

CRANFIELD UNIVERSITY

NICK KALARGEROS

**A METHODOLOGY TO COMPUTERISE QFD'S APPLICATION AND
ENHANCE ITS INTEGRITY PURPOSE AND ACCEPTANCE WITHIN
THE EUROPEAN AUTOMOTIVE INDUSTRY**

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

MPhil THESIS

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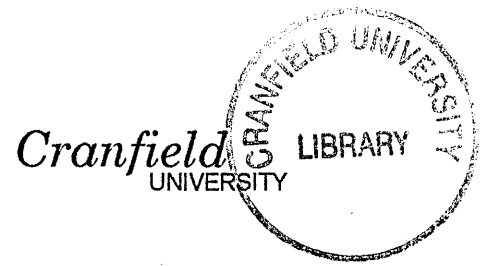
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**A Methodology to computerise QFD's application and enhance its
integrity purpose and acceptance within the European Automotive
Industry**

Supervisor : Dr J X Gao

September 1997

**This thesis is submitted in partial fulfilment of the requirements for
the Degree of Master of Philosophy**

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ABSTRACT

Companies are increasingly looking up to QFD as a key to capture the customers voice and to encourage team members to communicate more effectively with each other. QFD is a complex and very time consuming process therefore difficult to implement. Owing to the complexity of this technique in the European Automotive Industries, its implementation generally relies upon specialists and consultants. A lack of clear understanding between the industrial participants results in a somewhat disrupted implementation. Moreover individual competitiveness and an increasing need for recognition will prevent them from putting faith in the mechanics of the technique and from reaching a team consensus. Under these circumstances the QFD implementation will not be pure.

There is a great deal of QFD work which is available for all those with time to analyze and argue its particular points. But there is an increasing desire in some places i.e. the Automotive industry for practical information and applied knowledge about QFD. Moreover a lot of automotive business like the idea of implementing the technique but they don't know how. Obviously there are places that people can learn about QFD and there are consultants who can help them implement it. The problem which arises by this approach is the lack of understanding within the business. That means consultants may not understand a company and its needs when implementing QFD but they will propose solutions. More important they have no reason to argue with any of the company's members therefore they can easily agree for a look alike implementation of the technique.

Considering the above statements the purpose of this project is to eliminate any misunderstanding of the technique, by describing the technique in a simple manner recommending its implementation to the product development process using fuzzy logic and a typical spreadsheet PC software. Finally an enhancement in the communication between the members of the product development team and the acceptance of the technique can be achieved representing the team member's preferences in a fuzzy manner and calculating the group decision using a methodology proposed in this project. Therefore QFD will be available to industry as a user friendly tool which can be applied to vital decision making during the product development stage, ensuring that the end product is a good result, taking the technique from the papers and putting it into practice.

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Notations

ASI:	American Supplier Institute
ASQC:	American Society for Quality Control
CAD:	Computer Aided Design
Consensus:	Mutual agreement
CWQC:	Company Wide Quality Control
FMEA:	Failure Mode and Effect Analysis
“Hows”:	Technical Response for “Whats”
HoQ:	House of Quality
ISO:	International Organisation of Standards
PC:	Personal Computer
QFD:	Quality Function Deployment
QS9000:	Quality Standards
SQC’s:	(end products) Substitute Quality Characteristics
TFN:	Triangular Fuzzy Number
TQM:	Total Quality Management
VOC:	Voice Of the Customer
VOCT:	Voice Of the Customer Table
“Whats”:	Customers Needs (Requirements)

Nomenclature

$< :$	Less than
$\leq :$	Less than or equal to
$> :$	Greater than
$\geq :$	Greater than or equal to
$\mathbb{R}^+ :$	Set of positive real numbers
$\in :$	Belongs to
$\{X \mid P(X)\} :$	Set X determined by property P
$A \cap B :$	A set intersection B set
$A \cup B :$	A set union B set
$\sum :$	Summation
$ A :$	Cardinality of crisp or fuzzy set A
$\overline{A} :$	Complement of set A

Eleanor Roosevelt quote

"The future belongs to those who believe in the beauty of their dreams"

Dedicated to:

Lofti Zadeh for his courage and grand paradigm shift

*To the Ancient Hellenic Philosophical Spirit which built the infrastructure in the
research for the knowledge of human values.*

and

to the memory of my brother; Giorgio

Chapter One

Introduction

1. - Introduction

1.1 - The European Automotive Industry within the Global perspective

The production of a new car has long been a source of fascination and excitement. In the competitive environment of the 1990s and the preparation for the next millennium their role goes well beyond curiosity and excitement. The development of new cars has become the focal point of the Automotive Industrial Competition. This competition is driven mainly by three forces that have emerged in the last twenty years: the emergence of intense international competition; the creation of fragmented markets populated by demanding and sophisticated customers; and the diverse transformation of the technological change. These increasing forces have combined to push new automotive products development to a highly sophisticated and competitive arena. International players possess similar basic skills, compete in the same business with similar fundamentals, but bring different backgrounds, cultures and experience, therefore different approaches to the International market. In addition a growing number of competing brands demands greater world-wide share.

Considering the intense situation of the current automotive market and the customers with their reduced spending, requires an emphasis on quality, value and affordability (Crow Kenneth, 1992) and on the other hand the technology which has become more complex, more diverse and rapidly evolving it becomes obvious why all these brand “players” have to be more capable and diverse. Moreover it is extremely important to counter competitors that they move quickly with well-differentiated products if they want to survive and prosper. Obviously one can see why these issues have a direct impact on the automotive business growth, which has slowed significantly, and on the number of car models which have multiplied dramatically.

Welcome to the global 90's where traditional distinctions between domestic and foreign automotive products are blurry. Where the internationalisation of many markets and industries lead to a more intense competitive interaction, and the

current economical pressures introduce an era of industrial downsizing and restructuring. Where diversity, flexibility, effectiveness and efficiency are the keywords for industrial survival. Where the lack of these ingredients mandates outright crisis. Where according to (Ederhard C.Stotko, 1994 and (Clark B.Kim, Takahiro Fujimoto, 1995) the once strong and dominant European companies like BMW and VW face serious competitive threats in all markets. One may wonder what made the European Automotive Industry (the birthplace of car manufacturing) to open their market ? The following paragraphs attempt to answer to this question with a direct comparison between the successful Japanese approach and the European approach.

Historically and according to the (Clark B.Kim, Takahiro Fujimoto, 1995) European Automotive Industry has products with strong company identity or common engineering philosophies which are dominant in their entire product range and line. The customer has different expectations from different car manufacturers. Therefore different brand products were less subject to direct comparisons. However the context of a European brand automotive product had to maintain the continuity of the brands concepts while offering the expected to the European customers, value and performance. The emerging result of this kind of product development was to have a long product life cycle with heavy emphasis on engineering elegance and continuity of design. Obviously this is far from the flexible and efficient way that Automotive companies have to operate.

Another major drawback of the European Automotive Industry is the “black or white” approach to thought and action. Innovation and exploration has its source in the increasing need for recognition which results in the individual competitiveness and the separation of human actions from the forces of nature. Besides that in order to accommodate such approach and mentality they create high rationale and hierarchical structures that emphasise engineering functionalism and class. On the other hand during the last twenty years the Japanese and recently the Chinese and Korean automotive companies have become increasingly competitive. One may argue the point that these companies have not created the novelties that the European Automotive rivals have, but they have taken full advantage of them. Their culture developed with different priorities. Strength and success were accomplished through consensus and accommodation among groups. In contrast with the European companies Japanese

companies accommodate their culture within simpler and flatter structures. This traditional attitude so perplexing to the European culture is basic to Japanese business transactions today, from the smallest firm to the largest high-tech company. The question is what they did to achieve this business mentality ?

The activities and focus was in the invention implementation and adoption of the TQM (Total Quality Management) approach with its numerous powerful statistical, and planning tools i.e. Affinity Diagram, Tree Diagram, Matrix Diagram, Taguchi methods, FMEA, QFD, etc., all of which have stressed customer driven planning, continuous improvement and employee empowerment. TQM tools dynamically assisted in creative thinking and problem solving. These are not physical or highly analytical tools; instead they are methods that relate ideas to ideas, ideas to data, and data to data, that encourage team members to communicate more effectively with each other and help teams to pragmatically formulate business problems and their solutions. In addition their increased realisation that engineering design is where the greatest level of product quality and industrial productivity is obtained (Scrage, Daniel P., McConville, James, Martin, Christopher L.,1990) has helped them to create and develop tools and methods which ensure design integrity and duty to the real customers needs.

1.2 - The complexity of the product development process

According to (Scrage, Daniel P., McConville, James, Martin, Christopher L,1990) the product development process is : “The process of devising a system, component, or process to meet desired needs. It is a decision making process in which the basic sciences, mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction testing and evaluation. In other words it is considered as product development process the “*Art*” of engineering which takes an idea and following all the relevant known engineering principles, produces something that corresponds to this idea.

The words synthesis, analysis, iteration and trade off are most often heard when referring to the product development process which consists of a hierarchical

sequence of steps. This thesis was undertaken with an ultimate goal the synthesis in mind. According to (Scrage, Daniel P., McConville, James, Martin, Christopher L,1990) and the author's own experience it is believed that the drawback in the European industry and education is that the majority of people find it easy to analyse phenomena, methods and findings, but when it comes to the terms of composing this understanding of the analysis they find it extremely difficult. Product development in the Automotive Industry has peculiar characteristics. A car is complex, a 'fabricated-assembled' product, comprising of a large number of components, functions and process steps. Moreover the product is complex from the buyer's perspective, giving rise to numerous dimensions and factors. Although the automobile has a long history and the customers generally have a good deal of experience with it, buying one involves a very complicated evaluation of many criteria some of which are highly subjective, subtle, multifaceted, fuzzy and holistic. Therefore the customers needs and criteria that relate to the automotive product have to be translated and addressed during the design process, where hundreds or thousands of technical decisions are made.

1.3 - Product development process and quality issues

There are numerous definitions of quality and the reason is that it is perceived in a different dimension. Quality is like beauty, it is in the eye of the beholder and it is whatever our customer consider to be. According to (Juran, J, 1988) "Quality is defined by its fitness for use and purpose. The fitness for use is determined by those features of the product which the user can recognise as beneficial to him. To the user quality is not conformance to specifications because he seldom knows what is in them. The International Organisation for Standardisation (ISO) (John A Goldsmith, 1990) defines: "Quality is the totality of features and characteristics of a product or service that bear on its ability to satisfy given needs".

Though quality was considered as an elitistic objective some years ago (F.Franceschini & S. Rosseto, 1995), it has become the keyword for survival in today's competitive market. Under Japanese pressure and upon consideration of the things they have achieved in the Automotive Industry, we may realise that quality is an attribute that involves a lot more than ISO's definition. Generally as customers or producers we judge the quality of a product from four main directions;

from its multidimensional attributes , from its relative value to us, from its dynamicity (time dimension) and from its globality. In other words quality in a product is a goal and experts believe that practically all of a product's cost and quality are committed by decisions taken during its development process [(Scrage, Daniel P., McConville, James, Martin, Christopher L,1990) and (Swift K.G.Allen A.J, 1992) and (Mirup M., 1992)].

1.3.1 - Quality Lever

The effectiveness of a problem prevention can be described with the aid of the quality lever (Figure 1) (Eccles E.W, 1994). It describes the effectiveness of product improvements made at different times in the product development process. To rectify problems downstream after the main elements of a design have been finalised is expensive. Once a product has gone into production, design changes become very expensive. Frequently changes have to be introduced which are not ideal because of the implications a redesign would necessitate.

However if we foresee problems in a product development and prevent them at the design stage this will yield returns at 100 to 1. We mentioned earlier that the Japanese product development process focuses on preventing rather than reacting on product problems. This is because quality is “built - in” the design rather than added it later when the details of a product may not be able to facilitate it.

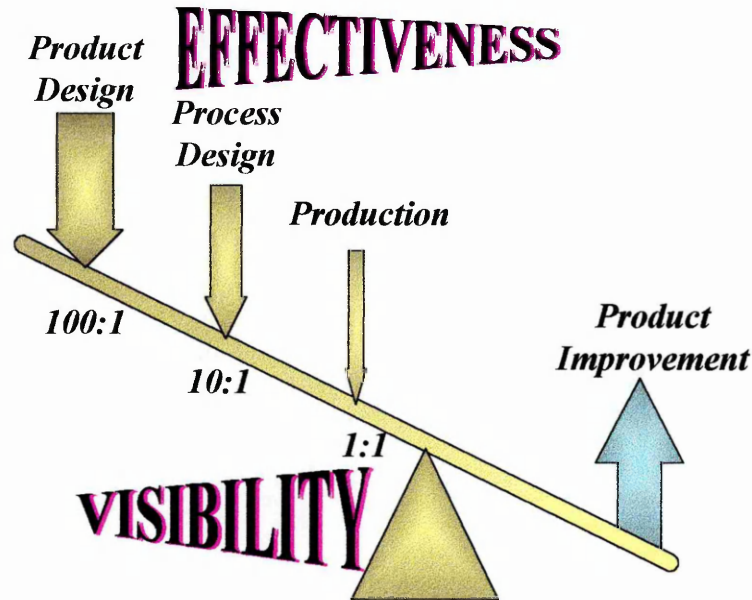


Figure 1
Product Improvement Payoffs

A preventative approach is that it can be contrary to the traditional European prevailed attitudes. Production problem solving is highly visible and can be beneficial to certain individuals in a business enterprise (Eccles E.W, 1994) "*Fire fighting*" can be exciting and is regarded by some managers as their important role in the business. Designers who prevent problems largely go unnoticed and unrewarded (Ralph L. Liberatore, 1993). Obviously this in the long run damages the competitiveness of the business. However companies need a disciplined approach to product design in order to shift the problem solving emphasis from the production stage to the early design stage. Quality Function Deployment is one of the methodologies which can provide invaluable help in supporting this approach.

1.3.2 - Quality Assurance

According to (M Braunperger, 1996) a product's life cycle is mainly divided into three phases: product planning, realisation and utilisation. According to these phases the quality assurance areas are:

- 1) In the Development, where the product is planned on the basis of an initial idea and then built and tested until production maturity.
- 2) In the Production, where manufacturing and assembly of the production vehicles is taking place according to the final documentation from the development.

- 3) In the Field operation phase, where vehicles are delivered to the customer from the production plant.

Quality assurance in the development phase means avoiding same mistakes, considering customer complaints and design quality within the product. On the other hand quality assurance in the production phase means monitoring and controlling of the entire production process so that product faults can be identified and directly eliminated. Finally quality assurance in the field phase means the identification and elimination of faults on the finished product, purchased by the customer.

