling and test equipment required to perform such maintenance internally. On the other hand, an outside maintenance provider will have many contracts and a larger density of work to carry out such tasks at a lower cost to the operator. The reasons for outsourcing can be summarized as stated in [Office of Aviation Research, 2003], as:

- ⇒ Outsource maintenance requirements in excess of baseline capacity.
- ⇒ Outsource maintenance for specific A/C type, e.g, Outsource maintenance for aircraft that constitutes a small of the airlines fleet.
- ⇒ Outsource maintenance for a specific maintenance function, e.g. engine overhaul.

However, airlines or military units are responsible for operating their aircraft safely and must ensure that any maintenance work contracted out is performed according to the carrier's policies, procedures, and requirements. The FAA and CAA are responsible for certifying airlines or repair stations operations and then performing periodic inspections to ensure continued compliance with safety regulations. This has been reflected by the following new requirements for repair stations as cited in [O'Brien Bill (http://www.faa.gov/avr/afs/news/archive/october/145.htm)]**:**

- ⇒ Sets up some new definitions for accountable manager, article, directly in charge, and line maintenance.
- ⇒ Requires a new repair station manual to be developed that explains how the repair station operates and its procedures to ensure the article worked on is properly approved for return to service.
- ⇒ Requires a new quality control manual that is similar to the currently required inspection procedures manual.
- ⇒ Allows for satellite repair stations as long as the satellite repair station is in the same country as the repair station that has managerial control over the satellite repair station.
- ⇒ Allows limited-rating repair stations the option to develop a capability list that identifies articles by make and model that the repair station can approve for return to service. These articles must be listed on the repair station’s operation specifications.
- ⇒ Sets contract maintenance requirements (outside work), including work performed by a non-certificated person.
- ⇒ Eliminates the limited rating for manufacturers.
- ⇒ Rewrite the housing requirement for an airframe rating to require permanent housing that encloses the largest type and model of aircraft listed on its operations specifications.
- ⇒ Training programs must be approved by the FAA and in place in (2) years.

3.2.4 The Structure for an Engineering Organization

The structure for an effective aircraft maintenance and engineering organization currently varies with the size and type of organization. It may also vary with the management philosophy of the company. However, one thing must be kept in mind that the organizational structure must allow the company to meet its goals and objectives, and that each unit within the company must be endowed with sufficient personnel and authority to carry out those objectives and meet those goals [Kinnison, 2004]. The basic organizational for a mid-sized airline is shown in figure (3.1).

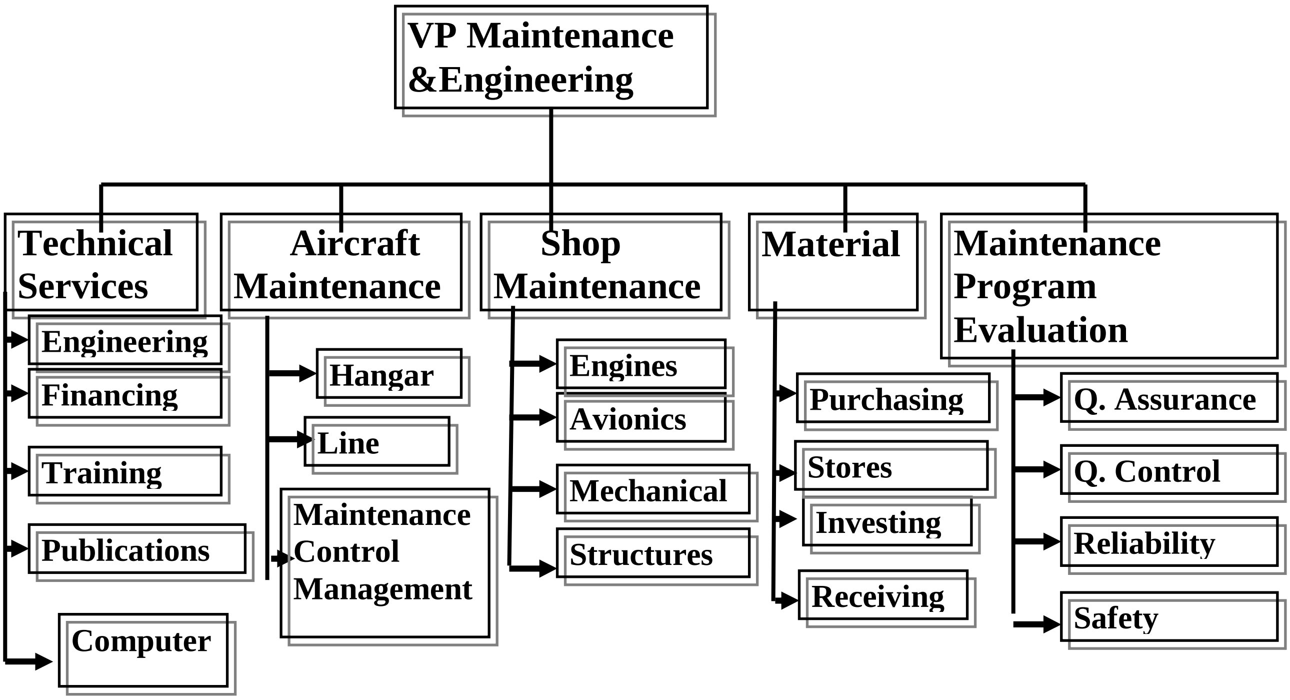


Figure 3.1: A Typical Maintenance & Engineering Organization

Source: [Kinnison, 2004].

There are three basic concepts underlying this structure; two of which come from traditional management thinking. These are the concepts of ***span of control***, and the ***grouping of similar functions***. The third concept is some-what unique to aviation: the ***separating of production activities*** (maintenance and engineering) from the oversight functions of inspection, control, and monitoring quality assurance, quality control, reliability, and safety. The span of control concept states that a supervisor or manager can effectively supervise or control three to seven people [Kinnison, 2004]. Any less than three would be infective use of time and manpower, and more than seven would spread the boss too thin. In the organizational structure as stated previously in figure (3.1) above, this concept was widely applied. For example the Vice President for maintenance and engineering supervises five directors. Each director has the necessary number of managers under him/her to carry out the prescribed functions of the directorate. By limiting the number of people that a manager has to supervise, the organization's work is divided into pieces that are more easily managed without losing the people-to-people contact that is so necessary for a happy and efficient workforce. At lower levels of the organization, where the actual maintenance work is performed by workers with many different skills, the span of control is usually not so narrow. A line manager or maintenance supervisor may have as many as (20) or (30) of these specialists to supervise. But at the upper management levels, it is better that it's kept as a span of control at the lower number. This is not to say that a wider span cannot be utilized, however, all management activities must be organized to work with the available resources and within its management's capabilities and philosophy.

The second basic philosophy of an organizational structure is the grouping of similar functions under one director, manager, or supervisor. This covers all maintenance activities (line, hangar, and Maintenance Control).

3.3 Human Factors in Aircraft Maintenance

A sound aircraft inspection and maintenance system is important in order to provide the public with a safe, reliable air transportation system [FAA, 1991]. Such system is complex with many interrelated human and machine components. Under the auspices of the National Plan for Aviation Human Factors, the FAA has recognized the importance of the role of the human in aircraft safety, focusing research on aircraft inspector and aircraft maintenance technician [FAA, 1991], [FAA, 1993]. The classic term "pilot error" or "human error" is attributed to accidents or incidents over 75% of the time; however, a study conducted in the United States found that 18% of all accidents indicate maintenance factors as a contributing agent [Phillips, 1994]. As a result of such incidents the public has become more aware of the importance of aircraft maintenance as a safety issue, and both the civil aviation industry and its regulatory bodies have responded with programs to increase safety. Such programs have included hardware-based initiatives, such as the FAA Aging Aircraft Program, and human factors initiatives by the FAA and many international bodies, for example, by Transport Canada and the European JAA [(Anand K. Gramopadhye et al., 2000]. To this end, flight safety, health and safety at work, and the quality standards are important critical issues in any aircraft maintenance environment. The workplace environmental conditions can impact on the quality of work performance and worker fatigue. In aviation maintenance each day the workers are sometimes faced with sub-optimal work conditions which contribute to stress, pressures and fatigue. These conditions must be controlled. However, if they cannot be controlled then the working system must help the human to work in a manner that is safe, healthy, efficient, and effective. The quality management system in aircraft maintenance needs to be a closed-loop system where mistakes and failures will not be allowed to happen. This is why assessment in the quality management in aircraft maintenance is essential.

The evaluation of the system should cover all aspects of maintenance including safety management and risk awareness issues. Also, it should further include organizational issues, work site conditions, and human factors in maintenance. Human factors in the aircraft maintenance approach are considered as the centre of the maintenance system. In addition, the following actions have to be considered as essential elements in an aircraft engineering working environment in order to positively ensure that all the activities are safe for the human being; the actions are:

- ⇒ Risk assessment
- ⇒ Safe systems of work (Maintenance Procedures)
- ⇒ Wearing Personal Protective Equipment
- ⇒ Safe Working at Height Rules and Regulations
- ⇒ Electricity safety precautions
- ⇒ Having first aid at work
- ⇒ Fire precautions
- ⇒ Hearing conservation
- ⇒ Safety precautions on radiation hazards.
- ⇒ Having a proper reporting accident system
- ⇒ Safety Signs

Further, taking the human factors into consideration, there is a lot of pressure, stress, fatigue, and other working and environmental conditions that occur between the time the aircraft goes for inspection and repair to the time when the aircraft is made safe and ready for flight. A flow-chart of the maintenance and inspection process as presented in figure (3.2) [Anand K. Gramopadhye et al., 2000] is needed in order to simplify such a complicated task and reduce the possibility of missing any task.

Inspection Flow Chart Maintenance Flow Chart

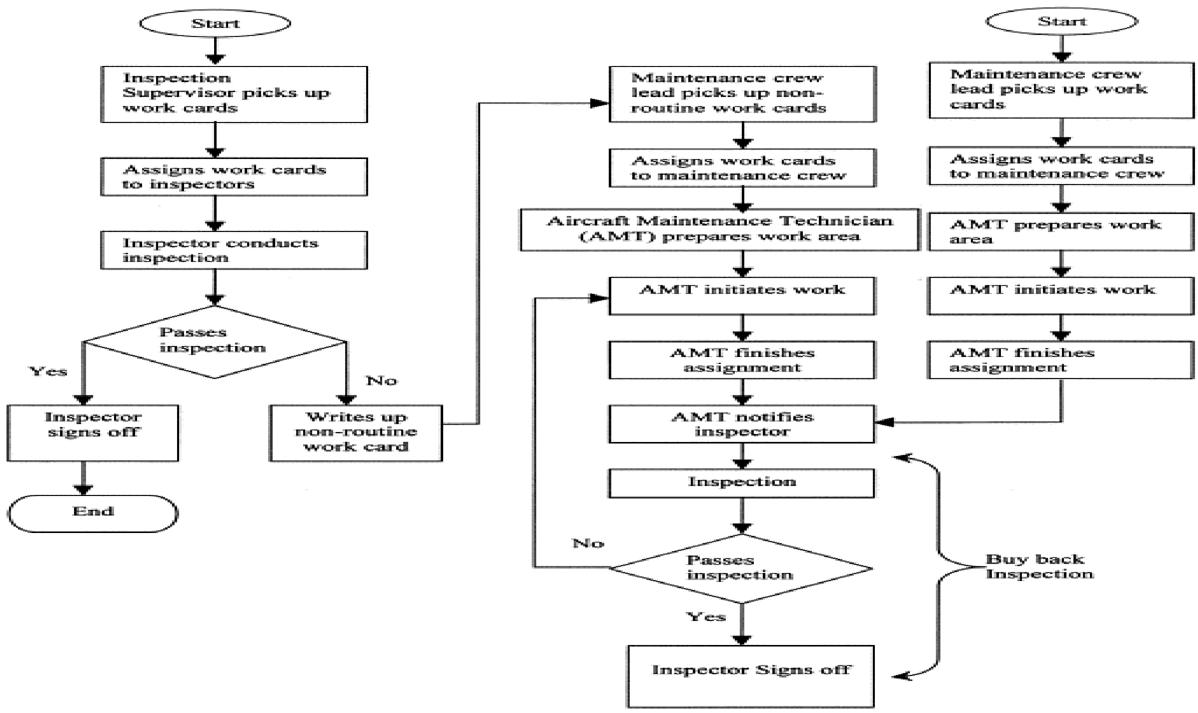


Figure 3.2: Aircraft Maintenance Process Flow-chart
Source: [Anand K. Gramopadhye et al., 2000]

Human factors in aviation have traditionally centered on aircrew and air traffic control errors, but the increasing numbers of maintenance and inspection errors have seen the rise of human factors research and the intervention in this arena. In this regard, various human factors studies in aircraft maintenance-related issues have been initiated by agencies such as the FAA and NASA, by aircraft manufacturers, and by aircraft maintenance industry, examples of these initiatives are: the National Aging Aircraft Research Plan, the "Safer Skies" initiative, the White House Panel on Aviation Safety, and NASA's aircraft maintenance program. The objective of all of these is to identify research issues and to promote and conduct both basic and applied research related to human factors in aircraft maintenance.

3.4 Quality Management in Aircraft Maintenance

Quality Management is a normal work planning and management control, aiming at using time and manpower in the most efficient manner. The setup and the quality management organizational chart will vary depending on the size of the organization, and its management philosophy. In figure (3.3) a general layout of a quality management organizational chart is presented. Nevertheless, the management must be able to produce objective evidence of a planned and controlled approach to the achievement of quality. Objective evidence is obtained by carrying out quality assessments and audits throughout the organization. The Quality Management System in an aviation maintenance workplace must be subjected to senior management review and internal quality auditing from time to time. Once assessments/audits are done, then it is the responsibility of that section/department to effectively carry out the corrective actions.

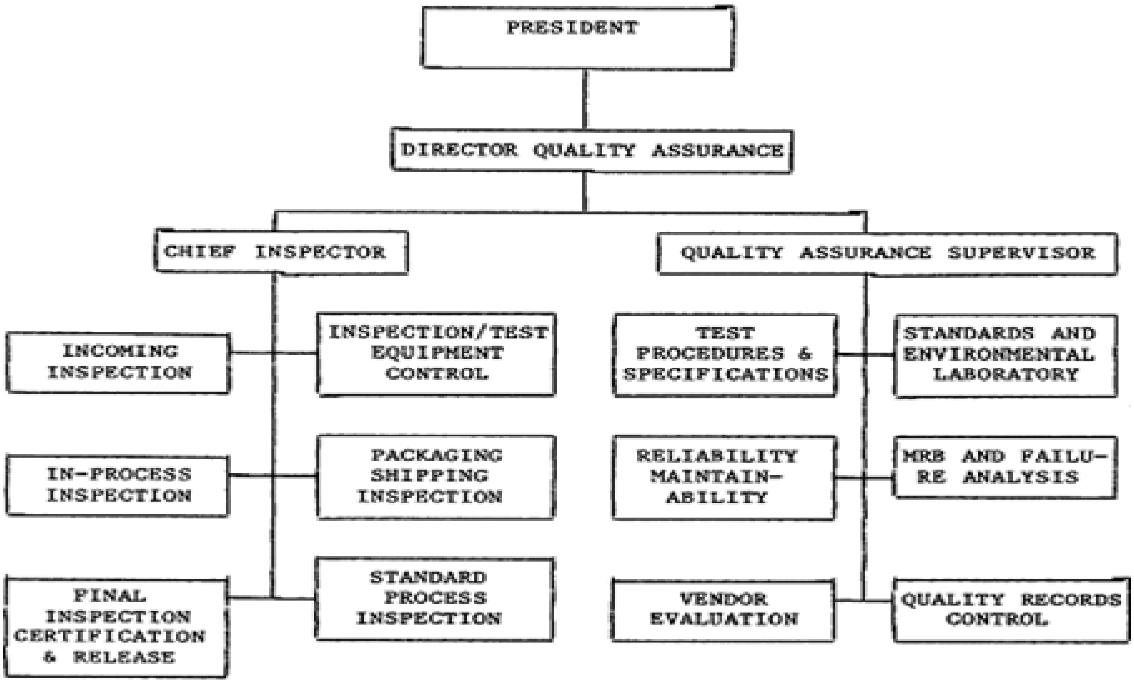


Figure 3.3: A General Quality Management Organizational Chart

There is another method of verifying the effectiveness of the quality system or identifying where corrective action is required, this tool is called Quality Audit. JAR-OPS define an audit as: "a systematic and independent comparison of the way in which an operation is being conducted against the way in which the published operational procedures say it should be conducted". An audit aims to provide information from a detailed examination of all aspects of system quality. The quality audit is constructive in nature, and conducted with the co-operation of those being audited and without prejudice to the primary task. If any non-conformity found from the audit, the quality assurance program should then ensure the corrective actions are taken in response of the finding.

In an aircraft maintenance organization, "quality" relates to the way that people carry out their tasks, and can be related to the foundation for continually improving performance. It involves establishing a culture to embrace all the activities which enable the teams to give complete customer satisfaction at the most economical cost. For the aircraft maintenance organization this entails providing a quality maintained airplanes on time schedule, and with a least reasonable price to airlines and military. Table (3.1) shows the process of the aircraft from being built until it goes for servicing and then used to carry passengers or carry out an operational mission.

The A/C manufacturer provides the A/C
⇩
The Airline(s)/Military flies the A/C
⇩
The Airline(s)/Military carry out the maintenance or issues the A/C to a maintenance provider
⇩
The maintenance organization buys spare parts and tools from the supplier
⇩
The maintenance organization repairs the A/C
⇩
The A/C is given back to the Airline/Military which is used to carry passengers or carry out an operational mission

Table 3.1: The Aircraft Process

From the above a customer chain can be identified; organizations who maintain aircraft are supplied with tools, spare parts, and with all the ground support equipment to meet their maintenance task, they in turn supply serviceable aircraft to the Airline(s)/Military to meet their tasks on time schedule. Moreover, since quality requires a partnership between customer and supplier, it is important that an aircraft maintenance organization cares about its customers by determining and agreeing their true need and not assume that the maintenance organization knows their needs better than they do.

3.4.1 Aircraft Maintenance and Quality Assessment

Effective operation of a quality management system for aircraft maintenance builds upon safety, and risk-based decision making concepts. Some of the principal tools for quality and safety management in maintenance are:

A. Inspection. This is the simplest form of quality and safety oversight which provides valuable insights into quality and safety performance. It is carried out informally by "walk arounds" of all areas of the organization. The focus of inspections should be on the quality of the “end product or service”.

B. Surveys. Surveys can provide management with an indication of the levels of quality, safety, and efficiency within its organization. They are usually independent of routine inspections by company management. Surveys can also provide important diagnostic information about daily activities.

C. Quality Assurance. As was discussed previously, a quality assurance system defines and establishes an organization’s quality policy and objectives. Moreover, it identifies problems and improves procedures in order to meet corporate objectives.

D. Safety Audits. Safety auditing provides a means for systematically assessing how well the organization is meeting its safety objectives.

In order to assess maintenance, suitable measures have to be in place. These measures should be defined during the maintenance strategy setting process. Different types of measures can be selected, those that can be related to equipment user results, or those related to maintenance effectiveness. Both of the two measures are important to gauge the effectiveness and efficiency of maintenance and maintenance support activities. User-related performance factors can be expressed in terms of:

- ⇒ Production capacity
- ⇒ Availability of equipment or production
- ⇒ Downtime or outages
- ⇒ Safety and environmental performance
- ⇒ Regulatory compliance
- ⇒ Operating cost
- ⇒ Maintenance cost
- ⇒ Corporate profit
- ⇒ Product quality

Whereas the purpose of maintenance related measurement is to measure the effectiveness of maintenance and maintenance support. Measurements related to specific equipment or groups of similar equipment may include:

- ⇒ Availability, reliability and maintainability;
- ⇒ Downtime or outage time;
- ⇒ Mean time between failures;
- ⇒ Mean time between repairs;
- ⇒ Planned and unplanned maintenance cost

In general, there exist many types of quality management assessment, but none is specific to aircraft maintenance organizations. Moreover, there are many types of audits; for example, in an aircraft maintenance organization in the Air Force; there exist three types of audits; two of which are at station/unit level. These are the Routine Audit and the Task Audit. The third one is normally carried out by the Headquarters and known as the Command Audit. A routine audit is carried out periodically at intervals determined by the senior engineering and maintenance officer in the station/unit. A routine audit examines the management system by comparing current practices with the written requirement and can be applied to all activities within the work area. A task audit is a special type of audit which may be applied to resolve a particular technical, or management problem. This is done at station/unit level and normally will be a directive from the senior engineering and maintenance officer, and is usually initiated after a serious quality failure or customer complaint. The Command Audit is a tool to assist the Director of Engineering and Maintenance in an Air Force organization, or Vice-President for Engineering and Maintenance in civil engineering maintenance organization in verifying the effectiveness of the quality system within the audited department/section. The command audit either in civil or military, has two main function; firstly; assessing the station/unit, or department/section management system, and secondly, validating the organization been audited internal quality assurance system.

In the civil aviation there are two classes of audits. The first one is the "combined" (large and small), which is a complete review of a company's operation and maintenance systems. The second audit is the "specialty audit"; this is the most common audit, focusing on one type of organization under the branch's functional area. The specialty audit will encompass most organizational elements appropriate to the scope of approval.

3.4.2 Importance of Quality Management in Aircraft Maintenance

Aircraft maintenance is already a significant business activity. Time to delivery and higher standards of service are business imperatives in aerospace maintenance. The implications of a delay in maintenance are only too obvious and very noticeable. A lower quality of service is unacceptable as it compromises the safety of air travel. The current deregulation moves in the airline industry have further intensified competition, squeezing less cost-effective operators out of the industry. As a result, many airlines now have to keep operating costs down. This has a knock on effect on maintenance organizations, as the measure of how efficient an aerospace maintenance and repair service is the repair turntime. This is defined as the duration taken to repair or overhaul aircraft components and the time when returned as useable to the customer. A longer turntime constrains airlines to either maintain a higher stock level of spares or force the Aircraft to remain grounded if no inventory is available. Hence, a repair company's maintenance and repair turntime becomes a crucial deciding factor in the airline's repair decision process.

The three criteria that an airline customer looks for in a maintenance provider are: quality of repair, short turntime, and competitive price. An aerospace repair facility that is able to provide high quality engineering service with a short turntime, and at competitive prices is highly sought after. A search of the relevant literature shows that quality management is already practiced by some aerospace companies in the USA and Europe. For example, General Electric [Stanley, W K., 1994], Pratt and Whiteny [Stanley W K., 1995], and Allied Signal [Shah S., and Wokeli. G., 1991]. For those companies to install quality management is motivated by a realization that the company's survival is at stake. Quality management has been implemented primarily to change the existing culture and to improve their competitive advantage [Okland J S., 1993], [Williams R J., 1994]. Some tangible benefits arising from this implementation include a shorter manufacturing cycle time, lower inventory, lower reject rate and increased customer satisfaction.

As can be seen from the literature above that everyone at the workplace is involved somehow in the quality management system, and that everyone owns the system. Therefore, everyone at the workplace should respond to the quality challenge by thinking quality in everything that he does. Getting the job correct first time to the required standards should be a prime objective of all personnel in an organization, especially in an aircraft engineering maintenance as there is no space for mistakes to be allowed to happen, as it costs lives and money.

3.4.3 Quality System Documentation

A quality system cannot function effectively unless everybody in the organization knows what it is. Moreover, the quality system documentation is part of the organization's management system documentation. Therefore, in order for the organization to function properly everything needs to be documented and that everyone within the organization should have a common understating of the system needs. The following are some essential documentation of having at the workplace:

Quality plan: This is a document setting out the specific quality practices resources, and sequences of activities relevant to a particular product, service, contract, or project [Ashford, 1989].

Quality Manual: BS 5750, part 0.2 defines the purpose of a quality manual as; "to provide an adequate description of the quality management system while serving as a permanent reference in the implementation and maintenance of that system". The quality manual specifies the Quality Management System in an organization and demonstrates the organization capability in providing that service or product in an efficient and cost effective manner. It also contains the standards upon which the quality management system operates. These standards are based on the ISO standards series.

Quality Audit and Corrective Action System: The quality audit is a system to determine whether the quality is being complied with, and is effective and economical. Whereas the corrective action system ensures that corrective actions are taken after the quality audit to correct the quality of a service or product. For effectiveness it is essential that the root causes of a problem is identified, and that corrective actions are targeted specially at the root cause and not just the symptoms.

Any organization that provides a service, manufactures, or repairs a product could not function without some form of documentation. Without the evidence provided by documentation, quality control, quality assurance, and quality management could not exist. Records are needed to demonstrate the effective operation of the quality control system, and to provide objective evidence of quality to customers. Example of these records is: inspection reports, specification test results, training records and qualification certificates, audit reports, calibration records, job cards and work sheets.

3.5 Military Aircraft Maintenance and Quality

The aim of an aircraft maintenance branch in any military organization is to provide that unit with the engineering support needed to meet its defense objectives to make maximum use of the resources at its disposal in order to have the aircrafts ready when needed. A well managed maintenance activity optimizes equipment availability and minimizes downtime at a reasonable cost. On the other hand, a poorly functioning maintenance department will misuse limited resources and over-utilize operational assets in achieving command objectives. If the maintenance activity of a military unit is not functioning properly, the unit will experience difficulties in functioning at its full operational capacity. Readiness in the military terms implies that an aircraft is able to fly safely and that all systems needed to complete the assigned mission are operating. Achieving and maintaining readiness is the most important function of a military flying maintenance department. However, measuring readiness is much more difficult than defining it.

The maintenance organization of a tactical Air Force has operated under the concept of centralized control and authority due to its combat operations requirement and secretes. This concept has worked well in the past considering the relatively stable environment in which was operated. In today's rapidly changing environment, this might not be the most efficient way to continue operating an air force aircraft maintenance organization. In figure (3.4), a combat oriented organizational chart is shown.

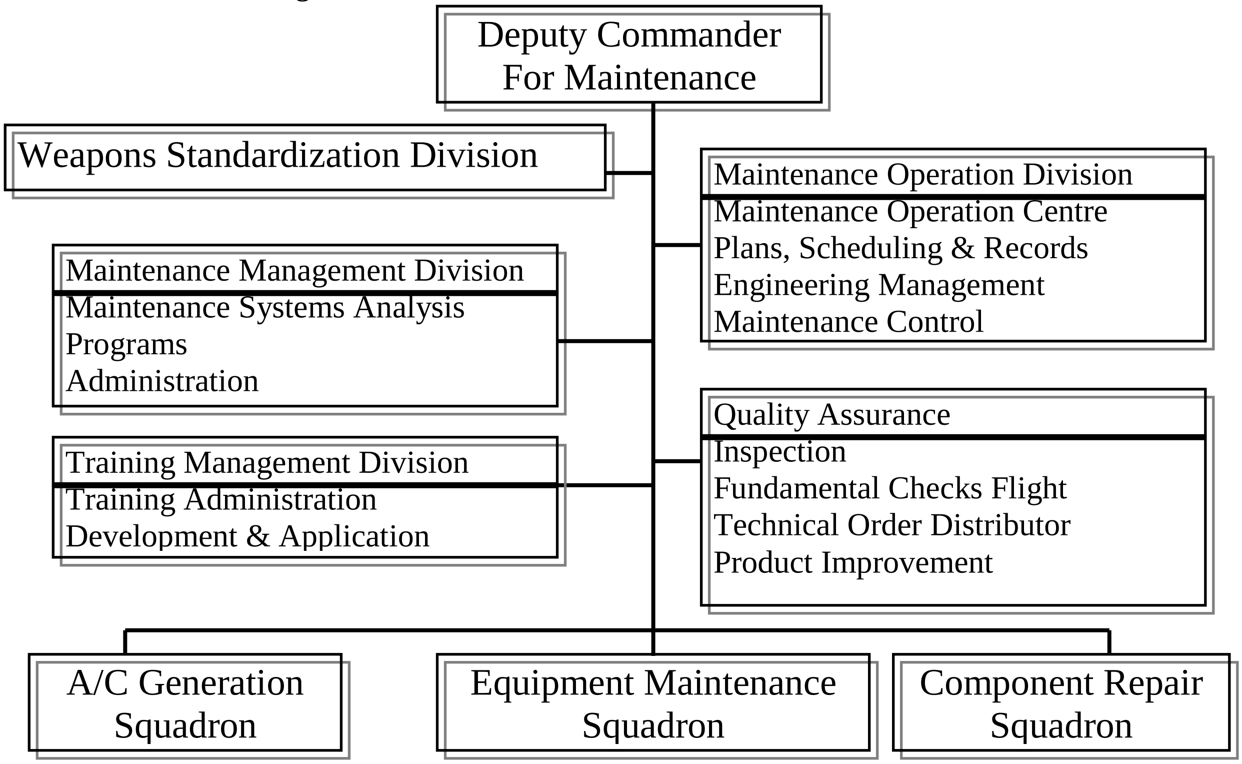


Figure 3.4.: A Combat Oriented Organizational Chart
Source: [Rudolph Ventresca, 1991]

A military example of an aircraft maintenance organization will be briefly considered. This will cover looking at the "Hawk Aircraft Maintenance". This includes second and third line maintenance. Part of the Hawk Aircraft Maintenance is the "Hawk Major Servicing" which entails an in-depth depot level maintenance. This will be discussed below.

3.5.1 Hawk Aircraft Maintenance and Quality

The "Hawk Aircraft Maintenance Organization" is a military entity. Its mission is to carry out an in depth servicing for the Hawk Aircraft in order to have aircraft availability for training fighter pilots. This covers a range of servicing types as presented in table (3.2).

Type of Servicing	Durability (Flying Hours)	Time taken for the servicing (Weeks/Months)
Primary	125 hrs	2 weeks
Primary star	250 hrs	1 month
Minor	500 hrs	6 weeks
Minor star	1000 hrs	16 weeks
Major	2000 hrs	6 months

Table 3.2: Hawk Aircraft Servicing

The highest level maintenance is the major servicing which is carried out every (2000) flying hours or (14) years which comes first. Currently it takes (6) months to do this task; during which the aircraft stays on ground all this time. This entails deep maintenance where many components get removed, serviced, and then returned to the aircraft. Due to operational requirement in order to have more aircraft available for flying to train more fighter pilots, the visibility for time reduction of the above stated servicing from the current (6) months to (4) month was considered. This will entail a need for organizational change in various aspects. It will require a major turnround in the "Hawk Aircraft Maintenance Organization" performance and its ability to deliver a well maintained aircraft within the new time scale, which is (4) months instead of (6) months. This new requirement for organization transformation has to have some quality criteria basis in order to have an organization committed to excellence through process management, customer focus and employees involvement. Some sort of quality planning tool have to be considered to help the "Hawk Aircraft Maintenance Organization" to meet its customer needs (military pilots/government) for Major Servicing time reduction (from 6 months to 4 months) due to operational requirement in having more trained fighter pilots. This planning tool will be discussed in chapter five of this thesis.

3.6 Risk Awareness in an Aircraft Maintenance

Quality affects everyone associated with providing a service or product. Moreover, safety at work is everyone's business. Taking this in mind, then the work of everyone in the organization influences the quality of the service/product that is given to the customers. Therefore, the delivery of a quality service/product is essential. The primary objectives of Risk awareness in an organization are to secure the safety and welfare of everyone at work, (employers, employees, contractors, and visitors). There are many risks that exist in an aircraft operating environment, some are very dangerous that certain general safety precautions have to be taken in order to prevent any death or injury to personnel, these risks such as: electricity, fire, noise, radiation, working at height, dealing with Highly Flammable Liquids and Substances Hazardous to Health, Non Destructive Testing, and all sorts of bad weather conditions (rain, snow, sun, wind, thunder and lightening, etc), especially when working in the line.

Achieving Risk awareness in an aircraft working environment is by taking a professional and responsible attitude towards the safety at work, using the skills, knowledge and experience to ensure the safety of ourselves, our work colleagues and everyone in the working environment. By preventing injuries and accidents at work, the organization can save time and money. Areas that are covered by Risk awareness in an aircraft maintenance environment to ensure safety at work are stated below:

- The Management
- The Workplace
- Control of Substances Hazardous to Health
- Provision and Use of Work Equipment
- Computers
- Fire
- Electricity
- Noise
- Using Highly Flammable Liquids & Petroleum, Lubricants, and Oils
- Construction
- Radiation

Risk awareness involves taking action to prevent incidents which could harm people in the workplace or damage equipment within the organization. Professional attitude is important because human factors are one of the major causes of accidents and incidents. Figure (3.5) shows an aircraft maintenance working environment.

Figure 3.5: Aircraft Maintenance Working Environment

Due to the nature of work in an aviation maintenance environment, there is always an element of risk in what is being done in such organization. Risk assessments, should be carried out on all significant risks in the workplace. Assessments should be made available to all employees, at the workplace. Also, any defect in the design or condition of buildings or equipment which may consider presenting a hazard to safety should be reported. Therefore, risk awareness at work means using the rules and regulations within the organization to ensure the safety and welfare of all personnel at work. As the likelihood of anyone being seriously injured through a work related activity depends on the Safety Awareness of everyone at work. The golden rule to be remembered is that risk assessments prevent panic and avoid accidents and injury. And it is the intention of risk awareness to eliminate, or reduce to an absolute minimum, the risk at work as far as possible.

3.7 Safety Culture in an Aircraft Maintenance

Workplace environmental conditions can impact the quality of work performance. This can be seen every day in aviation maintenance as workers are sometimes faced with sub-optimal work conditions which contribute to fatigue, and stress. When these conditions can be controlled they must be. However, if such conditions cannot be controlled then the working system must be made in a way that helps the human to work in a manner that is safe, healthy, efficient, and effective.

On a study carried out by University of Illinois on safety culture in a regional airline says that "as recently as 1998 empirical efforts to study the concept of safety culture in the complex, high risk aviation industry have remained unsystematic, fragmented, and in particular underspecified in theoretical terms" [Pidgeon quoted in von Thaden et al., 2003]. Safety culture is defined by [Zhang et al., quoted in von Thaden et al., 2003] as "a proactive function

of the whole infrastructure and of priorities, and alternatively as an enduring characteristics of an organization that is reflected in its consistent way of dealing with critical safety issues".
Safety culture is both attitudinal and structural, relating to individuals and organizations. In effective safety cultures, there are clear reporting lines, clearly defined duties, and well understood procedures, so that everyone knows what to do, and how to do it. On the other hand, a poor safety culture in an aircraft maintenance organization can lead to unsafe work practices not being corrected, as personnel use to adapt to working in such conditions without noticing the unsafe practices that they do. Management's success in creating a positive safety culture in aircraft maintenance departments will derive in large to how the quality management system is implemented in such organizations.

3.8 Case Studies - Examples of Aircraft Maintenance Organizations

Here, the author will consider looking at two examples; the first one will discuss an example of an airline maintenance organization, whereas the second one will deal with a military example of an aircraft maintenance entity.

3.8.1 Case Study 1 - Aircraft Maintenance - KLM Royal Dutch Airline

3.8.1.1 Introduction to the Case Study

KLM Royal Dutch Airline Engineering and Maintenance has been chosen as an airline case study because KLM has been in service sine (1919)***;*** just a bout the world's oldest airline. This airline not only carries out its own maintenance (in-house maintenance) but acts as a maintenance provider for other airlines. It also has merged with Air France industries creating one of the world's leading maintenance providers, carrying responsibility for the full fleet of both parent airlines (over 550 aircraft) and supporting more than (150) major international airlines. In addition, KLM Engineering and Maintenance is a fully accredited JAR/FAR145 organization, holding certificates from many countries throughout the world. Engineering services provided by KLM Engineering and Maintenance are available for a variety of products; aircraft types and customers.

3.8.1.2 Line Maintenance

KLM Engineering and Maintenance is responsible for the transit maintenance of a large group of international airlines in (50) stations around the world with a wide range of capabilities [www.klm.com]. This includes platform checks and other daily checks. In addition, customized packages such as A-checks or more extensive maintenance requirements can still be provided on request. For example KLM line maintenance capability at its main hub at Amsterdam Schiphol airport can provide the following tasks:

- ⇒ Technical Handling
- ⇒ Assistance
- ⇒ Pre-flight Services
- ⇒ Night-stop Services
- ⇒ Weekly checks
- ⇒ A-checks
- ⇒ H-checks

- ⇒ Modification and damage repair
- ⇒ Cabin Maintenance
- ⇒ Aircraft On Ground support
- ⇒ Cleaning (exterior, interior as well as customized deep cleaning programs)

Whereas the KLM line maintenance international can cover what was mentioned above, plus other activities like; Aircraft on Ground support, De-icing, and In-flight Entertainment.

3.8.1.3 Maintenance, Repair and Overhaul

As a full-service Maintenance, Repair and Overhaul provider, KLM is involved in the day-to-day maintenance operations of many airlines. On-time delivery, careful progress reporting and flexibility are key factors in the hundreds of C and D checks that KLM carries out in cooperation with customers. Also, Based upon KLM Engineering and Maintenance's in-house engineering capability, KLM can provide to its customers special programs. Typical examples of some of these servicing activities and programs are [www.klm.com]:

- ⇒ Airframe heavy checks (C, D, and intermediate checks)
- ⇒ Component maintenance
- ⇒ Major airframe repairs and modification
- ⇒ Avionics upgrades
- ⇒ Bulkhead repairs
- ⇒ Cockpit upgrades
- ⇒ Composite repairs
- ⇒ Fortified cockpit doors
- ⇒ Forward lower Cargo Doors AD 737
- ⇒ Fuel Quantity Indication modification 737
- ⇒ Pylon modifications 747
- ⇒ Rudder modification 737
- ⇒ Section 41 modification
- ⇒ Weight & Balance all aircraft

3.8.1.4 Engine Maintenance

KLM Engineering and Maintenance is also involved in engine maintenance and overhaul. Therefore as part of the KLM strategy in this domain and in trying to maximizing engine on wing time, the following has been done:

- ⇒ A facility has been constructed at Amsterdam Airport Schiphol increasing the capacity to (350) shop visits a year.
- ⇒ New product lines for CFM56-7 and CF6-80E1 maintenance are included in the engine shop, as well as extensive in-house repair capabilities for CF6 and CFM56-7 engines.

3.8.1.5 Component Maintenance

Being involved in the daily operations of its aircraft and many other airlines, KLM Engineering and Maintenance focus also on component management. In this regard KLM Components capabilities can be seen as presented in table (3.3).

	737 300-500	737 600-900*	747 200-400	DC10/MD11	757 / 767	Fokker 50/70/100
Avionics	•	•	•	•	•	•
Electronics	•	•	•	•	•	•
Hydraulics	•	•	•	•	•	•
Pneumatics	•	•	•	•	•	•
Fuel systems	•	•	•	•	•	•
Mechanics	•	•	•	•	•	•
Structures	•	•	•	-	•	•
Interiors	•	•	•	•	•	•
Wheels, Tires, Brakes	•	•	•	•	•	•
AOG support	•	•	•	•	•	•

Table 3.3: Components Management
Source: [www.klm.com]

3.8.1.6 KLM Merger with Air France

Air France and KLM agreed to merge in 2004 in order to create Europe's largest airline group via a holding company structure called Air France-KLM, with both of them remaining as a flag carriers. This led KLM Engineering and Maintenance and Air France Industries to merge together creating one of the world's leading maintenance providers, carrying responsibility for the full fleet of both parent airlines (over 550 aircraft) and supporting more than (150) major international airlines [**www.klm.com**]. This further led to the Creation of one of the largest worldwide Maintenance, Repair and Overhaul providers with:

- ❑ Full capabilities for both Airbus & Boeing product lines
- ❑ Scale & capacity to meet maintenance requirements of major airlines
- ❑ Strong Original Equipment Manufacturer relation/partnership
  - ➯ Airbus, Boeing, G.E., Thales, etc.
- ❑ Large customer base
  - ➯ 2002 – 03 third party turnover for Air France: €540m
  - ➯ 2002 – 03 third party turnover for KLM: €329m

3.8.1.7 Summary of Case Study

KLM Maintenance and Engineering is not only an in-house maintenance but it is counted as one of the major Maintenance, Repair and Overhaul provider servicing a variety of aircraft types, engine maintenance, line maintenance, and component maintenance. KLM Maintenance and Engineering with its merger with Air France Industries has given it the full capabilities to carry out a wide spectrum of aircraft maintenance, and tied its relations with Original Equipment Manufacturers and other agencies and suppliers. From what was said about KLM Maintenance and Engineering, safety of the maintenance and the human in such working environment should always be as first priority requirement.

3.8.2 Case Study 2 - Aircraft Maintenance - A Military Unit Example

This case study example is quoted from a Naval Postgraduate School, Monterey, California thesis report named "An analysis of the maintenance performance measurement system for LAMPS MK 111 Helicopter squadrons", [Keyes Richard, 1993].

3.8.2.1 Introduction to Case Study

The objective of the American Naval Aviation Maintenance Program is "to achieve and continually improve aviation material readiness and safety standards established by the Chief of Naval Operations, with optimum use of manpower, material, and funds." [OPNAVINST, 1989]. These standards include the repair of aeronautical equipment at a level that ensures the optimum use of available resources, the protection of weapon systems through an active corrosion control effort, the active use of the Planned Maintenance Program, and the collection and use of data to improve the performance of the maintenance personnel and the material condition of the equipment [OPNAVINST, 1989].

3.8.2.2 Performance Improvement Goals

The Naval Aviation Maintenance Program has listed several broad performance improvement goals in an effort to continuously improve the maintenance practiced by the fleet aviation units and meet the stated objectives. These goals are:

- ⇒ Increased readiness
- ⇒ Improved quality
- ⇒ Improved deployability
- ⇒ Improved sustainability
- ⇒ Reduced costs
- ⇒ Enhanced preparedness for mobilization, employability, and contingency operations
- ⇒ Enhanced supply availability
- ⇒ Improved morale and retention [OPNAVINST, 1989].

3.8.2.3 Performance Elements

The Naval Aviation Maintenance Program notes seven performance elements that are to be the focus of the performance improvement effort. These seven performance elements are Productivity, Effectiveness, Efficiency, Quality, Innovation, Quality of Work Life, and Budgetability. These performance elements are the foundation of the Naval Aviation Maintenance Program performance improvement effort. Each element focuses on a part of the maintenance process. The Naval Aviation Maintenance Program charges all maintenance personnel to actively pursue any opportunity to achieve gains in any of these areas.

3.8.2.4 Levels of Maintenance

Aviation maintenance within the Department of the Navy is broken into three distinct strata. The delineation is based on the type of maintenance conducted and the level of assembly, sub-assembly, or component that can be repaired by the activity.

a. Depot-Level Maintenance

Maintenance that is performed at naval aviation industrial establishments to ensure continued flying integrity of airframes and flight systems during subsequent operational service periods.

Depot-level maintenance is performed on material requiring major overhaul or rebuilding of parts, assemblies, subassemblies, and end items. It includes manufacturing arts, making modifications, testing, inspecting, sampling, and reclamation. Depot-level maintenance supports lower levels of maintenance by providing engineering assistance and performing maintenance that is beyond the capability of the lower level activities [OPNAVINST, 1989].

b. Intermediate-Level Maintenance

Intermediate-level maintenance is the responsibility of, and performed by, designated maintenance activities in support of using organizations. The Intermediate-level maintenance mission is to enhance and sustain the combat readiness and mission capability of supported activities by providing quality and timely material support at the nearest location with the lowest practical resource expenditure [OPNAVINST, 1989].

c. Organizational-Level Maintenance

0rganizational-level Maintenance is normally performed by an operating unit on a day-to-day basis in support of its own operations. The 0rganizational-level maintenance mission is to maintain assigned aircraft and aeronautical equipment in a full mission capable status while continually improving the local maintenance process [OPNAVINST, 1989].

3.8.2.5 Upkeep Maintenance

There are two fundamental types of maintenance performed within the naval aviation maintenance system: rework and upkeep. The maintenance department of an aviation squadron is restricted to upkeep maintenance. Upkeep maintenance is further differentiated by being either scheduled or unscheduled.

a. Scheduled Maintenance

Scheduled maintenance is described as the "periodic prescribed inspection/servicing of equipment, done on a calendar, mileage, or hours of operation basis." [OPNAVINST, NAMP, 1990]. Because this type of work is conducted on a periodic basis, scheduled maintenance is a fairly predictable factor in the planning process. In the LAMPS MK III community, there are two primary categories of scheduled maintenance conducted by the Organizational-level maintenance activity: phase and calendar inspections. Both of these inspections are designed to preserve the material condition of the aircraft and inspect certain items for wear. Phase inspections are conducted on a 150 flight hour interval. Phases are major repair actions that take two to four days to complete. Calendar inspections occur at a fixed time interval. Currently, there are (7), (14), (28), (56), (112), and (224) day inspections conducted on the SH-60B helicopter. The time periods for these inspections run concurrently. When the aircraft is deployed, the time period for these inspections is halved, with the exception of the 7-day inspection. Scheduled maintenance consists of two distinct phases. The first is the "look phase." In this phase, all the requirements for the completion of the inspection are performed, and any discrepancies or maintenance problems are documented. The second phase is the "fix phase" where the discrepancies discovered during the "look phase" are corrected.

b. Unscheduled Maintenance

Unscheduled maintenance is defined as "maintenance, other than the fix phase of scheduled maintenance, occurring during the interval between scheduled downtime maintenance periods" [OPNAVINST, NAMP, 1990]. In essence, unscheduled maintenance is the repair work required because of malfunctioning equipment. The inherent unpredictability of unscheduled maintenance often shapes the apportionment of the squadron's resources (man-hours and parts) to remedy the problem in a timely manner.

3.8.2.6 Organizational Maintenance Activity

The organizational level maintenance activity is the lowest level in the maintenance hierarchy. The maintenance performed is usually at the aircraft subsystem level. Rarely do 0rganizational-level technicians diagnose and repair the internal components of the equipment; instead, the component is removed and replaced. The objectives of all 0rganizational-level maintenance activities are:

- ⇒ Improved performance and training of personnel
- ⇒ Improved aircraft, equipment, and system readiness
- ⇒ Improved maintenance integrity and effectiveness for all material
- ⇒ Improved safety
- ⇒ Improved usage of manpower and material
- ⇒ Improved planning and scheduling of maintenance
- ⇒ Improved management and evaluation of work performance
- ⇒ Improved quality of the end product
- ⇒ Improved attainment and retention of combat readiness
- ⇒ Improved continuity when aircraft or personnel are transferred between commands. [OPNAVINST, 1989].

An example of a typical navy organizational maintenance department organization chart is illustrated in figure (3.6).

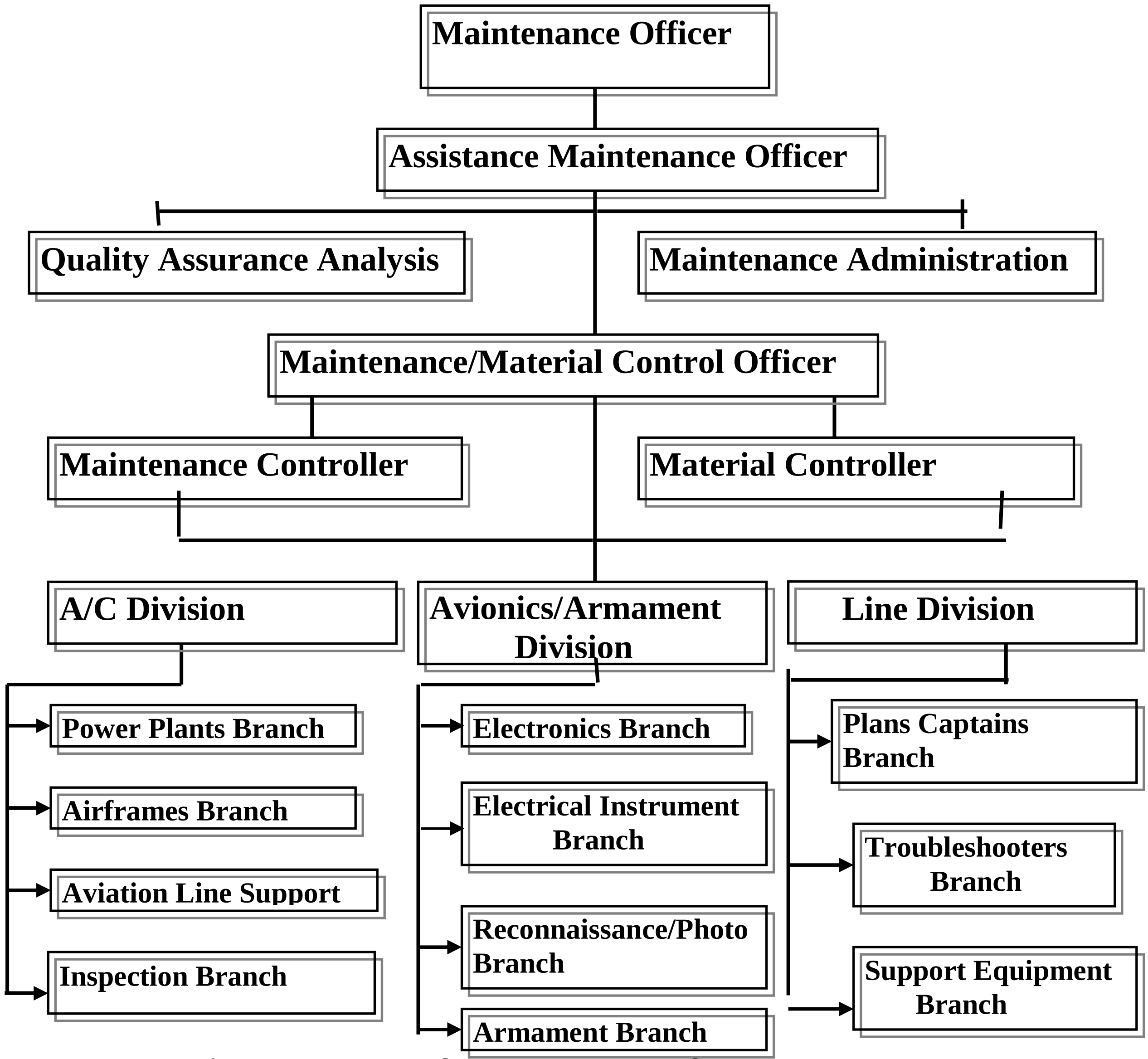


Figure 3.6: A Typical Navy Organizational Maintenance Department

Source: [Keyes Richard, 1993]

The Naval Aviation Maintenance Program is the foundation on which all aircraft maintenance is based. The program delineates the duties and responsibilities of all participants in the maintenance effort and provides detailed instructions for the documentation of maintenance actions. In addition, it stipulates specific reporting responsibilities and provides a basis for organizing the maintenance department in an aviation squadron. This highlights the need for having a well structured quality maintenance management to be in place.

3.9 Conclusion

An airplane has an economic life of about twenty five years in service. To remain in serviceable conditions all those years, regular checks and repairs are conducted at different intervals. This requires a management system to deal with. Moreover, the maintenance has to be encompassed with a quality management system. The quality system in aircraft maintenance organizations is a sub-system within the overall aircraft transportation management system. As quoted in [BS 5750, part 0] "the quality system should only be as comprehensive as needed to meet the quality objectives", also "a quality management system should be developed and implemented for the purpose of accomplishing the objectives set out in a company's quality polices". These two quotations make it clear that the first objectives in establishing a quality system should be to satisfy the internal needs of the organization and this should be addressed in a systematic way. Therefore, it is the management of the organization responsibilities to ensure that:

a. The standards and procedures at the workplace meet the quality requirement.

b. Explain the Quality Management System to everyone affected, and ensure that everyone understands what is involved.

c. Provide facilities and equipment as required, provided it can be shown to be cost effective.

d. Train staff in quality techniques relevant to their jobs.

The individual responsibilities in order to help the management in maintaining a quality management in the workplace are as follow:

a. From the individual detailed knowledge of his/her job, he/she can help the management improve and develop quality procedures.

b. The individual can help the management by understanding and applying the necessary requirements of the quality system.

c. To come forward with suggestions and ideas for improvements in any aspect of the organization work.

In summary the differences in organization design and structure between the two cases discussed; KLM (as an airline) and the military unit as follow:

- KLM organization is driven by safety and economic considerations, whereas the military organization is driven by safety and command considerations.
- Military organization is composed of layer of units with a more complex control hierarchy.
- KLM maintenance organization is also compatible with delivering maintenance services to other customers; it acts as a maintenance provider.
- There are few differences between the two entities in the physical maintenance procedures.
- There is clear difference between the two entities in the management of the maintenance activities.

In this chapter the integration of aircraft maintenance with the quality practices in this field were sighted. This provides a good infrastructure for the author to further investigate the airlines/military customer needs in order to translate these requirements to a Quality Function Deployment. Quality Function Deployment philosophy will be discussed in the next chapter for utilization in the enhancement of the assessment of quality management in aircraft maintenance at later stages of the thesis.

CHAPTER 4

QUALITY FUNCTION DEPLOYMENT

4.1 Introduction

The Quality Function Deployment method is a learning technique setting the path between customer demands and product development. In Quality Function Deployment operation, matrices are used to describe the relation between different customer needs, and design requirements. Many companies from various sectors are incorporating Quality Function Deployment as an integral part of company-wide quality practice. It has been widely applied in industries such as aerospace, industrial engineering, software engineering, construction and marketing, training and education services, and others. As an example, some of the first worldwide known United-States of America companies to adapt Quality Function Deployment included 3M Company, Baxter Healthcare, Chrysler, Ford Motor Company, General Motors, Goodyear, Hewlett-Packard, IBM, Kodak Eastman, Motorola, NASA, Polaroid, NCR, and Xerox.

The aim of this chapter is to introduce Quality Function Deployment. The chapter is divided into four sections. The first section presents an overview of Quality Function Deployment by stating its first elements, with insights to the House of Quality. The second section provides historical background to the applications and developments of Quality Function Deployment, and to how it fits in the organization. The third section discusses the tools and techniques of the Quality Function Deployment. The last section talks about the uses of Quality Function Deployment as a quality tool in industrial engineering and services.

4.2 First Elements about Quality Function Deployment

The Quality Function Deployment concept has been first developed in Japan in (1966) by Yoji Akao and disseminated through a paper in (1972). It arrived in the United-States in (1984), and later on, it got spread in other industrial countries [Clausing, 1994]. Quality Function Deployment is a planning methodology for translating customer needs into appropriate product/service features. The intents of applying Quality Function Deployment are to incorporate the customer needs into the various places of the product development cycle for a new product, or a new version of an existing product, through marketing surveys and interviews and to assume the achievement of customer-required quality [Ezop et al., 1989], [Bossert, 1990]. The "voice of customer" is expressed in the customer's terms which can be in the form of linguistic or crisp variables [Sullivan, 1986]. To this end, Quality Function Deployment can be customized to a specific project, whether it is a product, a service, software, or a combination of products.

Quality Function Deployment focuses on delivering positive value by seeking out both spoken and unspoken needs, translating these needs into actions and designs, and communicating these throughout each organization on the value chain to the end customer. In addition, Quality Function Deployment allows customers to prioritize the requirements and to benchmark them against the competitors. Then, the Quality Function Deployment helps the company to optimize those aspects of the products or services that will deliver the greatest advantage. In general, as was cited from the literature, Quality Function Deployment has been utilized in areas such as promoting cross-functional teams, improving companies' internal communication between the different departments, and in translating the customer requirements into the language of the organization. In Quality Function Deployment, several tools are employed to clarify vague requirements, discover hidden ones, and prevent changes or misunderstandings be correctly analyzing their cost benefits [Mazur, 1997], [Rings et al., 1998]. Promoting the development of these tools was a study done in Japan in (1984) that demonstrated that there were different types of requirements that needed different approaches to understand them [Kano et al., 1984].

The Quality Function Deployment can be broken down into two main activities: product quality deployment and deployment of quality function. The product quality deployment translates the "voice of customer" into product control characteristics. Whereby, deployment of quality function assures that the customer required quality is achieved. The presented merits of Quality Function Deployment are summarized as follows:

- ⇒ Reduce frequency of design alternation
- ⇒ Cut down research time
- ⇒ Lessen conflictions in manufacturing process
- ⇒ Lower research expenditures
- ⇒ Promote consumers satisfaction
- ⇒ Transfer experience effectively

The above stated merits can be achieved by streamlining processes and reducing rework and waste. This can be done by increasing the likelihood that a product or process design will not have to be changed or redone. This dampening effect comes about because Quality Function Deployment allows developers to evaluate proposed mid project changes against the same criteria used to evaluate all design decisions at the beginning of the project. The team has simply to add the new proposed change to the Quality Function Deployment matrices and apply the same analysis to it as that they applied to all the earlier decisions. This systematic analysis helps developers avoid panicky, rushed decisions that fail to take the entire product and all the customer needs into account. Most midcourse corrections are easily rejected or postponed when Quality Function Deployment analysis is applied to them. In addition, focusing product and process development on the work that most matters to the customer. This is another way of saying the work that gets done is what Quality Function Deployment analysis has shown to be most clearly related to meeting customer needs. Moreover, Quality Function Deployment contributes to increased revenues by helping organizations to concentrate their efforts on customer needs, and to accurately and effectively translate customer needs into the right product design or the right service characteristics. Quality Function Deployment is also an important key to cycle time reduction, as organizations could lose competitiveness if this matter is not taking early on the development process.

In addition, Quality Function Deployment is used as a systematic approach in order to translate customer requirements into engineering specifications in product design. It is a tool that integrates an organization's diverse information source during product and process development [Dean E.B., 1992]. This tool can be used to decompose tactical strategic plans into workable strategic functions. Through Quality Function Deployment analysis, conceptual requirements in strategic plans can be translated into program items that are capable of producing improvement. Two Quality Function Deployment processes that are widely accepted and used as effective processes; the American Supplier Institute's four phase approach as presented in figure (4.1), and the GOAL/QPC Matrix of Matrices approach [Revelle, J.B., Moran J.W., and Cox, C.A.,1998].

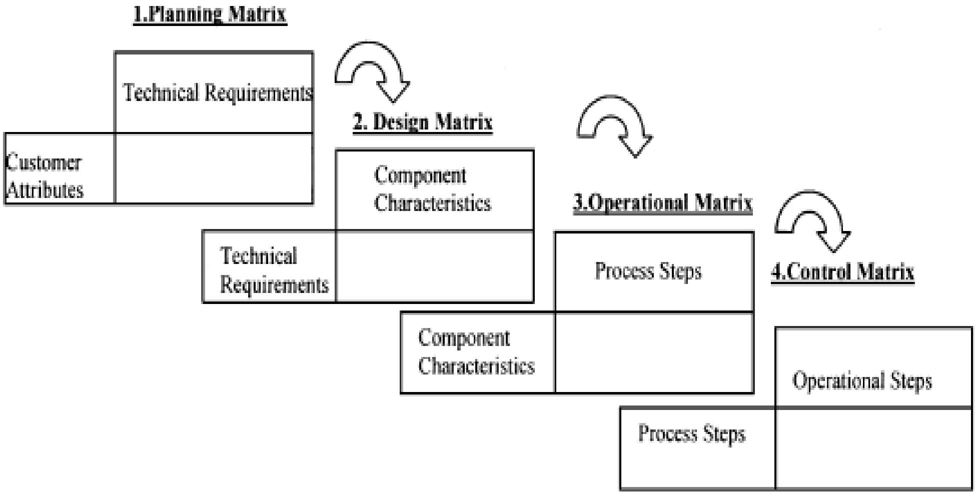


Figure 4.1: The Four-Phase Approach of Quality Function Deployment
Source: [International Journal Production Economics, 2000]

The American Supplier Institute's four-phase approach translates the customers' needs into technical requirements, and subsequently component characteristics, process steps and operational steps [Revelle J.B., Moran J.W., and Cox C.A., 1998]. The four key phases in the approach of Quality Function Deployment as presented on the previous figure (figure 4.1) are:

a. Planning Matrix – provides a link between customer needs and product control characteristics. Characteristics that posses a strong relation to meeting customer needs, are important to customer and have poor performance, must be transformed into actions to ensure that the "voice of customer" is heard. On the contrary, those characteristics that are not as critical in meeting customer needs will not be considered in the subsequent deployment process.

b. Design Matrix – translates the output of the planning matrix into components characteristics. During this, both customer requirements and final product control characteristics which are directly related to customer needs, are identified and are deployed further using the quality control charts.

c. Operational Matrix – in this approach the quality control charts signify the transition from deployment to production. Critical product and process parameters are identified and are deployed in operation instructions.

d. Control Matrix – based on the critical product and process parameters, the operating instructions define the operator's requirements. These instructions for example convey to the operator information pertaining to the parts involved in the operation, the number of parts to be checked, and the inspection methodology.

4.3 Traditional Quality Systems vs. Quality Function Deployment

Basically, Quality Function Deployment is designed to improve customer satisfaction with the quality of the provided products and services. The question is, what can Quality Function Deployment do that is not already being done by the traditional quality systems? To further enhance the understanding, the differences between the modern quality systems and traditional quality approaches concepts can be summarized as follows:

The traditional quality approaches – These approaches focus on work standards [Love, 1986], automation to eliminate people, or in more knowledgeable organizations, quality improvement teams to empower employees to resolve problems [Mazur, 1995]. However, and as organizations finding out that the absence of the problems is not enough when being in a sector with financial constraints, for example the aircraft maintenance industry market.

Modern Quality Systems - Quality Function Deployment is quite different from the traditional quality systems which aim at minimizing negative quality (such as poor service, broken product). With those systems, the best which can be gained from them is nothing wrong, which is not enough when improved efficiency is expected. In addition to eliminating poor service, positive quality must be maximized in order to create value.

The Quality Function Deployment approach – As one of the modern quality systems, the Quality Function Deployment is quite different from the traditional quality systems. Quality Function Deployment concentrates on maximizing customer satisfaction (positive quality), measured by metrics, such as repeat business. It focuses on delivering value by seeking out both spoken and unspoken needs, translating these into actionable services, and communicating this throughout the organization [Mazur, 1995]. In addition Quality Function Deployment allows customers to prioritize their requirements, by the concept tell us how we are doing compared to other operators, and then direct us to optimize those aspects of our service that will bring the greatest advantage. This means the companies will not be wasting money, time and human resources on services that the customers do not want. This then, entails that the companies understand their customer requirements.

4.3.1 Types of Customers Requirements

To satisfy customers, we must understand how meeting their requirements affect their satisfaction. Although there may be some theoretical difficulties (see Arrow's impossibility theorem in Annex D), this question can be dealt with in practical grounds. For that, it is useful to consider three types of customer requirements as depicted in figure (4.2) [Kano et al., 1984]. Some details about these types of customer requirements are the following:

Revealed Requirements – Also, known as normal requirements. These are typically what the company gets by just asking customers what they want. These requirements either satisfy or dissatisfy in proportion to their presence or absence in the product or service. On time aircraft delivery after servicing would be a good example. The faster or slower of on time aircraft delivery, would mean that the customer with either like or dislike the maintenance provider, and either to continue or not continue servicing their aircrafts with the same organization. This requirement would have an impact on the maintenance provider's reputation.

Expected Requirements – These are the basic expectations of the service without which, the service may cease or to be of value; their absence is very dissatisfying. They are so basic that the customer may fail to mention them until the company fails to deliver them. For example, the replenishment of aircraft engine with oil after servicing it. The customer will not think of it, but if the maintenance provider gets the aircraft with no oil in the engine; then the customer will be very dissatisfied. Therefore, expected requirements must be fulfilled in order to have a satisfied customer.

Extra Requirements – They are difficult to discover. They are beyond customer's expectations. Their absence does not dissatisfy, their presence boost the level of service, [Mazur, 1993]. For example, replacement of a full set of parts instead of just replacing the only damaged one with no increase in price would build a more trustful and coherent relation between the customer and the service provider. These are the things which give reputation to the company providing the service. This comes under the responsibility of the service provider to explore on customers beyond satisfaction of level of service.

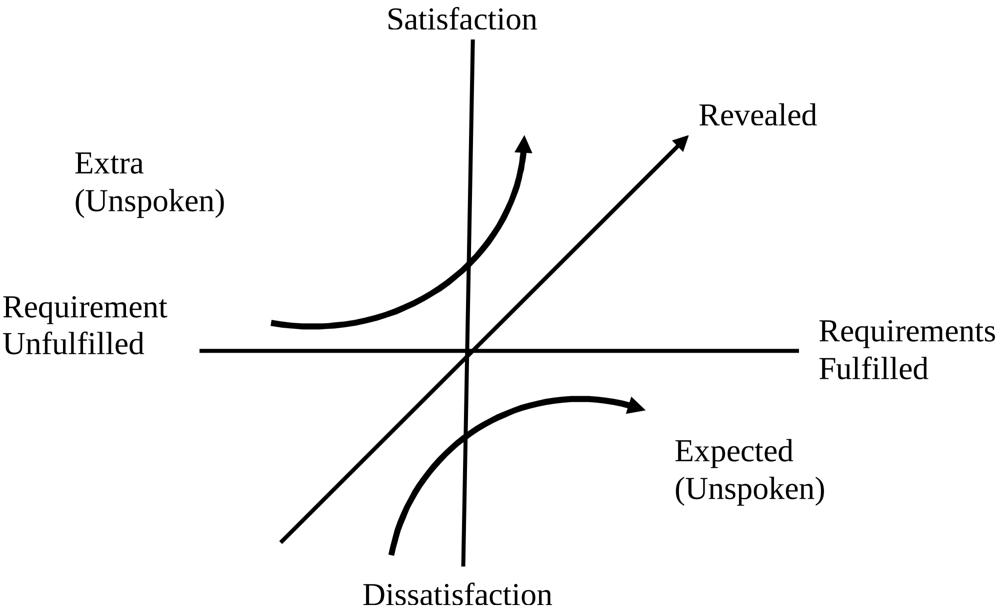


Figure 4.2: The Kano Model (adapted)
Source: [Kano et al., 1984]

Quality Function Deployment is a complex and very time consuming learning process [Freeze and Aaron, 1990]. To increase integrity and coherence, its learning process is deployed graphically through the construction of House of Quality [Hauser and Clausing, 1988]. The House of Quality consists of several sections or sub-matrices joined together in sequence; each contains information related to the others. The House of Quality and its related issues are discussed below in detail.

4.4 The House of Quality

The House of Quality grid is the most recognized form of Quality Function Deployment [Hauser and Clausing, 1988]. It displays the customer's wants and needs the "voice of the customer". It is utilized by a multidisciplinary team to translate a set of customer requirements, using market research and benchmarking data, into an appropriate number of prioritized engineering targets to be met by a new product or service. In the House of Quality, the customer requirements are called the (WHAT`s), which represent a structured list of requirements derived from customer statements. The technical requirements are known as the (HOW`s), which represent a structured set of relevant and measurable product characteristics. The final output of the matrix is a set of target values for each technical requirement to be met by the new design. The House of Quality is a sort of conceptual map, which provides means to the interfunctional planning and coordination of product improvement and product development. As a result, the House of Quality can be built in many shapes and forms. The general format of the House of Quality as presented in figure (4.3) is made up of the components as addressed below:

- Customer requirements. Also known as the "voice of customer". It displays the "WHATS" the customers want from the product to be developed. It contains customers' wishes, expectations, and requirements for the product.
- Customer importance rating. Once the "Whats" are in place, the customer needs to provide numerical ratings to these "Whats" items in terms of their importance to the

customer. A normal numerical rating of 1 to 5 is often used, in which number 5 represents the most important and 1 the least important.

- Competitive evaluation. In this block, a comparison is made with other equivalent products and services. The comparison results will help the developer position the product on the sector as well as to find out how the customer is satisfied now by the product or service. For each product/service, the customer for example gives 1 to 5 ratings against each customer requirement, 5 being the best satisfied and 1 the worst.
- Technical specifications. These are the technical specifications that need to be built into a product with the intention to satisfy the customer requirements. They are sometimes referred to as the "Hows", because they are the answers to customer requirements; how can the requirements be addressed and satisfied. These are the engineers' understanding in technical terms to what the customer really wants. The technical specifications have to be quantifiable or measurable so that they can be used for design.
- Relationship matrix. This is used to maintain the relationship between customer requirements and design requirements. It corresponds to the "Whats" vs. the "Hows". A weight of 1-3-9 or 1-3-5 is often used for internal representation of relationship, for example 1 being weak, and the biggest number being the strongest relationship.
- Correlation matrix. It is the triangular part in the House of Quality (the “roof “). It is used to identify which "Hows" items support one another and which ones do not. Positive correlation help identify the "Hows" items that are closely related and avoid duplication of efforts. Whereas negative correlation represents conditions that will probably require trade-offs.
- Target goals. These are the “How much” of the technical "Hows" items. They provide designers with specific technical guidance for what have to be achieved, as well as objectively measuring the progress. The goals have to be quantified in order to be specific and measurable.
- Degree of technical difficulty. This is the assessment conducted by the technical team. It helps to establish the feasibility and reliability of each "Hows" item. A rating of 1 to 5 is used to quantify technical difficulty with 5 being the most difficult, and 1 being the easiest.
- Technical competitive evaluation. It is used for comparing the new product with competitors' products to find out if these technical requirements are better or worse than competitors. A rating of 1 to 5 is used with 5 being the best and 1 being the worst.