However a quality shortcoming will affect the above areas. Generally and for this thesis the main causes of quality shortcomings in the European Automotive Industry are:

- Emphasis of quality assurance on the realisation and utilisation phases (M Braunperger, 1996). Obviously this has a negative quality impact on the product quality. As it was mentioned earlier the most important and efficient phase to introduce change is during the development phase.
- Long information paths between all the departments concerned in the feedback of the causes of faults in any phase of the product process planning. According to (Clark, K.B and Fujimoto T., 1992) two-thirds of all technical modification can be avoided by better communication and discipline in the course of the project.

1.4 - The key to the future success of the European Automotive Industry

Undoubtedly the 90's raise the importance of the customer to business survival (Mill Helen, 1994). Historically and during previous decades somewhere in the technology push and financial boom the need to listen to the customer needs in the European Automotive Industry seemed to diminish. It becomes obvious that this "lack of customer care" is the main negative factor for its present state of severe difficulty and outright crisis (Ederhard C.Stotko, 1994). It is self evident when studying the quality of Japanese Automotive Products. Moreover it is this extreme

care and attention to the voice of the customer (VOC) which gave them the leading edge and growth during this decade, upon European ground.

According to (M Braunperger, 1996) the very highest product quality and level of technical innovation, the finest standards of comfort and convenience, an elite brand image and consideration of economic operating factors are all points that the customer by now regards as self evident. Product quality has developed in recent years from a strategic competitive advantage into the most important of all the preconditions for competitiveness and hence an undoubted survival factor for the manufacturer concerned. The quality concept is today strongly connected with customer satisfaction (Bergman B. Klefsj B., 1991). New approaches are emerging and are built around the idea of more customer focus and empowerment of cross-functional teams. The customer must experience a pride in owning the product and the people within the organisation must experience a pride and satisfaction in their work (Lynn Bishop - Gains, 1990). The primary philosophy of which is that quality products cannot be delivered as long as design and manufacturing activities are performed in isolation (Sriraman, Vedaraman, Tosirisuk, Phadhana, Chu, Hsing Wei, 1990).

One important reason for the Japanese success is the consequent and systematic use of statistical methods and TQM during different stages of the design and manufacturing process. The implementation of such concepts or methods has found difficult ground in the European Automotive Industry, mainly because of the way it is operating. According to (Gopal K. Kanji, 1990) many of them still believe that achieving quality is far too expensive to be justified. On the other hand it is increasingly seen that high customer quality standards such as the ISO 9000 or QS9000 are implemented but according to (Alain Michel Chauvel, 1994) this is not good enough because their customer will not accept them as infallible evidence to the commitment they owe him. Marginal modifications or extensions of the present system will certainly not be sufficient. According to (Gopal K. Kanji, 1990) much of the present negative results in the European Automotive Industry are down to the above issues and the management's lack of understanding and arrogance which protects and defends others. Therefore with modern concepts such as TQM is fair to say that they will never be implemented within a short period of time without prior and preceded changes in the attitude and culture.

Today the driving force of change is the acute economic pressure, which threatens the existence of European Automotive companies. Reducing product cost in the short term is a high priority and many current product development projects are initiated with that goal in mind. In the long run though current ways of product development need improvement. This is a painful moment of truth, because directly or implicitly it is a criticism on the current leaders in the European Automotive Industry and their practises, a recognition of their own shortfalls (Ederhard C.Stotko, 1994). This process will never be comfortable and difficult as it sounds, they must think in terms of "building" and "creating" -- as opposed to "protecting" and "defending".

Drastic changes are needed throughout the industry to regain global competitiveness. If European Automotive industries want to regain leadership, they have to fight for it. This change of the mind-set implies the voluntary intellectual recognition, that current or old practices can no longer cope with the new tasks and issues. From this must follow the conviction, that there must be better ways. Those better ways must not be seen solely in a technical sense of new methods or techniques, but rather more holistically as "*human-centred*" new total Industrial Systems. These systems have to take advantage of the education and knowledge of the people who work with, and their inherent performance and potentials.

One of the most popular techniques which provides invaluable support in these organisational changes is QFD. QFD is revolutionising the way a company operates and how it goes about meeting customer requirements consistently, confidently, economically and competitively. Unlike many other tools and techniques that can be incorporated more or less into the existing systems as a bolt-on, QFD operates differently. It challenges the working culture peoples attitudes and interaction processes and attempts to optimise creative contributions internally that would lead to satisfying the customers requirements.

1.5 - The role and the importance of QFD

As mentioned QFD can be considered as a good vehicle for introducing change and can carry out cultural transformations. In addition it enables organisations to be proactive rather than reactive. Nowadays the customer loyalty is of paramount importance and the only way to maintain it is by keeping the customer continuously satisfied. QFD amplifies the customers voice to all levels of the organisation and educates people to think about doing what the customer wants rather than doing things for the customer.

The most successful products are those which meet customer requirements (Eccles E.W, 1994). If the customers requirements are vaguely defined then frequently the design develops along the path of the strongest personality in the product development process. Whether this is what the customer wants, becomes hit and miss. QFD is a methodology which assists in ensuring that the product meets the requirements of the customer. It helps a company focus on the aspects of its products which are important to their customers and hence those elements which are crucial to being successful in the market place.

Despite the best intentions of all concerned in the product development process one can notice that in the large European Automotive organisations frequently the end product result is not meeting the customer's requirements. The crux of the problem is to define and communicate the VOC (Voice Of the Customer) in an appropriate and meaningful way throughout the organisation. QFD provides a solid methodology for establishing and communicating this information by focusing an organisation's efforts to the customers satisfaction. With such information the many trade off decisions involved in the design process are guided by what the customer wants rather than what may be convenient. Within an appropriate framework QFD can assist in implementing strategies to reduce product introduction lead times which can assist in successful products.

Finally the product realisation process for complex products i.e. cars, involves numerous teams addressing diverse engineering, manufacturing, financial, legal, marketing, logistics and servicing issues. To guide such an effort a structured methodology is needed to ensure that the appropriate issues are considered and sound decisions are made. QFD can be used to channel this information flow in a

structured formalism and acts as a link between all areas. QFD plans the actions before the crisis. It is a good proactive tool which brings out all of the issues before actions are taken. It ties the issues together in a useful way which can reassure better decisions between alternative subsystems and components for the design of a whole car or any part of it.

1.6 - The role and the importance of Fuzzy Logic

As mentioned earlier companies aim to stay competitive by improving quality and customer satisfaction of their products, while streamlining their product design into an ultraefficient process. QFD is a Japanese technique that provides invaluable support and guidance to these vital issues. QFD uses HoQ (House of Quality, see chapter 2) to organise, communicate, and manage the information from diverse sources in a single representation used to identify improvements in the design, development, and manufacturing process. QFD makes clear the connection between engineering decisions and their impact on the customer. Various inputs in the form of judgements and evaluations are required during the QFD analysis. All the input variables in this analysis are usually treated as numeric variables.

Obviously QFD as an information and communication tool, involves human thinking and feeling with some comprehension. This comprehension involves the representation of our thinking and feeling in numerous forms like pictures, images, daily language and value systems. If one considers that the power of human thinking and feeling is much higher than the power of a living language then it seems impossible to guarantee a one-to-one mapping of problems and systems in our imagination and in any logical model or methodology i.e. QFD. The complete description of a real system often would require far more detailed data than a human being could ever recognise, simultaneously process and understand. Real situations are very often not crisp and deterministic and they cannot be described precisely.

Most of the European traditional thinking and analysis tools for modelling and reasoning are crisp, deterministic and precise in character. This conventional dual logic describes, expresses and analyses phenomena with a statement of true or

false (black and white), but nothing in between. That means an element in this thinking process can belong either to a set or not and in optimisation a solution is either feasible or not. Precision assumes that the parameters of a model represents exactly either our perception of the phenomenon modelled or the features of the real system that has been modelled. Generally precision also implies that the model contains no ambiguities. However the usefulness of a mathematical language to model this dual logic became undisputed, since the in depth analysis of the phenomenon wished to be modelled would become feasible. Obviously there are limits to the usefulness of this classical mathematical language based on the true or false statements, in modelling particular systems and phenomena.

Real situations are very often uncertain or vague in a number of ways. Fuzzy logic enables us to model vagueness in data and relationships in a formal way. The vagueness may be due to randomness, the uncertainty of an event or occurrence. A basic concept in fuzzy logic is linguistic variables, which is defined as a variable whose values are words or sentences in a natural or synthetic language. The ultimate goal of fuzzy logic is to represent human thinking and feeling in a manner faithful to the human style of processing information, as well as in a form amenable to computer manipulation (L.P.Khoo, N.C. Ho, 1996). It can be viewed as a language that allows one to translate sophisticated statements from natural language into a mathematical formalism. With this mathematical form of knowledge, we are able to collect ideas, preferences and opinions from numerous individuals and draw upon the work done by others in the past (technological, corporate history). This past knowledge can be manipulated, and utilised effectively. This technique has been developed and accepted as being effective when applied to complex control systems and techniques within a wide range of engineering disciplines.

The described method in this thesis utilises a user friendly QFD decision platform and analysis tool in order to guide design and decision making strategies. The information contained in the QFD methodology is only qualitative in nature and therefore its mathematical manipulation is accomplished utilising classical mathematics. Fuzzy logic offers solutions to problems where concepts are subjective, quantities are known only imprecisely and system models are descriptive rather than analytic. While approaches based on classical mathematics require accurate equations to model real-life behaviour, fuzzy logic can

accommodate the ambiguities of real-life human language and logic. It provides both an intuitive method for describing systems in human terms and automates the conversion of those system specifications into effective models.

1.7 - The objectives of this project

The overall aim of this project is to simplify and enhance QFD's integrity, purpose and acceptance in the European Automotive Industry utilising fuzzy logic principles. This is achieved by describing the concept and its steps in a simpler structural form and by proposing its implementation to the product development process utilising a PC based spreadsheet or database software.

Therefore the objectives of this project are:

- 1) To simplify QFD's documentation
- 2) To investigate the capabilities and limitations of the current QFD methodology
- 3) To investigate problems and difficulties arising from the way QFD is currently implemented
- 4) To propose and develop a QFD methodology which can provide enhancements in its integrity purpose and acceptance
- 5) To develop a way to implement the proposed process into any common PC software i.e. spreadsheet, database

Chapter Two

The QFD approach

2. - The QFD approach

2.1 Origin and definition of QFD

According to (Schubert, Michael A., 1989) QFD was developed in Japan by Dr Shigeru Mizuno from the Tokyo Institute of Technology. During the late 60's and early 70's, Dr Mizuno worked with Kobe Shipyards of Mitsubishi Heavy Industries Ltd on product planning. In 1972 he developed the 'quality tables' to help support planning which later evolved in to QFD. Toyota (Autobody Group) took notice of Mitsubishi's success in the middle 70's, and spent over 3 years studying the technique, developing it with case studies. They began using it officially during 1977 and have reaped great benefits such as: 60% reduction in product cost, 50% reduction in new model development time and a production start-up essentially free from "learning curve"(Schubert, Michael A., 1989, Nichols Keith , Flanagan Derek, 1994 and Kathawala Yunus, Motwani Jaideep, 1994).

From the 70's onwards the number of QFD articles in Japan grew exponentially. One contributing reason according to (Schubert, Michael A., 1989) is that QFD is a method of implementing CWQC (Company Wide Quality Control). or TQC (Total Quality Control). It was launched in America during 1983 by the Ford Motor Company and Cambridge Corporation. According to (Adams, Robert M., Gavoore, Mark D.,1990) QFD as a concept was brought to the US by Yoji Akao in 1983 through an article in Quality progress the official magazine of the American Society for Quality Control (ASQC) and 3M was the first corporation to first use the technique in a project. According to the same paper the concept hit the Automotive industry via Ford which transplanted the concept in 1985 and began encouraging its divisions and suppliers to investigate and use it. Though it is not quite clear when QFD arrived in Europe it is believed that it came from the American academics and industrials during the early 90's mainly from the Automotive sector. It appears that it came officially in Europe by ASI (The American Supplier Institute) through a conference in Italy in 1992 which was organised by Galgano and Associati.

According to the textbooks the Japanese words behind QFD methodology are: hin shitsu, ki nou, ten kai. By tolerating some room for interpretation these words literally mean (Figure 2):

- Hin Shitsu: Quality, Features, Attributes, Qualities.
- Ki Nou: Function, Mechanisation.
- Ten Kai: Deployment, Diffusion, Development, Evolution.

The six Kanji Characters which are translated in English as Quality Function Deployment (QFD)

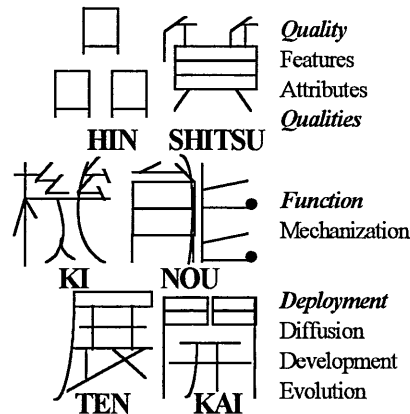


Figure 2

The origins of QFD word and meaning

There are numerous ways that QFD has been defined during the last decade in USA and Europe, here the author provides the ones he found most interesting.

- Professor Yoji Akao (Professor of Management Engineering, Tamaqawa University, Japan) who was responsible for its inception defines it: 'QFD is converting the customer's demands into 'quality characteristics' and developing a design quality for the finished product by systematically deploying the relationships between the demands and the characteristics, starting with the quality of each functional component & extending the deployment to the quality of each part & process'
- The American Supplier Institute (ASI)(American Supplier Institute, 1987) defines QFD as "A system for translating consumer requirements into appropriate company requirements at each stage from research and product development, to engineering and manufacturing, to marketing/sales and distribution".
- According to (Adams. R.M, 1992) "A technique or a discipline that can improve the process of developing and producing products. It deals with "Verbal data"

and accomplishes this task not by requiring massive investments in engineering or manufacturing, but by capturing the customer's needs and focusing on meeting as many of them as possible"

- According to (D'Egidio, F.,1992) 'QFD is a series of techniques used to translate the Voice Of the Customer, subjective and imprecise, into objective and relevant products and specifications.'
- According to (Fortuna R.M, 1988) 'QFD is a systematic means of ensuring that customer or marketplace demands (requirements, needs, wants) are accurately translated into relevant technical requirements & actions throughout each stage of product development.'

The author perceives QFD as a versatile democratic communicating tool which provides a solid structured basis to understand the exact customer needs and their corresponding Design Targets and Quality Assurance Points. But lets see how one can approach and implement this powerful technique.

2.2 - Voice Of the Customer "VOC" and its dimensions

According to (Fortuna R.M, 1988) "The voice of the customer is the point of departure for QFD". It drives the process. Listening to the customer, understanding the customer, and interpreting and translating what the customer says forms the philosophical heart of QFD". But do I have the right VOC ? It is difficult to know whether the VOC has been understood (Martin Geiger , Wilhelm Steger, 1995). Every QFD practitioner stresses the need to speak to the customer frequently and from the initiation of the project till the end of it and beyond. What happens when the customer describes his/her needs in terms of "intuitive system" or "easy to use". For one will be a trivial interpretation but does this interpretation capture his true meaning?. In the previous chapter we saw that QFD assumes that customers "Whats" are right therefore we base our entire product development to satisfy them. Numerous practitioners state that it may take several weeks to thoroughly gather and structure the "Whats" then only several days or even hours to generate a set of "Hows" along the top of the planning matrix. All of them agree though that it is vital to get a reliable understanding of customers needs since this would be the most important underlying assumption into our further product development process.

QFD is extremely good at showing the positive aspects of where the “Hows” support the “Whats”. What it is not good at, is to research and acquire the right customers “Whats”. When defining the “Whats”, words such as implied, fast, comfortable and others can have multiple meanings depending on the context in which they are described. By looking at the work patterns of a customer, this can reveal many hidden secrets as to what is required. If time is spent observing how customers go about using the products there will be a richness to the understanding of their needs since "Action speaks louder than words" . Therefore this information overflow may or may not make sense with the kind of product one is about to develop. In addition inadequate knowledge into customers needs may lead him to a bad product development which obviously will have a bad impact on his business.

The following sections describe mechanisms and methods which can help us to gather, analyse and structure in a meaningful way the customers needs. In addition we are going to see how we can take full advantage of this information by its utilisation into QFD matrices.

2.2.1 - Types of Customer

As mentioned earlier it is of paramount importance to know the customer the question though is “Who is the Customer ?”. Some people assume the customer is the person who makes the decision to buy the product. Others believe that it is the person who buys and uses the product. Obviously these may be very different people. For instance in the Automotive industry we will find that the product development process has to consider “the buyer” in the case we produce automotive parts for the car maker, “the government” since several laws and legislations would need to be satisfied before we are eligible to sell the products and finally “ the physical buyer / user” which is the person who is going to use and leave with the product. Of course one may expand the chain as much as he wants by adding, “stakeholders”, “managers”, “executives”, “engineers”, “assemblers”, “industrials” and so on. Obviously these customers have to be identified before the primary stage of the QFD matrix since our development process may well involve some or all of these “Customers”. In all cases we need to define who is the “Key Customer”.

The first step in defining the key customer is to make a list of all the “Customers”. Then we can brainstorm in order to identify their degree of importance. Generally speaking three major types of customers are identified currently in business. These are:

- ♦ **The Internal Customer;** we classify as internal customers those within the business who are linked somehow with the product development process and its industrialisation. However these may be people in the production line, in the product assembly, in the quality control and so on.
- ♦ **The Intermediate Customer;** we classify as intermediate customers those who are buying, distribute and promote the products. However these may be the distributors, retailers, promoters and so on. This group of customers are important because they know their customers needs. Therefore the ability to satisfy their needs will determine how well they will sell and promote the products in the marketplace.
- ♦ **The External Customer;** we classify as external customers those who are buying and use the products. These are the consumers, the most important group type of customer. The ability to satisfy their needs and requirements will determine the business success or failure. If these customers do not buy the products then the intermediate customers will not buy them either, hence the business will fail to survive.

2.2.2 - Capturing the Voice of the Customer

Now the decision has been made as to the “who the customer is” and the level of his importance in the product development process. Therefore the next step to take is to find out the customers product needs. To do so a number of ways may be used i.e. , by interviewing them, by observing them using the current product or by taking into consideration their complaints about the current products and so on.

A very popular way to capture the VOC is by interviewing them. Numerous practitioners find this as the best way because they harness a direct relationship with the customer and that helps them to build a better knowledge of their requirements and needs. A good approach when interviewing the customer is to

have pre-set open ended questions because this helps to gain a quick broad perception about what they need from the product. Normally the results acquired with this type of interview are a set of phrases representing somehow their needs and what they want. Generally customers don't structure their thoughts about their needs partly because very few of them feel very comfortable with the process and partly because they mix their needs with their feelings, complaints, comments and suggestions about the current product. The important thing though is that all these comments, phrases, ideas and so on have potential value during the product development process. On the other hand the QFD process needs their "true" needs, however we have to sort the information into some categories. One way of doing this categorisation, imposed by QFD practitioners is with the utilisation of the VOCT (Voice Of the Customer Table).

The VOCT is aimed at capturing the context of the customer needs, so that the larger portion of them can be identified and understood. We should not confuse VOCT matrix function with the typical matrix. The way VOCT works is to quantise the linguistic data in a series of columns in such a way that it may provide us with visual clues. (Figure 3). In brief VOCT consists of the following parts:

[illegible]

Figure 3
Voice of the Customer Table

- ◆ *The ID Column*; identify the source of customers phrase
- ◆ *The Customer Demographic Column*; where information like age, income bracket, occupation, location and so on is provided

- ◆ *The Customer Need Column*; which contains the wants or needs of the customer as they appear in the Affinity Diagram (Described in the Appendix “Useful TQM tools in QFD’s informational flow”). In this column we should pay extra care in the wording.
- ◆ *The Use Section*; which holds information that describes what customers do that have implications in our product design. i.e. think of a coffee company and what they may consider as customer needs. For example if the customer use the coffee as a means of socialisation, perhaps they can design it as a low caffeine drink but if he use it as a morning stimulant, perhaps a strong coffee will be more appropriate. Now the Use section has several subsections. These are the what, when, where, why, how. A bulleted example is following in order to illustrate this:
 - ◆ *Customers statement* “When I drink in the morning my coffee in the office...in order to keep myself awake” the “In the morning” will go to the “When” , the “in the office” will go to “Where” “to keep myself awake” will go to “Why”.
- ◆ By doing this exercise it is possible to analyse and uncover as many aspects of the situation and the way the product affects the customers satisfaction. Therefore we gain a better understanding of the product and the customers needs.

Additionally to this exercise a lot of practitioners categorise those needs further with the use of another table which will give them an indication as to whether this need should be included in the target value, in the SQC’s and so on. A further analysis and explanation is beyond the scope of this theses. What we should bear in mind is that the purpose of this information gathering is to reassure information clarity about the customers needs and to distinguish these needs in such a way as to use them in the QFD matrix in its most effective sections. i.e. in the coffee example the fact that the coffee may be used as a stimulant (wake up tonic) by the customer, “What” may be more effective if it is used as product target and so on.

2.2.3 - Levels of Customer Requirements

In this information gathering about the customer and his needs, a better understanding between the levels of his requirements and the way he may express them may be useful. It may be arguable whether we need to know this type of information before the direct VOC capturing or afterwards. The author believes

that afterwards is more appropriate since it prevents preoccupation with the customer. However there are four levels of customer requirements. The task in the product development process is to satisfy the requirements in the following sequence: (Figure 4)



Figure 4

The levels of customer requirements and the difficulty sequence in responding to them.

- 1) **Expecters** ; These are the basic expected requirements. These are often so obvious and basic to the customer that they may fail to mention them - until they are not present. These are basic expectations without which the product may cease to be of value. Their absence is very dissatisfying.
- 2) **Spokens** ; These are the revealed requirements. These are the needs which typically the customer will request if asked. These requirements satisfy or dissatisfy the customer in proportion to their presence or absence in the product.
- 3) **Unspokens** ; These are requirements that the customer hasn't considered. There are numerous times that we don't know what we want unless we see it. Therefore these may be the customers hidden expectations. However selling to the customer a product that falls short of expectations leaves a negative perception about the business and it may take several years to overcome this perception.
- 4) **Exciters** ; The unexpected features of a product are exciters. These features make the product unique and distinguish it from the competitors. Generally they are difficult to discover because they are beyond the customers expectations. Their absence doesn't dissatisfy. Their presence really excites. These are things that make the customers come back since they feel that the

company explores their needs further, designing the products with a definite focus on their needs.

2.2.4 - Kano's Model

The levels of customer requirements were described by Noriaki Kano (Akao Yoji, 1990) in a slightly different way to that mentioned earlier. It is his descriptions which were used in many businesses. Kano's model provide us with a mechanism which relates product characteristics (SQC's) with the level of the customers satisfaction. This model divides product characteristics into three distinct categories of which affect the customers in a different way. These categories are (Figure 5) :

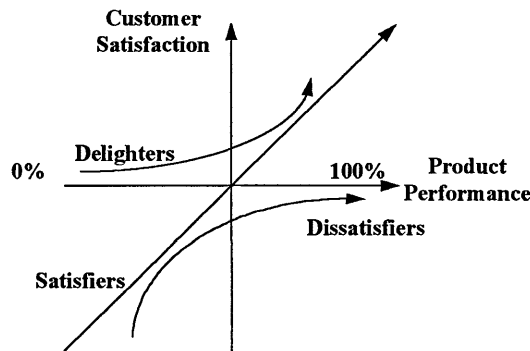


Figure 5
Kano's Model

- 1) **Dissatisfiers or 'Must Be'**; Are the product characteristics that the customer will take for granted when they are present, but will cause dissatisfaction when they are missing. Dissatisfiers are the absence of 'expected quality', 'expected performance' etc..
- 2) **Satisfiers or 'Straight - Line Characteristics'**; Are product characteristics that the customer ask for. The more we provide of a satisfier the happier the cutomer will be.
- 3) **Delighters or 'Exciting Characteristics'**; Are product characteristics that are pleasant surprises for the customer. If they are not present the customer will not be dissatisfied but their presence makes them unique from the competitors. A number of products with delighters today become the satisfiers of tomorrow. The reason is once we introduce an exciting feature today,

tomorrow it will be imitated by others therefore it loses its novelty and fails to excite.

2.3 - Product Types

So far we have seen several ways to understand the customers "Wants" and several ways to satisfy them. Obviously the customers "Wants" have to be satisfied through the products, since that will secure and expand the business. However a decision has to be made about the type of product to be developed. The three types of new products which exist in today's global competitive environment are:

- 1) **Breakthrough products;** These are technology based products, which are driven by basic research in the universities, national laboratories, major businesses. This research is focused on finding new materials and technologies. The results or findings of this research passes through the development or advance development teams of a business which refines and implements them into products.
- 2) **Follow on products;** These are new products within existing product families which are introduced in the marketplace because of their price performance improvement characteristics. Generally products driven by changes in customers expectations or changes in competition, technology, different market opportunities and so on.
- 3) **Modified products;** These are enhancements on existing products that are made essentially for cost reduction or specific customer inputs or options. They are simple in nature and require little engineering effort.

It is believed that the breakthrough products have the largest impact on our long financial business health. On the other hand these products require greater risks since the knowledge about them and their results in the marketplace cannot be accurately predicted. The follow on products are the ones that reassure our competitive presence in the marketplace. Therefore it is vital to keep them healthy, and cost and market driven. Without them we don't have a presence without breakthrough products we don't have a future.

2.4 - Building the House of Quality (HoQ)

As previously stated QFD is a communication and translation methodology. It translates various inputs into required outputs at all stages of the product development. The primary element of this process is the House of Quality (HoQ) where all the relationships and comparisons will be acquired. It starts with the customers input 'What' or the Voice of the Customer (VOC). Then the VOC is grouped logically and then processed into a quantifiable output (measurable product goals or requirements). By application of the engineering 'know-how', 'How' is to be accomplished. Relationships between the 'What' and 'How' are then established in order to clarify the main product key points.

Because of the unique way in which individuals perceive QFD, its views have undergone dramatic change during recent years (Chang, Chia-hao, 1989) but there is a general agreement on its basic representation. In this thesis the author expresses and reinforce the general overview of the most recent and well argued version of the technique.

The heart of QFD is the House of Quality (HoQ) which can be constructed as shown in Figure 6 , it consist of the following parts:

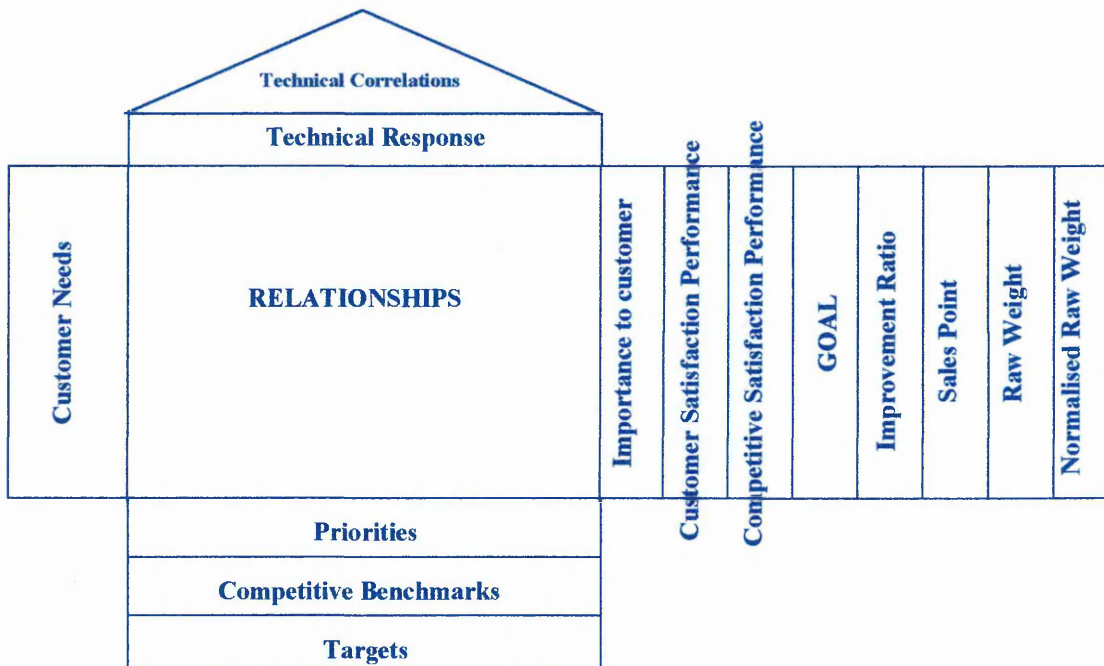


Figure 6

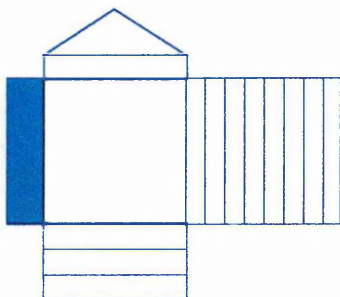
The House of Quality (HoQ)

- **The customers needs or “Whats”:** a list of characteristics of the product defined by the customer;
- **Technical response or “Hows” or SQC:** a list of ways to achieve customer ‘What’;
- **Technical correlation:** which shows the relationship between the ‘Hows’;
- **Priorities:** the relative contributions of the SQC to overall customer satisfaction;
- **Competitive benchmarks:** the factor by which the organisation is in comparison with the competition;
- **Targets:** target values indicating the level of technical characteristics the customer wants;
- **Relationships:** systematic means of identification to the level of relationship between a product characteristic and a way of achieving it;
- **Importance to the customer:** a related factor of importance is assigned for its customer need;

- **Customer satisfaction performance:** is the customer's perception of how well the current product is meeting his needs;
- **Competitive satisfaction performance:** is the competition's customers perception of how far the current product was in order to meet their needs;
- **Goal:** where decision acquired on what will be the goal they want to aim for each customer need;
- **Improvement ratio:** where decision acquired on what level of improvement in their customer performance they want to aim for in meeting each customer need;
- **Sales Point:** contains information characterising the ability to sell the product based on how well each customer need is met;
- **Raw Weight:** contains a computed value from the data and decisions made in order to model the importance to the development team;
- **Normalised Raw Weight:** where the raw weight values are expressed as percentage.