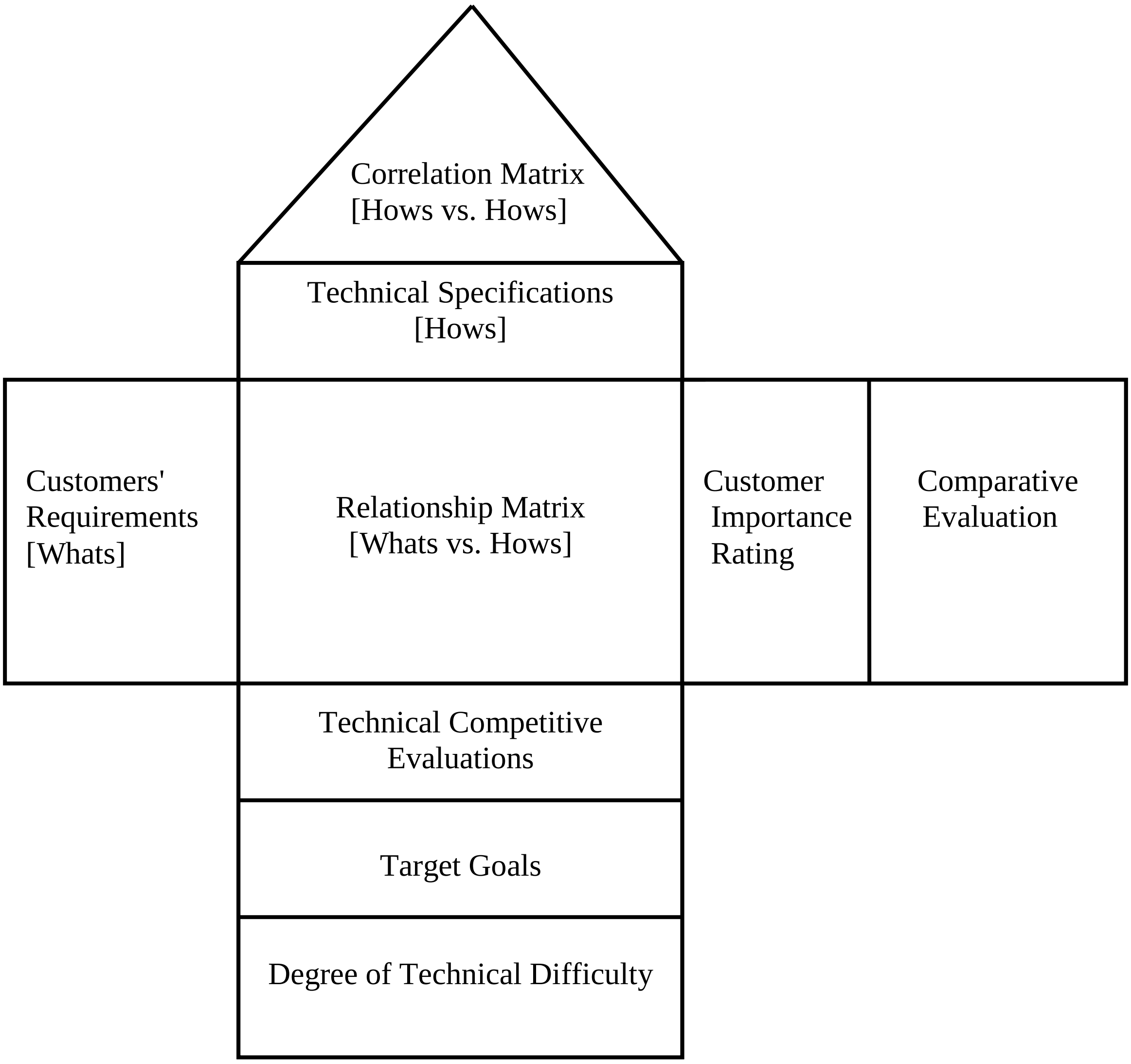


Figure 4.3: House of Quality in Quality Function Deployment
Source: [Menks et al., 2000]

The House of Quality planning process is summarized into the following steps [Wang J., 1999]:

⇒ Obtaining the customer attributes and their relative importance;
⇒ Developing design requirements responsive to customer attributes;
⇒ Relating design requirements to the customer attributes;
⇒ Completing the customer competitive survey;
⇒ Performing the competitive technical benchmarking;
⇒ Determining the relationships among design requirements;
⇒ Calculating the technical importance ratings of design requirements and evaluating their technical difficulties and estimated costs.

4.5 The Tools of a Comprehensive Service Quality Function Deployment

Quality Function Deployment uses problem-solving and planning tools drawn from a set called the "seven management and planning tools" [Cohen, 1995]. Lists of the tools and even the actual number of tools vary a bit from one reference source to another, but most of the tools appear in all lists. Typical tools and techniques which are the mainstays of Quality Function Deployment are:

- ✓ **Affinity Diagrams** are used to surface the "deep structure" of voiced customer requirements. Also, makes a good first step for creating hierarchy diagrams. Building an Affinity Diagram involves the recording of each statement onto separate cards which are then sorted into groups with a perceived association. A little card which summarizes the data within each group selected from its members or is created where necessary. For example, the demanded qualities for a particular service were grouped using the Affinity Diagram as presented in figure (4.4). The demanded quality items are the imprecise words that describe what it takes to satisfy the customer, and they normally become the input rows to the House of Quality.

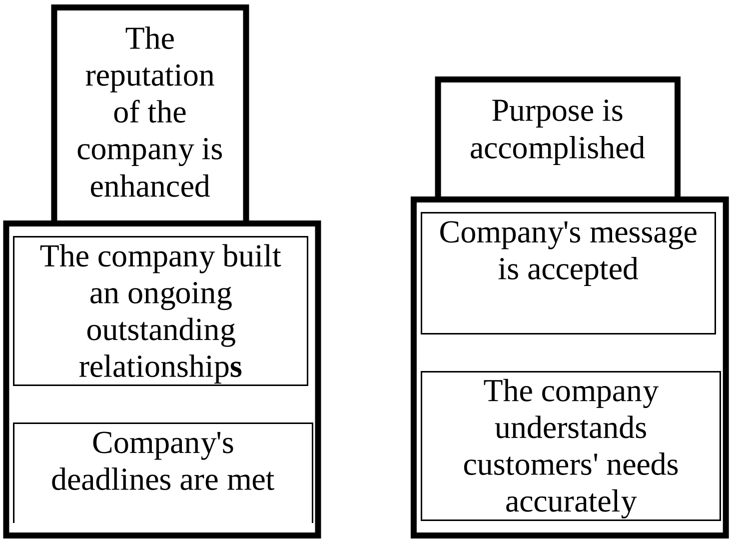


Figure 4.4: An Example of Affinity Diagram for Demanded Quality for Particular Task in a Company

- ✓ **Hierarchy Diagrams** also called tree diagrams or systematic diagrams. Such diagrams are found throughout all Quality Function Deployment deployments to check for missing data, to align levels of abstraction of the data, to diagram the why/how nature of functions and to diagram failures. It is built from the top down in an analytical manner. An example of a Hierarchy Diagram for a specific computer program is as presented in figure (4.5).

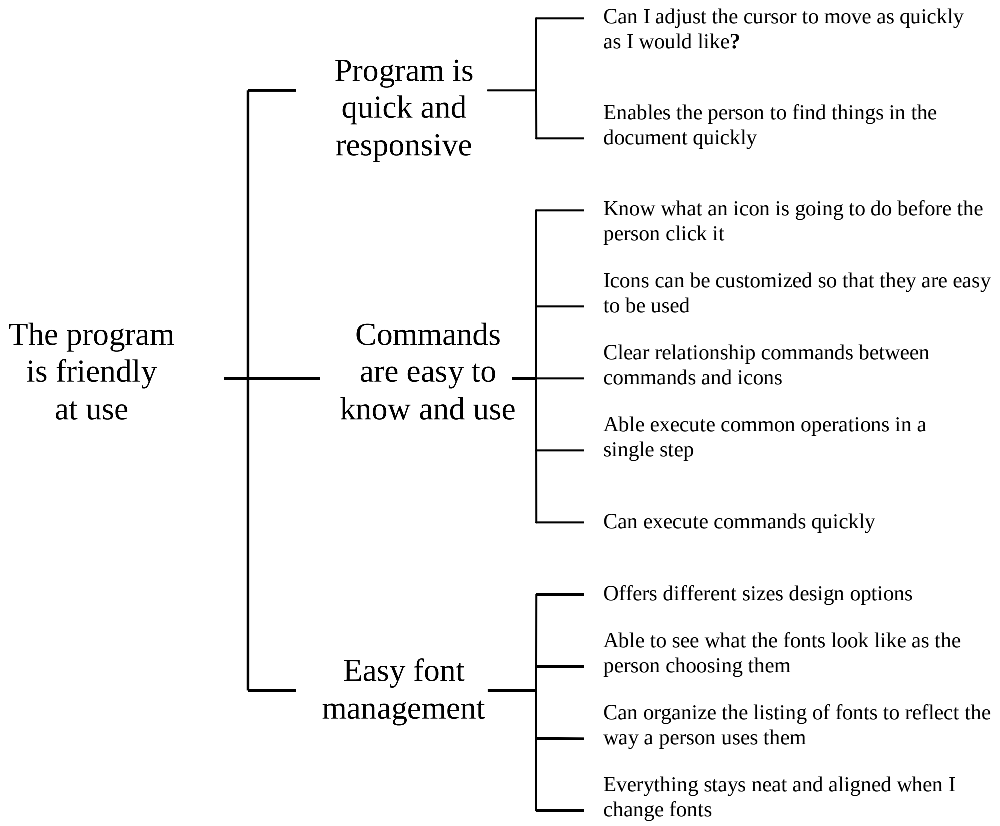


Figure 4.5: An Example of Hierarchy Diagram for a Specific Computer Program

- ✓ **Matrices and Tables** are used to examine two or more dimensions in a deployment. Common types include documenting relationships, prioritization and responsibility matrices. The matrix is a tool which lies at the heart of many Quality Function Deployment methods. By comparing two lists of items using a rectangular grid of cells, it can be used to document a team's perceptions of the interrelationships that exist, in a manner which can be later interpreted by considering the entries in particular cells, rows, or columns. In a prioritization matrix the relative importance of items in a list and the strength of interrelationships are given numerical weightings, which would be shown as numbers or symbols as presented in figure (4.6).

Importance of row items							
A 2	2 / 4	5 / 10		4 / 8	1 / 2		
B 5					3 / 15		
C 3	5 / 15			6 / 18			1 / 3
D 2		3 / 6			8 / 16	3 / 6	2 / 4
E 4		3 / 12					4 / 16

Figure 4.6: An Example of a Matrix Diagram

Tables are used in Quality Function Deployment to study the implications of gathered or generated items against a specified list of categories. For example such tables would include production planning and analyzing customer statements in the voice of the customer as presented in figure (4.7).

Part 1

ID	Customer demographic (Who)	Voice of the customer	Use									
			What		When		Where		Why		How	
			Internal /External (I/E)	Data	I/E	Data	I/E	Data	I/E	Data	I/E	Data

Part 2

Reworded Data	Demanded Quality	Quality Characteristics	Function	Reliability	Comment

Figure 4.7: An Example of Tables Diagram

- ✓ **Analytic Hierarchy Process:** is used to prioritize a set of requirements, and to select from alternatives to meet those requirements. This method employs pairwise comparisons on hierarchically organized elements to produce a very accurate set of priorities [Saaty, 1990], [Tone and Manabe, 1990]. An example in figure (4.8) of Analytic Hierarchy Process showing the prioritization of engineering managers' needs in a company. The information was obtained from a study to find the appropriate quality management education for engineering undergraduates as was found in [Glenn Mazur, 1996].

Comparison of the relative importance with respect to goal

	TECHNICAL	ORGANIZATIONAL	INNOVATION
Quality	2.0	6.0	7.0
Technical		5.0	3.0
Organizational			3.0

Abbreviation	Definition
Goal	Appropriate quality management education for engineering undergraduates
Quality	Quality minded in understanding customer and solving problems
Technical	Broad technical background to handle difficult tasks
Organizational	Organized approach to work
Innovation	Familiar with innovative methods and techniques

Quality .524 ---
Technical .304 --
Organizational .106 ----------------------------
Innovation .065 -------------

Figure 4.8: An Example of Analytical Hierarchy Process

- ✓ **Relations Diagrams**, also called interrelationship digraphs, can be used to discover priorities and root causes of process problems and unspoken customer requirements.

- ✓ **Process Decision Program Diagrams:** these are used to analyze potential failures of new processes and services.
- ✓ **Blueprinting** is used to depict and analyze all the processes which are involved in providing a product or service [George and Gibson, 1991]. A variant of the diagrams used in time/motion studies.

4.6 Applications and Developments of Quality Function Deployment

Quality Function Deployment has been successfully used in many industries. For example in the Japanese industries was used in agriculture systems, construction equipment, consumer electronics, home appliances, integrated circuits, software systems, steel, synthetic rubber, and textile. Quality Function Deployment is not only a technical method, but also a managerial methodology that can help enhance the organization and managing effects. Technically, Quality Function Deployment can reduce the product development time, while simultaneously improving product quality and delivering the product at a lower cost [K.J. Kim, 1993]. Quality Function Deployment can also facilitate continuous product improvement with emphasis on the impact of organization learning on innovation [C.P.M Govers, 2000]. [Zultner, 1994] classified the applications of Quality Function Deployment in three groups as: hardware, software, and service. [Hunt, 1998] emphasizes that the general applicability of Quality Function Deployment is not only in the traditional area of product, service, and software, but also to the area of strategy development and deployment.

Quality Function Deployment contributes to increased revenues by helping organizations to concentrate their efforts on customer needs, and to accurately and effectively translate customer needs into the right product design or the right service characteristics. Quality Function Deployment is also an important key to cycle time reduction.

On the other hand, however, Quality Function Deployment also has some drawbacks, for instance, the amount of time to implement it [Cohen, 1995], the difficulty in manually recording the Quality Function Deployment matrix in an electronic form [M. Wolfe, 1994], and the qualitative and subjective decision-making process [V. Bouchereau, 2000]. These drawbacks have promoted the need for new approaches to the application of conventional Quality Function Deployment approach [V. Bouchereau, 2000]. Various quantitative methods, such as Analytic Hierarchy Process, artificial neural networks, and fuzzy logic are combined with Quality Function Deployment, and proposed to provide a more objective and precise approach for its implementation. It has also been extended and modified to make it more representative and applicable, for example, enhanced Quality Function Deployment [D. Clausing, 1994], and their information system for Quality Function Deployment [J.A. Harding, 2001].

4.6.1 Quality Function Deployment as a Quality technique

Quality control has been in existence for a long time, but was not an engineering technique until the 1920s when statistical theory started to be applied effectively to quality control as a result of the development of sampling theory [Prinns, 2000]. Since then statistical quality control concerning sophisticated control charts have been applied to many manufacturing areas. Among the many tools used in quality control, Quality Function Deployment is one of the effective tools for product and process development.

Quality Function Deployment is a technique that can be applied for detecting the defects at the design stages of products or services. As shown in figure (4.9), [Ur Rahman, 1995], [Field and Swift, 1996] a product undergoes a number of phases before it reaches the market for end users. The figure shows the quality management approaches, and the techniques associated with the stages of product development. Generally, all the three approaches are important to maintain and improve quality. However, it is the degree of emphasis among approaches that would make all the difference. Today, good quality is considered as being more of a function of good design than of process control. There is evidence that, by better understanding customer needs and carefully incorporating these needs into product design, companies can reduce significantly the number of design changes in the innovation process, and reduce start-up costs and lead times for product development. The techniques must be considered as an integral part of the quality system. To this end, the Quality Function Deployment can be chosen as a good quality technique for improving quality at the off-line stage, or quality by design approach.

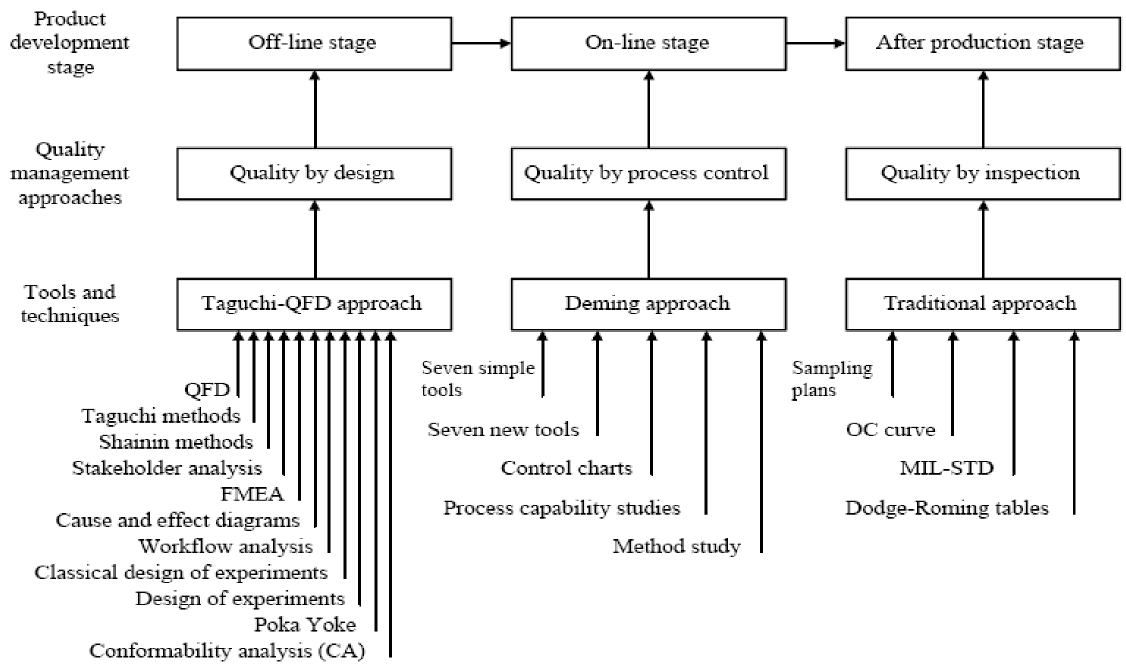


Figure 4.9: Product Development Stages, Quality Approaches & Techniques

Source: [Ur Rahman, 1995], [Field and Swift, 1996]

4.6.2 Use of Quality Function Deployment in Industrial Engineering and Services

Quality Function Deployment did not become a recognized tool until (1972) when it was applied at the Kobe shipyards of Mitsubishi heavy industries in Japan [Prasad, 1998]. Quality Function Deployment reached its peak and was fully utilized in Japan in the 1970s when Toyota Auto Body developed a quality table that had a "roof" on top, and nicknamed this table as "quality house", which was then known as the House of Quality as was described previously. The formal introduction of Quality Function Deployment to the USA and Europe was not until (1983) [Menks, 2000]. And the first recorded case studies in Quality Function Deployment were in (1986) when Kelsey Hayes used Quality Function Deployment to develop a coolant sensor, which fulfilled customer requirements [Prasad, 1998]. Since then, Quality Function Deployment has been applied and implemented in many major industries and service organizations. In 1983, a number of leading North American firms discovered this powerful tool and have been using it with cross-functional teams and concurrent engineering to improve their products, as well as the design and development process itself [Akao, 1990], [Sullvian, 1986], [King, 1987]. For example, Quality Function Deployment was an important part of Florida Power and Light's successful bid to become the first non-Japanese Deming Prize reception in (1990) [Webb 1990], [Bodziony, 1995]. From the literature, it was cited that, since (1981), Quality Function Deployment has been successfully applied to many industrial engineering and service organizations. The focus in this regard has been on industries like the auto-mobiles, electronics, software, and manufacturing.

Furthermore, various quantitative methods have been suggested to be used in Quality Function Deployment to improve its reliability and objectiveness, noticeably the fuzzy logic. In this regard, many researchers, like [Shen et al., 2000], [Wang, 1999], and [Zhou, 1998] have put forward a fuzzy Quality Function Deployment which integrates the fuzzy set theory with classical Quality Function Deployment to tackle the uncertainty, subjective, vague and imprecise problem in implementing procedure. This issue will be discussed in detail in chapter (6).

4.7 Conclusion

Quality Function Deployment can play an important role in helping organizations become stronger, and therefore more likely to survive, more secure, and more able to expand [Cohen, 1999]. This can be achieved by minimizing negative quality (such as poor service, broken product), and cycle time reduction. Also Quality Function Deployment can serve as a flexible framework, which can be modified, extended, and can be combined with other quality design and improvement technique. However, although the Quality Function Deployment capabilities have been demonstrated, it worth mentioning that this method also has some weaknesses and drawbacks. Examples of some of the most noticeable ones are: ambiguity in determining the voice of the customer, managing the many items in the House of Quality and conflicts between customers' requirements.

In conclusion, and in spite of the above mentioned problems, it can be said that Quality Function Deployment however still has a wide range of benefits which have already been fully explained in this chapter. Quality Function Deployment systematizes the improvement of quality, technology, cost, and reliability of both the process of planning and delivering it. In order to integrate the use of Quality Function Deployment with aircraft maintenance, the application of classical Quality Function Deployment in aircraft maintenance organizations will be discussed in the next chapter. This will lead to applying some of the tools of Quality Function Deployment which have been discussed in this chapter.

CHAPTER 5

ENHANCED ORGANIZATION OF AIRCRAFT MAINTENANCE THROUGH QUALITY FUNCTION DEPLOYMENT

5.1 Introduction

In chapter four it was made apparent that Quality Function Deployment is a powerful qualitative tool for translating customer requirements into service or product features. Quality Function Deployment has been opposed by some authors to other Systems Engineering techniques. This position is wrong since Systems Engineering and Quality Analysis acts in two different fields, the technical and the qualitative, which are often complementary to get satisfying solutions to problems related with the effective optimization of production organization. The main purpose of this chapter is then to show how the combination of multi criteria analysis of different technical solutions, combined with specific Quality Function Deployment studies, can lead to sound decisions. This chapter shows how Quality Function Deployment can provide decisive information to improve decision making in the field of aircraft maintenance organizations. This is illustrated by a practical situation in which decisions have to be taken in order to reduce the time taken for the major maintenance of a fleet of aircraft. This is relative to an "In-house Maintenance" which is done by aircraft maintenance organization every 2000 flying hours and covers in-depth maintenance tasks. Here it is supposed that, due to new operational requirements implying a higher fleet availability, there is a need to decrease the time for major servicing from the current six months to only four months.

5.2 The Current Aircraft Maintenance Organization

The case considered is an "In-House Maintenance", which is a sub-system of a transportation organization as depicted in figure (5.1) which works under a collaborative planning process that aims for the overall efficiency and productivity. The figure below displays the different actors involved with the air transport organization, including its maintenance facilities.

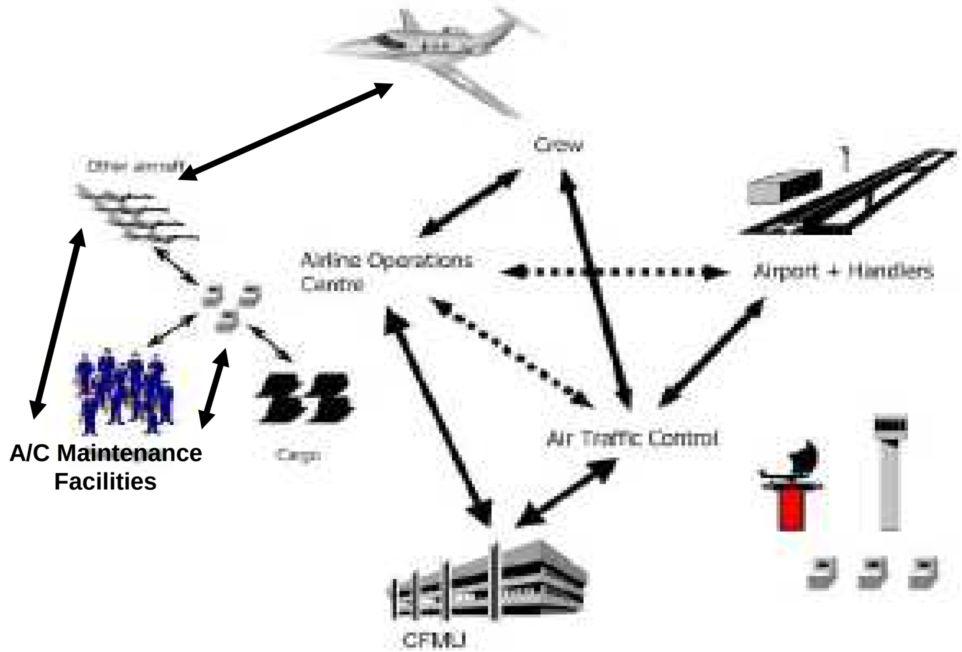


Figure 5.1: A Typical Aviation Organization

The organizational chart for the considered aircraft maintenance organization is as presented in figure (5.2).

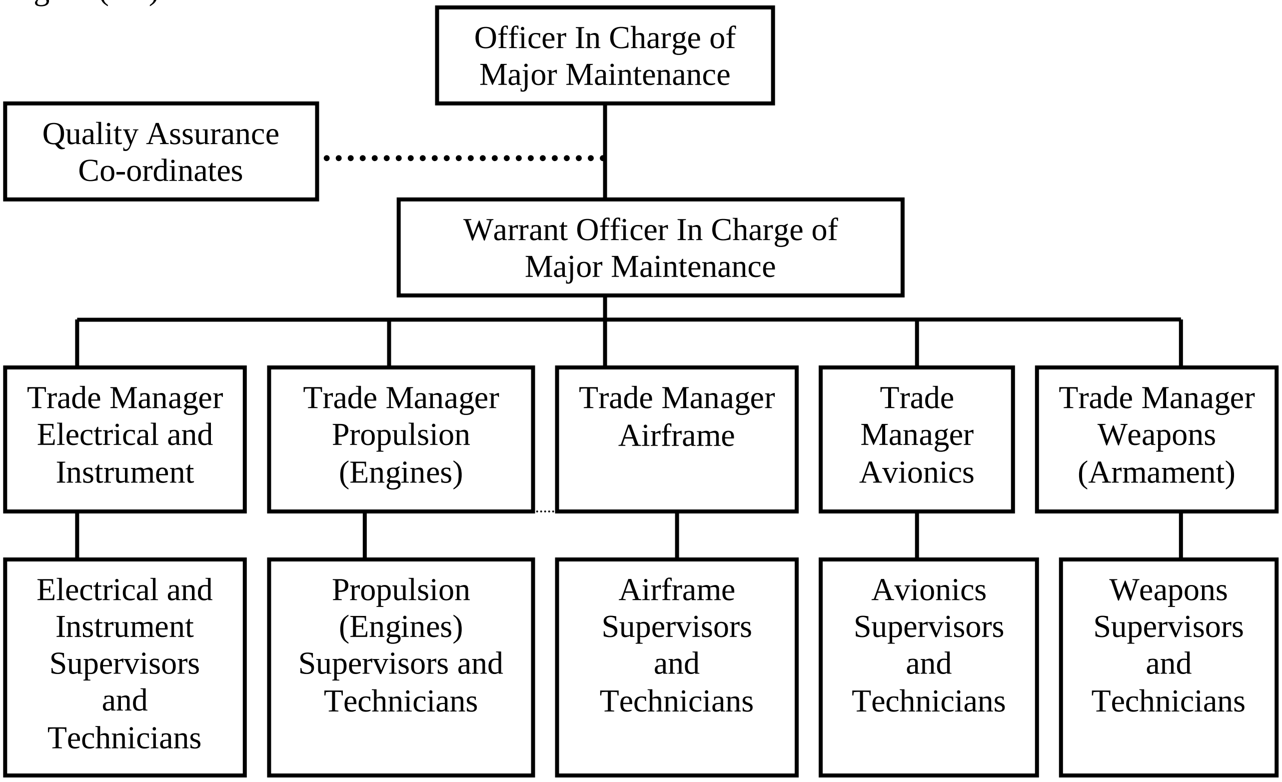


Figure 5.2: Aircraft Maintenance Organizational Chart

The Aircraft Maintenance Organization works on a system of five trades: airframe, propulsion or engines, avionics which consists also of communication and radar, electrical and instrument, and weapons. Each trade has its own responsible trade manager, who has some trade supervisors and technicians working under him. The trade manager assigns the work to the technicians who are supervised by the trade supervisors. Quality assurance coordinators only monitor the process by ensuring that the job is done in accordance with the laid down procedures and that there is no deviation from these procedures and standards.

5.3 Current Aircraft Maintenance Processes

The tasks to be carried out during the maintenance process from the start of the servicing until the aircraft is made serviceable and ready for flight are presented in figure (5.3).

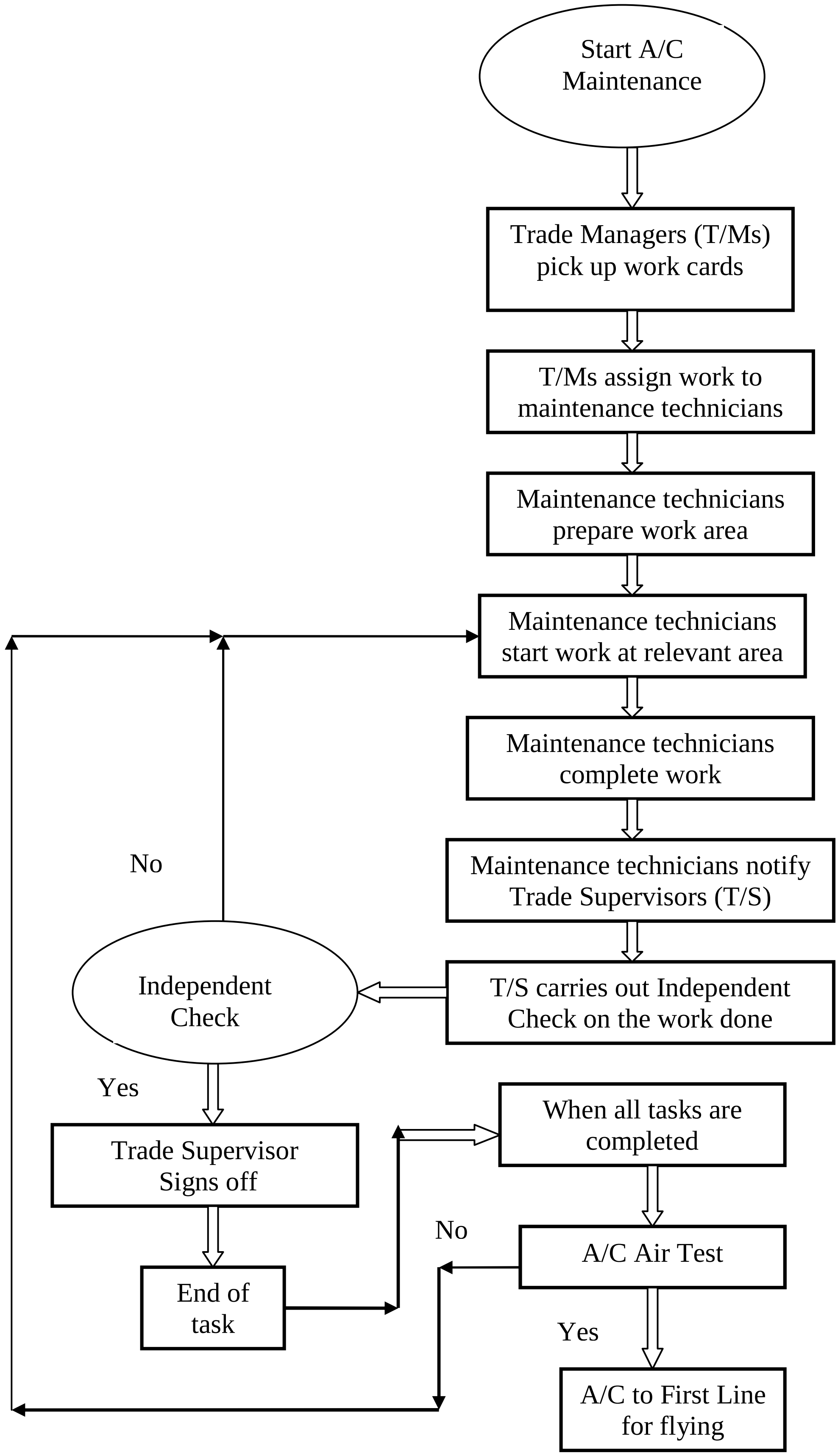


Figure 5.3: Maintenance Process

Scheduling for aircraft maintenance tasks needs to be optimized so that composed requirements can be met in aircraft maintenance process. This process includes the preparation of many things such as assigning personnel to the tasks, ensuring that tools, and support equipment are available, preparing the required operating maintenance and safety procedures and manuals. In the case considered, scheduling of maintenance of the fleet for major servicing is done by using the Program Evaluation and Review Techniques (PERT) with Gantt charts as an analyzing tool for completing the tasks and in facilitating decision making. In the current organization of maintenance activities, the work days are based on a working week from Saturday to Wednesday from 7 A.M to 2 P.M with two break times; 15 minutes each, the first one is at 0930 hours and the second at 1130 hours. In this case maintenance is done in sequence, one task after another as presented in figure (5.4).

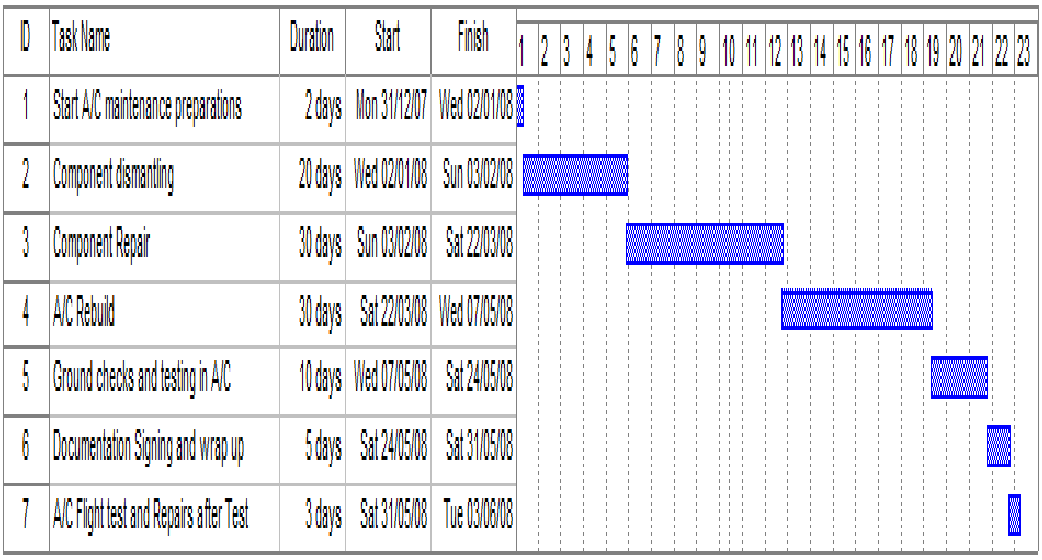
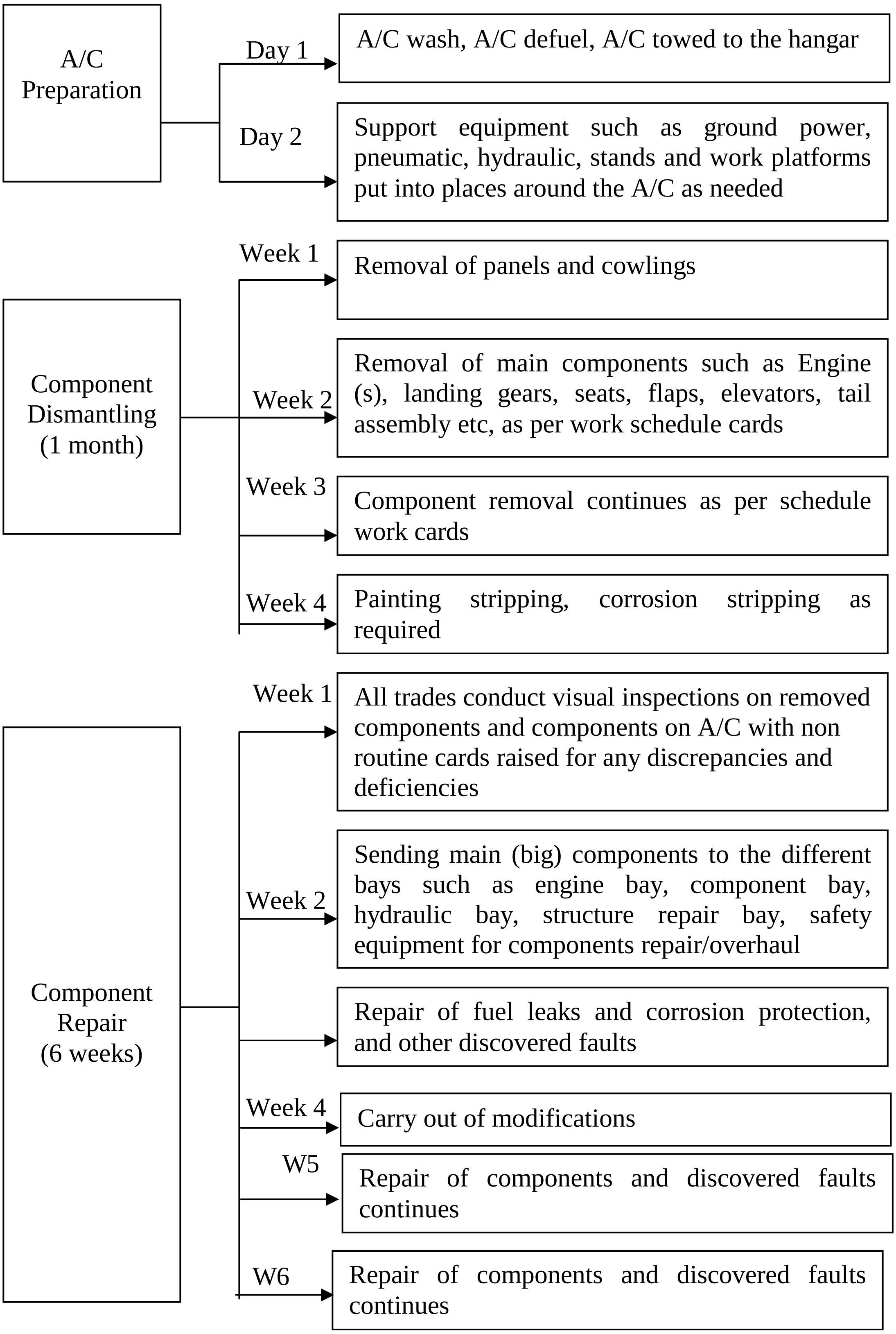


Figure 5.4: Current GANTT Chart of Main Maintenance Activities

Tasks stated on the above process chart are further explained below in detail as displayed in figure (5.5). All trades will be working at the same time in their relevant areas of specialization.



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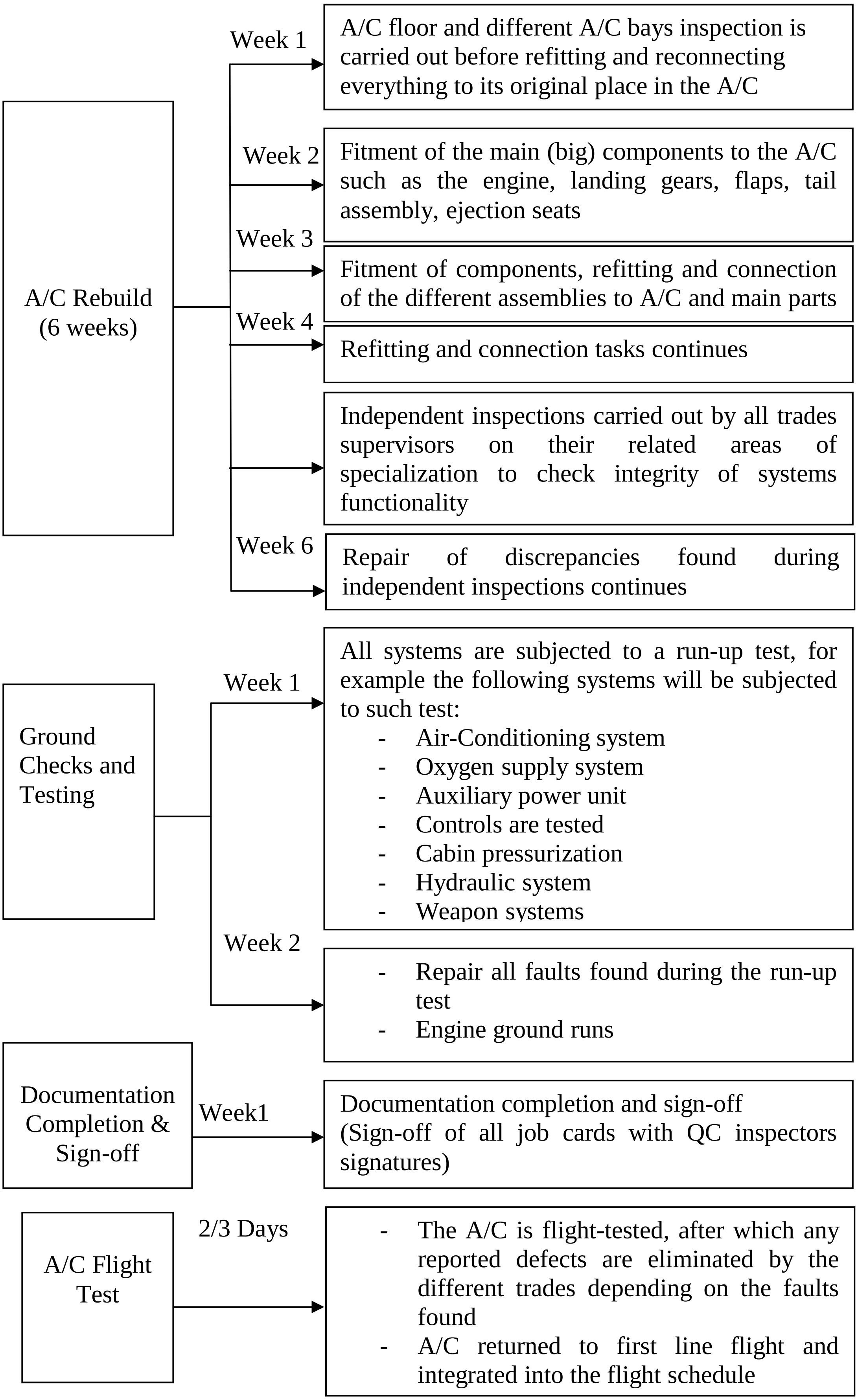


Figure 5.5: Detailed Description of Major Servicing

5.4 Requirement for Time Reduction in the Major Servicing

The working assumption is that currently major servicing which is done every 2000 flying hours takes six months to be completed. It is also supposed that in order to have aircraft availability for flying due to an operational requirement, the servicing time needs to be reduced to four months. The challenge of reducing the time taken for the major servicing from six months to four months is displayed in figure (5.6).

Maintenance Current Situation	Maintenance Future Solution
- Major servicing takes 6 months	- Major servicing takes 4 months
- Done at 2000 flying hours or 14 years which comes first.	- Done at 2000 flying hrs or 14 years which comes first.
- 2 Aircraft per a year	- 3 Aircraft per a year
- 32 Persons	- 32 Persons
- 5 days a week (7 working hours per a day)	- 5 days a week (7 working hours per a day)

Figure 5.6: The Challenge for Organizational Change

Such challenge will not only deal with time, but will involve a structural transformation, covering many aspects of the organization, such as installations, equipments and machines, human skills and processes, as well as managerial modifications. At this stage different choice with respect to installations, equipments and manpower should be considered.

5.5 Technical Solutions Analysis and Ranking

To the possible physical modification (installations, equipments and processes) of the maintenance organization of interest to meet the new objectives, must be associated a compatibility matrix such as:

Installations, Equipments & Processes	1	2	3	4	5	6
1	**1**	**1**	**0**	**0**	**1**	**0**
2	**1**	**1**	**0**	**0**	**1**	**0**
3	**0**	**0**	**1**	**0**	**0**	**0**
4	**0**	**0**	**0**	**1**	**0**	**1**
5	**1**	**1**	**0**	**0**	**1**	**0**
6	**0**	**0**	**0**	**1**	**0**	**1**

Figure 5.7: Compatibility Matrix between Projects

The compatibility matrix displays the installations, equipments and processes which can be integrated together and those which are incompatible between them. This allows defining a complete set of concurrent projects *S* to achieve the organization objectives. For instance for the above matrix we get:

$$S = \{(1), (2), (3), (4), (5), (6), (1,2), (1,5), (2,5), (4,6), (1,2,5)\} \quad (5.1)$$

To each of these projects are associated different performance indexes relative to the reduction of delays and costs.

For instance for a given new maintenance organization project, the resulting main maintenance activity GANTT chart could be such as:

ID	Task Name	Duration	Start	Finish
1	Start A/C maintenance preparations	2 days	Mon 31/12/07	Wed 02/01/08
2	Component dismantling	20 days	Tue 01/01/08	Sat 02/02/08
3	Component Repair	30 days	Sat 19/01/08	Wed 05/03/08
4	A/C Rebuild	30 days	Wed 20/02/08	Tue 08/04/08
5	Ground checks and testing in A/C	10 days	Tue 01/04/08	Wed 16/04/08
6	Documentation Signing and wrap up	5 days	Wed 16/04/08	Wed 23/04/08
7	A/C Flight test and Repairs after Test	3 days	Wed 23/04/08	Mon 28/04/08

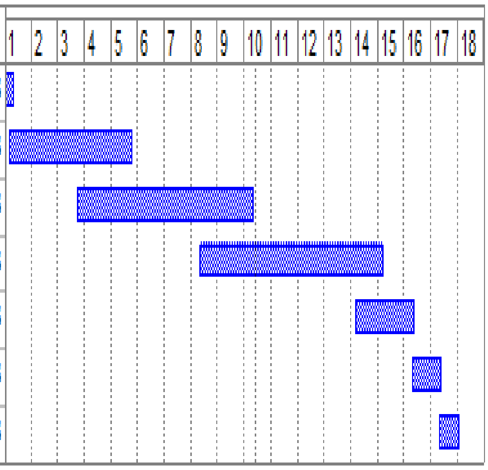


Figure 5.8: GANTT-Chart for a Candidate Maintenance Organization Project

A new set of candidate projects, S^*, $S^* \subset S$, can be defined by exclusion from S of projects which are unable to meet the delay reduction requirement or those which are too expensive or even those which are not non inferior in the Pareto sense (see figure 5.9).

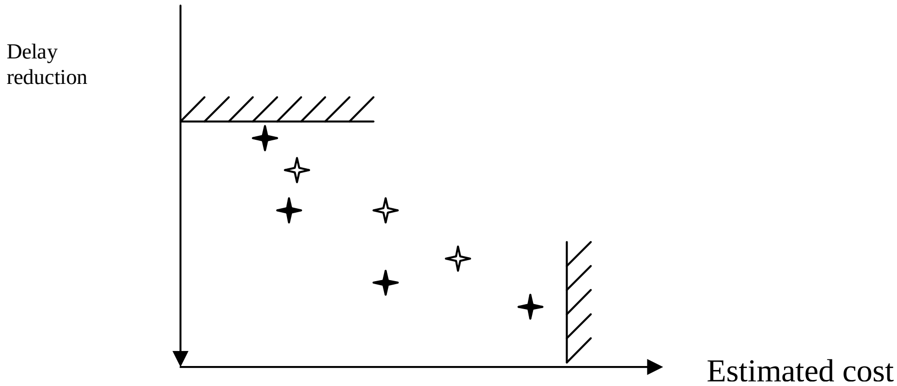


Figure 5.9: Inferior (✧) and Non Inferior (✦) Solutions

It appears that Quality Function Deployment should be applied to each of the remaining project since the other providences to be taken on qualitative grounds are in general dependent of the retained projects. Then a comparison, on qualitative grounds of the different candidate (non inferior Pareto) solutions should be performed to get final decision and recommendations to enhance the aircraft maintenance organization.

5.6 Quality Function Deployment Procedure

As already presented and discussed in figure (4.1) in the previous chapter, the Quality Function Deployment consists of four main phases. This procedure approach of Quality Function Deployment stages is introduced to aircraft maintenance servicing time reduction from the current six months to four months as previously presented in figure (5.6). The construction of the Quality Function Deployment including the building of the House of Quality for the aircraft maintenance is covered below in detail.

5.6.1 The Keystone Customer (Common to all projects)

Quality Function Deployment can accommodate multiple customers. The first step is to identify the "keystone" customer, who ultimately determines the success or failure of the service provided. In this case, as presented in figure (5.10), the primary customer for the aircraft maintenance organization is the Air Transport Organization Management, second is the pilots and third is the first line maintenance department. The first line department is responsible to provide safe aircraft on a daily basis to the company so that the pilots can carry out the flight missions scheduled by the Air Transport Organization Management.

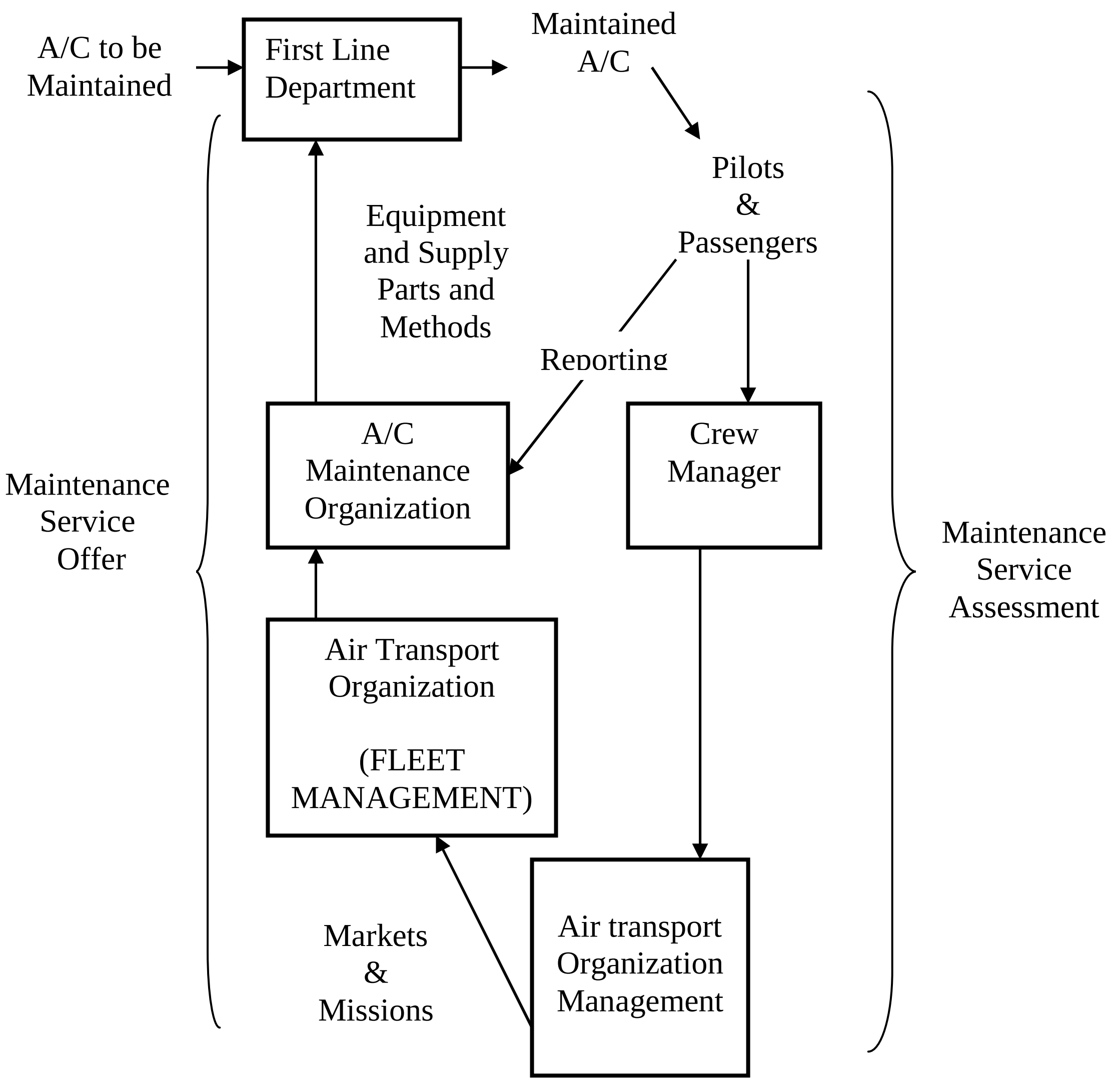


Figure 5.10: Customer Loop for Aircraft Maintenance Organization

If the aircraft maintenance organization does not satisfy first line department needs, the whole quality chain can collapse since aircraft servicing will not be done on scheduled time, pilots will have to wait while the maintenance teams are hurrying and airborne missions will be delayed.

5.6.2 Key Quality Function Deployment Elements for Aircraft Maintenance Projects

The key planning elements of Quality Function Deployment for aircraft maintenance taking all the aspects of planning of a given project in order to meet the objectives such as time reduction for the fleet aircraft major servicing from (6) months to (4) months is depicted in Figure (5.11).

Customer Needs	Planning Matrix	Deployment Matrix	Process Planning & Quality Control	Operating Instructions	Satisfied Customers
-Increase fleet availability - maintain aircraft reliability - Meet New Servicing Times - Minimize complexity -Commitment and Long Relationship - Safety Awareness	- Resources -Manpower - Processes - Maintenance Control ressources	- Definition of new installations and equipments - Qualified and Skilled Workforce - Structured Management System - Well Defined Company Procedures	- New installations quality control - New Tasks Definition & Requirement - Assessment and Audits Program - Proper Employment System & Human Resource Management - Partnership with Legal and Safety Authorities	- Apply Safety and Quality Standards - Quality Assessment/ Audit & Feedback Safety Precautions - Closed Loop Reporting System & Feedback - Supplier and Partnership Relations - Integration with the customer & Workforce -	- First Line Dept. - Pilots - Air transport organization

Figure 5.11: The Key Elements of Quality Function Deployment for Aircraft Maintenance

Experts' opinions have been obtained using some of the known techniques which covered in this case a mix of questionnaires, interviews and quality reports obtained from the quality management department. A report covering this issue is available but not enclosed into this thesis report.

The objectives, procedures and results involved with the Quality Function Deployment approach for aircraft maintenance can be summarized as follows:

A). Leadership and Management, including;

- Policy & Strategy
- People Management
- Safety and Quality Standards
- Safety Culture and Awareness
- Partnership & Resources

B). Processes, including;

- Policy Statement, Procedures, & Instructions
- Human Resources Management System

- Health and Safety At Work, Quality Standards, Audits & Assessments
- Training, Education, and Continuous Improvement
- Customer Relationship/Joint Venture

C). Results, consisting of;

- Goal/Objective Results
- People Results
- Safe Place of Work & Safety Results
- Innovation Results
- Society/Customer Results

5.6.3 Construction of the House of Quality for Each Candidate Project s∈ S*

The House of Quality built for a given maintenance enhancement project translates the demanded quality items by the customer into measurable attributes of quality. The House of Quality for the Aircraft Maintenance Organization as presented in figure (5.12) takes into account all the related aspects of leadership, strategic planning and its deployment, human resources, process management, partnership and resources, the risk awareness situation, the pressures for aircraft on time schedule turn round, and the quality aspects.

The first column of the House of quality provides the degree of importance of the customer requirements:

$$\pi_i \quad \text{with } \pi_i \in \{0,1,2,3,4,5\} \quad i = 1 \text{ to } m \tag{5.2}$$

where ‘0’ stands for “no importance” to ‘5’ which stands for “most important”.

The central matrix $H = [h_{ij}]$ is such that:

$$h_{ij} \in \{0,1,2,3,4,5\} \quad i = 1 \quad to \quad m, \quad j = 1 \quad to \quad n \tag{5.3}$$

where ‘0’ stands for no dependence to ‘5’ which stands for “very strong dependence”.

Then the degree of importance of design requirement *j* is given by:

$$u_j = \sum_{\text{"Whats" } i} \pi_i \; h_{ij} \qquad j = 1 \text{ to } n \tag{5.4}$$

And the performance of the overall project is given by:

$$\phi = \sum_{\text{"Whats" } i} \sum_{\text{"Hows" } j} \pi_i \; h_{ij} \tag{5.5}$$

Whats \ Hows	Degree of Importance	Strategy and planning	Leadership & Management	Implementat installation	New Procedures	New Resources	New Skills Manpower	Manuals	Maintenance Control	Safety Standards	Quality Standards	Assessment & audits
	π_i	1	2	3	4	5	6	7	8	9	10	11
Increase Fleet Availability	5	4	0	4	5	5	5	4	3	4	4	3
Maintain Aircraft Reliability	5	4	3	3	4	3	5	3	3	4	4	3
Meet New Servicing Times	5	0	0	4	4	4	3	4	4	3	4	4
Minimize Complexity	4	3	4	3	4	4	3	0	3	4	4	3
Commitment& Long Term Relationship	3	3	4	3	3	3	3	2	3	0	3	3
Safety Awareness	3	3	3	3	4	4	4	4	3	3	4	3
Absolute Weight	u_i	70	52	85	102	97	98	73	80	78	94	80
Relative Weight %		7.7	5.7	9.35	11.2	10.67	10.78	8.03	8.80	8.58	10.34	8.80

Figure 5.12: Example of House of Quality for an Aircraft Maintenance Project

5.7 Final Project Selection

The final project selection can be based on the degrees of importance (π_i) of the "*whats*" of the different House of Quality ($[h_{ij}^s]$) developed for each project *s*. A figure of merit for a given project *s* can be such as:

$$\phi_s = \sum_{\text{"Whats" } i} \sum_{\text{"Hows" } j} \pi_i \ h_{ij}^s \tag{5.6}$$

Taking into consideration the concurrent projects *S* to achieve the organization objectives as was previously mentioned; $S = \{(1),(2),(3),(4),(5),(6),(1,2),(1,5),(2,5),(4,6),(1,2,5)\}$.

For the example above, we get:

u_i	70	52	85	102	97	98	73	80	78	94	80

Then,

$$\phi = \sum_{i=1}^{11} u_i = 909 \qquad (5.7)$$

Then, the selected maintenance reorganization project will be such that:

$$s^* : \quad \phi_{s^*} = \max_{s \in S^*} \{\phi_s\} \qquad (5.8)$$

Unless a budget constraint must be also satisfied. This question will be tackled on methodological grounds at the end of the next chapter.

5.8 Quality Function Deployment Results for Selected Project *s**

From the Quality Function Deployment, after calculating the relative importance weights in the House of Quality, it can be seen which particular technical requirements are important to improve first.

5.8.1 Relative Degrees of Importance

This shows where efforts could be concentrated for organizational quality improvement and the importance of decision making in some of the areas as presented in the graph in figure (5.13). For example, taking the first top four, "new procedures" was determined to be the most important technical requirement at a score of 11.2%. "New skilled manpower" in the second place with 10.8% score. The third most important technical requirement was found out to be "new resources". The fourth quality requirement is "quality standards", and so on. So in order to be able to reduce the major Servicing working time from 6 months to 4 months these areas need to be on the top of the priority of the planners for the stated improvement. These quality characteristics are further discussed below in detail.

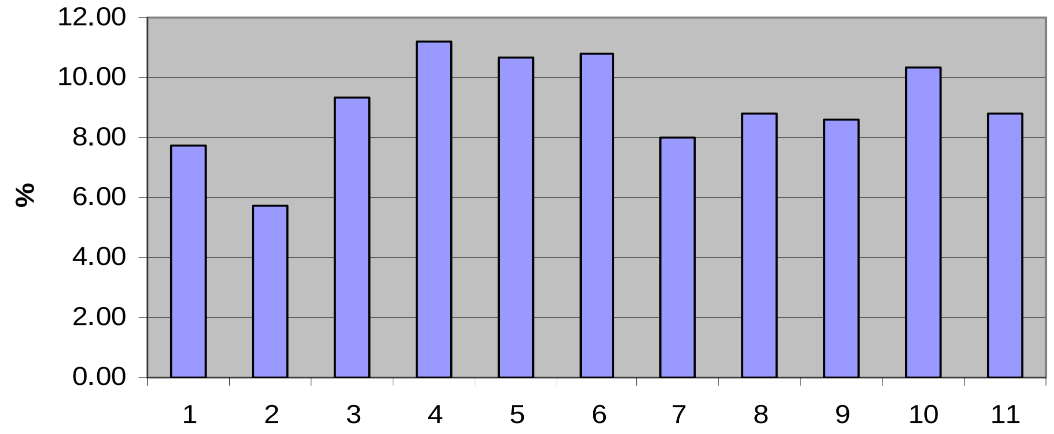


Figure 5.13: Comparison of Relative Weights of Design Requirements

New procedures (requirement 4): This characteristic was determined as the most important technical requirement. The maintenance plan consists of a structured set of tasks that include activities, procedures, resources and time scale required to carry out maintenance. Such tasks require stringent procedures to be in place to handle the different activities. The procedures include maintenance manuals, terms of references and safety precaution procedures. Also, works scheduling and programming such as Gantt charts and Program Evaluation and Review Techniques are important for simplifying the tasks and decision making.

New skilled manpower (requirement 6): In today's aviation maintenance technicians must keep up to date not only with hardware changes but also with the vast body of regulations under which maintenance is performed. For example, Boeing Company estimates that for every hour a plane is in flight, maintenance crews spend about three and a half hours working to maintain it. That is why having qualified workforce in this domain is so important. Nowadays there is scarcity in this field due to the high demand for maintenance qualified personnel.

New resources (requirement 5): This was found out to be in the third place as the most importance technical characteristics. In the maintenance domain, it is rather important to manage the use of resources, and to plan their best utilization. It is also essential to prioritize the available equipment according to the maintenance strategy.

Quality standards (requirement 10): The fourth important issue is quality standards. Therefore, in order to satisfy the customer, the company should meet the required quality standards. This entails having all required standards and procedures such as: safety and quality standards, safety culture awareness, risk management awareness, quality assessments and audits, laid down health and safety at work procedures, safety precautions for all the different anticipated hazards in the work area. Also, certification by quality bodies is important for example, ISO standards, FAA and CAA, and others.

5.8.2 Recommendations from Quality Function Deployment Results

After performing the Quality Function Deployment, and especially the results from the House of Quality and the relative degrees of importance, certain suggestions against the most important issues are proposed in order to achieve the overall objectives of the aircraft maintenance organization. These proposals are as briefly listed below:

New procedures: Having new or revised procedures from time to time is an essential requirement in aircraft maintenance. Aircraft publications, manuals and all relevant documentations are updated through amendments from the manufacturer. New procedures when applied properly no doubt will have an effect in increasing aircraft availability, maintenance reliability, and in meeting new servicing target times. The new procedures should cover all the structured set of tasks which include all activities, procedures, resources and time scale required to carry out maintenance.

New skilled manpower: This can be achieved by having a recruitment system in place to select the appropriate candidates for the job. Further more, personnel continuation development and training career path is needed in the organization to ensure that engineers and technicians are up to date and are equipped with the latest information in their field of specialization. On the other hand, providing a safe working environment and a generous pay and incentive scheme is an attractive media for employees.

New resources: To handle this issue, there exist special techniques to deal with the management of resources such as:

- ⇒ Probabilistic inventory models.
- ⇒ Selective control polices along with some heuristics. This entails the use of a set of procedures to classify items into homogenous groups based on their characteristics. Some of the many selective control procedures are: Pareto analysis, Fast slow and non-moving analysis, and scarce difficult and easy to procedure analysis. Such techniques lead to appropriate heuristics.
- ⇒ Material Requirement Planning/Manufacturing Requirement Planning applied to maintenance. The Material Requirement Planning technique has been used mostly for spare parts procurement in scheduled maintenance.

Quality standards: There is an essential need to apply local and international quality standards and procedures. Also, there is a need to overcome a lot of pressure either organizational or individual in meeting the deadlines in order to have the aircraft maintained on time to the appropriate standards. In addition, special safety and environmental procedures should be in place to deal with some concerning issues such as disposal of hazardous material and consumables, radiation aspects, Non-Destructive Testing, working at height, fatigue, stress and others. Doing this will lead to having satisfied first line department by offering a quality service to the pilots due to the availability of aircraft to fulfill an operational requirement. This further aims to creating a highly motivated workforce that will do the job correctly, first time, every time.

Strategy planning needs to be in place in any organization that is seeking efficiency and productivity. The plan needs to be re-evaluated from time to time; such an update is required in order to meet new organizational needs.

As a general observation, from what has been cited from the aircraft maintenance organization, it is also proposed in general that dual trade system is implemented, by amalgamating airframe trade with the propulsion trade, and armament with electrical and instrument. By doing this, the organization will work on (3) trade system than the previous (5) trade system. This can be implemented by adhering to the following:

- ⇒ Technicians to be cross trained to the appropriate opposite trade
- ⇒ After cross training, technicians to be permitted to carry out tasks to producer level in his non basic trade

Also, as a general point, multi-skilling of technicians can be considered by permitting technicians after a proper training to work on tasks that are generic. For example if an airframe technician is about to work on a task that requires disconnecting of a plug, he does not have to wait for an electrical and instrument technician to come and disconnect such plug for him. This is what is meant by the multi-skilling approach. This can be done by cross training technicians to work on small tasks that are out of boundary of their basic trade.

5.9 Conclusion

The main purpose of this chapter has been to show how the combination of multi criteria analysis of different technical solutions, combined with specific Quality Function Deployment studies, can lead to improved aircraft maintenance effectiveness. This chapter has shown how Quality Function Deployment can provide decisive information complements to overcome the indecision resulting from a situation with non-inferior candidate solutions. This has been illustrated by a practical situation in which decisions had to be taken in order to reduce the duration of the major maintenance visit for a fleet of specific aircraft.

The proposed approach, although complete and coherent, appears to force and may be to deviate in some way the final decision, since only crisp opinions are required at all steps from experts either from the Systems Engineering area or from the Quality Analysis area. Then, in the next chapter, the analysis and decision approach developed here will be extended, using fuzzy modeling, to situations in which expert opinions are expressed in a way where uncertainty remains present so that it can be taken into account explicitly when making decisions.

CHAPTER 6

FUZZY MODELING

AND

QUALITY FUNCTION DEPLOYMENT

6.1 Introduction

Classical Quality Function Deployment analysis makes use of crisp values to describe and process qualitative opinions and this appears a priori not only unnatural but also a possible source of distortion for the final decision making. So it is of utmost interest to get a way to manipulate the qualitative concepts involved with Quality Function Deployment with linguistic terms and qualitative reasoning. Fuzzy Logic appears to provide the tools to help decision-makers to translate and turn feasible linguistic Quality Function Deployment assessments. Some of the more relevant work in this area have been done recently by [Liu,2005], and in this chapter many views adopted come from his work.
In Quality Function Deployment, the input data, such as relative importance of customer attributes, are usually determined by a interdisciplinary team [Akao, 1990]. The interdisciplinary team has to find a consensus about these evaluations through negotiation of trade-offs, based on engineering experience, customer responses, and statistical experiments. Due to imprecise and subjective design information available in the early design stage, it is difficult to assess the performance of a design using classical quantitative values (one real number, a “crisp” value for the evaluation of a given aspect) from each team member. It is more natural to allow team members to describe the performance of each criterion with some linguistic-qualitative terms, such as (*important*, *unimportant*, *very important*, etc). These linguistic terms can be represented with fuzzy set theory and manipulated with fuzzy logic. In this regard, some attempts have already been performed in order to provide a mathematical basis to qualitative reasoning applied to Quality Function Deployment [Chan et al., 1999], [Wang, 1999].

6.2 Introductory Elements about Fuzzy Logic

Fuzzy logic was first introduced by Lotfi Zadeh from the University of California at Berkeley in (1965). Although fuzzy logic formalism and sudsequent technology are relatively new, their use is becoming more and more widely applied. Since (1965) on, many applications of fuzzy logic have been developped leading to important industrial achievements such as in the year (1987), the first subway system in Japan which working under a fuzzy logic-based control system. This project was perceived as a big success and resulted in a fuzzy boom. Industry as well as universities got interest in developing new fuzzy logic based systems. This resulted in what can be seen in today's industry in that almost every intelligent machine has to some extent a fuzzy logic technology inside it. For example fuzzy logic theory is used in automobile and other vehicle subsystems, such as the automatic transmissions and cruise control. It is also used in air conditioners, digital cameras, washing machines and other home appliances, and many other uses. It is worth mentioning that research and development in this domain have been actively progressing along the last decades. In the 80’s, Dubois and Prade from the IRIT research laboratory at Toulouse developped a full Possibilistic Theory from basic fuzzy sets concepts [Dubois and Prade, 1980]. While authors such as Mora-Camino applied with success fuzzy modelling in the field of transportation systems operations and planning [Mora-Camino F. et al., 2004], and in advanced technological fieds such as flight control [Mora-Camino et al., 1995]. Also continuation on fuzzy applications in software, complementary to firmware, including fuzzy expert systems and integration of fuzzy logic with neural-networks and genetic algorithms, with the ultimate goal of building "self-learning" fuzzy control systems.

On the Quality Function Deployment research side, there has been recently an intensive research to develop fuzzy logic related quality analysis and decision techniques and theories. For example [Fung et al.,1998] developed a hybrid system to incorporate the principles of Quality Function Deployment, analytical hierarchy process and fuzzy set theory to deal with a complex and imprecise problems encountered in customer requirement management. They designed an analytical tool for prioritizing the customer requirements. Another interesting one is [Chan et al., 1999] and [Wang, 1999] that considered Quality Function Deployment planning as a multi-criteria decision problem and proposed a fuzzy outranking approach, to prioritize the design requirements identified by a Quality Function Deployment process.
Fuzzy set theory has been developed to meet the objective of solving decision problems in which descriptions of activities, observations, and judgments are by nature subjective, vague and imprecise. The term 'fuzzy' generally refers to the situation where no accurate value can be assigned to a parameter characteristic of some activity or judgment. A classical set is defined by its characteristic function which takes value one inside the set and zero outside the set. Classical set theory cannot be adapted to the imprecise and vague notions that are found in many domains and whose values cannot be summarized to a single number. It is this kind of consideration which has led Zadeh to develop fuzzy set theory as a tool to model and assess the performance of complex systems. The notion of fuzziness is common on the daily life, such as the perceived noise level in a street, the degree of comfort in a room, the food services in restaurants, and so on. Such examples of objects cannot be suitably described by traditional set theory in which an object is either in a set or is not and cannot partially belong to a set, but they can be easily well represented using fuzzy set theory. Annex E presents the basis of Fuzzy Set Theory and Fuzzy Logic.
For example let X be a discrete set of objects, called the universe. A fuzzy set A in X is characterised by a membership function of $\mu_A(x)$ which associates each element in X with a value of interval of [0, 1], and is usually denoted by the set of pairs A= {(x, $\mu_A(x)$), x$\in$ X}. When $\mu_A(x) = 0$, x is absolutely not in A while $\mu_A(x) = 1$ means that x belongs absolutely to the fuzzy set of A. This can be summed up by:

Classical Theory: $$\mu_A(x) = \begin{cases} 1 & if\ x \in A \\ 0 & if\ x \notin A \end{cases} \qquad A \subset X$$

Fuzzy Set Theory: $$\mu_A(x) \in [0,1] \quad \forall\, x \in A \qquad (6.1)$$

The use of the interval [0, 1] provides a convenient domain for continuous gradation. It should be noted that in general precise membership values do not exist and are usually subjectively assessed or assigned in each context. For more details on fuzzy set theory refer to Annex E. Figure (6.1) displays comparatively the representation of complementary linguistic variables such as “low” and “high” using either classical logic or fuzzy logic.