QFD is extremely good at showing the positive aspects of where the "Hows" support the "Whats". In reality each design is about balancing off a whole series of conflicting trade offs: (least cost Vs higher performance; Higher performance Vs least weight, more features Vs increased reliability etc.). These hundreds of conflicts have to be blended into a final concept which out-performs the competition. The following sections of this chapter will illustrate this invaluable mechanism by describing the individual parts of the HoQ in detail.

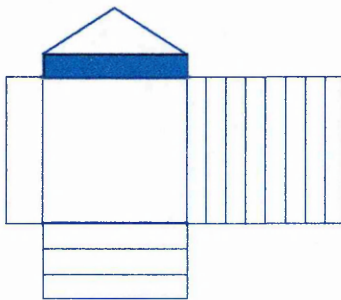
2.4.1 - The Customer Needs or "Whats"



As previously explained QFD starts with the VOC's (Voice of the Customer) acquisition. Previously the VOC dimensions being analysed (customer type, level of satisfaction etc.) and explained ways of processing them in order to place them in the QFD chart. The reader should note that previously in the brief explanation of the HoQ parts it was stated that "What" is a list of characteristics of the product defined by the customer. Though there are numerous textbooks and papers that fail to clarify this point the author believes that at this preliminary phase of QFD's

structuring, the vagueness of the customers statements should be eliminated. Therefore it is proposed that a clear distinction between customer “What” which is a list of clear characteristics and VOC which can be a list of vague, general and difficult characteristics or statements. In other words the vague and sometimes unstructured customers statements (VOC) have to be processed in a qualitative and quantitative form “Whats” so that we can reassured a clear technical response.

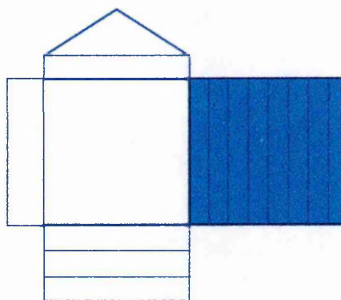
2.4.2 - Technical Response “Hows” or SQC (Substitute Quality Characteristics)



In this “Hows” row the technical response or way of achieving the customers “Whats” is placed. Virtually any idea that can help find the solution to a “What” is a “How”. Obviously in this field the collective knowledge of the company and its disciplines are utilised. It is extremely important to include as many ideas and

solutions as possible in order to reassured a good and accurate translation of the customers language to the company’s product language. This product language is called SQC. SQC may describe the product from any variety of viewpoints. Many practitioners call SQC’s as product or design requirements. There is an open field for debate as to whether SQC is something that was just defined or something more like product function, performance measurements, product subsystems etc. That’s why a lot of practitioners prefer to name this response as “Hows” and leave it to each individual perception for interpretation. In this theses we are going to use both terms just for convenience and of familiarity terms.

2.5 - The Planning Matrix



This is a series of matrices which is very important for strategic planning and market research. It is the section where marketing provides its input with quantified data results from their surveys and customer research . Now these data are ranked in order to express the customers priorities according to his wants and needs. This data

includes: the relative importance to the customers needs, their satisfaction levels with the current products, the direct comparison between the product and the ones in competition from the customers viewpoint and finally the strategic goals setting for the new product.

The planning matrix is extremely important because it provides invaluable information in a very systematic way. Moreover it expands the perception of the products. In brief the planning matrix answers the following vital questions:

- ◆ How important is this particular need to the customer.
- ◆ How good is the response today to this particular need.
- ◆ How well the competition is responding to this need today.
- ◆ What could be the next development target for this need.
- ◆ If response to the need is at a satisfactory level, what could be the positive impact on sales.

In the following sections the Planning Matrix is covered in more detail.

2.5.1 - The Importance to the customer

As the title implies this section is where quantified data results for the concept of rating the customers needs, is taking place. Normally these results are acquired upon consideration of the represented market segment and they are based on a number of surveys, market research and the development teams own viewpoints. The three popular ways to acquire them are:

- ◆ ***The Absolute Importance methodology;*** where results are obtained by a survey in which the respondents (Customers) are asked to rate the importance of each need on a scale defined by the product company. The positive side is that this approach eliminates professional market research firms. Therefore the development team is entirely liable for their acquisition and interpretation. The negative side is that a lot of times the customer becomes unable to prioritise his needs resulting in an overestimation of his “true” requirements.
- ◆ ***The Relative Importance methodology;*** where results are obtained by a survey in which the respondent (Customers) are asked to rate their needs in comparison to one another. The positive side is that it is very difficult for the customer to overestimate his needs. The negative side is that it demands more time from the customer.

- ♦ **The Ordinal Importance methodology;** where like the Relative importance methodology the customer compares the needs with one another. Unlike the Relative Importance in which they rate the result of their comparisons is Ordinal, the customer just indicates the rank of importance to his needs. The negative side of this approach is that the scoring of his needs becomes quantised.

2.5.2 - The Current Product Satisfaction Performance

In this section we place the customer's perception of how well the current product responds to his needs. Again we can use several ways to acquire this piece of information. Typically we have to compose a set of questions where all of the customers product needs are included. A quantified response is requested within a scale, as to the level at which the customer feel satisfied with the existing product.

2.5.3 - The Competitive Satisfaction Performance

In this section we place the competitive analysis of the existing product. If a competitive product is to be produced we certainly have to consider its competition. The competitors customers are approached in order to get their response for the level at which the existing product did not satisfy them and the level at which the competitor's product did. This vital information in the QFD matrix provides a clear picture of the current product weaknesses and strengths. In addition this information can be acquired in terms of Technical Response (SQC). Therefore this helps to capitalise on strengths and eliminate weaknesses.

2.5.4 - The Goal

In this section the decisions are made for the targets we want to set for each individual customer need. This forms part of the product strategy. It was stated earlier that the approach should focus on capitalising on the strengths and eliminating the weaknesses. This area is where improvements are quantified, improving products in certain areas and remaining stable in areas of strength. In

other words this is the section where decisions are made regarding how much emphasis is to be given to each customer need during the product strategy.

2.5.5 - The Improvement Ratio

In this section we calculate the measure of effort we need to apply in order to achieve the goals set previously. The calculation is:

$$\text{Improvement Ratio} = \frac{\text{Goal}}{\text{Current Product Satisfaction Performance}}$$

So as one may see the more aggressive the target goal in comparison with the current satisfaction performance, the larger the improvement ratio, which means that fulfilment of this customer need becomes more strategically important. One should note that this ratio sometimes can be deceptive.

For example when the current satisfaction is very low and the target is to increase satisfaction then this ratio becomes very large. On the other hand when current satisfaction is already high then improvement does not have any impact. When the customer performance is quite low then it's relatively easy to make modest improvements. But when the customers performance is high then any improvement becomes increasingly difficult to approach.

This phenomenon is known as the "Low hanging fruit", because the low fruits are easy to see and pluck. In our case the lower the current performance is, the easier it is to improve it. Once the low hanging fruits are removed the higher fruits remain to be plucked. The problem is that the higher the hanging fruits are, the more difficult is to see them and pluck them. Therefore the better the current performance the more difficult it becomes to improve it. So if this technique does not provide the results which would be expected logically what can be done? Once spotted this type of phenomenon has two alternatives. The first one is the "Improvement difference" and the other is the "Degree of Difficulty".

The Improvement difference is defined as :

$$\text{Improvement Difference} = 1 + (\text{Goal} - \text{Current Satisfaction Performance})$$

The benefits of this alternative is that all improvement increments irrespectively of whether they are starting from high or low customer performance have the same impact on the overall importance of a customer attribute / need. In the instance that the goal is the same as the current performance, the difference will be (0) hence the result will be (1) which means this attribute will remain untouched. The negative side of this approach is that it does not resolve completely the “low hanging fruit phenomenon”, in the case of high existing performance.

The Degree of difficulty is the method which eliminates this phenomenon by direct judgement. In other words requires no calculation in any value with any other, instead requires a scale and a direct specification to the degree of improvement required in order to acquire the targets. i.e. 1 for no change, 1.2 for a moderate change, 1.5 for a difficult change and so on.

2.5.6 - The Sales Point

In this section is placed the existing information which characterises the ability to sell the product based on a good response to this particular customer need. For example if a car is produced with no need for maintenance then this becomes the strong selling point and so on. The sales point does not carry a big influence in the planning matrix. On the other hand it gives marketing a chance to rate whether or not they would get leverage out of any improvement in each customer need. It should pointed out that failure to keep perspective in this field will lead to numerous debates with other practitioners and accountants. The reason is that all along the planning matrix there is a need for common sense when interpreting numerical data and it should not be translated literally. Finally the sales point is dependent again upon the comparison with the competition and on how important it may be to the customer.

2.5.7 - The Raw Weight

In this section the calculation of the overall importance of each particular customer need is placed in relation to the development process. The calculation that is taking place is:

$$\text{Raw Weight} = \text{Importance To the Customer} * (\text{Improvement Ratio or Difference}) * \text{Sales Point}$$

The higher the Raw weight is the more important the corresponding customer need is to the product development process. As one may see raw weight is a numerical representation embodying the customers satisfaction performance, implementation effort and sales potential. Therefore it provides a strategic business perspective on the importance of the customers needs in relation to the success of the developing product.

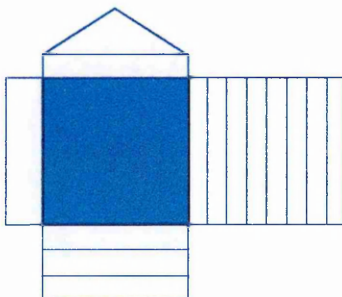
2.5.8 - The Normalised Raw Weight

This section calculates the ratio of each raw weight with the sum of the raw weights. We obtain information in a scale range of 0~1 or 1% to 100% which concerns the overall importance each customer need has to the development process. Hence;

$$\text{Normalised Raw Weight} = \frac{\text{Raw Weight}}{\text{Sum of Raw Weight}}$$

It is obvious that raw weight and normalised raw weight carries the same information with the raw weight. The only difference is that normalised raw weight is more convenient for subsequent calculations in the QFD and more friendly to its interpretation.

2.6 - QFD Matrix Relationships



In this section of the HoQ the relationships between “Hows” and “Whats” are taking place. At this point the attention is drawn to the fact that we deal with the relationships matrix once we have finish with the planning matrix.

By now a substantial amount of information is determined i.e. “Whats”, “Hows” and the strategic market research information and decisions within the planning matrix. With all this information gathering the next task is to fill the relationships section which will provide a mapping between “whats” and “Hows” . Each relationship cell is a representation of the judgement

for the relationship degree between “Whats” and “Hows”. In other words each relationship cell represents the strength of the bond between each customer need with each technical response. This strength is known as the “impact of the SQC”.

Obviously the amount of *impact* directly affects the product response to the *customer needs*. Generally speaking in QFD four possibilities of *impact* are recognised. These are :

- 1) **Customer satisfaction performance** with respect to the need **is not linked** to the SQC. However any changes in the amount of SQC will not affect the customers satisfaction performance.
- 2) **Customer satisfaction performance** with respect to the need **is possibly linked to** the SQC. However for any large changes in the amount of SQC a small change in the customers satisfaction performance may occur.
- 3) **Customer satisfaction performance** with respect to the need **is moderately linked to** the SQC. However for any large changes in the amount of SQC moderate changes in the customers satisfaction performance may occur.
- 4) **Customer satisfaction performance** with respect to the need **is strongly linked to** the SQC. However for relatively small changes in the amount of SQC a significant change in the customers satisfaction performance may occur.

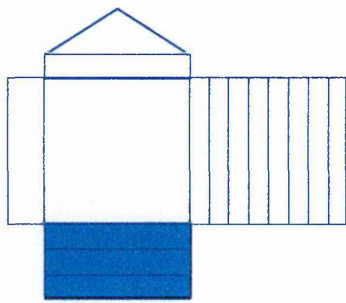
Most common			
		Numerical	Other
Symbol	Meaning	Values	Values
	Not linked	0	0
▲	Possibly Linked	1	5
○	Moderately Linked	3	7
◎	Strongly Linked	9	10

Figure 7
Popular impact symbols and their represented values

The reader should note that all the amounts of *impact* are considered positive. This means that for any positive change or positive improvement in the amount of SQC a proportional amount of improvement occurs increment in *customers satisfaction performance*. Of course one may consider the amounts of *impact* to be negative as well. In this case the amount of positive or negative improvement in *customers*

satisfaction performance will be dependent accordingly upon the positive or negative amount of *impact*. In figure 7 a representation of the popular impact symbols together with their common values is included. In Chapter 6 the author critically comments on these values and recommends an alternative for those who feel that the process should not be restricted to a quantified representation of the impact, since nothing in life is so crisp and clear.

2.7 - The “How Much” matrix



This is a series of matrices, very important for quantification of the individual SQC contribution to the *overall customer satisfaction*, to the factor by which the company is in comparison with the competition and finally to the target values at which SQC's have to respond in the product during development.

The “How Much” matrix is essential because it provides us with quantified information for the products demanded SQC targets, and the difference in the customers satisfaction if we deviate from those. In the following sections the How much matrix is covered in greater detail.

2.7.1 - Priorities of Substitute Quality Characteristics

Having determined the amount of *impact* in each cell in the relationships matrix simple calculations are performed in order to acquire one of the key QFD results; the relative contributions of the SQC to the *overall customer satisfaction* or *SQC priorities*. These simple calculations are consisting of the multiplication between the normalised raw weight and the numerical value for the corresponding relationship bond.