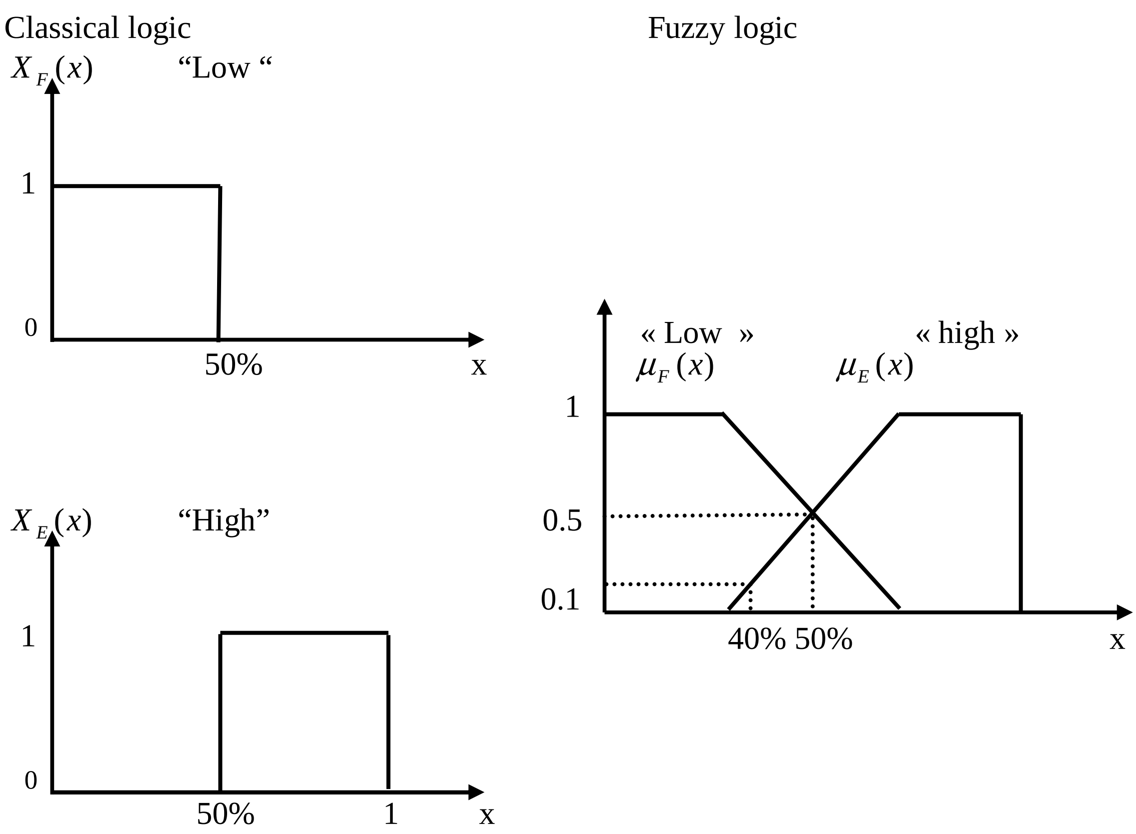


Figure 6.1: Comparison between Logic and Fuzzy Logic Representations of Linguistic Variables

6.3 Fuzzy Representation of Linguistic Variables

Fuzzy logic is known to deal efficiently with linguistic, vague, and uncertain data. Its use in many applications has been justified by this property. Linguistic terms are commonly used in Quality Function Deployment processes [Shiang-Tai Liu, 2005]. The adopted linguistic terms can be named differently depending on the choice of the person or the team designing the Quality Function Deployment. Then, the wording will be different from one Quality Function Deployment study to another. In general, however, these terms will look quite similar. Moreover, within the framework of fuzzy set theory, instead of assigning discrete values as ratings (for example ratings from 1 to 9 to represent the assessments of customer needs from 'very unimportant' to 'very important'); these ratings will be expressed as fuzzy sets (for the previous example, from $M_1 = \text{'}approximately 1\text{'}$ *to* M_{10} = 'approximately 10') in order to take into account the imprecision of people's qualitative assessments. These fuzzy sets can be specified as suitable trapezoidal or triangular fuzzy numbers. In this chapter, triangular fuzzy numbers will be adopted; they are represented in figure (6.2). Triangular fuzzy sets bring the desired property of fuzzy sets but limit the number of parameters to describe them to three.

Very Unimportant	unimportant	Medium	Important	Very Important

$M_0 -- M_1 -- M_2 -- M_3 -- M_4 -- M_5 -- M_6 -- M_7 -- M_8 -- M_9 -- M_{10}$

[0,0,1] [0,1,2] [1,2,3] [2,3,4] [3,4,5] [4,5,6] [5,6,7] [6,7,8] [7,8,9] [8,9,10] [9,10,10]

Figure 6.2: Linguistic and Fuzzy Description of the "Level of Importance"

After assigning fuzzy numbers, the corresponding membership functions can be obtained as represented in figure (6.3).

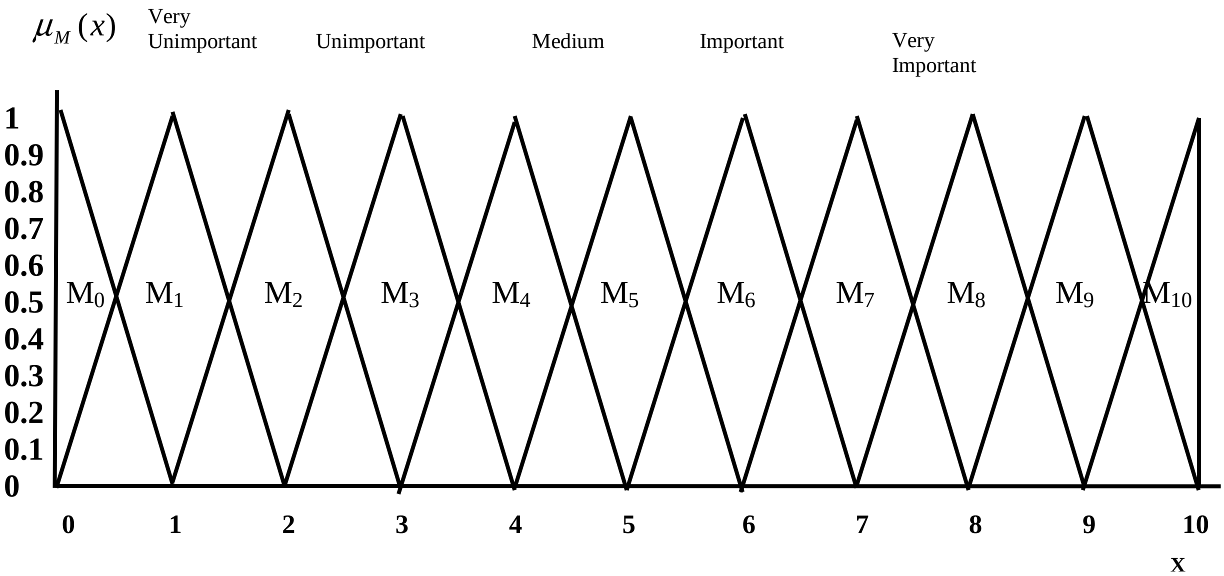


Figure 6.3: Associated Membership Functions
($M_0 =' approximately\ 0\ '$ *to* $M_{10} =' approximately 10'$ **)**

Therefore, let *x* be a variable whose value is to be assessed over a universe *U*. A fuzzy subset *A* of *U* is defined by a given application μ_A from *U* to the real interval [0, 1]. For every $x \in U$ a value $\mu_A(x)$ is associated where:

$$0 \le \mu_A(x) \le 1 \qquad (6.1)$$

Function μ_A is called the "membership function" of the fuzzy set *A*. For each element in $x \in U$, the value $\mu_A(x)$ is not necessary equal to 0 or 1, and it is called the membership degree to *A*: $\mu_A(x) = 0$ means x definitely does not belong to *A*, meaning that x does not satisfy at all the vague property of *A*.
For example let consider the fuzzy set *A* in R^2 which is supposed to represent a temperature critical area within an engine part during a maintenance test:

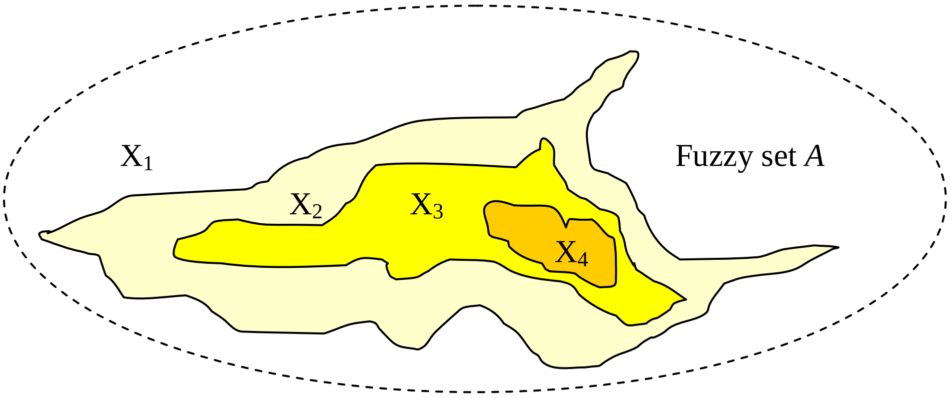


Figure 6.4: Example of Fuzzy Set

Here we have for instance: $\mu_A(X_1)=0$, $\mu_A(X_2)=0.35$, $\mu_A(X_3)=0.70$ and $\mu_A(X_4)=1$.

6.4 Fuzzy Weighted Averages

When the relative weight of customer attributes and the relationship measure between customers' attributes and design requirements are represented as fuzzy numbers, the calculation of the technical importance of the design requirement falls into the category of fuzzy weighted averages. In this section we will develop a method to compute fuzzy averages as an extension of classical Quality Function Deployment.

6.4.1 Fuzzy representation of knowledge about the process to be improved

Let $\tilde{W}_i = \{w\mu_{\tilde{w}_i}(w_i) | w_i \in W\}$ denote the fuzzy relative weight of customer attribute *i*, and $\tilde{X}_{ij} = \{x_{ij}, \mu_{\tilde{x}_{ij}}(x_{ij}) | x_{ij} \in X\}$ denote the fuzzy relationship measure between customer attribute *i* and design requirement *j*, where *W* and *X* are, respectively, the crisp sets of the possible values for the relative weights and the relationship measures. Here $\mu_{\tilde{w}_i}$ and $\mu_{\tilde{x}_{ij_i}}$ are respectively the membership functions of the fuzzy numbers $\tilde{W}_i$ and $\tilde{X}_{ij}$.

Often there is some correlation between different design requirements and it is necessary to take into account the degrees of dependence between design requirements. Writing D_{kj} the degree of correlation between the k^{th} design requirement and the j^{th} design requirement, then [Fung et al., 2002], and [Tang et al., 2002], it is useful to introduce:

$$\tilde{X}^*_{ij} = \sum_{k=1}^{n} \tilde{X}_{ik} D_{kj}, \tag{6.2}$$

where $\tilde{X}^*_{ij}$ is the actual relationship measure after consideration of the correlation between the design requirements. Note that the correlation matrix *D* is a symmetric matrix. Naturally a design requirement has the strongest dependence on itself, i.e. D_{jj} is assigned to be 1. If there is no dependence between the k^{th} and the j^{th} design requirements, then $D_{kj} = 0$.

Even it appears also natural to assign a fuzzy number to the dependence degree between two design requirements. In that case matrix D becomes a fuzzy matrix $\tilde{D}$ and we have:

$$\tilde{X}_{ij}^* = \sum_{k=1}^{n} \tilde{X}_{ik} \tilde{D}_{kj} \qquad (6.3)$$

6.4.2 Technical importance of a design requirement

Considering *m* customer attributes and *n* design requirements, the technical importance of the design requirement *j* is defined as:

$$\tilde{Y}_j = \sum_{i=1}^{m} \tilde{W}_i \tilde{X}_{ij}^* / \sum_{i=1}^{m} \tilde{W}_i \qquad j = 1,\dots,n, \qquad (6.4)$$

where $\tilde{Y}_j$ is also a fuzzy number.

To simplify the computation of the technical importance of the design requirements, it could be assumed, like in [Chan et al., 1999], that $\sum_{i=1}^{m} \tilde{W}_i$ is equal to 1; however here $\sum_{i=1}^{m} \tilde{W}_i$ will remain to be considered a fuzzy number.

There are several methods to compute fuzzy weighted averages [Lee and Park 1997], [Kao and Liu 2001]). One of the more effective is the one proposed by [Kao and Liu, 2001] which is as follows:

Define the α-cuts of $\tilde{W}_i$ and $\tilde{X}_{ij}$, with $0 \le \alpha \le 1$, as:

$$(W_i)_\alpha = \{w_i \in W_i \mid \mu_{\tilde{W}_i}(w_i) \ge \alpha\} \forall i \qquad (6\text{-}5\text{-}a)$$

$$(X_{ij}^*)_\alpha = \{x_{ij}^* \in X_{ij}^* \mid \mu_{\tilde{X}_{ij}^*}(x_{ij}^*) \ge \alpha\}, \forall i, j \qquad (6\text{-}5\text{-}b)$$

where $(W_i)_\alpha$ is the interval with the lower bound $(W_i)_\alpha^L$ and upper bound $(W_i)_\alpha^U$ at the α-level. Similarly, $(X_{ij}^*)_\alpha$ is the interval bounded by $(X_{ij}^*)_\alpha^L$ and $(W_i)_\alpha^U$ for α. Figure (6.5) illustrate α-cuts for triangular fuzzy sets.

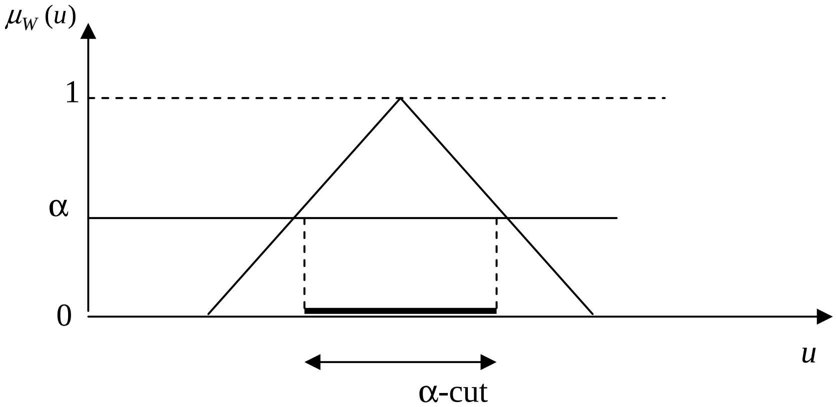


Figure 6.5: Illustration of α-Cuts

They can also be expressed in another form:

$$(W_i)_\alpha = \left[(W_i)^L_\alpha, (W_i)^U_\alpha\right] = \left[\min_{w_i}\left\{w_i \in W_i / \mu_{\tilde{w}_i}(w_i) \geq \alpha\right\}, \max_{w_i}\left\{w_i \in W_i / \mu_{\tilde{w}_i}(w_i) \geq \alpha\right\}\right] \quad (6.6\text{-a})$$

$$(X^*_{ij})_\alpha = \left[(X^*_{ij})^L_\alpha, (X^*_{ij})^U_\alpha\right] = \left[\min_{x^*_{ij}}\left\{x^*_{ij} \in X^*_{ij} / \mu_{\tilde{X}^*_{ij}}(x^*_{ij}) \geq \alpha\right\}, \max_{x^*_{ij}}\left\{x^*_{ij} \in X^*_{ij} / \mu_{\tilde{X}^*_{ij}}(x^*_{ij}) \geq \alpha\right\}\right] \quad (6.6\text{-b})$$

These intervals indicate where the relative weight of customer attributes and the relationship between the customer attributes and the design requirements lay at possibility level α.

According to Zadeh's extension principle [Zadeh, 1978], the membership function $\mu_{\tilde{Y}_i}$ can be derived from the following equation:

$$\mu_j(y_j) = \sup_{x^*, w} \min\left\{\mu_{\tilde{w}_i}(w_i), \mu_{\tilde{x}^*_{ij}}(x^*_{ij}), \forall i, \middle| y_j = \sum_{i=1}^{m} w_i x^*_{ij}\right\} \quad (6.7)$$

6.4.3 Computation of the Membership Function for the Technical Importance of a Requirement

At a specific α-level of $\tilde{Y}_j$, equation (6.7) states that one needs:

$$\mu_{\tilde{w}_i}(w_i) \geq \alpha \text{ and } \mu_{\tilde{X}^*_{ij}}(x^*_{ij}) \geq \alpha, \forall\, i, j \quad (6.8)$$

and at least one $\mu_{\tilde{w}_i}(w_i)$ or $\mu_{\tilde{X}^*_{ij}}(x^*_{ij})$ equal to α such that:

$$\mu_{\tilde{y}_j}\left(\sum_{i=1}^{m} w_i x^*_{ij} / \sum_{i=1}^{m} w_i\right) = \alpha \quad (6.9)$$

with

$$y_j = \sum_{i=1}^{m} w_i x^*_{ij} / \sum_{i=1}^{m} w_i \quad (6.10)$$

To find the membership function $\mu_{\tilde{y}_j}$, it is sufficient to find the right and left shape functions of $\mu_{\tilde{y}_j}$. This is equivalent to find the upper bound $(Y_j)^U_\alpha$ and lower bound $(Y_j)^L_\alpha$ of $\tilde{Y}_j$ at the α-level with a changing α value. Since $(Y_j)^U_\alpha$ is the maximum of $\sum_{i=1}^{m} w_i x^*_{ij} / \sum_{i=1}^{m} w_i$ and $(Y_j)^L_\alpha$ is the minimum of $\sum_{i=1}^{m} w_i x^*_{ij} / \sum_{i=1}^{m} w_i$, the upper and lower bounds of the α -cut of $\tilde{Y}_j$ can be obtained as solutions of:

$$(Y_j)^U_\alpha = \max \sum_{i=1}^{m} w_i x^*_{ij} / \sum_{i=1}^{m} w_i \quad (6.11\text{-a})$$

with

$$\left.\begin{array}{l}(W_i)_\alpha^L \le w_i \le (W_i)_\alpha^U, i = 1,..., m \\ (X_{ij}^*)_\alpha^L \le x_{ij}^* \le (X_{ij}^*)_\alpha^U, i = 1,..., m\end{array}\right\} \quad (6.12)$$

and of:

$$(Y_j)_\alpha^L = \min \sum_{i=1}^m w_i x_{ij}^* / \sum_{i=1}^m w_i \quad (6.11\text{-b})$$

under constraints (6.12).

By intuition, the maximum of y_j happens at $(X_{ij}^*)_\alpha^U$ and the minimum of y_j happens at $(X_{ij}^*)_\alpha^L$. Thus, the variable x_{ij}^* in the objective functions (6.11-a) and (6.11-b) can be replaced respectively by $(X_{ij}^*)_\alpha^U$ and $(X_{ij}^*)_\alpha^L$ and the constraints $(X_{ij}^*)_\alpha^L \le x_{ij}^* \le (X_{ij}^*)_\alpha^U$, $i = 1,..., m, j = 1,..., n,$ can be deleted from both optimization problems.
Following the variable transformation of [Charnes and Cooper, 1962]:

$$t = 1/\sum_{i=1}^m w_i \quad \text{and} \quad v_i = tw_i \quad (6.13)$$

problems (6.11-a) with (6.12) and (6.11-b) with (6.12) can be transformed to the conventional linear programming problems of the following forms:

$$(Y_j)_\alpha^U = \max \sum_{i=1}^m v_i (X_{ij}^*)_\alpha^U \quad (6.14\text{-a})$$

under

$$\left.\begin{array}{l}t(W_i)_\alpha^L \le v_i \le t(W_i)_\alpha^U, i = 1,..., m \\ \sum_{i=1}^m v_i = 1 \\ t, v_i \ge 0\end{array}\right\} \quad (6.15)$$

and

$$(Y_j)_\alpha^L = \min \sum_{i=1}^m v_i (X_{ij}^*)_\alpha^L \quad (6.14\text{-b})$$

under constraints (6.15).

The α-cuts of $\tilde{Y}_j$ is the crisp interval $[(Y_j)_\alpha^L, (Y_j)_\alpha^U]$ solved from problems (6.11-a) with (6.15) and (6.11-b) with (6.15).
By enumerating different values of α, the membership function $\mu_{\tilde{y}_j}$ can be constructed progressively. For two possibility levels α_1 and α_2 such that:

$$0 < \alpha_2 < \alpha_1 \le 1 \quad (6.16)$$

The feasible regions defined by α_1 are smaller than those defined by α_2. Consequently:

$$0 < \alpha_2 < \alpha_1 \leq 1 \Rightarrow (Y_j)^U_\alpha \leq (Y_j)^U_{\alpha_2} \text{ and } (Y_j)^L_\alpha \geq (Y_j)^L_{\alpha_2} \tag{6.17}$$

In fact, the right shape function is non-increasing and the left shape function is non-decreasing. This property, based on the definition of 'convex fuzzy sets' [Zimmermann, 1996], assures the convexity of $\tilde{Y}_j$. If both $(Y_j)^U_\alpha$ and $(Y_j)^L_\alpha$ are invertible with respect to α, then a right shape function $R(y_j)$ and a left shape function $L(y_j)$ can be obtained. From $R(y_j)$ and $L(y_j)$, the membership function $\mu_{\tilde{Y}_l}$ is constructed as:

$$\mu_{\tilde{Y}_j} = \begin{cases} L(y_j), & (Y_j)^L_{\alpha=0} \leq y_j \leq (Y_j)^L_{\alpha=1} \\ 1, & (Y_j)^L_{\alpha=1} \leq y_j \leq (Y_j)^U_{\alpha=1} \\ R(y_j), & (Y_j)^U_{\alpha=1} \leq y_j \leq (Y_j)^U_{\alpha=0} \end{cases} \tag{6.18}$$

In most cases, $(Y_j)^U_\alpha$ and $(Y_j)^L_\alpha$ cannot be solved analytically. Similar to the other calculation methods [Dong and Wong, 1987], [Liou and Wang, 1992], [Lee and Park, 1997], the numerical solutions for $(Y_j)^U_\alpha$ and $(Y_j)^L_\alpha$ at different possibility α-levels can be collected to approximate the shapes of $R(y_j)$ and $L(y_j)$. Notably, [Kao and Liu ,2001] have shown that the membership function of the weighted average could be nonlinear, while the relative weights of the customer attributes and the relationship between customers attributes and design requirements have all linear membership functions.

6.5 Utility Based Fuzzy Ranking Method

Via problems (6.14-a) with (6.15) and (6.14-b) with (6.15), the technical importance of the design requirements can be calculated in fuzzy terms. Here we propose an approach to rank the different technical requirements once the degree of importance of a technical requirement has been established in fuzzy terms.

6.5.1 Utility of a Technical Requirement

Most of the existing fuzzy ranking methods [Yager, 1981], [Choobineh and Li, 1993], [Modarres and Sadi-Nezhad, 2001], [Tran and Duckstein, 2002] are based on area measurements, which requires the exact forms of the membership functions of fuzzy numbers to be ranked. It appears that it is not only an empirical approach but also that it results in a rather tedious computational process. Moreover, these approaches cannot be applied if the membership functions of the concerned fuzzy numbers are not explicitly known. Here we consider a technique, based on the method of [Chen, 1985], which avoids this difficulty by considering the maximizing and minimizing sets which will help to catch in some way the left and the right trends of the concerned fuzzy evaluation.

Denote:

$$S_j = \{ z \mid \mu_{\tilde{y}_j}(z) > 0 \}, \quad S = \cup_{j=1}^n S_j, \quad z_{\min} = \inf S \quad \text{and} \quad z_{\max} = \sup S \tag{6.19}$$

The fuzzy maximizing set *M* of order *k* is a fuzzy set with the following membership function [Chen, 1985] (see also figure 6.6):

$$\mu_M(z) = \begin{cases} \left[(z - z_{\min})/(z_{\max} - z_{\min})\right]^k & , \quad z_{\min} \le z \le z_{\max} \\ 0, & \textit{Otherwise} \end{cases} \qquad (6.20)$$

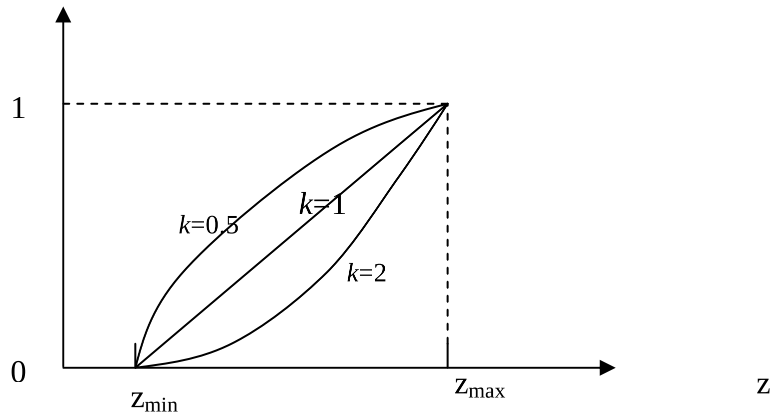


Figure 6.6: Different Maximizing Fuzzy Sets for the Left Shape
(*k*=0.5, 1 and 2)

For k>1, the membership value increases faster than proportional, indicating that the decision maker has an adventurous character. For k<1, the membership value increases slower than proportional, indicating that the decision-maker possesses a conservative preference. [Chen et al., 1992] recommended to adopt k =1, value which has been adopted in the present study.
From $\mu_{\tilde{y}_j}$ and μ_M, the right utility of the fuzzy technical importance of the design requirement $\tilde{Y}_j$ is defined as [Chen, 1985]:

$$U_M(j) = \sup_z(\min\{\mu_{\tilde{y}_j}(z), \mu_M(z)\}) \qquad (6.21)$$

The maximizing set M and the right utility U_M are used to measure the right trend of a fuzzy number.
In the same way, we can define the membership function of order *k* for the minimizing set G and the left utility $U_G(j)$ as:

$$\mu_G(z) = \begin{cases} \left[(z_{\max} - z)/(z_{\max} - z_{\min})\right]^k & , \quad z_{\min} \le z \le z_{\max} \\ 0, & \textit{Otherwise} \end{cases} \qquad (6.22)$$

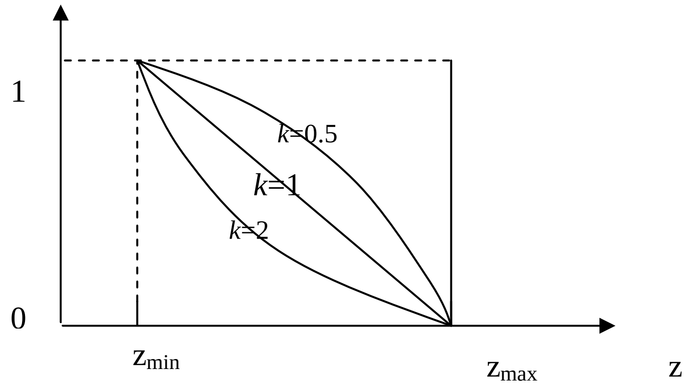


Figure 6.7: Different Maximizing Fuzzy Sets for Right Shape
(*k*=0.5, 1 and 2)

and

$$U_G(j) = \sup_z (\min \{\mu_{\tilde{y}_j}(z), \mu_G(z)\}) \qquad (6.23)$$

The minimizing set G and the left utility U_G are used to measure the left trend of a fuzzy number. Combining the right and left utilities, one derives the total utility $U_T(j)$ of each fuzzy technical importance of the design requirement $\tilde{Y}_j$. In [Chen, 1985] the proposed empirical formula is as follows:

$$U_T(j) = [U_M(j) + 1 - U_G(j)]/2. \qquad (6.24)$$

another possibility could be:

$$U_T(j) = (a + U_M(j))/(a + U_G(j)) \qquad (6.25)$$

where a is a real positive parameter. What is important here is that we get a unique number to characterise the design requirement and that is quite useful for ranking.
Ranking the fuzzy technical importance of the design requirement $\tilde{Y}_j$ is then based on their corresponding total utility values $U_T(j)$.

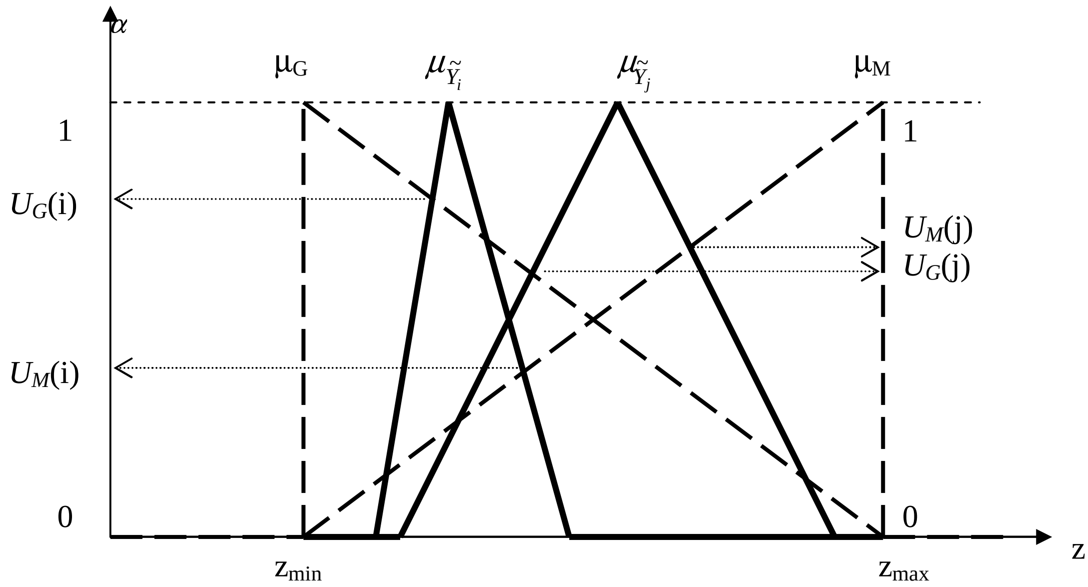


Figure 6.8: Right and Left Utilities of Design Requirements (*k*=1)

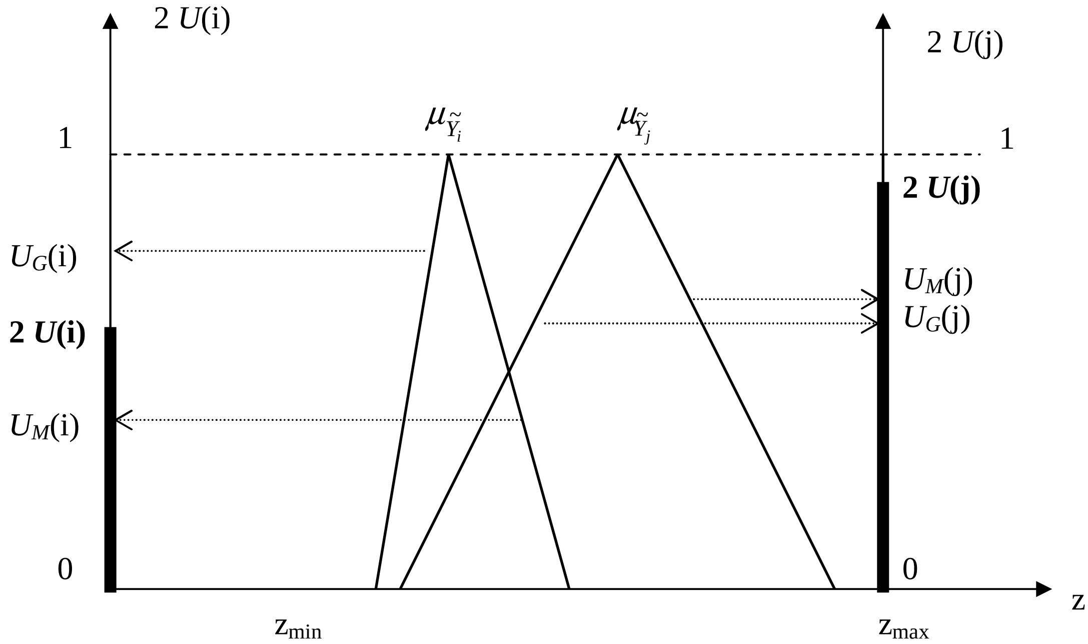


Figure 6.9: Total Utilities of Design Requirements (*k*=1)

In the case of figures (6.8) and (6.9), it is clear that the utility of technical requirement *j* is higher than the one of technical requirement *i*.

6.5.2 Computation of the Utility of a Given Design Requirement

To calculate the total utility $U_T(j)$, the exact form of membership function $\mu_{\tilde{y}_j}$ is required. However, a proper substitution can avoid this requirement. According to (6.20), $\mu_M(z)$ is a left triangle increasing from 0 to 1 in the domain of $z_{\min}$ and $z_{\max}$.

In general, it intersects each $\mu_{\tilde{y}_j}$ at two points, one at the right shape function and the other at the left shape function of $\mu_{\tilde{y}_j}(z)$.

From (6.20), $U_M(j) = \sup_z \min\{\mu_{\tilde{y}_j}(z)\}$ is the right intersection point of $\mu_{\tilde{y}_j}$ and μ_M. Let α_M denote the α-level for $\mu_M(z)$. Taking the inverse function of $\mu_M(z)$ in (6.20) derives $z = z_{\min} + (z_{\max} - z_{\min})\alpha_M$. Then $U_M(j)$ is the maximum of the minimum of $\mu_{\tilde{y}_j}(z)$ and $\mu_M(z)$ with respect to z. It occurs at a value z, such that $\mu_{\tilde{y}_j}(z) = \mu_M(z)$ on the right shape function of $\mu_{\tilde{y}_j}(z)$. From problem (6.14-a) with (6.15), for calculating the right shape function of $\mu_{\tilde{y}_j}$, the above idea can be formulated as the following nonlinear program:

$$z = \max \sum_{i=1}^{m} v_i (X_{ij}^*)_{\alpha_M}^U \tag{6.26}$$

with

$$\left.\begin{array}{l} \sum_{i=1}^{m} v_i (X_{ij}^*)_{\alpha_M}^U = Z_{\min} + (z_{\max} - z_{\min})\alpha_M \\ t.(W_i)_{\alpha_M}^L \le v_i \le t(W_i)_{\alpha_M}^U, \; i = 1,\dots,m \\ \sum_{i=1}^{m} v_i = 1 \\ t, v_i \ge 0 \qquad 0 \le \alpha_M \le 1 \end{array}\right\} \tag{6.27}$$

This program is similar to problem (6.14-a) with (6.15) only adding one constraint to force the equality of $\mu_{\tilde{y}_j}(z)$ and $\mu_M(z)$, and a new variable α_M is introduced. When the variable α_M is set to a specific value, the objective function of problem (6.14-a) with (6.15) is linear and the feasible region defined by its constraints is a convex set. Then, there exists a global optimum solution for (6.26) with (6.27) if α_M is specified. Fortunately, since μ_M is strictly decreasing and the right shape function of $\mu_{\tilde{y}_j}$ is non-increasing, there is only one intersection point. Then problem (6.26) with (6.27) has only one feasible point which is of course the global optimum solution. From figure 6.8, it is clear that only when α_M is equal to the α value of the intersection of μ_M and of the right shape function of $\mu_{\tilde{y}_i}$, which is $U_M(j)$, the problem will have a feasible solution. If k ≠ 1 is chosen in (6.20), then a simple variable substitution of $(\alpha_M)^{1/k} = \hat{\alpha}_M$ indicates that the k^{th} power of the solution of problem (6.26) with (6.27) will be the solution for α_M.