Lets consider the normalised raw weight with elements (B,C,D,E,F,G,H) Figure 8 and the corresponding numerical values of the SQC. Now the SQC priority will be:

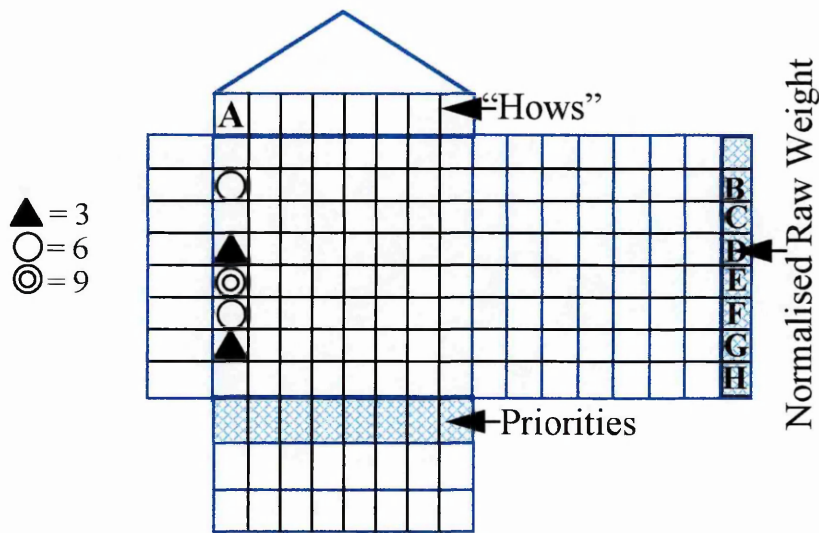


Figure 8

Example in the calculation of the normalised raw weight

$$\text{PrioritySQC} = (B * 6) + (D * 3) + (E * 9) + (F * 6) + (G * 3)$$

This priority SQC total is called the *contribution of the SQC* to the overall customer satisfaction. The larger the contribution, the more influence the SQC has on the *Customers Satisfaction Performance*. Therefore the more important it will be to implement this SQC to the product during its development.

2.7.2 - Competitive Benchmarks

It is self evident to the reader that in order to invest in the development of a product it is essential to know of it's competitors in order to make sure that it's development will result a competitive product. Competition analysis can detect the most popular product features and market trends. By now it is known which SQC's are more important to the product, therefore by selectively benchmarking them according to the ones in competition, results are achieved. Once the SQC's have been prioritised can be set targets for them. The ones with the high contribution values to the customers needs require the attention. The reason is that QFD

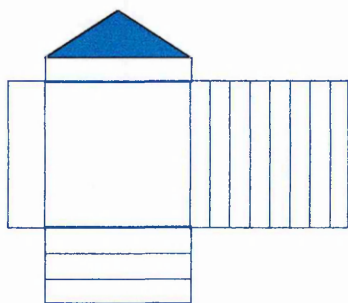
analysis indicates that the performance of these SQC's will strongly influence the customers satisfaction. Hence the QFD process at this stage provides the basis for a strategic competitive benchmarking. The highest ranking SQC's are the ones which will determine the success of the product thus these are the ones which should be examined in the competitive offerings.

2.7.3 - Targets.

This is the area where specific product targets are set for each requirement. From the previous matrix the competitors SQC values were determined therefore these can guide the decisions through the values in order to make the vital strategic decisions, whether to match them or to exceed them. Therefore it may be appropriate to set aggressive target values for those SQC's. Subsequent steps have to be taken to reassure these targets are met in the following stages of product development.

Obviously setting SQC targets will drive all the subsequent product development activities. The importance of the QFD analysis in these target values is that they provide context. This context is related to the customer needs, to the competitions performance and finally to the businesses current performance. The rank ordering of the targets is based on systematic analysis done in the relationships section and of course all the prior QFD analysis process. This ranked order is traceable because all the decisions affecting the rank ordering are recorded in the QFD's matrix.

2.8 - The Technical Correlation's "AKA Roof Matrix"



Amongst all of the definitions mentioned earlier in this chapter it was stated that QFD is a communication tool. In fact QFD is perceived by many practitioners as the key to concurrent engineering. One of the main problems within concurrent engineering is the visibility of activities and knowledge across perspectives. Aka roof ensures knowledge across different disciplines within the same product development team.

The Technical Correlation's section provides this mechanism to emphasise the areas in which important technical communication should exist, to reassure a good response on the SQC's. It is the most underexploited part of the HoQ and it is often called the *Aka roof*. It maps interrelationships and interdependencies between SQC's.

Once a good understanding of a technical concept is achieved, we are able to see that by changing one SQC some others may be influenced. i.e if the concept was a warm smooth cup of coffee and one of its SQC's was temperature of the water then by changing the temperature to lets say a lower temperature then this change may

✓✓	Strong Positive Impact
✓	Moderate Positive Impact
	No Impact
✗	Moderate Negative Impact
✗✗	Strong Negative Impact

Figure 9

Degrees of Technical Impact

influence a number of other SQC's i.e. taste, smoothness, aroma.

In QFD normally we identify five degrees of technical impact between SQC's (Figure 9). These symbols carry no directional connotation. The reason is that numerous practitioners treat this impact as a bi-directional one. Then if either SQC varies, the other will vary according to the type of correlation's described between them. On the other hand numerous practitioners believe that it is more constructive to indicate a direction of impact (Figure 10) because it may come to a strong argument for an impact upon the X SQC to the Y SQC but no impact of Y SQC to the X SQC. i.e. In the previous coffee example changing the temperature may change the coffees taste but does not mean that by changing the coffees taste we can change its temperature.

As we said earlier one important benefit of the technical correlation's is to indicate which teams or individuals must communicate with each other during the product development process. The reason is that if A Team finds difficulties on meeting its X SQC target then they should make the B Team aware of which Y SQC target values are highly dependant on the X SQC. There are a lot of informal methods to further understand this kind of information. One method which seems

✓✓	Strong Positive Impact, left to right
✓	Moderate Positive Impact, right to left
	No Impact
✗	Moderate Negative Impact, right to left
✗✗	Strong Negative Impact, left to right

Figure 10

Degrees of Technical Impact with Direction of Impact

to gain ground lately is the construction of a Responsibility Matrix. This Matrix typically displays all the SQC's of the developing product and the responsible person on meeting those needs. Finally one should know that by ignoring these vital interrelationships it invites a chaos to the vital product development process. Hence it is wise to keep things clear from the start in order to avoid bad surprises.

2.9 - The Four QFD Phases

The HoQ phase as mentioned provides the most critical information regarding our relationship with the customer and our area of competition (marketplace). The voice of the customer though doesn't stop here, it has to be driven throughout the company. Therefore a series of matrices or QFD phases are utilised where the VOC is systematically cascaded to the entire product process planning. In other words these four QFD phases are a guide through the product development cycle from product design to production. These phases are shown in Figure 11:

1) Design (Product Planning). In this phase the customer helps define the product requirement. QFD matrix helps the team translate customers needs into 'What' and after their determination the development of the matrix starts.

The team creates different ways of achieving the requirements 'How'. Prior to their evaluation some of them will be carried out to the next phase.

2) Details (Part Planning). When the 'How' are carried over from phase 1, they become the 'What' for the 2nd phase. In this phase lie all the details and the components necessary to produce the product acquired. The details emerging from this phase have the closest and strongest relationship to correspond satisfactorily to the product requirements specified by the customer.

3) Process (Process Planning). This matrix is developed to show the processes required to produce the product. The 'How' from the 2nd phase become the 'What' for this 3rd phase. The process of this phase will ensure the awareness of the customers product requirements acquired from the previous phases.

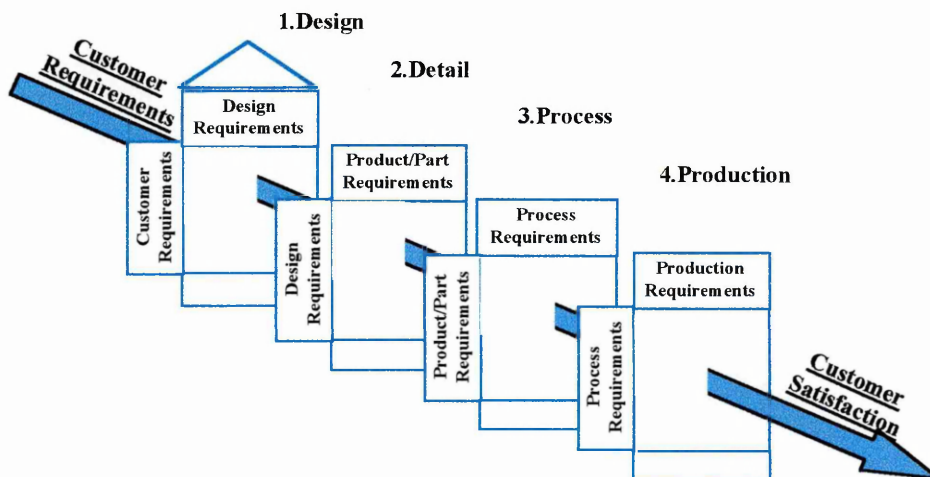


Figure 11

The Four QFD Phases from Product Design to Production

4) Production (Operation Planning). This matrix is developed to show the way of production to produce a high quality product according to the customers requirements. The 'How' from the 3rd phase become the 'What' for this 4th phase.

2.10 - Overview of QFD's informational flow and its natural links with the existing TQM tools

As already mentioned QFD is dealing primarily with the design aspects of a product by starting with the end objective and then determining the means by which that objective is to be achieved. QFD joins the voice of the customer with the voice of the product development process. QFD links these two vital voices by

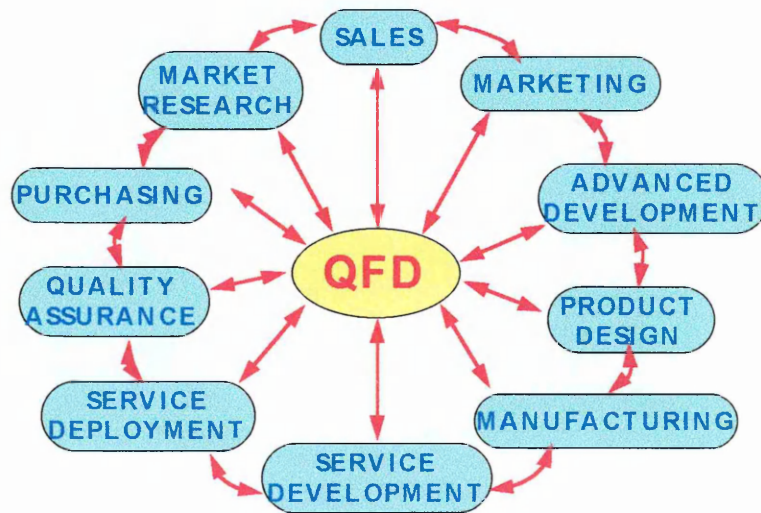


Figure 12

QFD as an organiser in the co-operation between cross functional teams of the product development process

aiming at the optimisation of the product development process with the true and well captured customers requirements. Obviously this involves numerous people from different backgrounds and disciplines. To accomplish this a systematic approach towards the co-operation between cross functional teams is required (Figure 12).

As one may gather from the previous paragraphs the implementation stages of the QFD process are heavily dependant on the processed data and ideas (inputs). Obviously this processed data has to be reliable, logical and clear so that the participants in the product development process can agree with them. It is evident that when a team has reached a mutual agreement (consensus), then they are more keen, willing to participate and contribute to the products plan, design and

manufacture. This will retain integrity of the democratic and logical principles adopted by QFD at each decision point.

In order to address the above issues the following five facets have to be maintained:

- 1) customer focus,
- 2) management by facts,
- 3) continuous improvement,
- 4) total investment,
- 5) systematic support.

These facets are also the main template of the concurrent or simultaneous engineering. However to address these facets a series of tools are utilised prior or in conjunction with the QFD process. These tools are well known in TQM (Total Quality Management) and intend to promote a more creative, effective and reliable approach to the product development process. They are necessary in order to place the emphasis on the customers voice and to provide a detailed documentation of the product development teams efforts. Figure 13 illustrates the relationship

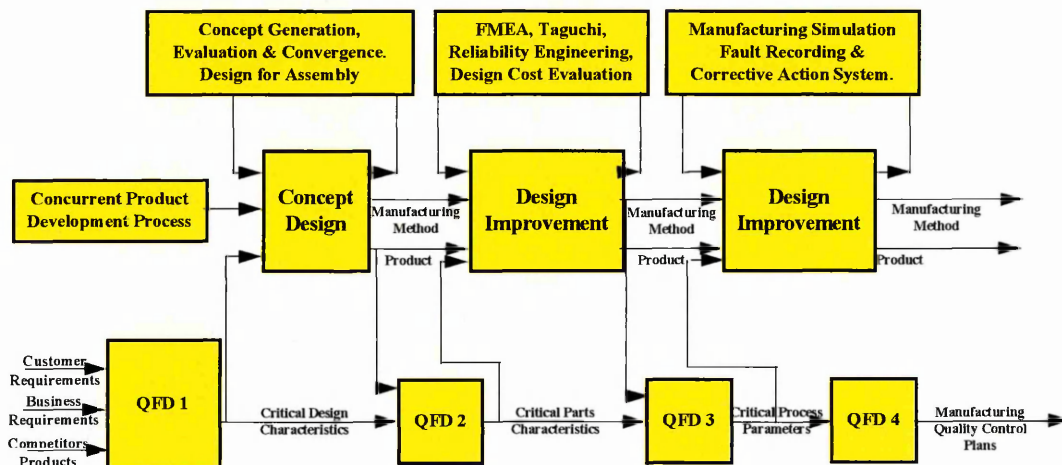


Figure 13

The relationship between QFD other TQM tools at the design process,
Shown without their informational feedback loops.

between QFD and the TQM tools at the design process level without their informational feedback loops.

In the Appendix a number of the most popular TQM tools are included. These are perceived by the author as the most promising, which can be used in conjunction with QFD in order to provide enhancements in its healthy implementation in the European Automotive Industry. One may argue that it is relatively straightforward to understand the tools described. However, it is quite difficult to optimally arrange and utilise the tools as a complete set, to permit the most direct understanding and visualisation of problems.

In summary, the use of these tools is highly dependent on the problem to be solved. Some results may be so obvious as to not warrant the use of tools; other problems may be so obscure that the tools are unable to provide visualisations which will assist the participants in squeezing knowledge from the evidence that has been provided. In general, the use of the entire toolset provided or its subset has the potential to provide great enhancements in the healthy implementation of QFD, by providing visualisations and analysis of all the information at hand.

Contrary to what is suggested in most of the literature there is a need to be flexible in how we use these tools. It is nice to establish a structured way to perform QFD studies, but there is no harm in having more alternatives to choose from if each one is well defined. It is important to understand that there is no clear answer to when one must use each tool and analysis in the product development process.

Chapter Three

The Capabilities and limitations of QFD

3. - The Capabilities and limitations of QFD

3.1 - Introduction

The Darwinian theory of evolution describes survival through natural selection. Phylogenetic trees illustrate the diversification of species by tracing the biological phyla through time. Observation of the ends of most of the branches of tree leads us to restate Darwin's theory as "*the demise of the unfit*" (Maturana, H.R. & F.J. Varela , 1992). This restatement is far more appropriate to large enterprises such as the automotive industry and is far more representative of the resulting global enterprise tree. If an enterprise fails to improve and introduce flexible design and manufacturing systems then it is in a branch of the tree which is likely to be terminated.

Companies can use QFD to produce flexible design and manufacturing systems and to create a competitive advantage, even in the midst of an environment marked by recession. In fact companies that have used QFD have reduced prototype development cycles, improved quality and reduced costs. In some organisations whilst maintaining and enhancing design quality, QFD has helped to reduce design time by 40% and design cost by 60% (Kathawala Yunus, Motwani Jaideep, 1994). Others state that the use of QFD in their business had an outcome of 25% less engineering changes, 50% less time to develop the product specifications, 20% less product cost and 30% fewer warranty problems (Nichols Keith , Flanagan Derek, 1994). However these are some of the cases where QFD was totally successful. Obviously there are cases where QFD was totally unsuccessful.

This chapter deals with the results of numerous documented cases related with QFD's implementation i.e. (Kathawala Yunus, Motwani Jaideep, 1994) (Nichols Keith , Flanagan Derek, 1994) and will examine QFD's main capabilities and limitations. Moreover it deals with the critical factors affecting its healthy implementation in the European Automotive Industry.

3.2 - QFD's main capabilities and limitations

The uniqueness of QFD as a powerful and capable technique in the product development process is well highlighted in numerous articles and papers. These statements are classified as follows :

- ☑ ***It understands all the customer needs;*** Inadequate research into customers needs leads to varied, uninformed opinions. This leads to disagreement among the developers as to the customers needs. Such disagreements in turn create delays in decision-making, reversal of decisions and individuals working at cross purposes. QFD provides a standardised method of systematically representing the customers needs. The standard representation can then be used as a basis for itemising differences of opinions, which can be researched as needed. QFD's standardised method of mapping these customised needs to products, helps to reduce further differences in opinions. Moreover it enhances and preserves the message of the customers preferences throughout all of the inter-related steps associated with the product development process.
- ☑ ***Enhances and encourages feasible and cost effective designs through clear and consistent communication;*** Typically products are conceived by a core team. Once they have worked out the system level details to a certain point they will normally decompose the design into subsystems. They then decide that certain subsystems will be undercarried from external or internal people. The undercarrier will then work on an assigned task and when it is either finished or at an allocated intermediate point then the results will be presented to the core team. This *"throw it over the wall"* method often leads to unsatisfactory even disastrous results, because the undercarrier while meeting the allocated targets set by the core team will not have completely understood and met the ultimate customers needs. Developing a subsystem by simply meeting targets perceived from a core team is like driving a car without looking at the road and having a navigator sitting next to the driver. There are too many details on the road, the cars speed and so on which we must take into account when driving. These things can not be communicated accurately or in time for a safe journey. However some other approach to communicate requirements is necessary. QFD helps by providing a focus for discussion and translation of the customers needs to each level of the developer and supplier organisation, using terminology and language appropriate to that level. In a sense the discussions in QFD inherent sense and meaning.

☑ ***It is an excellent documentation tool of the product development process;***

QFD excels in the way it produces a documentation of decisions made in the product development process. It addresses both long and short term product needs and decisions. It breaks and registers decisions into smaller components of understanding and this leads to a coherent and consistent overall decision. It answers any raised questions or addresses it to the process. In addition it is easier for the newcomers to follow. It can be used as a framework for future similar decisions. Therefore it takes advantage of all the efforts that went into the previous decision with a minor expenditure of effort. QFD allows to express of different viewpoints and captures all of them (Lyman Dilworth, 1992). It can define as well the translation and transformation, and compare any opinion with another. It is within its nature to display complicated and difficult information into small digestible parts and display it as an overall picture. Each person in the development team can find the information easier to understand because it is in their own terms and language.

☑ ***It is a reliable decision making technique;*** QFD balances market opportunities and the company's strengths, by it's inherent ability to focus on the consequences of an undertaken decision, making comparison more meaningful. Traditionally the decision making process is carried out by the higher ranks of an enterprise. Often with the decisions being made by those who perhaps do not have the full understanding of the product development phase or at least not as much understanding as those people who are directly involved in the product development phase. However the utilisation of QFD enables the lower ranks of the hierarchy who know the facts to made the decisions. Therefore they understand the impact of their job on customers satisfaction therefore each individual holds responsibility for the course of their decisions or actions resulting in a cut back on all of the product reviews (Crow Kenneth, 1992). Consequently the technical review and the decision making becomes streamlined.

☑ ***Reduced lead times;*** By increasing the investment in “up-front” planning, a trade off is made against overall product development timing.

☑ ***Minimises launch errors;*** Products that have been planned better with manufacturing and assembly considerations from the start, require fewer corrections when in full production.

☑ ***Reduced launch cost;*** Improving planning and testing earlier in the product development cycle directly translates into fewer changes (quality lever).

- ☑ **Improved product quality;** Products that are planned better generally are better.
- ☑ **Increased productivity;** Products that are designed with minimal changes and perform better, cause fewer disruptions in the assembly and manufacturing plants. Less 'fire fighting' translates into increased productivity, better utilisation and better cost.
- ☑ **Reduced development costs;** Understanding what the product's weakness and strengths are and coupling this with a good grasp of the customers demands, allows a rationalisation of resources. Effectively utilised resources translates into reduced development costs.
- ☑ **Warranty and failure reduction;** Better products always result in improved performance that may translate into reduced warranty costs.
- ☑ **Improved customer satisfaction;** By providing the customer with "exciting quality" as well as what they are demanding, their satisfaction can only improve. Improved quality at a lower cost is always attractive.
- ☑ **Increased market share;** QFD is aiming to generate profits by providing targeted customers with benefits not already available from competitors. QFD is a vital component to the market share. It provides integration across functional areas within a firm, a necessary condition to present a uniform image to customers (Kymal, Chad A., Ryan, Michael J., Fornell, Claes G, 1990). Therefore customers buy more product and the market share increases.
- ☑ **Preserves knowledge;** Employing the discipline of QFD will result in a detailed audit trail that is easily followed, to assess the impact of potential change or look for sources of problems. It provides a model for inexperienced engineers to follow and partially offsets the knowledge drain that occurs when employees with years of experience retire or leave.

On the other hand the problems arising from QFD's implementation are:

- ☒ **Matrices can be large and complicated;** Naturally QFD consists of large matrices which provide a cognitive heavy load of details. In addition there is little automation of even its basic routine functions, resulting in great difficulty in the effective comparison between alternatives (O'Connor Laurie, Partridge Doug, Seely Bruce, Guthmiller Wayne, 1992). This has a negative effect on QFD's integrity, because complicated things and tools are error prone.

☒ ***Too demanding as first project unless tolerances for learning curve;***

Product development team members are pressurized to meet schedules on current projects, in addition they will need a considerable amount of time to become familiar with the technique, hence QFD's implementation adds to this pressure with inadvertently negative results.

☒ ***Contradicts existing mindset and culture;*** Traditionally the western society's basic values in interpersonal relationship fosters individuality, autonomy, pride in aggressive and outspoken behavior and formation of groups that put the good of the individual before the good of the group. Given these values it is not surprising why managers and supervisors are perceived as the most important customers. The informal reward system teaches that, to go ahead employees must give their managers and supervisors what they really want, which is not necessarily what the customer says, wants or even needs (Ralph L. Liberatore, 1993). This is reinforced by the organisational design system, which has traditionally been vertically and functionally focused on making immediate supervisors happy. Employees therefore deduce that their customers are not as important as their supervisors. QFD by its own nature stimulates change. Obviously change never is easy and most people will resist its implementation especially when this change neglects this traditional vertical approach and introduces a proactive and global way of thinking and perceiving decisions.

☒ ***No product paradigm to follow;*** Successful pilot projects are needed within a company in order to shift the emphasis from the question "Will QFD work for us?" to "How we can make it our only way of starting business"(Domp, Ellen R., Culver, Robert C., Rawcliffe, Richard H., 1991).

☒ ***Encourages team decisions (team consensus) and not dominant decisions (Voice of the dominant manager, engineer. etc.);*** QFD's proper implementation creates a fear, to certain dominant individuals within an organisation, that they somehow are eliminated (Barnard Bill, 1992). However the acceptance and the integrity of the technique is at great risk since its proper and integral implementation will become an opening to another battlefield of *internal politics*.

3.3 - The critical factors affecting QFD's successful implementation

The acceptance of the QFD technique by the European Automotive industry is disappointing. At the heart of the problem is the failure to understand the very nature of the technique. The key to QFD's healthy and successful implementation is to invest on what is important and to resist what is not. In other words it is very important to know which critical factors add value and subtract cost in QFD's implementation within the product development process.

As mentioned in previous chapters the introduction of QFD as the primary method of new product development stimulates organisational change. Obviously any sort of change needs time to evolve. The problem with the European Automotive industry today is that allows no time for this evolution in self realisation and improvement. The reason is that the dominant impose need from the industry itself to "make profit while changing to be able to make profit" demands certain conditions and commitments from those who undercarry the responsibility of this change.

Because of the unique way in which QFD has to be implemented in the Automotive industry there is a plethora of articles and papers attempting to explain critical factors that one has to consider for its healthy implementation. In general two types of critical factors tend to inhibit a successful QFD implementation: the organisational and the technical. The organisational critical factors in QFD implementation relate to the way a company operates, and to managerial styles and disciplines function. Company operations involve the existing culture and the way things happen or are allowed to happen. The technical critical factors involve a lack of support, acknowledgement or facilitation of the know-how in QFD's implementation i.e. lack of education.

3.3.1 - Organisational aspects (Company Culture)

One of the things that is not often highlighted is the fact that successful QFD application relies heavily on the level of commitment and culture that the company has or adopts (Adams, Robert M., Gavoor, Mark D., 1990). Many viable techniques or programs are first introduced with a great deal of optimism only to fail into disuse a short time later. This principal failing stems from the company's unwillingness to make fundamental changes in order to fully utilise the techniques benefits. Therefore QFD's subtle message here is that the old way of developing and launching products has changed and it requires support from the entire organisation.

According to (Warren, James A, 1990) culture is the combined state of mind of all employees that determines how people will support a company, whether or not they will volunteer any extra effort, as well as how they will respond to the customer. The objective is to improve a company's culture by increase the discretionary effort which gives a company access to the creative abilities and support of the entire workforce. To achieve that a Marketing Science Institute Study in the subject of "Corporate culture"(Barnard Bill, 1992) suggests that the best culture to support customer orientated systems such as QFD is the one providing market culture with a goal achievement orientation stressing competitive advantage, the worst is hierarchy culture stressing rules and procedures.

As stated earlier corporate culture must change in order to support new ways of thinking i.e. QFD. However in most cases because the culture is so established and ingrained, it resists change; attempting to change the established culture cannot work unless it is disabled (Ralph L. Liberatore, 1993). This is not however to be accomplished with a frontal assault, that even if successful can be proverbial surgery that results in the patience death. Top down planning and guidance is required but implementation should occur from the bottom up to develop ownership. Employee involvement must be based on communicating the QFD goals and providing necessary training. The business process needs to be examined, streamlined and restructured. This is to be compatible with team orientated approaches , integrated technical systems, digital product models and QFD. Proactive management leadership, planning, good communication and attention to

detail will pay off. A discerning management will know whether problems are technical or human, and how much of which strategy applies to particular problems. The above statements are perfectly in line with Ford (Vora, Lakshmi S., Jackson, Philip C., Veres, Robert E., 1989), Renault (Renault- the search for excellence, 1991) and Chrysler (Henry J. Ziaja, 1990) where they state that their managerial style has recently undergone a major change from product culture to people culture.

QFD needs healthy grounds which means it is entirely based on human dignity and clear relations. In a political environment with egocentric management it becomes highly corrupt and gives the wrong results (Barnard Bill, 1992). To change this bad attitude management and senior engineers have to learn to lead by knowledge and not by authority. They should challenge themselves not to be held back by their inflated egos but rather to fight it and push forward until they have achieved and mastered the team orientated philosophy. Clear relations, communication and customer orientation is fundamental for future business success. They have to allow the team members to have direct external contact with the customer, because it provides them with the knowledge of their customer. They create a personal relationship which harness the business links and the human relationships so everybody is more relaxed in communications. Therefore QFD members will be able to focus on facts rather than feelings or convictions.

Finally a fair reward system for using clean and successfully proven processes and techniques is vital. Often performance appraisals and pay rises are based on history and solely on managerial subjective evaluation. They are based on how well one satisfies certain individuals expectations. However problem solving and “fire-fighting” provide the grist for making heroes. Problems are usually well known internally and make problem solvers highly visible and well rewarded. This in turn encourages problem solving rather than problem prevention. People who prevent problems are often unknown and unrewarded. The QFD process is both problem solving and future orientated. Moreover because it is future orientated it is often perceived as a threat to the historical elements of performance appraisals.

3.3.2 - Technical aspects

It appears that there is no pure QFD process. The QFD global management philosophy is hard to find in Europe. Most companies implement what they feel like or whatever their management learnt via a consultant during a 2 or 3 (at the most) day course and they think that this is all about QFD has to offer. By comparing QFD implementation in Japan with that in Europe it is easy to conclude that there is so much more to be gained by the profession, by applying the technique in a co-operative and team orientated way..

QFD is a unconventional approach to the design process. Although this process is a series of simple and clear steps, its implementation in an organisation will be restricted by those accustomed to sequential product design, who perceive it as a radical change. To convert the design process from a sequential operation with clearly differentiated functions to one that involves the simultaneous involvement of several inter-organisational members and units could encounter enormous barriers and a tremendous amount of effort. Therefore the effective use of QFD in the product development process imposes the understanding of its purpose by all the team members. A good facilitator who has a good knowledge of the mechanics of the techniques and has good interpersonal skills will enhance and have a positive effect on its healthy implementation. More importantly he will be able to guide this team by looking after the allocation of resources under feasible and well understood targets.

Traditional manufacturing quality control is achieved via inspection of the physical products, by observing and measuring them. QFD helps a company shift from inspecting products to designing quality into products. QFD involves many intangibles long before the design hits the drawing board. This is the stage when quality can be designed into the product. The technical function is vital to a company's business. The changing business environment requires ever-increasing value added into the products. This value added is provided by the company's technical expertise. However the better the technical people understand QFD and the customers needs, the better they could determine the effort required to fulfil them.

It should be mentioned though that no one should expect miracles. Research shows that only about 20% of QFD users realise identifiable short-term advantages in the market-place, but over 80% get strategic benefits such as increased understanding of the customer, increased communication and shared vocabulary among divisions, fewer downstream engineering changes and faster decision making. In other words listening to the customer is widening the scope of the problem to cover functions and skills that are not currently involved.

To conclude QFD encourages creativity, innovation and adding value for the end customer. Above all it will not work unless there is a team approach. It therefore values individuals contributions but also encourages the collective contributions of those carrying out the task of delivering the customer wants. However managers are needed who understand the potential of this technique and scientists and engineers are needed who understand the management's constraints in the QFD implementation.