In the same way, let a new variable α_G denote the α-level for $\mu_G(z)$. Finding $U_G(j)$, the supreme of the minimum of $\mu_{\tilde{y}_j}(z)$ and $\mu_G(z)$ with respect to z, is equivalent to finding the value z such that $\mu_{\tilde{y}_j}(z) = \mu_G(z)$ on the left shape function of $\mu_{\tilde{y}_j}$, which, according to problem (6.14-b) with (6.16), can be formulated as:

$$z = \max \sum_{i=1}^{m} v_i (X_{ij}^*)_{\alpha_G}^L \qquad (6.28)$$

under

$$\left.\begin{aligned} &\sum_{i=1}^{m} v_i (X_{ij}^*)_{\alpha_G}^L = z_{\max} + (z_{\max} - z_{\min})\alpha_G \\ &t.(W_i)_{\alpha_G}^L \le v_i \le t(W_i)_{\alpha_G}^U, i = 1,...,m \\ &\sum_{i=1}^{m} v_i = 1 \\ &t, v_i \ge 0 \qquad 0 \le \alpha_G \le 1 \end{aligned}\right\} \qquad (6.29)$$

Here also this problem has only one feasible solution, happening at the intersection of μ_G and the left shape function of $\mu_{\tilde{y}_j}$ .If $k \neq 1$ is chosen for relation (6.22), then a simple variable substitution of $(\alpha_G)^{1/k}$ by $\hat{\alpha}_G$ can be employed to derive α_G. The optimal solutions α_M and α_G of respectively problem (6.26) with (6.27) and of problem (6.28) with (6.29) allow to derive from equation (6.24) the total utility $U_T(j)$ of the design requirement *j* of technical importance $\tilde{Y}_j$ which can be used for ranking. Then let $r_j \in N$, be the ranking of design requirement j, we have:

$$if \quad U_T(i) > U_T(j) \quad \Rightarrow \quad r_i > r_j \quad i, j = 1 \quad to \quad n \qquad (6.30)$$

If $U_T(i) = U_T(j)$, another criteria must be introduced to get a complete ranking of the different design requirements. A natural candidate is the cost associated with the implementation of a given design requirement.

Based on the derived ranking result, the design team can purposefully design and develop a product to achieve higher customer satisfaction and thus more competitive advantage.

6.6 Analysis of Selection Methods

Theoretically, a business sector should satisfy all the customer requirements in product design without considering the resource constraints. Nevertheless, the resource availability to meet the product design is impossible to be infinite. Therefore, we need to consider at least the budget factor.

Here we suppose for simplicity and to take profit of the previous ranking developments, that the utility provided by a set of design requirements is the sum of their utilities:

$$U(\{i, j, k, l\}) = U(i) + U(j) + U(k) + U(l) \quad \forall\, i, j, k, l \qquad (6.31)$$

Then, if we assume that a design requirement *j* must be implemented in single piece, without considering possible different degrees of achievement, let *Cj* be its cost and let C be the total available resource. The following knapsack problem [Bernhard Korte et al., 2005] can be stated:

$$\max_{\underline{x}} \quad \sum_{j=1}^{n} U(j)\, x_j \qquad (6.32)$$

with

$$\sum_{j=1}^{n} C_j \; x_j \le C \qquad (6.33)$$

where

$x_j = 1$ if design requirement j is selected and $x_j = 0$ otherwise. (6.34)

Following the idea of [Bode and Fung, 1998], when the budget is limited, one can first allocate the budget to the top ranking design requirement $j*$ given by:

$$U(j^*) = \max_{j=1\ to\ n} U(j) \qquad (6.35)$$

until its target is met. The next highest ranking design requirement will be assigned afterward and so on until the budget is exhausted.
However this approach is in general not optimal and may lead to overlook a better combination of design requirements.
Another empirical approach, which as an heuristic character is such as:

- First to compute effectiveness indexes such as:

$$e_j = U(j)/C_j \quad j = 1\ to\ n \qquad (6.36)$$

- Then to rank the different design requirements according to decreasing effectiveness indexes.
- Finally the previous selection process is adopted.

In general this method should provide better results than the first one; however it is still very possible that the optimal solution is here again overlooked.
In fact, problem (6.32) with (6.33) and (6.34) is known to be a combinatorial problem of the NP-Complex class of complexity [Mora-Camino, 2003]. But since in general the number of candidate design requirements is rather limited, an exact solution technique, such as Dynamic Programming [Bertsekas, 1995] can be adopted to solve it.
Note here that, since in this case exact solution methods should be feasible from the computational point of view, other approaches dealing directly with the fuzzy representation of the importance of the design requirement could be considered [Hussein et al., 1993].
It is quite unlikely that any design requirement will be completely abandoned for budget reasons. So, in the case in which there can be different degrees of achievement of a same design requirement j, $d = 1$ to D_j, the utility of each level of achievement of design requirement j, $U(j,d)$, should be computed and the corresponding costs, C_{jd}, should be taken into account. The resulting optimisation problem becomes:

$$\max_{\underline{x}} \quad \sum_{j=1}^{n}\sum_{d=1}^{D_j} U(j,d)\, x_{jd} \tag{6.37}$$

with

$$\sum_{j=1}^{n}\sum_{d=1}^{D_j} C_j \; x_{jd} \le C \tag{6.38}$$

and

$$\sum_{d=1}^{D_j} x_{jd} \le 1 \quad j = 1\, to\; n \tag{6.39}$$

where

x_{jd} =1 if design requirement j is selected
with degree of achievement d and x_j = 0 otherwise. (6.40)

Here also, different approximate solution methods can be considered, but in that case the exact approach becomes much more demanding in computational terms.

6.7 Conclusion

Fuzzy set theory is well adapted to describe and process approximate or imprecise information, many times given through linguistic variables. And in many complex situations, this is exactly the language used by experts to provide their assessments and opinions. From a set of approximate data, given by intervals, or a set of linguistic evaluations, it is easy to produce a set of describing fuzzy sets which can be processed, compared and ranked. Then, the whole Quality function Deployment process can be realized using fuzzy representation, leading at the end to the ranking of candidate design requirements. Since this processing is in no mean heavy, many scenarios or degree of detail of design requirements (possible degrees of achievement) can be considered and assessed, so that the best solution can be identified.

CHAPTER 7

ILLUSTRATION OF FUZZY QUALITY FUNCTION DEPLOYMENT

7.1 Introduction

The objective of this chapter is to illustrate the method which has been proposed in chapter 6 to develop a fuzzy approach for Quality Function Deployment. It appears of interest to take into account the uncertainties present in the experts' opinions, this has led to adopt triangular fuzzy numbers to quantify the customers' objectives and their relations with the candidate design requirements.
Here we consider two situations:

- one in which uncertainty degrees are assigned arbitrarily to the crisp opinions of experts, this results in processing what is called "uniform fuzzy numbers". Then the solution is quite near the solution of the crisp one, providing an image of the uncertainty of the final result;
- one in which the uncertainty which is processed is the one expressed effectively by the experts with respect to each parameter.

The formalism of the process is enhanced by introducing new classes of fuzzy numbers and by selecting the basic fuzzy operations which will be used in the resulting fuzzy calculus.

7. 2 Definitions and Notations

Consider triangular fuzzy numbers δ_i given by the triplet $(\alpha_i, \beta_i, \gamma_i)$ such as in figure (7.1):

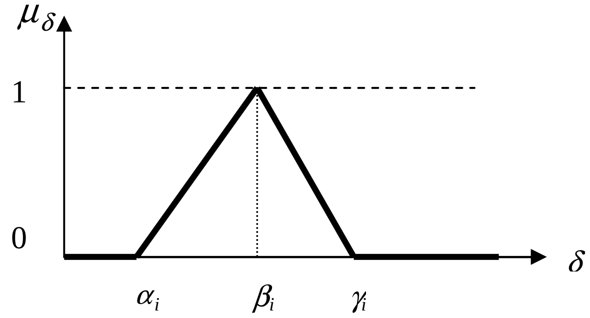


Figure 7.1: Triangular Fuzzy Number Representation

where:

$$(\alpha_i, \beta_i, \gamma_i) \in R^3 \text{ and } \alpha_i \le \beta_i \le \gamma_i \text{ with } \mu_\delta(\beta_i) = 1 \qquad (7.1)$$

Observed that this class of triangular fuzzy numbers can be called the class of "quasi real numbers" since given one of them, δ, there exists only one value of $x \in R$ such that $\mu_\delta(x) = 1$.
From figure (7.1) it can be seen that (α_i, γ_i) is the base of the fuzzy number and β_i is its more plausible value.
We adopt here as "addition" over these quasi real numbers, the operation ⊕ such as:

$$\forall \ (\alpha_i, \beta_i, \gamma_i) \in R^3 \text{ and } \forall (\alpha_j, \beta_j, \gamma_j) \in R^3 :$$

$$(\alpha_i, \beta_i, \gamma_i) \oplus (\alpha_j, \beta_j, \gamma_j) = ((\beta_i + \beta_j + \alpha_i + \alpha_j)/2, \beta_i + \beta_j, (\beta_i + \beta_j + \gamma_i + \gamma_j)/2) \qquad (7.2)$$

Example: (2,3,4) ⊕ (4,6,7) = (7.5, 9,10)

This choice makes arithmetic average of the left and right uncertainties of the two fuzzy numbers which are summed up. Other choices such as:

$$(\alpha_i, \beta_i, \gamma_i) \tilde{+} (\alpha_j, \beta_j, \gamma_j) = (\alpha_i + \alpha_j, \beta_i + \beta_j, \gamma_i + \gamma_j) \tag{7.3}$$

$$(\alpha_i, \beta_i, \gamma_i) \tilde{\oplus} (\alpha_j, \beta_j, \gamma_j) = (\beta_i + \beta_j - \min\{\beta_i - \alpha_i, \beta_j - \alpha_j\}, \beta_i + \beta_j, (\beta_i + \beta_j + \min\{\gamma_i - \beta_i, \gamma_j - \beta_j\}) \tag{7.4}$$

which in the first case (equation 7.3) can be called “pessimistic” and in the second case (equation 7.4) can be called “optimistic”, could have been done.

With respect to the multiplication between fuzzy numbers we adopt here the following definition:

$$\forall\ (\alpha_i, \beta_i, \gamma_i) \in R^3 \text{ and } \forall\ (\alpha_j, \beta_j, \gamma_j) \in R^3$$
$$(\alpha_i, \beta_i, \gamma_i) \otimes (\alpha_j, \beta_j, \gamma_j) = (\alpha_i.\alpha_j, \beta_i.\beta_j, \gamma_i.\gamma_j) \tag{7.5}$$

Example: (2,3,4) ⊗(4,6,7) = (8, 18, 28)

Other definitions could have been such as:

$$(\alpha_i, \beta_i, \gamma_i) \tilde{\times} (\alpha_j, \beta_j, \gamma_j) = (\beta_i\beta_j - \min\{\beta_i - \alpha_i, \beta_j - \alpha_j\}, \beta_i.\beta_j, \beta_i\beta_j + \min\{\gamma_i - \beta_i, \gamma_j - \gamma_i\}) \tag{7.6}$$

$$(\alpha_i, \beta_i, \gamma_i) \tilde{\otimes} (\alpha_j, \beta_j, \gamma_j) = (\beta_i\beta_j - (\beta_i - \alpha_i + \beta_j - \alpha_j)/2, \beta_i\beta_j, \beta_i\beta_j + (\gamma_i - \beta_i + \gamma_j - \beta_j)/2) \tag{7.7}$$

The first case (equation 7.6) can be termed “very optimistic”, while the second case (equation 7.7) can be termed “rather optimistic”.

So to perform the evaluation associated to the House of Quality in the Quality Function Deployment approach, the quantities:

$$\tilde{U}(j) = \underset{\text{"whats"}i}{\tilde{\oplus}} (\tilde{\pi}_i \tilde{\otimes} \tilde{h}_{ij}) \qquad j = 1 \text{ to } n \tag{7.8}$$

and

$$\phi = \underset{\text{"hows"}j}{\tilde{\oplus}} (\underset{\text{"whats"}i}{\tilde{\oplus}} \pi_i \tilde{\otimes} h_{ij}) \tag{7.9}$$

should be computed.

7.3 First Illustration of Fuzzy Quality Function Deployment

In this section, we illustrate the fuzzy approach for Quality Function Deployment proposed in chapter (6) in the case in which the degrees of importance of the "whats" and the connection measure between the "whats" (customer attributes) and the "hows" (design requirements), are such that the degree of uncertainty is symmetric and constant. We speak about "uniform fuzzy numbers", a particular case of quasi real numbers.

7.3.1 Uniform Fuzzy Numbers

Here we consider the uniform fuzzy numbers Δ_i , i = 0 to 5, such as:

- for Δ_0 :

$$\mu_{\Delta_0}(x) = 0 \quad if \;\; x < 0, \quad \mu_{\Delta_0}(x) = 1 - x \quad if \;\; x \in [0,1] \quad and \quad \mu_{\Delta_0} = 0 \quad if \;\; x > 1 \tag{7.10}$$

- for Δ_i , i = 1 to 4:

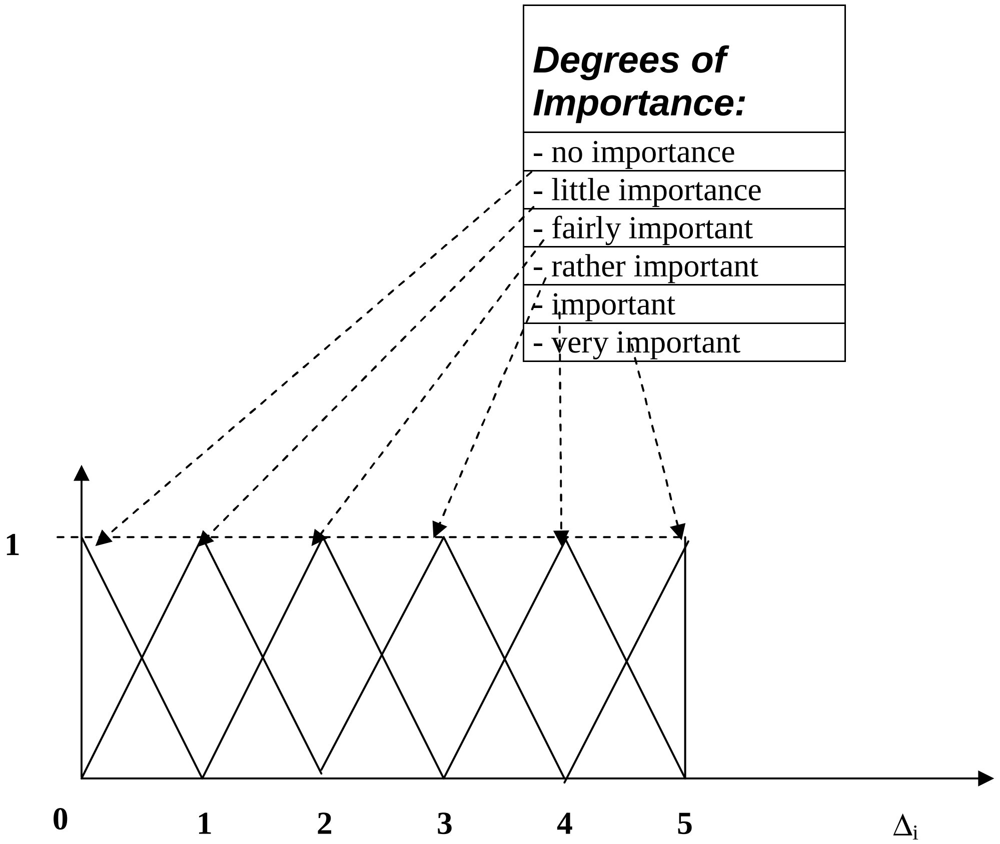
$$\mu_{\Delta_i}(x) = 0 \quad if \;\; x < i-1 \; or \; x > i+1,$$
$$\mu_{\Delta_i}(x) = x - i + 1 \quad if \;\; x \in [i-1, i] \quad and \quad \mu_{\Delta_0} = i + 1 - x \quad if \;\; x \in [i, i+1] \tag{7.11}$$

- for Δ_5 :

$$\mu_{\Delta_0}(x) = 0 \quad if \;\; x < 4, \quad \mu_{\Delta_0}(x) = x - 4 \quad if \;\; x \in [4,5] \quad and \quad \mu_{\Delta_0} = 0 \quad if \;\; x > 5 \tag{7.12}$$

All this, means that uncertainty in this case is assumed to be the same in all declared degrees of importance and degrees of influence. This could characterize an arbitrary assignment of a uniform degree of uncertainty to a priori crisp evaluations.

In this section the definition of the degrees of importance of the customer requirements as shown in figure (7.2), adopt this model:



From 0 – No Importance to 5 – Very Important

Figure 7.2: Fuzzy Uniform Representation of the Degree of Importance

A different example which does not meet conditions (7.10), (7.11) and (7.12) is such as:

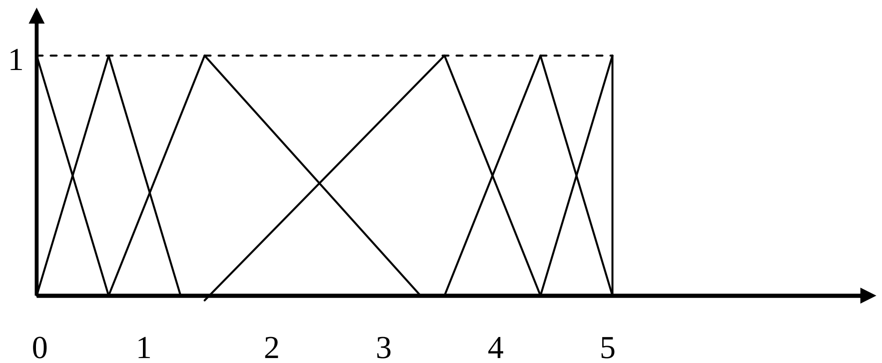


Figure 7.3: Fuzzy Non Uniform Representation of Degree of Importance

This definition will be adopted in the next section.

7.3.2 Construction of the Fuzzy House of Quality

Here we consider the scenario in which the parameters of the House of Quality are given by (see table 7.1):

Hows / Whats	Degree of Importance	Strategy and planning	Leadership & Management	Implementat installation 1	New Procedures	New Resources	New Skilles Manpower	Manuals	Maintenance Control	Safety Standards	Quality Standards	Assessment & audits
	π_i	1	2	3	4	5	6	7	8	9	10	11
Increase Fleet Availability	Δ_5	Δ_4	Δ_0	Δ_4	Δ_5	Δ_5	Δ_5	Δ_4	Δ_3	Δ_4	Δ_4	Δ_3
Maintain Aircraft Reliability	Δ_5	Δ_4	Δ_3	Δ_3	Δ_4	Δ_3	Δ_5	Δ_3	Δ_3	Δ_4	Δ_4	Δ_3
Meet New Servicing Times	Δ_5	Δ_0	Δ_0	Δ_4	Δ_4	Δ_4	Δ_3	Δ_4	Δ_4	Δ_3	Δ_4	Δ_4
Minimize Complexity	Δ_4	Δ_3	Δ_4	Δ_3	Δ_4	Δ_4	Δ_3	Δ_0	Δ_3	Δ_4	Δ_4	Δ_3
Commitment& Long Term Relationship	Δ_3	Δ_3	Δ_4	Δ_3	Δ_3	Δ_3	Δ_3	Δ_2	Δ_3	Δ_0	Δ_3	Δ_3
Safety Awareness	Δ_3	Δ_3	Δ_3	Δ_3	Δ_4	Δ_4	Δ_4	Δ_4	Δ_3	Δ_3	Δ_4	Δ_3

Table 7.1: Fuzzy House of Quality for Uniform Scenario

Where the 'increase of fleet availability" should be a "very important" customer requirement, as well as 'maintaining aircraft reliability' and 'meeting the new servicing times', while 'minimizing complexity' is judged "important" and 'commitments and long term relationing' as well as guaranteeing 'safety awareness' are judged "rather important" objectives. This results, according to the fuzzy scale of figure (7.1), in the first column of the above matrix.

Then the fuzzy degree of importance of each design requirement is computed as table (7.2):

$\tilde{U}_i$	α_i	β_I	γ_i
$\tilde{U}_1$	65	70	76.87
$\tilde{U}_2$	46.9	52	59.25
$\tilde{U}_3$	79.53	85	91.87
$\tilde{U}_4$	95.84	102	109.34
$\tilde{U}_5$	90.87	97	104.34
$\tilde{U}_6$	92.98	98	105.06
$\tilde{U}_7$	68.03	73	79.75
$\tilde{U}_8$	74.56	80	86.87
$\tilde{U}_9$	73.21	78	84.75
$\tilde{U}_{10}$	88.37	94	101
$\tilde{U}_{11}$	74.56	80	86.87

Table 7.2: Fuzzy degree of Importance of Design Requirement

The resultants fuzzy set numbers that have been gained from the illustration of the above fuzzy quality function deployment are presented on the graph in figure (7.4) below.

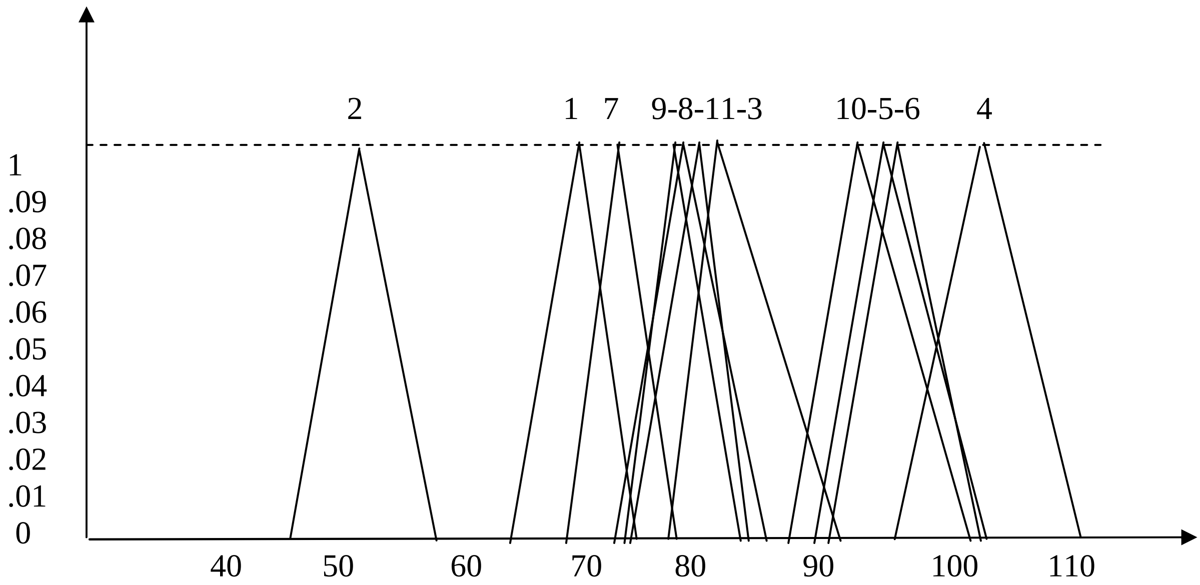


Figure 7.4: Fuzzy Degree of Importance of Design Requirements

It can be observed in figure (7.4) that the uncertainty obtained in the above evaluations of the degrees of importance of design requirements is quite the same. Then, the fuzzy ranking approach proposed in chapter 6 should produce a ranking very close to the ranking of the central values β_i of the $\tilde{U}_i$. What could make a difference is the consideration of a budget constraint.

7.3.3 Design Requirement Ranking and Selection

Writing:

$$\tilde{S}_j = \sum_{i=1}^{m} \tilde{\pi}_i \tilde{H}_{ij} = (a_j, b_j, c_j) \qquad j = 1 \text{ to } n \tag{7.13}$$

we can define $z_{\min}$ and $z_{\max}$ by:

$$z_{\min} = \min_{j=1 \text{ to } n} \{a_j\} \quad \text{and} \quad z_{\max} = \max_{j=1 \text{ to } n} \{c_j\} \tag{7.14}$$

Here we get specifically:

$$z_{\min} = 46.9 \quad \text{and} \quad z_{\max} = 109.3 \tag{7.15}$$

Then on figure (7.5) the fuzzy evaluations of the importance of the different design requirements are displayed:

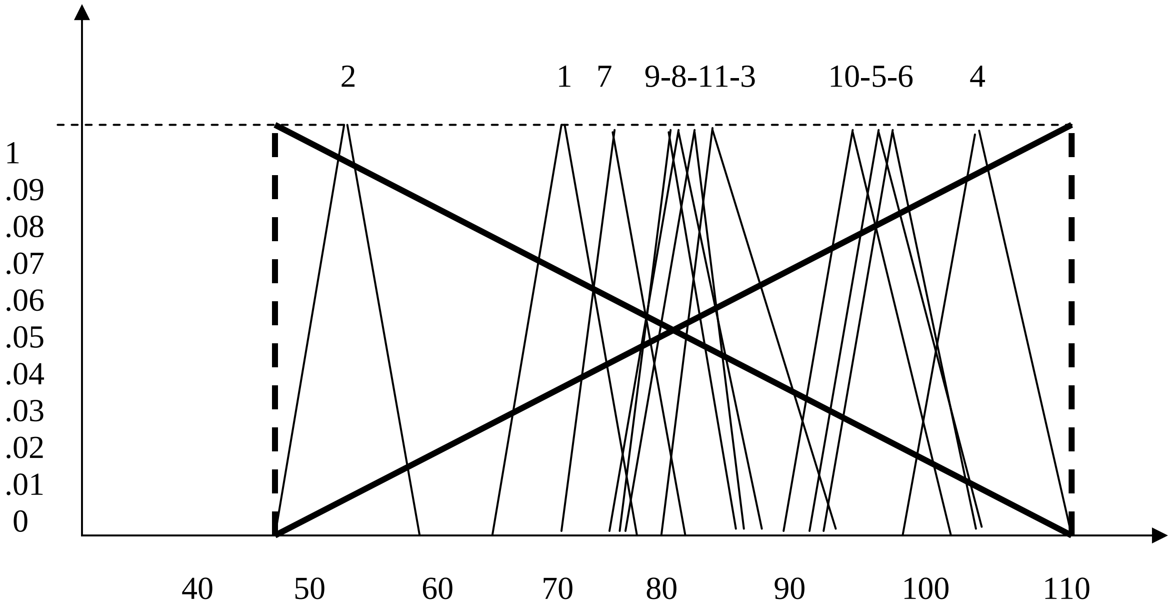


Figure 7.5: Right and Left Utilities of Design Requirements (*k*=1)

Then we can compute the respective utilities:

j	1	2	3	4	5	6	7	8	9	10	11
U(*j*)	0.34	0.12	0.69	0.94	0.81	0.82	0.41	0.59	0.55	0.72	0.62

Table 7.3: Total Utilities of Design Requirements

Then we get the ranking for the design requirements with respect to total utilities:

$$R4 > R6 > R5 > R10 > R3 > R11 > R8 > R9 > R7 > R1 > R2 \qquad (7.16)$$

Now completing the scenario by the costs involved with the implementation of each design requirement given in table (7.4):

j	1	2	3	4	5	6	7	8	9	10	11
C_j	100	80	60	85	90	105	65	50	40	60	95

Table 7.4: Costs of Implementing the Design Requirements

And with an allowed total amount of 600 monetary units for a total cost of 865 monetary units, the Dynamic Programming approach leads to the solution where the set of selected design requirements is {R9, R10, R8, R3, R4, R5, R6, R11} for a total amount of 585 monetary units and a total utility of 5.61 over a total of 6.48 i.e. 86.5% of total possible utility.

7.4 Illustration in the Case of Non Uniform Fuzzy Data

In this section, we illustrate the fuzzy approach for Quality Function Deployment proposed in the case in which the degrees of importance of the "whats" and the connection measure between the "whats" are given by non uniform fuzzy numbers to take into account the different levels of uncertainty associated with the different evaluations useful to build the House of Quality.

7.4.1 Construction of the Fuzzy House of Quality

Here also, the 'increase of fleet availability" is considered by the "customer" to "very important", as well as 'maintaining aircraft reliability' and 'meeting the new servicing times', while 'minimizing complexity' is still judged "important" and 'commitments and long term relationing' as well as guaranteeing 'safety awareness' are judged "rather important" objectives.
This result, according to the fuzzy scale of figure (7.2), in the first column of the following matrix:

Hows / Whats	Degree of Importance	Strategy and planning	Leadership & Management	Implementat installation 1	New Procedures	New Resources	New Skilles Manpower	Manuals	Maintenance Control	Safety Standards	Quality Standards	Assessment & audits
	π_i	1	2	3	4	5	6	7	8	9	10	11
Increase Fleet Availability	4.3,5,5	2,4,5	0,0,1	1,4,5	3,5,5	2,5,5	3,5,5	3,4,5	3,3,3	3,4,4	4,4,4	1,3,5
Maintain Aircraft Reliability	4.3,5,5	3,4,5	1.5,3,5	2,3,4	3,4,5	1,3,5	4,5,5	1,3,4	1,3,5	3,4,5	3,4,5	2,3,5
Meet New Servicing Times	4.3,5,5	0,0,0.7	0,0,1.5	2.5,4,4.5	1.5,4,5	3,4,4.5	1,3,5	1,4,5	2,4,5	1,3,5	2,4,4	3,4,5
Minimize Complexity	2,3.5,4.3	2,3,4.5	2,4,5	2,3,5	2.5,4,4.5	3.5,4,4.5	2,3,5	0,0,2	3,3,5	3.5,4,5	3,4,4.5	1,3,4
Commitment& Long Term Relationship	.7,1.5,3.5	2,3,4	1,4,5	2,3,4	2.5,3,4	2.5,3,5	2,3,4	1,2,4	1,3,5	0,0,1.5	2,3,4.5	2,3,5
Safety Awareness	.7,1.5,3.5	1.5,3,5	2,3,5	1.5,3,4.5	3,4,4.5	3.5,4,5	2,4,5	3,4,5	2,3,4	1.5,3,5	3,4,5	3,3,3

Table 7.5: Fuzzy House of Quality for Non Uniform Scenario

We get the fuzzy degree of importance of the design requirements table (7.6):

$\tilde{U}_i$	α_i	β_i	γ_i
$\tilde{U}_1$	55.61	59.5	70.02
$\tilde{U}_2$	35.12	39.5	50.75
$\tilde{U}_3$	69.92	74.5	84.35
$\tilde{U}_4$	84.29	89.50	97.89
$\tilde{U}_5$	79.87	84.50	94.63
$\tilde{U}_6$	80.82	86.00	96.12
$\tilde{U}_7$	59.93	64.00	74.20
$\tilde{U}_8$	65.32	69.50	79.50
$\tilde{U}_9$	69.78	73.50	83.03
$\tilde{U}_{10}$	79.75	84.50	93.88
$\tilde{U}_{11}$	65.48	69.50	77.52

Table 7.6: Fuzzy Degree of Importance of Design Requirement
(Non uniform fuzzy evaluations)

The resultants fuzzy set numbers that have been gained from the illustration of the above fuzzy quality function deployment are presented on the graph in figure (7.6) below.

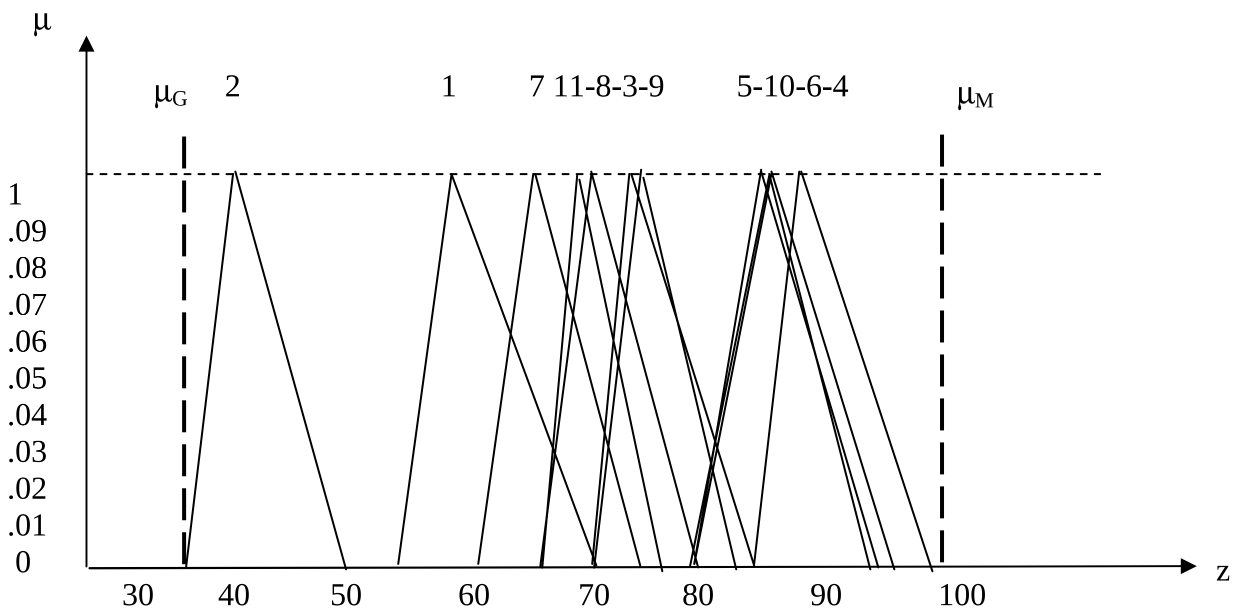


Figure 7.6: Fuzzy Degree of Importance of Design Requirements
(Non uniform fuzzy evaluations)

It can be observed in figure (7.6) that the uncertainty obtained in the above evaluations of the degrees of importance of design requirements are now quite different (see the basis of the different above fuzzy numbers). It appears also that the ranking of the more plausible values for the degrees of importance is different from the uniform case (figure 7.4).

7.4.2 Ranking the Design Requirements and Selection

Writing:

$$\tilde{S}_j = \sum_{i=1}^{m} \tilde{\pi}_i \tilde{H}_{ij} = (a_j, b_j, c_j) \qquad j = 1 \text{ to } n \tag{7.17}$$

we can define here also $z_{\min}$ and $z_{\max}$ by:

$$z_{\min} = \min_{j=1 \text{ to } n} \{a_j\} \quad \text{and} \quad z_{\max} = \max_{j=1 \text{ to } n} \{c_j\} \tag{7.18}$$

Here we get specifically:

$$z_{\min} = 35.12 \quad \text{and} \quad z_{\max} = 97.89 \tag{7.19}$$

Then on figure (7.7) the fuzzy evaluations of the importance of the different design requirements are displayed:

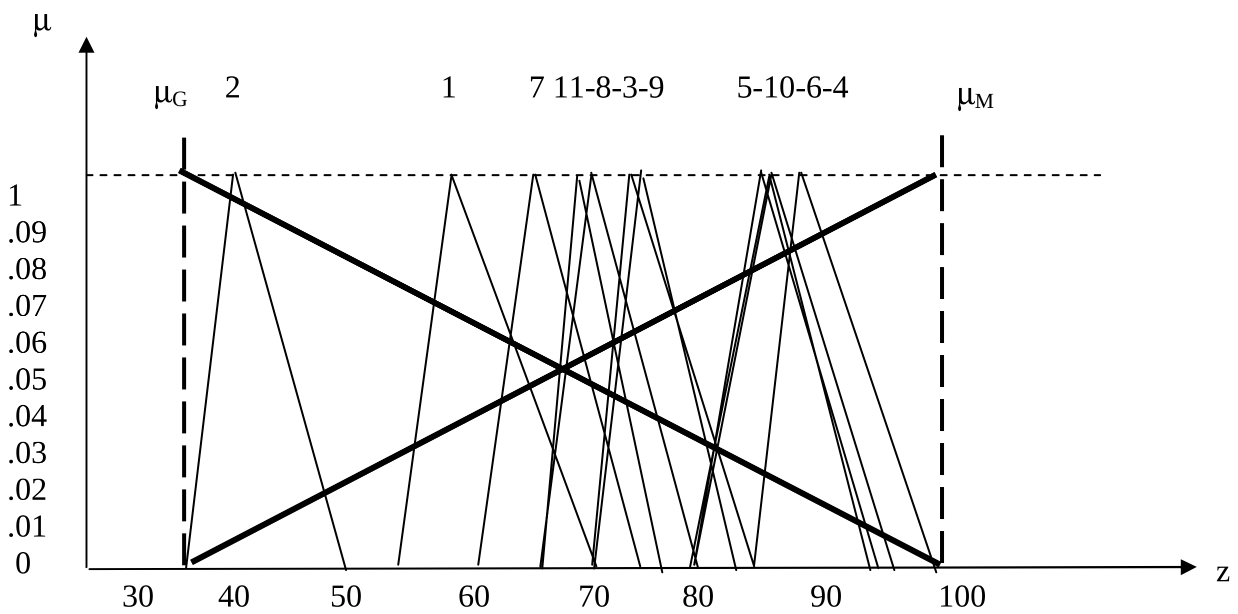


Figure 7.7: Right and Left Utilities of Design Requirements (*k*=1)
(Non uniform fuzzy evaluations)

Then we can compute the respective utilities as presented in table (7.7):

j	1	2	3	4	5	6	7	8	9	10	11
U(*j*)	0.57	0.145	0.45	0.84	0.78	0.76	0.44	0.42	0.63	0.77	0.51

Table 7.7: Total Utilities of Design Requirements
(Non uniform fuzzy evaluations)

Then we get the ranking for the design requirements with respect to total utilities.

$$R4 > R5 > R10 > R6 > R9 > R1 > R11 > R3 > R7 > R8 > R2 \tag{7.20}$$

Now completing the scenario by the costs involved with the implementation of each design requirement given in table (7.4), we get from Dynamic Programming, the following solution:

For an allowed total amount of 600 monetary units for a total cost of 865 monetary units, the Dynamic Programming approach leads to the solution where the set of selected design requirements is {R9, R10, R4, R5, R8, R3, R6} for a total amount of 555 monetary units and a total utility of 4.65 over a total of 6.315, i.e. 73.7% of total possible utility.
It appears that the solution obtained in this case is different from the uniform uncertainty one and that the expected performance is lower than in the case of uniform uncertainties. This is understandable since in the non uniform case, the overall level of uncertainty (compare table 1 and table 5) is much larger than the one chosen for the uniform uncertainty case. This proves the interest for the fuzzy approach of Quality Function Deployment.