Chapter Four

Fuzzy Logic approach and principles

4 - Fuzzy Logic approach and principles

4.1 - Overview.

The past few years have shown an increased interest in technologies modelled on some aspect of human function. Some of these e.g. artificial intelligence are rooted in the psychological domain. Others such as neural networks, genetic algorithms are inspired by consideration of biological processes. Common to all of these, e.g. the so called 'intelligent technologies', is a need to present human knowledge and to resolve complicated problems in a manner that is both faithful to the human style of processing information, as well as in a form amenable to computer manipulation.

In general the solution to complicated problems and the presentation of the human knowledge are dependent upon the construction of a mathematical model. The purpose of this model is to understand, represent and resolve some phenomenon of reality, be it natural or man made, by making adequate predictions or judgements. The ultimate goal in the construction of a mathematical model is to maximise its usefulness. In order to achieve that one should fully understand the relationships between the three key characteristics; i.e. complexity, credibility and uncertainty. Obviously one can only make approximations and this is the point where the allowance of uncertainty becomes very valuable because it tends to reduce complexity and increase credibility of the resulting model.

Recognition of this important role of uncertainty became quite explicit in the 1960s literature. It is generally agreed that an important point in the evolution of this concept was the publication of a seminar paper by Lofti Zadeh, (Zadeh L.A, 1965) where the theory of objects- *fuzzy sets*- with no precise boundaries was introduced. Nowadays fuzzy sets are one of the cornerstones in fuzzy logic.

4.2 - Historical roots of fuzzy logic

According to historians the progress in mathematical modelling essentially began with the work of the Greek philosopher Pythagoras who believed that matter was

essentially numerical and that universe could be defined as numerical relationships. By the 4th century B.C Aristotle developed and extended that belief to the way people think and make decisions by allying the mathematical precision with the search for truth. This search for truth was based on the *crisp set* or the “Law of the excluded middle” (S.Korner, 1967) (Mathematically expressed 1 or 0). According to this a sharp unambiguous distinction exists between True or False. For example the weather is *hot* or *not hot* but it cannot be in a middle state, i.e. hot and not hot. However in this precise view the parameters of a model represent exactly either our perception of the phenomenon modelled or the features of the real system that has been modelled. Eventually this is an indication of our assumption that the structures and parameters of the model are known and that there are no doubts about their values or their occurrence. Nevertheless Aristotle and his teacher Plato considered that there were degrees of true-false particularly in making statements for possible future events but it was rejected at the time. However Aristotelian logic by the 10th century was established as the basis of European and Middle Eastern thought. It has persisted for two main reasons; it simplifies thinking about problems and makes truth easier to prove and accept.

In the early 1990's Lukasiewicz proposed an alternative to Aristotles crisp set. He described a three valued logic (3 state logic), which can best be translated as the term ‘possible’, and assigned it a numerical value between true or false, which in mathematical terms is expressed as $[0,1,2]$. Lukasiewicz's student proposed the same three value logic mathematically as $[-1,0,1]$. However this alternative failed to gain wide acceptance.

It was not until relatively recently that fuzzy logic was discovered. Lofti A. Zadeh is known as the founder of fuzzy logic (Can Isik, 1991) , in 1965 where he observed that conventional computer logic was incapable of manipulating data representing vague human ideas i.e. “ warm weather”, “pretty tall”. However his search for truth was based on the *fuzzy sets*. According to this a distinction with various degrees of membership exists between True or False. In other words the distinction between the *hot* or *not hot* weather can have shades of hotness with a degree of uncertainty. This uncertainty is considered essential to science; and it is not only an unavoidable fact but a great utility. It is an important asset in the mathematical modelling, which can be traded for gains in other essential characteristics of models. This trade-off can then be utilised for constructing

models that are maximally useful with respect to the purpose for which they are constructed.

Obviously these benefits led numerous researchers and industrialists to play 'with' and understand this new and promising logic and to capitalise on its potential. More than 4000 publications have already existed in 1984 and by 1995 they had quadrupled. Most of them have advanced the theory in many areas but have made it more difficult for newcomers to find a good entry point and to understand and appreciate the philosophy and the potential applications of this theory. During the late 1980s and the beginning of 1990s fuzzy logic grew in the USA and expanded to the European Research Engineering world. More and more researchers and practitioners became aware of the benefits that arise from the use of fuzzy logic in vague situations.

In brief one can say that fuzzy set theory in the last two decades has developed along two lines:

- As a formal theory that when maturing became more sophisticated and specified and was enlarged by original ideas and concepts, as well as by embracing mathematics and their generalisation (fuzzifying them)
- As a very powerful modelling language that can cope with a large fraction of uncertainties in real life situations. Because of its generality it can be adapted to different circumstances and concepts. (In this theses it is adapted to the QFD techniques). This means that the context or the original concepts of fuzzy set theory have to be modified to handle this specific area. This adaptation has not yet progressed to a satisfactory level, leaving plenty of challenges to the ambitious researchers and practitioners.

4.3 - Fuzzy sets and fuzzy logic

Most of our traditional thinking and analysis tools for modelling, reasoning and computing are *crisp*, deterministic and precise in character. Crisp is a 'clear cut' attribute, Yes or No. In conventional dual logic a statement can be true or false but nothing in between. In a *set* theory an element can belong either to a set or not and in optimisation a solution is either feasible or not. Precision assumes that the parameters of a model represents exactly either our perception of the phenomenon

modelled, or the features of the real system that has been modelled. However the assumption is that the structures and parameters of the model are known and that there are no doubts about their values or their occurrence.

Real situations are very often uncertain or vague in a number of ways. Due to lack of information the future state of the system might not be known completely. Fuzzy logic enables us to model vagueness in data and relationships in a formal way. The vagueness may be due to randomness (uncertainty of events occurrence). Lets consider a car of four people travelling abroad on a hot sunny day as an example. Lets consider that the car is equipped with an air-conditioning device. As the day is hot the use of the cooling option of the air-conditioner may be appropriate. Obviously the adjustment of the temperature in order to satisfy all of them may be proved a difficult task. Different people define and perceive differently the hotness or coldness of their environment. However somebody is destined to compromise on his wishes for coldness or hotness a bit more than others. The question is if somebody wished to consider everybody's opinion in order to calculate and adjust the temperature as to satisfy all of them or at least make them feel equally compromised, what should they do?. There are a lot of ways to do this, in this theses the fuzzy calculation is recommended. However one should understand the concept of fuzzy sets and the way these could be represented.

Although the terms of fuzzy logic and fuzzy sets were mentioned earlier, one should distinguish their purpose of existence. The mechanics and calculations between fuzzy sets are parts of the fuzzy logic. In other words fuzzy logic is the sense of fuzzy sets which provides the underpinnings for designing and writing fuzzy models. It should be made clear that fuzzy set theory and the broader area of fuzzy logic itself is not a specific method for any particular application any more than Boolean logic. Fuzzy sets support a general theory of fuzzy logic or the fuzzy statement calculus.

4.3.1 - Basic concept of fuzzy sets

Fuzzy sets are functions that map a value that might be a member of a set to a number between 1 and 0, indicating its actual degree of membership. However when the degree of membership is zero "0" then it means that the value is not in

the set, on the other hand when the degree of membership is “1” then the value is completely representative of the set. In this case each membership function maps elements of a given ‘universal set X ’. More importantly its characteristic function allows various degrees of membership for the elements of a given set.

Therefore if X is a ‘universal set’ or a set of objects denoted generically by x i.e. $X=\{x\}$ then a fuzzy set A in X will be: $A = \{(x, \mu_A(x) | x \in X)\}$, where $\mu_A(x)$ is called the membership function or degree of truth. The range of the membership function is a subset of the nonnegative real numbers whose supremum is finite.

For example let universe of X be a set of temperatures such that $X = 2r, r \in \mathbb{R}^+$ and $r \leq 50$

The two basic methods to define these sets are:

- 1) The list method where ; $X = \{2,4,6,8,10,12...,48,50\}$
- 2) The rule method where; $X = \{X | P(X)\}$ $P(X) = 2r, r \in \mathbb{R}^+$ and $r \leq 50$

And lets define the term “hot” in terms of temperature expressed in Celsius;

$$\text{Membership function } \mu_A(x) \text{ can be characterised as: } \mu_A(x) = \begin{cases} 0 & \text{for } 0 \leq x \leq 6 \\ 0.1 & \text{for } 6 < x \leq 12 \\ 0.3 & \text{for } 12 < x \leq 18 \\ 0.5 & \text{for } 18 < x \leq 26 \\ 0.7 & \text{for } 26 < x \leq 32 \\ 0.9 & \text{for } 32 < x \leq 40 \\ 1 & \text{for } 40 < x \end{cases}$$

Note that this is how the author may define the term *hot*, somebody else may define $\mu_A(x)$ differently but the main idea remains the same regarding the way we assign degrees of membership.

Therefore the illustration of $\mu_A(x)$ is in the Figure 13.

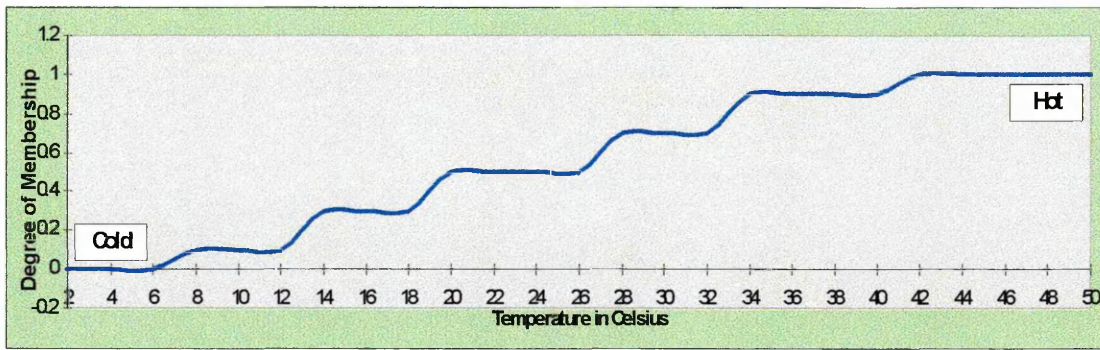


Figure 13

Graphical illustration of the fuzzy set A “the weather is ‘hot’ ”

In the previous figure 13 we see an approximate linear presentation of the fuzzy set A, concerning the *hotness* of the weather. It is an approximate linear representation, because the membership function $\mu_A(x)$ was not defined in a smoother mathematical manner i.e. in the transition of membership between 0.3 to 0.5, the 1 degree Celsius difference has a great impact on the membership. Obviously when one defines sets like this care is taken so as not to end up with this type of result i.e. it could be defined as;

$$\mu_A(x) = \begin{cases} 0.025 * x & \text{for } x \leq 40 \\ 1 & \text{for } x > 40 \end{cases}$$

The illustration of this is in the Figure 14.

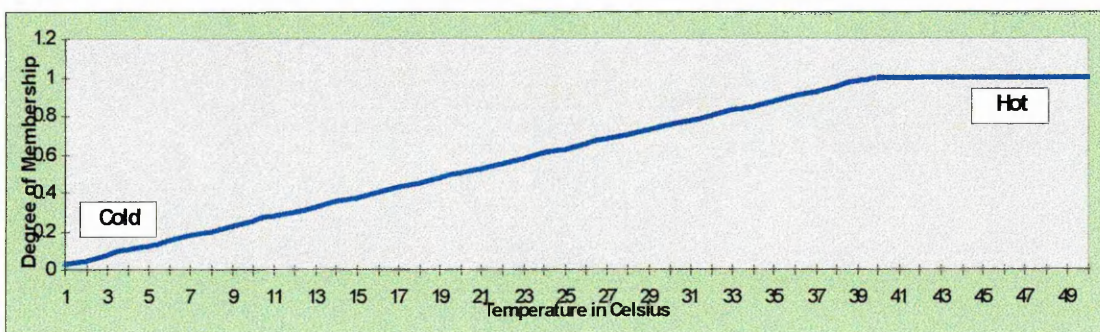


Figure 14

The fuzzy set A “the weather is ‘hot’ ” defined in a smoother way

So far we have seen a linear shaped graphical representation of the fuzzy sets membership function. This is the simplest fuzzy set and often a good choice when approximating an unknown or poorly understood concept. There are two states of a linear fuzzy set: the increasing and the decreasing. The increasing (Figure 13 and 14) starts at a domain value that has 0 membership value and moves to the right with values that have increasing set membership. The decreasing linear fuzzy set starts with a domain value that has 1 membership value and moves to the right with values that have decreasing set membership. Obviously there are other different shapes in which membership function can be represented. In a theoretical sense the number of shapes obtainable is infinite, for the purpose of this study two shapes will be used. The triangular and the trapezoidal.

The triangular membership function or TFN (Triangular Fuzzy Number) is the most frequently used function and the most practical. It starts with a domain value that has 0 membership value and moves to the right with increasing set values up to the membership value 1, then it continues moving to the right with values that have decreasing set membership down to 0 (Figure 15).

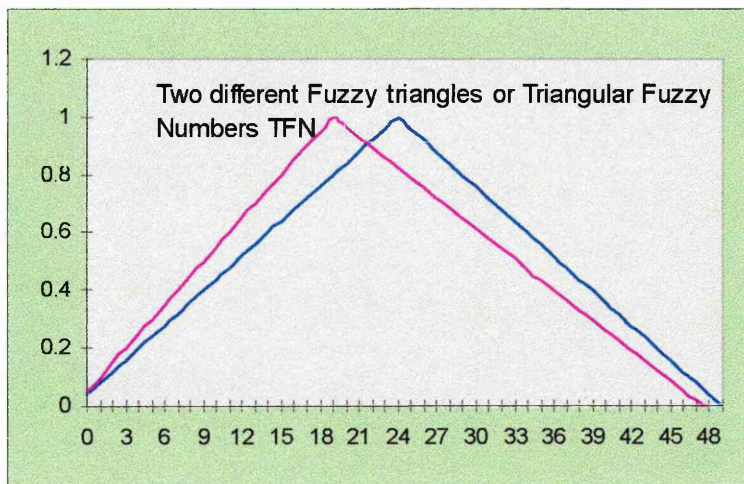


Figure 15
Graphical representation of a Triangular Fuzzy Number TFN

The trapezoidal membership function is used when less information is available. Again it starts with a nominal membership value 0 then increases up to a nominal value z where $z \leq 1$ and back to 0 membership by moving to the right with values that have decreasing set (Figure 16).