7.5 Conclusion

This chapter has illustrated the easy applicability of the approach proposed in chapter 6 to "fuzzify" the Quality Function Deployment process. This new process appears to be easily carried on. However it involves a volume of computations about three times the one of classical Quality Function Deployment, but this is in no means prohibitive. What is gained with this approach is mainly more confidence in the final result since the uncertainty present in the expressed opinions of experts are taken into account explicitly in the analysis and decision process.
In fact two situations have been considered:

- one in which uncertainty degrees have been assigned arbitrarily to the opinions of experts which were originally expressed by crisp numbers. In that case the solution is very similar to the one obtained in the crisp case when the crisp values are equal to the more plausible value of the same parameters.
- one in which the uncertainty which is processed is the one expressed by the experts with respect to each parameter. In that case, the solution can be noticeably different from the crisp one.

In both cases uncertainty intervals are obtained for the different evaluations performed during the Quality Function Deployment process and this is quite valuable for decision makers.

GENERAL CONCLUSION

General Conclusion

This chapter summarizes the analysis and findings presented on the previous sections of the thesis, and suggest certain recommendations in order to enhance quality methods applied to product and service organizations.

The performed research has investigated the issue of Quality Function Deployment in complex organizations with special interest for aircraft maintenance organizations. A method designed to improve quality management in such sectors has been proposed. Quality Function Deployment plays a central role in this proposal and its improvement using fuzzy set representation and fuzzy logic has been investigated.

The present research has been mainly motivated by the challenge of performing organizational changes for reducing the main maintenance cycle time for a particular fleet of aircraft. Such type of challenge does not only deal with time but involves a profound organizational transformation which should cover simultaneously many aspects such as installations, equipments and machines, as well as processes.

The proposed general solution approach is composed of the following steps:

- First a set of candidate physical and procedural modifications of the considered maintenance organization is identified.
- Then these candidate modifications can be associated to get whole projects by taking into account the aspects that can be integrated together and those which are incompatible. A compatibility matrix can be used at this stage.
- This results in the definition of a complete set of concurrent projects composed of a mix of these modifications, to achieve the organization objectives.
- Those projects which are obviously too expensive or far from meeting the customer objective are deleted.
- Only the set of Pareto non inferior projects are retained for further analysis.
- Quality function Deployment is applied to each of the candidate projects, providing in fine a performance index which allows their ranking and final decision about the selection of one of them.
- The results of the Quality Function Deployment process applied to the selected project are revisited to prepare a plan of actions for its implementation.

This approach has been illustrated in the case already referred where the main issue is reducing the maintenance cycle time for a particular fleet of aircraft. The resulting design requirements and suggestions, treated by degree of importance, have been explicated and discussed in chapter 5.
However, the classical Quality Function Deployment analysis which has been performed made use of crisp values to describe and process qualitative opinions resulting from imprecise and subjective information available in the early design stages. This may appear not only unnatural but also to be a possible source of distortion for the final decision making. So in the final part of this thesis it has been considered of utmost importance to be able to manipulate the concepts involved with Quality Function Deployment through linguistic terms and qualitative reasoning. Fuzzy Logic has appeared to be able to provide the tools to help

decision-makers to translate and turn feasible linguistic Quality Function Deployment assessments.

It has been shown then, how to represent these linguistic terms with fuzzy sets and to process them with adapted mathematical operators accordingly with the Quality Function Deployment approach. The computational side of the proposed fuzzy approach has been assessed, concluding clearly to its feasibility. The performed numerical experiments have shown that indeed, taking into account explicitly the uncertainty of experts' evaluations could change the results of the ranking following the Quality Function Deployment process. This proves the usefulness of this approach. So, the Quality Function Deployment phase of the above general solution approach can be enhanced noticeably adopting the proposed Fuzzy Quality Function Deployment.

New perspectives for improving the Quality Function Deployment process are:

-to take into account into the House of Quality of sector knowledge and a priori data through a conditional entropy maximization approach;

-to integrate the evaluation of organizational changes and cost considerations into a single framework, resulting in formulating fuzzy linear programs;

- to compare candidate projects not through crisp indexes but with fuzzy indexes, adopting for instance the ranking technique displayed in chapter (6).

Fuzzy set representation and fuzzy logic which could be also used in many other quality management related activities, such as quality control and diagnostic, appears to be a very important source of inspiration for Quality engineers and researchers involved in the development of new quality techniques to deal with complex product or service organizations.

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ANNEX A

EXPERTS IN THE FIELD

OF

QUALITY MANAGEMENT

Introduction

From the literature it has been found that quality experts, writers and authors constructed and provided a set of core assumptions and specific principles of management which can be synthesized into a coherent framework [Hill, 1993]. In order to understand these concepts and methods, this annex briefly discusses the contribution of the main five experts in this field who have written to assess the notion of quality management and its concepts. They are: W. Edwards Deming, Joseph M. Juran, Philip B. Crosby, Armand V. Feigenbaum, and Kaoru Ishikawa.

W. Edwards Deming

In the quality management literature, Edwards Deming is regarded as the pathfinder of modern quality management concepts. His philosophy is set out in his famous fourteen points as stated in table (A.1), which contributes to the creation of quality principles. Deming is also well known for his emphasis on Statistical Process Control (SPC) techniques that were originally introduced by A.W. Shewhart. Deming believed that top management is responsible for about 80% of quality problems, and therefore, it is the responsibility of top management to tackle these problems. He also believed in that quality is an important issue for developing company's performance [Deming, 1986]. On the other hand [Freed and Klugman, 1977] indicated that "Deming's belief is that if you improve the quality for your goods and services you will increase productivity, because there is less scrap and less work".

1. Create constancy of purpose for improvement of product and service.
2. Adopt the new philosophy.
3. Cease dependence on inspection to achieve quality.
4. End the practice of awarding business on the basis of price tag a lone.
5. Instead, minimize total cost by working with a single supplier.
6. Improve constantly and forever every process for planning, production and service.
7. Institute training on the job.
8. Adopt and institute leadership.
9. Drive out fear.
10. Break down barriers between staff areas.
11. Eliminate slogans, exhortations and targets for the work force. Also, eliminate numerical quotas for the work force numerical goals for the management.
12. Remove barriers that rob people of pride workmanship.
13. Institute a vigorous program of education and self-improvement for everyone.
14. Put everybody in the department to work to accomplish the transformation.

Table A.1: Deming's 14-Points
Source: [Deming, 1986]

Joseph M. Juran

Juran's message is that quality cannot happen by chance. He defined quality as "fitness for purpose or use". Like Deming, Juran believed that most quality problems are due to management, and that top management is responsible for solving these problems. Also, Juran had his own views in looking at quality, for example, [Juran, 1989] suggested that there are three managerial processes, termed as "The Juran Trilogy", in the quality improvement process. These processes are as presented in figure (A.1). The processes are:

- **Quality Planning:** this is a process of developing the products and their features. It identifies the customers and determines their needs and requirements. The process involves developing processes that are able to produce product features that are required by the customers, and transferring the resulting plans to operating forces.
- **Quality Control**: this is a process of examining and evaluating the product against the original requirements of customers, problems detected are then corrected.
- **Quality Improvement:** is a process of identifying the specific needs for improvement and setting up project teams that are responsible for identifying problems and solving them. The process involves allocating resources and providing training that are needed by the teams for achieving their goals.

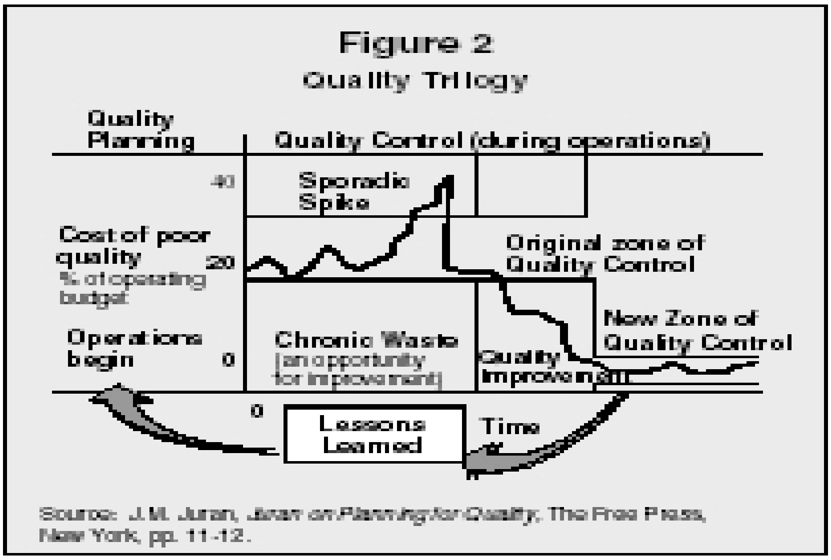


Figure A.1: The Juran Trilogy
Source: [Juran, 1989]

[Liston, 1995] mentioned Juran's ten points, which are listed in table (A.2) below.

1. Build awareness of the need and opportunity for improvement.
2. Set goals for improvement.
3. Organize to reach the goals.
4. Provide training.
5. Carryout projects to solve problems.
6. Report progress.
7. Give recognition.
8. Communicate results.
9. Keep the score.
10. Maintain momentum by making annual improvement as part of the regular system and processes of the company.

Table A.2: Juran's Ten Points
Source: [Liston, 1995]

Philip B. Crosby

Crosby is another quality expert. He is well known for his concepts such as, "Zero Defects", "Doing Things Right the First Time", and "the system of quality is prevention not appraisal". Crosby is concerned with the tools of TQM, and is often described as a TQM technician. He defines quality as "conformance to the requirements". Crosby offered a 14-point program as a guideline for quality improvement, [Crosby, 1980]. The 14-point program is as presented in table (A.3).

⇒ Management Commitment
⇒ Quality Improvement Team
⇒ Quality Measurement
⇒ Cost of Quality Evaluation
⇒ Quality Awareness
⇒ Corrective Action
⇒ Establish an Ad-hoc Committee for the Zero Defects Program
⇒ Supervise Training
⇒ Zero Defect Day
⇒ Goal Setting
⇒ Error Cause Removal
⇒ Recognition
⇒ Quality Councils
⇒ Do It Over Again

Table A.3: Crosby's 14-Point Quality Program
Source: [Crosby, 1980]

In addition, [Crosby, 1980] introduced the management maturity grid which is counted as a method for measuring the existing quality system and highlighting areas that need improvement. The grid consists of five main stages, these are:

1. Uncertainty stage: at this stage, management is aware that there exist problems of poor quality in the organization, but the causes of the problems are not known.

2. Awaking stage: at this stage, the basic problems remain the same with no consideration for long-term plan in solving such problems.

3. Enlightenment stage: at this stage, more attention is given to quality than at the earlier stages. Also, problems are looked at and resolved in a systemic way.

4. Wisdom stage: at this stage, the cost of quality is accurately estimated and problems are handled as they appear. This is regarded as the most critical stage of the five stages.

5. Certainty stage: at this stage, quality management becomes as a normal business of the organization's culture.

Armand V. Feigenbaum

Feigenbaum is known as the father of Total Quality Control, as he was its originator. He defined quality as the "the total composite product or services characteristics of marketing, engineering, manufacture, and maintenance through which the product and service in use will meet the expectation of the customer" [Feigenbaum, 1991]. On the other hand Feigenbaum defined Total Quality Control as "an effective system for integrating the quality development, quality maintenance, and quality improvement efforts of the various groups in an organization so as to enable marketing, engineering, production, and service at the most economical levels which allows for full customer satisfaction, [Feigenbaum, 1991]. Moreover, to achieve business success, Feigenbaum suggested that an organization must develop a quality control program that must foster sound business growth and provide major competitive advantage to a company. There are normally four steps to a total control program according to Feigenbaum, these are:

⇒ **Setting standards:** determining the required quality costs and standards.
⇒ **Appraising conformance:** comparing the conformance of the product or service to the standards.
⇒ **Acting when necessary:** correcting problems and their causes throughout marketing, design, engineering, production, and maintenance factors that influence user satisfaction.
⇒ **Planning for improvement:** developing a continuing effort to improve standards.

In addition Feigenbaum further developed the concept of the cost of quality, and showed how TQM could reduce the overall costs by very significant amounts. Feigenbaum's best known contribution is his ten benchmarks, which are:

1. Quality is a company-wide process.
2. Quality is what the customer says it is.
3. Quality and cost are a sum not a different.
4. Quality requires both individual and teamwork zealotry.
5. Quality is a way of managing.
6. Quality and innovation are mutually dependent.
7. Quality is an ethic.
8. Quality requires continuous improvement.
9. Quality is most cost-effective, least capital-intensive route to productivity.
10. Quality is implemented with a total with a total system connected with customers and suppliers.

Kaoru Ishikawa

This Japanese quality expert believed that quality control is a company-wide issue, placed great emphasis on "Quality Circles" in which employees must jointly and on voluntary basis form teams for problem solving, as a significant technique for solving quality problems, and as a tool for empowering employees from different levels in the decision –making and improvement processes. He is also known for his invention of the "Fishbone diagram", or what known as the "Cause and Effect" as presented in figure (A.2), which is used as an important tool for identifying and analyzing the causes of problems of poor quality.

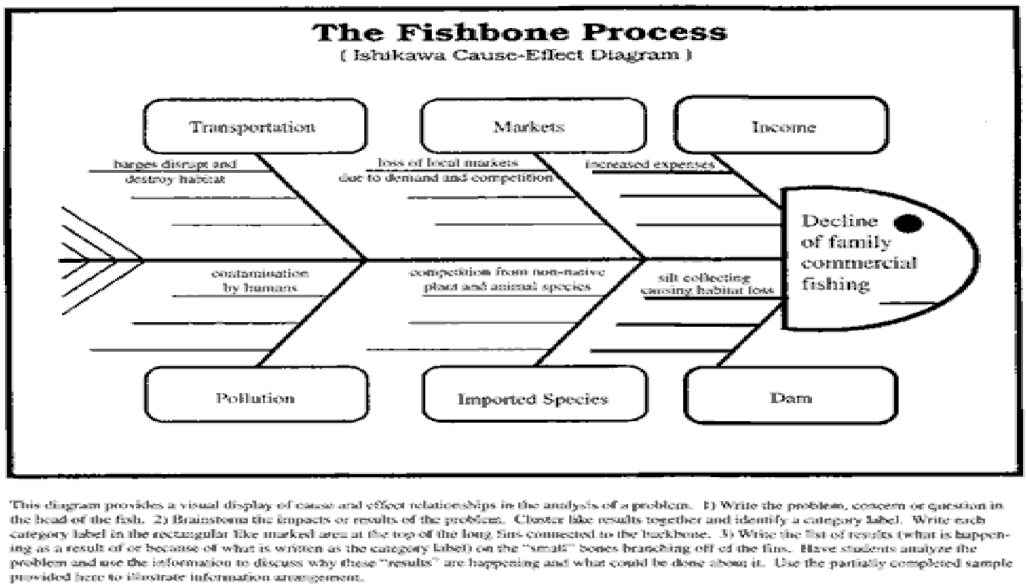


Figure A.2: Ishikawa, the Cause and Effect (Fishbone) Diagram
Source: [Ishikawa, 1985]

For transformation of a management process, according to Ishikawa, such process has six categories, these are:

- ⇒ Quality first-not short-term profit
- ⇒ Consumer orientation-not producer orientation. Think from the standpoint of the other party.
- ⇒ The next process is your customer-breaking down the barrier of sectionalism.
- ⇒ Using facts and data to make presentations-utilization of statistical methods
- ⇒ Respect of humanity as a management philosophy-full participatory management
- ⇒ Cross-function management

Conclusion

What was said above is only a glimpse on what the main experts have covered in this field; as such literature can not be covered in couple of lines only. These writers are considered as well known specialist, who have made a great contribution in the domain of quality management. Also, it worth mentioning that there are other many writers and researchers who have contributed in this field but were not mentioned in this annex.

ANNEX B

LIST OF PERFORMANCE MEASUREMENT FRAMEWORKS

Model/framework	Measures/Indicators/Criteria	Reference
Sink and Tuttle (1989)	Efficiency, Effectiveness, Quality, Productivity, Quality of work life and innovation, Profitability/budget ability, Excellence, survival and growth,	Sink and Tuttle (1989)
Du Pont Pyramid	Financial ratios, Return on investment (ROI)	Chandler (1977); Skousen *et al.* (2001)
PM matrix	Cost factors, Non-cost factors, External factors, Internal factors	Keegan *et al.* (1989)
Results and determinants matrix	Financial performance, Competitiveness, Quality, Flexibility, Resource utilization, Innovation	Fitzgerald *et al.* (1991)
PM questionnaire	Strategies, actions and measures are assessed, Extent to which they are supportive? Data analysis as per management position or function, Range of response and level of disagreement	Dixon *et al.* (1990)
Brown's framework	Input measures, Process measures, Output measures, Outcome measures	Brown (1996)
SMART pyramid (Performance pyramid)	Quality, Delivery, Process time, Cost, Customer satisfaction, Flexibility, Productivity, Marketing measures, Financial measures	Developed by Wang Laboratories. Lynch and Cross (1991)
Balanced Scorecard (BSC)	Financial, Customer, Internal processes, Learning & growth	Kaplan & Norton (1992)
Consistent PM system	Derived from strategy, continuous improvement, fast and accurate feedback, explicit purpose, relevance	Flapper *et al.* (1996)
Framework for small business PM	Flexibility, Timeliness, Quality, Finance, Customer satisfaction, Human factors	Laitinen (1996)
Cambridge PM process	Quality, Flexibility, Timeliness, Finance, Customer satisfaction, Human factors	Neely *et al.* (1997)
Integrated dynamic PM System	Timeliness, Finance, Customer satisfaction, Human factors , Quality, Flexibility	Ghalayini *et al.* (1997)
Integrated PM framework	Quality, Flexibility, Timeliness, Finance, Customer satisfaction	Medori and Steeple (2000)
Integrated PM system	Finance, Customer satisfaction, Human factors, Quality, Flexibility, Timeliness	Bititci (1994)
Dynamic PM Systems	External and internal monitoring system, Review system, Internal deployment system, IT platform needs	Bititci *et al.* (2000)
Integrated Measurement model	Customer satisfaction, Human factors, Quality, Flexibility, Timeliness, Finance	Oliver & Palmer (1998)
Comparative Business Scorecard	Stakeholder value, Delight the stakeholder, Organizational learning, Process excellence	Kanji (1998)
Skandia Navigator	Financial focus, Customer focus, Human focus, Process focus, Renewal and development focus	Edvinsson and Malone (1997); Sveiby (1997)
Balanced IT Scorecard (BITS)	Financial perspective, Customer satisfaction, Internal processes, Infrastructure & innovation, People perspective	ESI (1998) as mentioned in Abran and Buglione (2003)
BSC of Advanced Information. Services Inc (AISBSC)	Financial perspective, Customer perspective Processes, People, Infrastructure & innovation	Abran and Buglione (2003)
Intangible Asset-monitor (IAM)	Internal Structure: *Growth, *Renewal, *Efficiency, *Stability, Risk (Concept models, Computers, Administrative systems); External Structure: *Customer, *Supplier, *Brand names, *Trademark & image; Individual Competence: * Skills, *Education*Experience, *Values, *Social skill	Sveiby (1997)
Performance Prism	Stakeholders satisfaction, strategies, processes, capabilities, stakeholders contribution	Neely and Adam (2000)
QUEST	Quality, Economic, Social and Technical factors	Abran & Buglione (2003)
European Foundation for Quality Management (EFQM)	Leadership, Enablers: people management, policy and strategy, resources; Processes, Results: people and customer satisfaction, impact on society; and Business results	http://www.efqm.org/ as mentioned in Wongrassamee *et al.*(2003)

Table B.1: List of Performance Measurement Frameworks
Source: [Parida A., 2006]

ANNEX C

INTERNATIONAL QUALITY

ORGANIZATONS

1. The European Foundation for Quality Management (EFQM) Model

This model, developed by the European Foundation for Quality Management in 1992, is widely used by United Kingdom and European organizations, in both public and private sectors as a means of reviewing performance against internationally recognized best practice. The model is presented in figure (C.1).

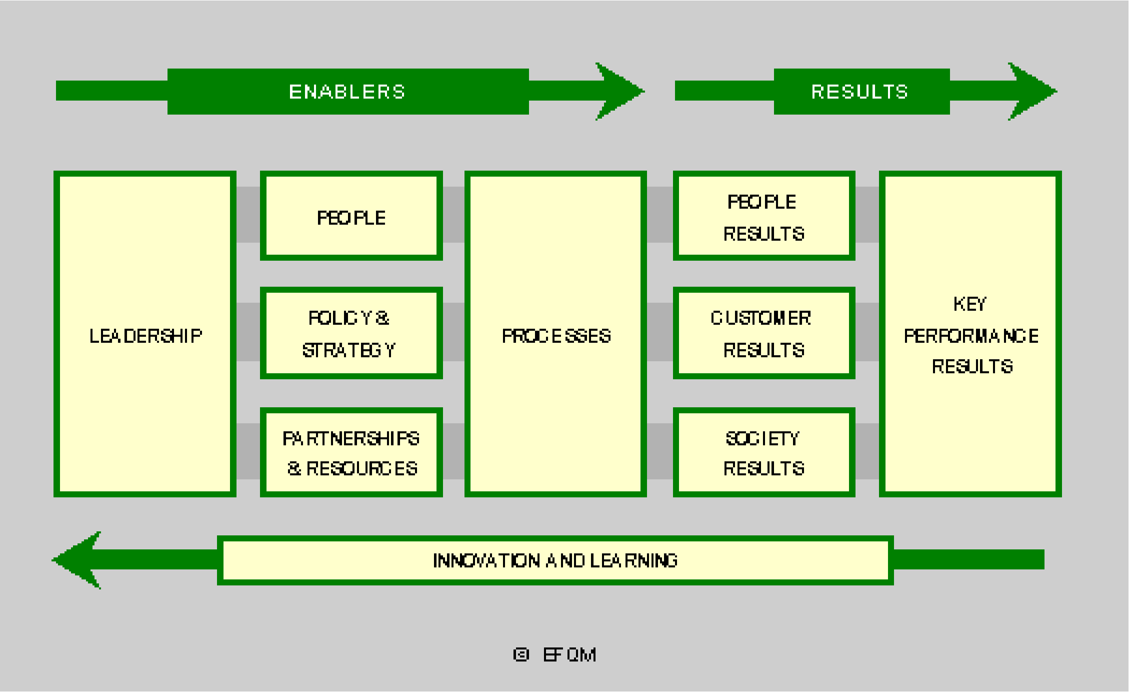


Figure C.1: European Foundation for Quality Management Excellence Model

The model is used as a practical tool in a number of different ways:

⇒ As a tool for self-assessment
⇒ As a way for benchmarking with other equivalent organizations
⇒ As a guide to identify areas for improvement
⇒ As a structure for the organization's management system

The EFQM is structured of nine criteria items, and 32 sub-criteria, against which organizations can assess their activities. The model is based on the principle that the five enablers of excellence are about leadership, policy and strategy, people, partnerships and resources, and processes. As stated by dolphin workbook, section "A" [dolphin™, 2003] that these activities enable excellent performance, as demonstrated by people results, customer results, society results, and ultimately, key performance results. Key performance results are the indicators of progress towards the organization's aims and objectives.

2. Malcolm Baldrige National Quality Award

This is a competition award to identify and recognize top-quality United States of America companies. This award was established in the United States of America by the Congress in 1987as a quality management system for manufacturers, service business and small business. Other categories were added later, for example, education and heath were added in 1999. The model addresses a broadly based range of quality criteria, including commercial success and corporate leadership. Its role is that once an organization has won the award it has to wait several years before being eligible to apply again. The Baldrige National Quality Program is a self-assessment and action planning program. This self-assessment profile is the organizational profile for a snapshot assessment of the organization. The recipients organizations of the award are selected on achievement and improvement in (7) areas known as the Baldrige criteria for performance excellence. These are:

- ⇒ Leadership
- ⇒ Strategic planning
- ⇒ Customer and market focus
- ⇒ Measurement, analysis, and knowledge management
- ⇒ Human resource focus
- ⇒ Process management
- ⇒ Business/organizational performance results

3. The International Organization for Standardization

The International for Organization Standardization is based in Geneva, Switzerland, and it is a worldwide federation of standards bodies from more than (110) countries. Its mission is to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services, and to developing cooperation in the spheres of intellectual, scientific, technological, and economic activity. ISO's technical work consists of developing international agreements, through a consensus-based process, for voluntary application. These agreements are published as International Standards. Moreover, the ISO describes standards for a Quality Management System addressing the process surrounding the design, development, and delivery of a general product or service. Organizations can participate in a continuing certification process to demonstrate their compliance with the standard.

The ISO 9000 family of standards was designed to be a generic process that can be used by manufacturing and service companies, worldwide. In addition, the ISO 9000 family of standards sees quality as a process. This is done, by the standard examining quality from beginning to end-user and considers service to be a part of the overall standard. ISO 9000 was developed by the International Standards Organization and details about the scope and implementation of the standard were established in 1987. The standards have been revised several times since then. The ISO standards have been broadened over the last few years to deal with other non-quality issues, for example, issues dealing with environmental standards under the general heading of ISO 14000, and ISO standards that deal with “knowledge management” as a distinct discipline, and others.

4. The Alliance for Performance Excellence

This is a network of states, local, and international organizations that uses the Malcolm Baldrige National Quality Award criteria and model at the grassroots level to improve the performance of local organizations and economies. Additional to the external assessment of the organization, the alliance offer many other services and education programs in the following fields:

- ⇒ Benchmarking
- ⇒ Consulting
- ⇒ Training on Kaizen theory
- ⇒ Six sigma
- ⇒ Lean manufacturing
- ⇒ Offers best practice workshops and conferences

5. Discussion

As can be cited from the literature above that each model has its own criteria and rules of the game. These models basic idea is the self assessment through a dedicated analysis of the performance of the quality system of the organization with the guidance of a list of criteria and sub-criteria. After the assessment which is done by the organization itself, a copy of the assessment would be sent to that particular model agent in order to benchmark the results with other organization in the same domain.

ANNEX D

ARROW'S IMPOSSIBILITY THEOREM

Arrow's theorem is related to Decision Theory, but it is often expressed in a non-mathematical way. The framework for Arrow's theorem assumes that there is a need to extract a preference order on a given set of options (outcomes). Each individual in the society (or each decision criterion) gives a particular order of preferences on the set of outcomes.
[Hazelrigg, 1996] has argued that design approaches such as the Quality Function Deployment, that seeks to optimize the value of a design to its different customers can lead to highly erroneous results. He bases this argument on the impossibility theorem first presented by Kenneth Arrow [Arrow, 1963]. Kenneth Arrow considered the problem of constructing a utility function to express the presence of a group and showed that apart in some very special case, utilities cannot be used. For further understanding this theorem the concept of utility is discussed below;

Utility is an economic value of preference. For example an individual's preference for three alternatives A, B, and C; where A is preferred to B, and B is preferred to C, can be expressed as: A > B > C
In this case each option can be assigned a utility level, as a measure of the level of each preference. The above could then be expressed through utility function as:

uA > uB > uC .

The impossibility theorem considers the preferences of a group of three rational individuals which are presented in the table (D.1) below where it appears that no consensus is possible in this case.

Individual	Preferences	A vs. B	B vs. C	A vs. C
1	A > B > C, A > C	A	B	A
2	B > C > A, B > A	B	B	C
3	C > A > B, C > B	A	C	C
Group preference		A > B	B > C	C > A

Table D.1: Arrow's Impossibility Theorem

Source: [Hazelrigg, 1996]

So to avoid this difficulty, Quality Function Deployment should adopt either a hierarchy of opinions or a global one resulting of the aggregation of individual ones.

ANNEX E

INTRODUCTION TO FUZZY LOGIC

1. Introduction

Fuzzy logic and fuzzy set was introduced by Zadeh Lotfi as an extension of classical set theory, and is built around the central concept of a fuzzy set membership function. Its concept is based on trading off between significance and precision. Fuzzy Logic is a convenient way to map an input space to an output space. This concept is used due to its many advantages, such as, its naturalness of its approach and not its far-reaching complexity, its flexibility, it's a very powerful tool for dealing quickly and efficiently with imprecision and non linearity, it's also tolerant of imprecise data as Fuzzy Reasoning builds this understanding into the process rather than taking it onto the end. As fuzzy logic is known to deal with linguistic, vague, and uncertain data, its use in many applications was utilized to fulfill this task. For instant it was utilized as a fuzzy approach to environment performance evaluation, and as an approach for developing metrics for determining knowledge management success, and many other applications.

2. Fuzzy Sets and Crispy Sets

Fuzzy set theory enables the processing of imprecise information by means of membership function. In contrast to Boolean Characteristics Mapping of a classical set (called crisp set) takes only two values: one, when an element belongs to the set; and zero, when it doesn't. In fuzzy set theory, an element can belong to a fuzzy set with its membership degree ranging from zero set to one. For example, this can be indicated by stating the difference between classical theory and the fuzzy set theory as shown below:

Classical Theory

$$\mu_A(x) = \begin{cases} 1 & IFx \in A \\ 0 & Ifx \notin A \end{cases}$$

Fuzzy Set Theory

$$\mu_A(x) \in [0,1]$$

Further more, crisp sets and fuzzy sets are usually identified with these membership functions as presented in figure (E.1), and (E.2).

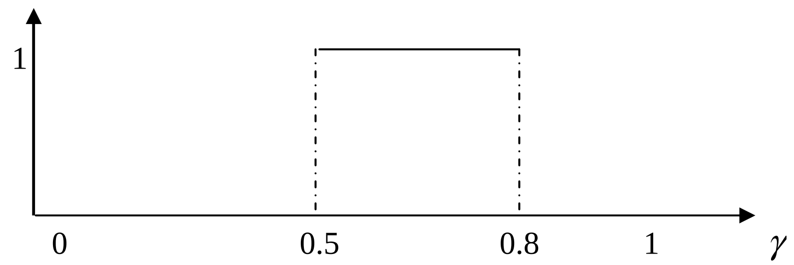


Figure E.1: Characteristic Function of a Crisp Set

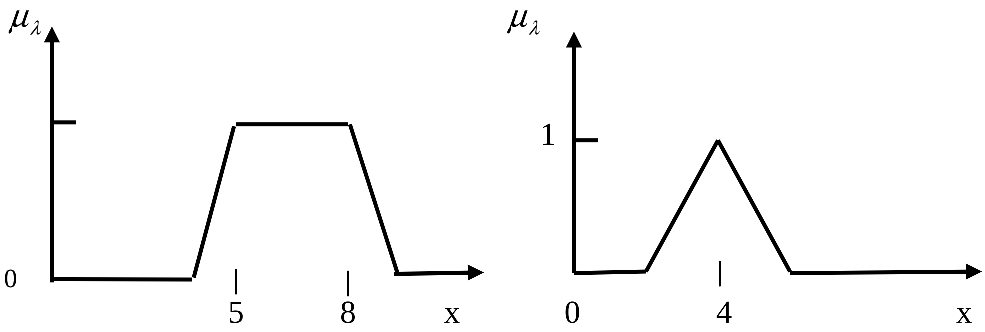


Figure E.2: Characteristic of Fuzzy Sets

3. Operations on Fuzzy Sets

In addition, basic operations can be introduced on fuzzy sets. Similar to the operations on crisp sets, it can be intersect, unify and negate fuzzy sets. These operations coincide with the crisp unification and intersection if only the membership degrees are considered between 0 and 1. Examples are presented in figures (E.3), (E.4), and (E.5) below. Figure (E.3) indicates Fuzzy set between 5 and 8 AND about 4 using the minimum method.

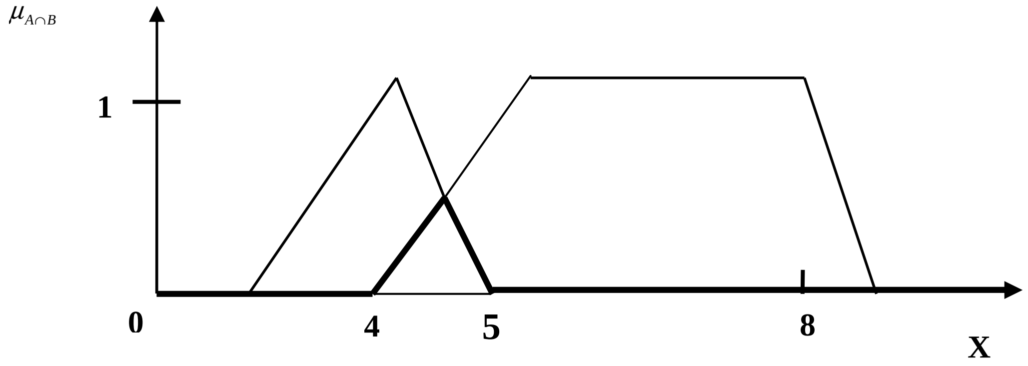


Figure E.3: Fuzzy AND using the Minimum Method

Set between 5 and 8 OR about 4 is presented in figure (E.4) below;

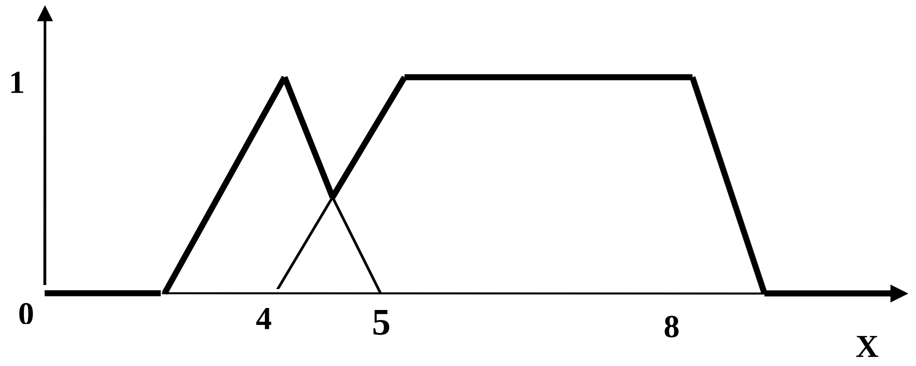


Figure E.4: Fuzzy OR using the Max Method

The NEGATION of fuzzy set A is as shown in figure (E.5) below;

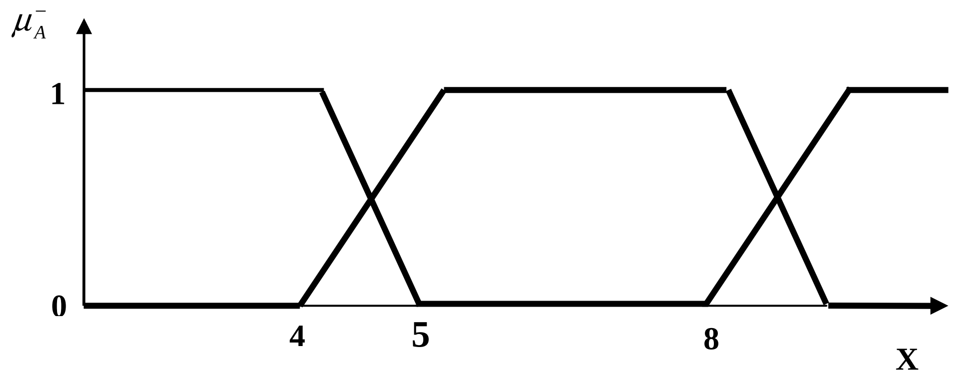


Figure E.5: Fuzzy NEGATION

4. Fuzzy Classification

Fuzzy classification is one application of fuzzy theory. Expert knowledge is used and can be expressed using linguistic variables. For example, the polarimetric variables entropy H and α– angle can be modeled as depicted in figure (E.6) below;

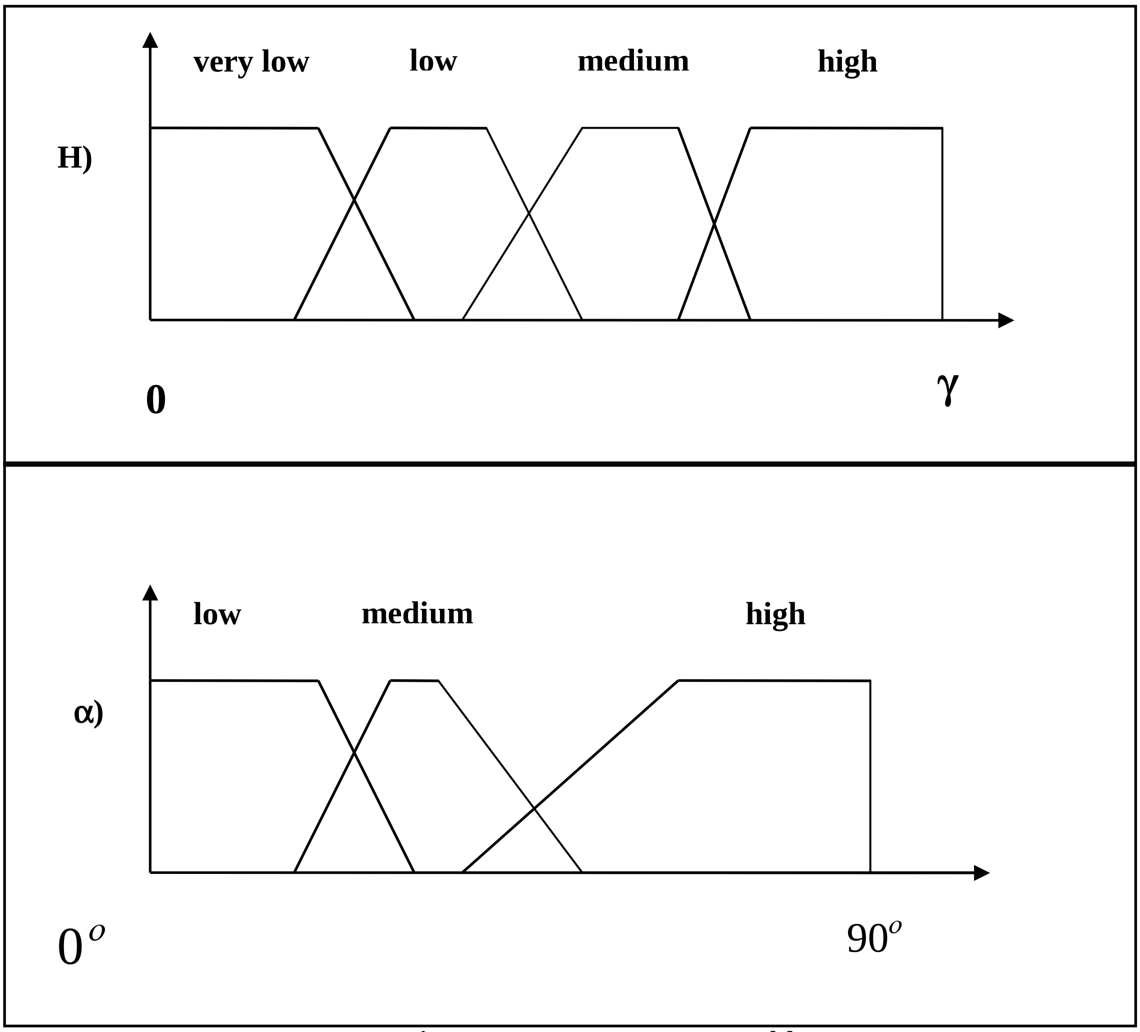


Figure E.6: Linguistic Variables

5. Acquisition of Knowledge and Designing the Rule Base (Inference Rules)

Fuzzy rules must be set in a linguistic form that will describe the relation between the inputs and the outputs. An example of such a linguistic rule is "**IF** temperature is cold ***THEN*** heater is high". To interpret this rule "**IF** temperature is cold **THEN** heater is high" by the first order formula Cold(x) →High(y) and assume that r is an input such that Cold(r) is false. Then the formula Cold(r)→High(t) is true for any *t* and therefore any *t* gives a correct control given *r*. Rules are usually expressed in the form: If variable Is set Then action. The example below considers an extremely simple regulator that uses a fan. The rules for this particular case will look like:

- ⇒ IF temperature is very cold THEN stop fan
- ⇒ IF temperature is cold THEN turn down fan
- ⇒ IF temperature is normal THEN maintain level of fan
- ⇒ IF temperature is hot THEN speed up fan

Fuzzy decision is a function of many fuzzy rules called the base rules. To get these rules, there exist many methods such as:

- The extraction of human knowledge and experience of the system operation is undoubtedly the most common method used for the control of complex systems. It can be obtained directly in the form of rules set out by experts in the control of the process, or from a set of data input-output representative of behaviour of the human operator. In the second case, it is to build fuzzy model actions taken by the operator.

- Getting the fuzzy controller by inverting the fuzzy model of the process. The reversal of this model leads directly to a fuzzy controller. However, the use of this model as inverse controller is only possible when the system is ordered to minimum phase. Otherwise, it would lead to instability of closed-loop system. The use of both direct and indirect (with inverted) fuzzy model the process leading to the laws of fuzzy decision by internal or predictive model.

- Expert knowledge concerning the behaviour of the process in certain situations (eg, temporal responses) can also be used for the realization of fuzzy controllers. There are also rules of equivalence between the classical type controllers "Proportional-Integrated Derivative (PID)" Controllers and fuzzy. Mac-Vicar Whelan table is one of the most used regulation tables in this domain. These controllers are fuzzy versions of standard controllers.

In fuzzy decision, the fuzzy rules are generally used in the form:

$$IF \quad \underbrace{(X_1 \quad is \quad A_1) \quad and \quad (X_2 \quad is \quad A_2)}_{\text{Condition}} \quad \text{THEN} \quad \underbrace{\text{(Y is B)}}_{\text{Conclusion}} \qquad [2.1]$$

When the fuzzy rules are semantically complex, they can easily be written and transformed to the general simple form of the same type as stated above in (2.1). Some examples are shown below:

- "$If \;\; (X_1 \;\; is \;\; A_1) \;\; Then \;\; (Y \;\; is \;\; B_1 \;\; Else \; Y \;\; is \;\; B_2)$" can be transformed to:

$$\begin{cases} "IF \quad (X_1 \quad is \quad A_1) \quad Then \quad Y \quad is \quad B_1" \\ \text{OR} \\ "IF \quad (X_1 \quad is \quad A_1) \quad Then \quad Y \quad is \quad B_2" \end{cases}$$

- "$If \ (X_1 \ is \ A_1) \ Then \ (Y \ is \ B_1 \ Unless \ X_1 \ is \ A_2)$" can be transformed to:

$$\begin{cases} "IF \quad (X_1 \quad is \quad A_1) \quad Then \quad Y \quad is \quad B_1" \\ \text{OR} \\ "IF \quad (X_1 \quad is \quad A_2) \quad Then \quad Y \quad is \quad A_2" \end{cases}$$

- "$If \ (X_1 \ is \ A_1) \ Then \ (Y \ is \ B_1 \ Else\,If \ X_1 \ is \ A_2 \ Then \ Y \ is\,B_2))$" can be transformed to:

$$\begin{cases} "IF \quad (X_1 \quad is \quad A_1) \quad Then \quad Y \quad is \quad B_1" \\ \text{OR} \\ "IF \quad (X_1 \quad is \quad A_1)_1 \quad and \quad X_1 \quad is \quad A_2 \quad Then \quad Y \quad is \quad B_2" \end{cases}$$

- "$If \ (X_1 \ is \ A_1) \ Then \ (If \ X_1 \ is \ A_2 \ Then \ Y \ is \ B_1)$"can be transformed to:

$$"IF \quad (X_1 \quad is \quad A_1 \quad and \quad X_1 \quad is \quad A_2 \quad Then \quad Y \quad is \quad B_1"$$

6. The Different stages of Fuzzy Decision

A fuzzy controller system is a knowledge-based reasoning, limited in depth. It uses sequential procedures consisting of computing the belonging degrees of the inputs. All the rules having a belonging degree different from zero in the left side are activated, after that the average of all the outputs is computed to get the final decision. The different steps are as presented in figure (E.7).

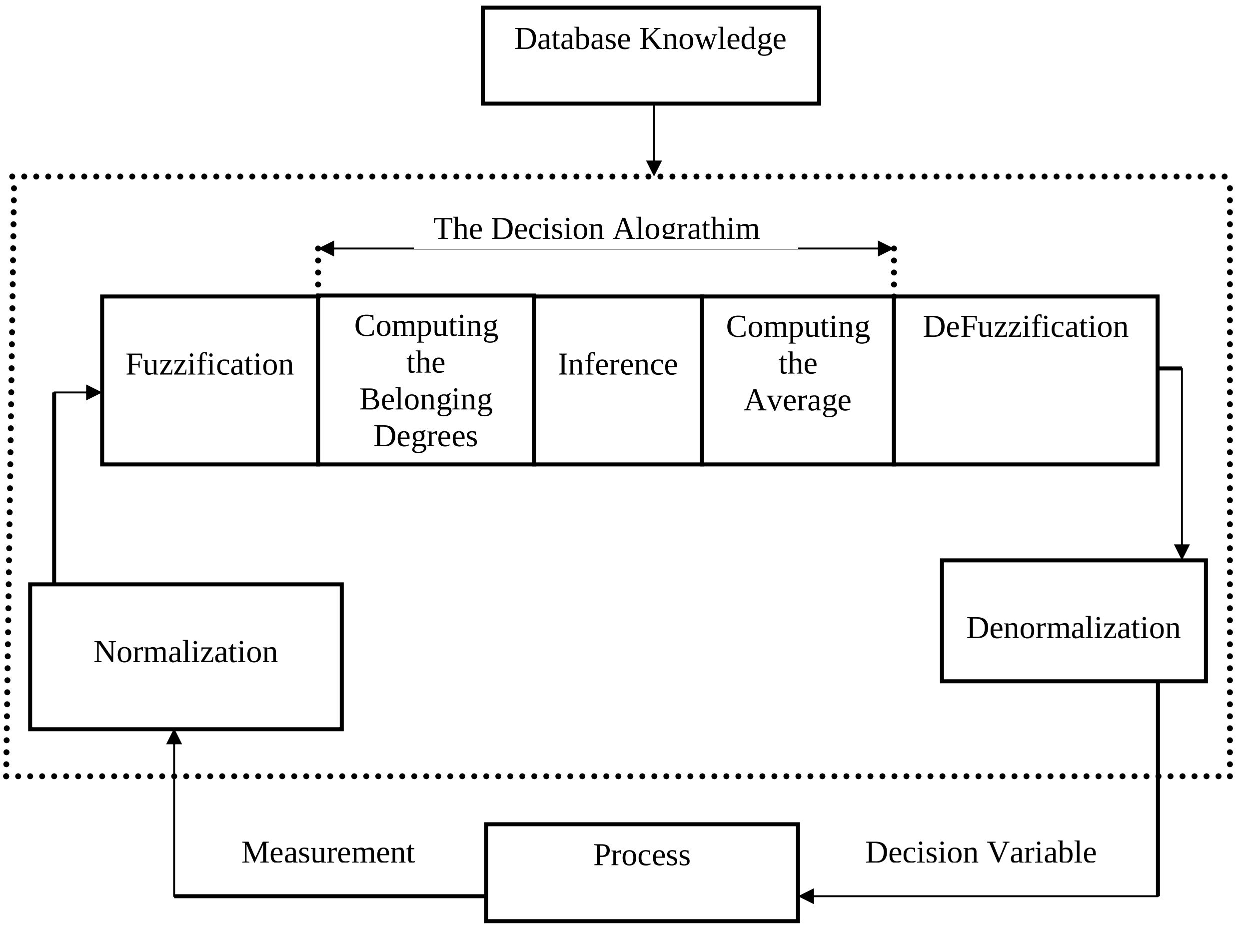


Figure E.7: Structure of the Base of Fuzzy Decision

The measurements are the inputs of the fuzzy controller. These measurements are generally consisting of the outputs of the process or some important quantities describing the dynamic evolution of the process. The outputs of the fuzzy controller are the decisions to be applied.

The knowledge database is composed of a rule base and information base which consists of:

⇒ Fuzzy sets describing the inputs and outputs of the fuzzy controller

⇒ The normalization and demoralization factors

The basis of rules contains rules in the form:

$"IF \quad (X_1 \quad is \quad A_1 \quad and \quad X_2 \quad is \quad A_2 \quad Then \quad Y \quad is \quad B_2"$

$X_1, X_2 \quad and \quad Y$ Are physical characteristics of the system, whereas $A_1 \, and \quad A_2$ are the linguistic labels.

There are two types of rules, they are:

⇒ Symbolic conclusion rules (Mamdani rules), where the zero of the rules are fuzzy. Example: If the error is "negative average" and the variation of the error is "small/low positive" then the order is "small/low negative".

⇒ The algebraic conclusion rules (Sugeno rules), where the zeros are not fuzzy, so defuzzification is not needed.

The normalization and de-normalization steps are optional. Physical measurements can be directly used in fuzzzyfication and defuzzication procedures

7. Fuzzification

Fuzzification consists of computing the belonging of each input to its related fuzzy sets. It is the projection of real physical values on the fuzzy sets characterizing these variables. In other words, it is the process of converting a crisp input value to a fuzzy value.

To get the belonging functions, there is no specific mathematical procedure; these functions can be (triangular, trapezoidal, exponential, gaussian). Some comparative studies have proved that, instead of the shapes of the belonging function, similar results can be obtained from closed loop configuration. The triangular functions are easier to be implemented in computer programming. The number of fuzzy sets is usually odd such as (3, 5, and 7), because the sets are symmetric with respect to zero. An example of function belonging triangular is given in Figure (E.8).

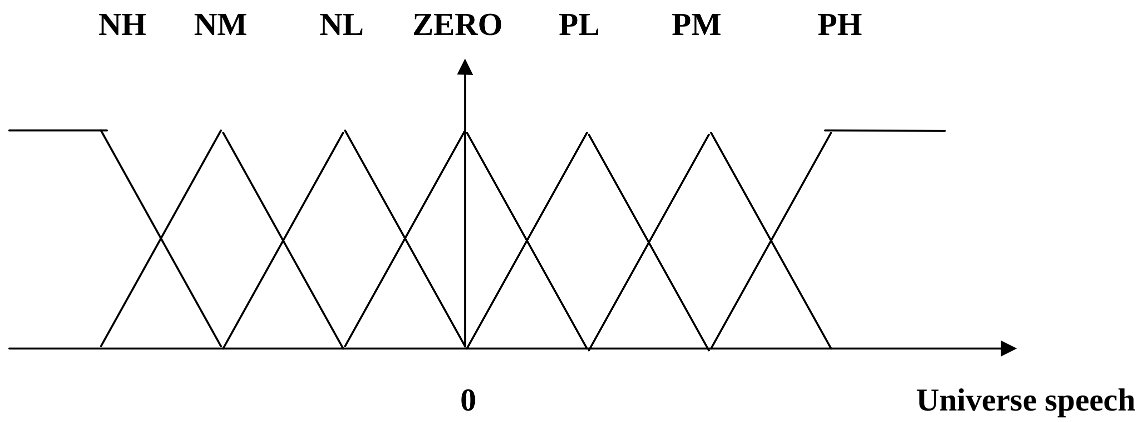


Figure E.8: An Example of Triangular Membership Functions

The abbreviations for the linguistic values are:
NH: "Negative High"
NM: "Negative Medium"
NL: "Negative Low"
ZE: "Zero"

PL: "Positive Low"
PM: "Positive Medium"
PH: "Positive High"

8. Fuzzy Inference

This is based on the utilization of an involvement operator, which is used to evaluate the truth degree of a rule ‘R’ in the form "If X is A then Y is B". In other words, this operator describes the strength of the linkage between the condition and the conclusion.

There are many and various operators of involvement according to the interpretation given to the involvement "A implies B" (A $\rightarrow$ B). Two types of involvement can be distinguished; classical type where "A implies B" is defined by "not A or B", conjunctive type where "A implies B" is defined by "A and B". The most commonly used operators are conjunctive.

Mamdani envolement (1974): $\mu R(x, y) = \min(\mu A(x), \mu B(y))$,

Larsen envolement (1980): $\mu R(x, y) = (\mu A(x).\mu B(y)$

Let's consider: "If the engine of the vehicle is big, so its fuel consumption is high. This rule will be used for a particular vehicle which we know precisely the engine capacity, which is not necessarily typical of the characterization "big", and must also provide a conclusion on its fuel consumption if the engine capacity is relatively high.

9. Aggregation of the Rules

Depending on the type of involvement, classical on conjunctive, the operator used to aggregate the rules is respectively conjunctive or disjunctive. Thus, usually the implication is of conjunctive type, so this involves the using of the operator "OR" to link the rules. In practical, the operator max is used:

$$\mu B^{'}(y) = \max_{i=1 \grave{a} n}(\mu B_i^{'}(y)$$

Before describing the next stage consisting of transforming the resulting sets from the aggregation of rules (fuzzy sets described by the function of belonging to a value $\mu B^{'}(y)$), to crisp value, let's consider the classical example using Mamdani reasoning.

The example illustrated in figure (E.9) considers the following rules:

$$R_1 : If\,(x_1 \;\; is \;\; ZE \;\; and \;\; x_2 \;\; is \;\; ZE) \;\; then \;\; y \;\; is \;\; ZE$$

$$R_2 : If\,(x_1 \;\; is \;\; PP \;\; and \;\; x_2 \;\; is \;\; PP) \;\; then \;\; y \;\; is \;\; PP$$

The Mamdani method as presented in figure (E.9) is based on the use of the operator min for the combination of condition and involvement. Each regulation is activated separately and the results are aggregated to describe the fuzzy sets of the output variable y. The aggregation of rules is carried out by the operation max.

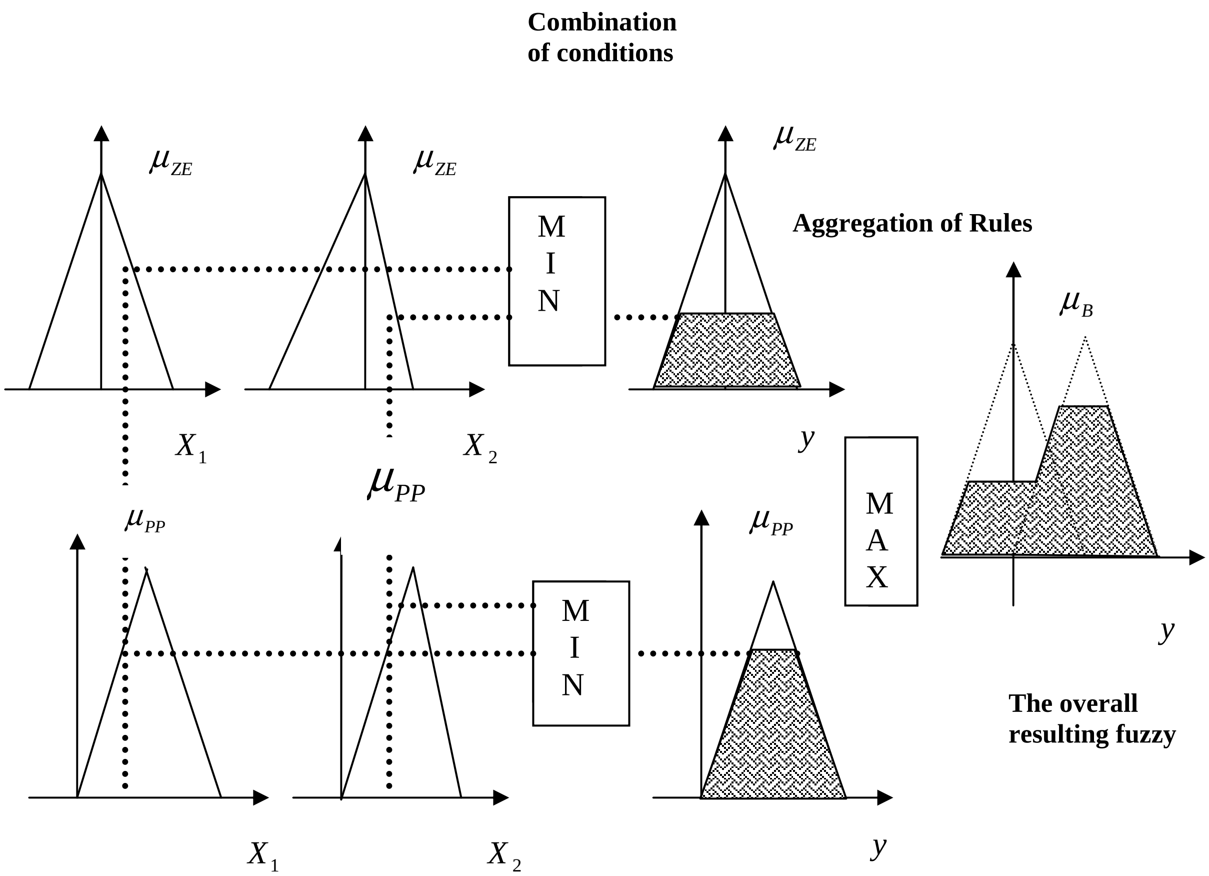


Figure E.9: Illustration of the Mamdani Method

10. Defuzzification

The defuzzification is transforming all fuzzy resulting sets from the aggregation to a specific order of magnitude. There are several methods to do this, including:

- ⇒ The method of height
- ⇒ The first of maximums
- ⇒ The last of the maximums
- ⇒ The average maximum
- ⇒ The centre of gravity
- ⇒ The centre of areas
- ⇒ The centre of the largest area
- ⇒ The centre of the maximums.

The most commonly used Defuzzification methods in fuzzy decision are the centre of gravity, the centre of areas and the centre of maximums.

The method of height and its variants

The method of the height chooses the greatest level of fuzzy decision as the value of maximum as displayed in figure (E.10).

$$\mu = \arg\{\max \mu_{B'}(y)\}$$

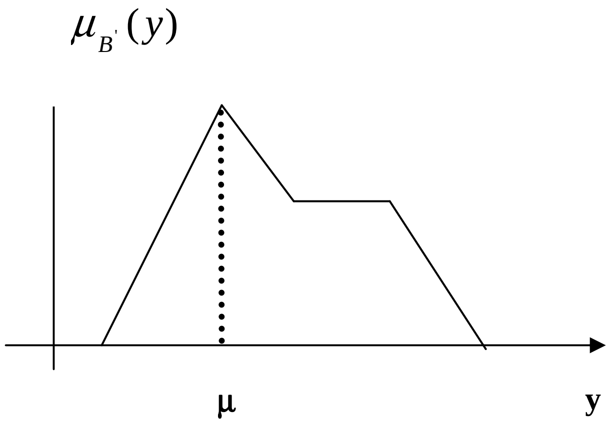


Figure E.10: Deffuzification using the Method of Height

In the case of function of belonging having more than one maximum, it would be a choice between the first of maximums, the last of the maximums or the average maximums. The average maximum is similar to the first and last of the maximum methods that consist computing the average. Figure (E.11) shows the variants for the method of height.

First max : $\bar{y}_1$

Last max : $\bar{y}_2$

average max $\mu = \frac{\bar{y}_1 + \bar{y}_2}{2}$

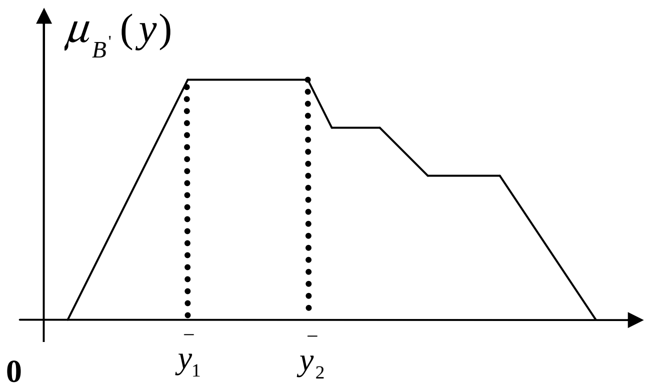


Figure E.11: Variants for the Method of Height

This method requires a small amount of calculations but can introduce discontinuities in the fuzzy decision, which explains why this method is not widely used.

The method of centre of gravity

The centre-of-gravity formula as presented in figure (E.12) is the most frequently used due to its preciseness. It gives directly the most representative value of the fuzzy output sets, but it needs a lot of computation.

$$\mu = \frac{\int_y \mu B1(y).y.dy}{\int_y \mu B1(y).dy}$$

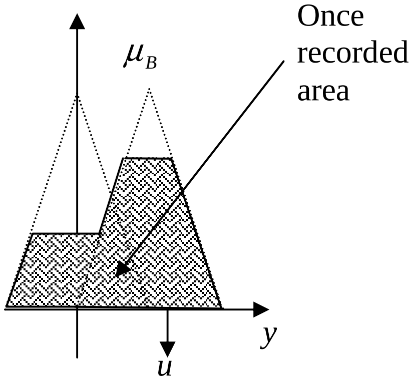


Figure E.12: Defuzzification Using the Centre of Gravity Method

The Centre of Areas Method

This method is similar to the previous one, but does not require calculating $\mu B^1(y)$. The idea is to consider the contribution of each area individually. The whole B 'is constructed from the sum of all the areas. Thus, areas that overlap, if they exist, are counted more than once as depicted in figure (E.13).

$$\mu = \frac{\int_y \sum_{i=1}^{n} \mu B_i^{'}(y).dy}{\int_y \sum_{i=1}^{n} \mu B_i^{'}(y).dy}$$

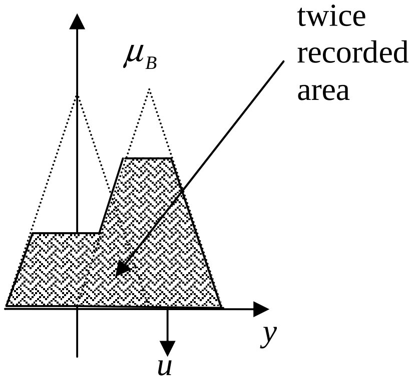


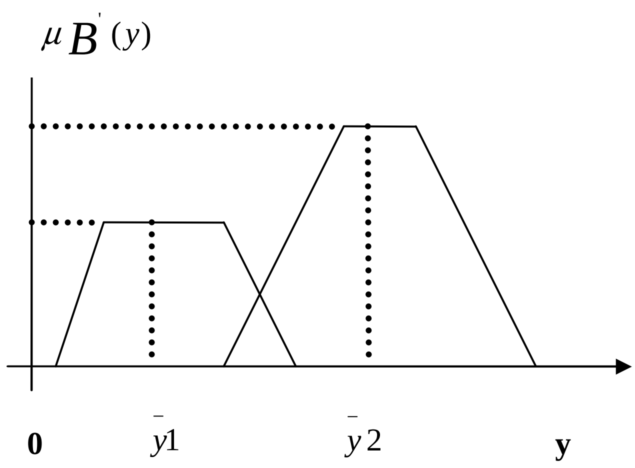
Figure E.13: Defuzzification using the Centre of Areas Method

The centre of the largest area

This method calculates the center of gravity of the largest area. This method is not commonly used.

The Centre of maximums

This method considers the maximums of each contribution and computes their weighted average as presented in figure (E.14).



$$\mu = \frac{\sum_{i=1}^{n} \mu B_i^{'}(\bar{y}_i).\ \bar{y}_i}{\sum_{i=1}^{n} \mu B(\bar{y}_{ii})^{'}}$$

Figure E.14: Defuzzification using Centre of Maximums Method

Sugeno’s Method

In the case of rules having polynomial conclusions (rules of Takagi-Sugeno), having the following form:

$$R_i : If\,(x_1 \ \ is \ \ A_1^i \ \ and \ \ x_2 \ \ is \ \ A_2^i \ \ and \ldots x_n \ \ is \ \ A_n^i) \ \ Then \ \ (y \ \ is \ \ f_i(x_1, x_2, \ldots, x_n))$$

The final decision is obtained by a simple weighted average according to the levels of activation of each of the rules $R_i \ (i = 1,\ldots,r)$:

$$\mu = \frac{\sum_{i}^{r} \alpha_{ij} \ . \ f_i \ (x_1, x_2, \ldots, x_n)}{\sum_{i}^{r} \alpha_i}$$

With $\alpha_i = T(\mu_{A_1^i}(x_1), \mu_{A_2^i}(x_2), \ldots, \mu_{A_n^i}(x_n))$

11. Denormalization

This last stage transforms the standardized values of the output variables of fuzzy decisions to their respective physical magnitude using the normalization factors.

12. Conclusion

Fuzzy controllers can be classified into several types with respect to the nature of their conclusion:

- ⇒ Symbolic (Mamdani type controllers).
- ⇒ Algebraic (Sugeno type controllers).

The major interest of fuzzy logic lies in its ability to translate a strategy used by qualified operator to a set of linguistic rules in order to be easily interpretable into fuzzy decisions.

This annex covered an introduction to fuzzy logic, where it has displayed the basics of fuzzy logic operations, fuzzy decision and numerical implementation.

Abstract

In this thesis, Quality Function Deployment for aircraft maintenance organizations is considered. Assessment and evaluation of quality management in aircraft maintenance organizations is the key to ensure safety, reliability, and the assurance of quality. At present, companies around the world have an absolute need for quality management systems in order to help them to develop and manage better their activities. Improving the way in which organizations handle their organizational management plays a major role in raising the standard of the quality of the product or the quality of the service they deliver. The challenge of implementing quality approaches in the management of aircraft maintenance organizations is appealing since it is recognized to save time and money. As a result, the organization can become more efficient, more competitive in its domain and finally more profitable. Quality management is, therefore, an essential function for maintaining and improving the quality of the services and products provided by aircraft maintenance organizations.

First necessary background and theoretical knowledge on aircraft maintenance organizations and quality management is presented in detail. This is achieved by performing an analysis of the needs and the means for improving quality in the maintenance activities. The proposed analysis approach is a combination of Quality Function Deployment, and Fuzzy Logic theory. The Quality Function Deployment is used as an analysis tool to translate the customer needs and requirements into service features. The Quality Function Deployment involves the construction of a matrix structure which allows the assessment and ranking of different course of action with respect to quality. Since many opinions from experts are expressed in linguistic terms it appeared that fuzzy logic could improve this analysis process. Then, the final part of the thesis is devoted to the development of a fuzzy quality function deployment. The proposed analysis approach is then illustrated in the case of aircraft maintenance organizations where the objective is to increase fleet availability, maintain aircraft reliability, decrease servicing time, and limit investment costs.

Key words: Industrial Engineering, Quality Management, Aircraft Maintenance, Quality Function Deployment, Fuzzy Logic, Fuzzy Modeling.

Résumé

Dans cette thèse, le déploiement de la fonction de la qualité pour l'organisation de l'entretien des avions est considérée. L'évaluation de la gestion de la qualité dans les organismes de maintenance des avions est la clé pour garantir la sécurité, la fiabilité et l'assurance de la qualité. De nos jours, les entreprises partout dans le monde ont un besoin absolu de systèmes, gestion de la qualité afin de les aider à développer et à mieux gérer leurs activités. La façon dont les organisations gèrent leurs gestions de l'organisation joue un rôle majeur dans l'amélioration du niveau de la qualité du produit ou la qualité du service qu'elles fournissent. Le défi de la mise en œuvre de la démarche qualité dans la gestion de la maintenance des avions est important car il doit conduire à des économies de temps et d'argent. La gestion de la qualité est, par conséquent, une fonction essentielle pour maintenir et améliorer la qualité des services et produits offerts par les organismes de maintenance des avions.

Dans cette thèse les prés requis et connaissances théoriques sur l'organisation de la maintenance et la gestion de la qualité sont présentés en détail. Ceci est réalisé en effectuant une analyse des besoins et des moyens pour améliorer la qualité dans les activités d'entretien. L'approche d'analyse proposée est une combinaison du déploiement de la fonction de la qualité et de la Logique Floue. Le déploiement de la fonction de la qualité est utilisé comme un outil d'analyse pour traduire les besoins des clients et les besoins en qualité des services. Le déploiement de la fonction de la qualité comprend la construction d'une structure matricielle permettant d’évaluer et de comparer les différents plans d’action. Puisque de nombreuses opinions d'experts sont exprimées en termes linguistiques, il semble que la Logique Floue pourrait améliorer ce processus d'analyse. La dernière partie de cette thèse est consacrée à l'élaboration du déploiement de la fonction de la qualité dans le cadre de la Logique Floue. L'approche d'analyse proposée est ensuite illustrée dans le cas de l'organisation de l'entretien d’une flotte d’avions. L'objectif est d'augmenter la disponibilité de la flotte, de maintenir sa fiabilité, de diminuer le temps du service de maintenance, de limiter les coûts d'investissement.

Mots Clés: Génie Industriel, Gestion de la Qualité, Entretien des Avions, Déploiement de la Fonction de la Qualité, Logique Floue, Modélisation Floue.