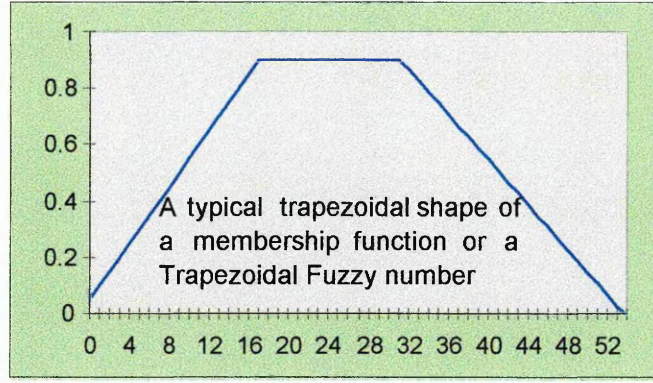


Figure 16

Graphical representation of a Trapezoidal Fuzzy Number

As mentioned earlier the triangular membership function or TFN (Triangular Fuzzy Number) is the most frequently used function and the most practical. However the basic operations be carried out are: addition, subtraction, multiplication and division.

Where applying these mathematical operations within 2 TFNs defined as $A(a1,a2,a3)$, and $B(b1,b2,b3)$ the following apply;

$$1) A + B = C\left(\left\{(a2 + b2) - \left[\frac{(a3 - a1) + (b3 - b1)}{2}\right]\right\}, (a2 + b2), \left\{(a2 + b2) + \left[\frac{(a3 - a1) + (b3 - b1)}{2}\right]\right\}\right)$$

$$2) A - B = C\left(\left\{(a2 - b2) - \left[\frac{(a3 - a1) + (b3 - b1)}{2}\right]\right\}, (a2 - b2), \left\{(a2 - b2) + \left[\frac{(a3 - a1) + (b3 - b1)}{2}\right]\right\}\right)$$

$$3) A * B = C\left(\left\{(a2 * b2) - \left[\frac{(a3 - a1) + (b3 - b1)}{2}\right]\right\}, (a2 * b2), \left\{(a2 * b2) + \left[\frac{(a3 - a1) + (b3 - b1)}{2}\right]\right\}\right)$$

$$4) A / B = C\left(\left\{(a2 / b2) - \left[\frac{(a3 - a1) + (b3 - b1)}{2}\right]\right\}, (a2 / b2), \left\{(a2 / b2) + \left[\frac{(a3 - a1) + (b3 - b1)}{2}\right]\right\}\right)$$

For a finite fuzzy set **A**, its *cardinality* $|A|$ will be defined as;

$$|A| = \sum_{x \in X} \mu_A(x)$$

i.e. for the first definition of "hot" is ; $|A| = 0 + 0.1 + 0.3 + 0.5 + 0.7 + 0.9 + 1 = 3.5$

Now **A's relative cardinality** will be defined as;

$$||A|| = \frac{|A|}{|X|} \text{ i.e. } ||A|| = \frac{3.5}{50} = 0.07$$

It can be interpreted as the fraction of elements of X being in A, weighted by their degrees of membership in A. Hence the relative cardinality of a fuzzy set depends on the cardinality of its universe X. So one has to choose the same universe if he wants to compare fuzzy sets by their relative cardinality.

4.3.2 - Fuzzy set operations

Membership function so far is discussed as if it is always based on a single criterion. Obviously this is not the case, even though it is the most common case. For example one may want to have the membership function “hot” depend on both the weathers temperature and its relative humidity (it is well known that humidity has a direct effect upon our perception of the weathers temperature). However we have to create a two dimensional member function. Consequently one may wish to have even more criteria, or to have the membership function depend on elements from two completely different universes of discourse. Therefore to be able to accomplish member functions the following fuzzy set operations exist:

Union

The union of two fuzzy sets means that any element belonging to either of the sets is included in the partnership. This is expressed as the maximum value for the two sets involved. However lets take two fuzzy sets A and B with membership functions μ_A and μ_B respectively, then union is defined as the maximum of these membership functions and is(Figure 17);

$$\mu_{A \cup B} = \max(\mu_A, \mu_B)$$

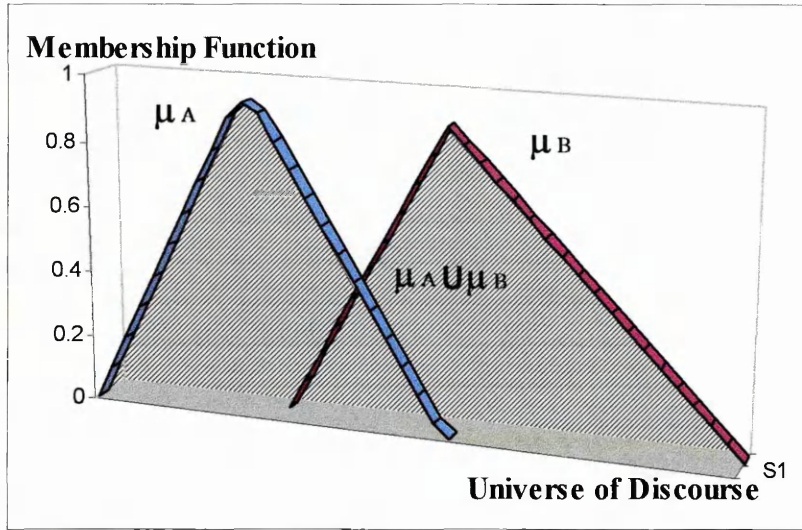


Figure 17

Union of two Fuzzy numbers μ_A and μ_B

Note: The union operation in fuzzy set theory is equivalent to the **OR** operation in Boolean algebra.

Intersection

The intersection of two fuzzy sets means that any element belonging to both of the sets is included in the partnership. This is expressed as the minimum value for the two sets involved. However let's take two fuzzy sets A and B with membership functions μ_A and μ_B respectively then intersection is defined as the minimum of these membership functions and is (Figure 18);

$$\mu_{A \cap B} = \min(\mu_A, \mu_B)$$

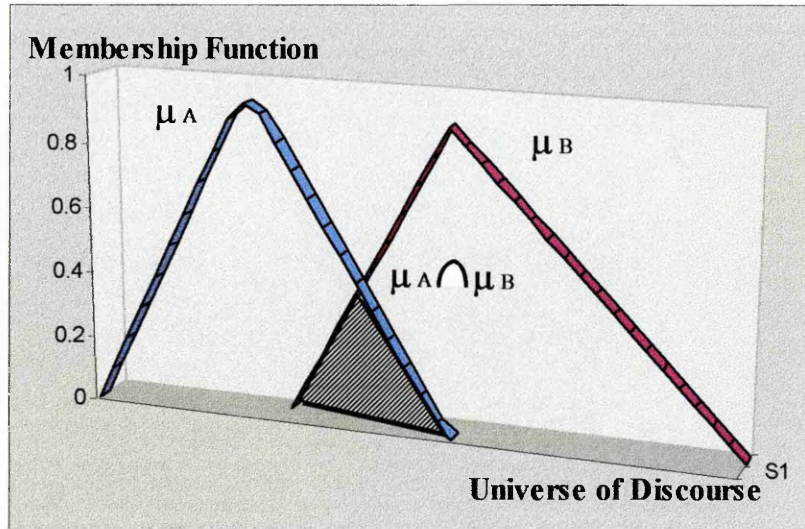


Figure 18
Intersection of two Fuzzy numbers μ_A and μ_B

Note: The intersection operation in fuzzy set theory is equivalent to the **AND** operation in Boolean algebra.

Complement

The complement of a fuzzy set means the negation of all the elements belonging to it. This is expressed as the unity membership value minus the set involved. However let's take a fuzzy set A with membership function μ_A then complement is defined (Figure 19);

$$\mu_{\bar{A}} = 1 - \mu_A$$

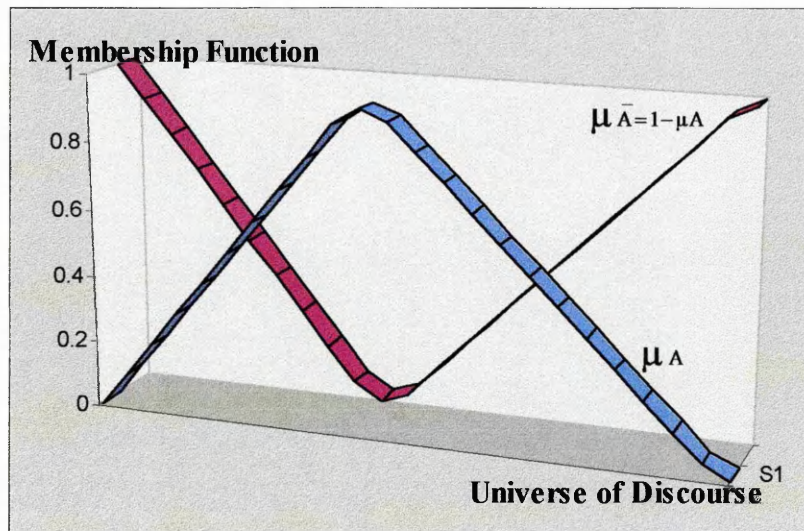


Figure 19
Complement of a Fuzzy number μ_A

Note: The complement operation in fuzzy set theory is equivalent to the **NOT** operation in Boolean algebra.

However from the above three operations the following operations apply as well;

⇒ **De Morgans law**

$$\overline{(A \cap B)} = \overline{A} \cap \overline{B} \text{ and}$$

$$\overline{(A \cup B)} = \overline{A} \cup \overline{B}$$

⇒ **Associativity**

$$(A \cap B) \cap C = A \cap (B \cap C) \text{ and}$$

$$(A \cup B) \cup C = A \cup (B \cup C)$$

⇒ **Commutativity**

$$A \cap B = B \cap A \text{ and}$$

$$A \cup B = B \cup A$$

⇒ **Distributivity**

$$A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$$

$$A \cup (B \cap C) = (A \cup B) \cap (A \cup C)$$

4.4 - Fuzzy logic and linguistic variables.

As mentioned earlier real situations are very often uncertain or vague in a number of ways. Fuzzy logic enables us to model vagueness within data and relationships in a formal way. A basic concept in fuzzy logic is linguistic variables, which is defined as a variable whose values are words or sentences in a natural or synthetic language (Can Isik, 1991). The ultimate goal of which is to represent human thinking and feeling in a manner faithful to the human style of processing information (L.P.Khoo, N.C. Ho, 1996). It can be viewed as a language that allows one to translate sophisticated statements from natural language into a mathematical formalism. With this mathematical form of knowledge we are able to collect ideas, preferences and opinions from numerous individuals and draw upon the work done by others.

At its root linguistic variables is the name of a fuzzy set. Earlier in the chapter an example was used in order to define “*hot*” according to the authors perception. As one may see this is a fuzzy set and consequently a simple linguistic variable which could be used in a rule based system in order to make decisions on *how hot the weather is*. (Figure 20)

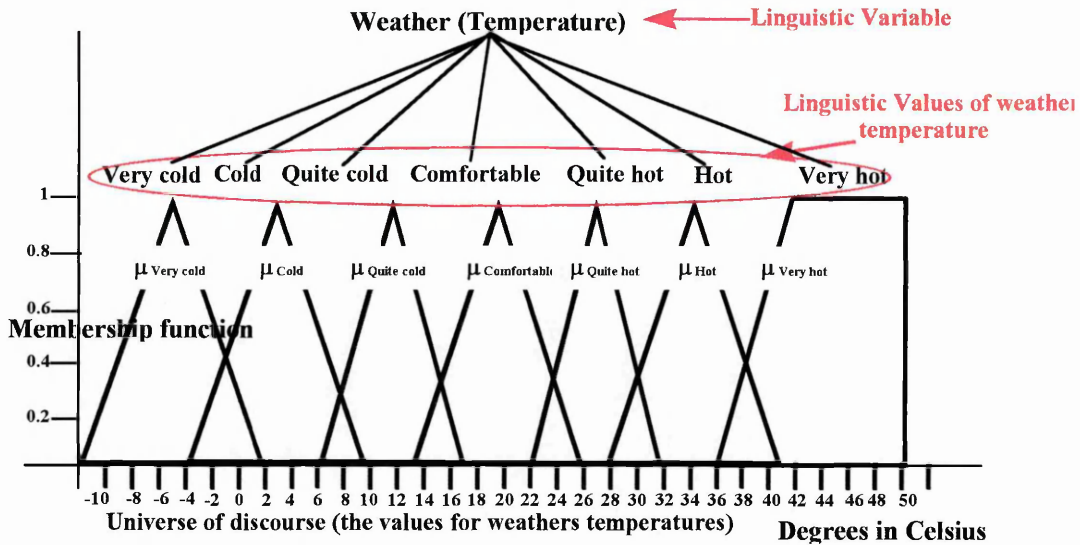


Figure 20

The linguistic variable of Weather Temperature

In this example, because there are more statements than the one on “the weather is hot” the TFN for “hot” gets a more reasonable dimension, i.e. [28,42] but not [0,50]

As one may see in figure 20 the linguistic variable of weather temperature carries a series of fuzzy sets (fuzzy qualifiers, often called hedges). These fuzzy sets change their shape in a predictable way, according to their predefined function and they work in the same fashion as adverbs and adjectives in the English language. This allows people to write expressive statements about related concepts.

Using figure 20 a linguistic variable in mathematical terms can be defined. However a linguistic variable is defined by a quintuple $(x, T(x), U, G, M)$ in which x is the name of the variable; $T(x)$ denotes the term set of x or the *linguistic values* of x , i.e. $T(x) = \{\text{very cold, cold, quite cold, comfortable, quite hot, hot, very hot}\}$. As one may see from the example its value is associated with a membership function $\mu_{T(x)}$ i.e. $\mu_{\text{very cold}}$, $\mu_{\text{very hot}}$ and so on. Now according to the previous definition for a fuzzy set is $A = \{(x, \mu_A(x)) \mid x \in X\}$ now A becomes a *semantic rule* and is symbolised as M . Therefore this will become $M(x) = \{(u, \mu_{T(x)}(u)) \mid u \in U\}$ i.e. $M(\text{hot}) = \{(u, \mu_{\text{hot}}(u)) \mid u \in U = [-10, 50]\}$. Finally G is a syntactic rule and is usually the form of grammar and generally textbooks would define it as a *term*.

Having this mathematical form of knowledge we are able to collect ideas, preferences and opinions from numerous individuals and draw upon the work done by others in the past (technological, corporate history). This past knowledge can be manipulated and utilised effectively in the decision making process or as a database of knowledge.

Chapter Five

**QFD implementation: A methodology to
enhance its integrity, purpose and
acceptance.**

5 - QFD implementation: A methodology to enhance its integrity, purpose and acceptance

5.1 - Overview of the proposed methodology and its application in the product development process

As mentioned in previous chapters research aimed at finding ways to improve the customers satisfaction and the end products quality has led to a greater understanding of the power of the decision making in the early design stages of the product development process. The reason is that at this stage numerous design decisions have to be made which will become the determining monitor factors of the available design alternatives at later stages of the product development process. However poor decision making will restrict this set of available design alternatives with irreversible results. Therefore every wrong early design decision is very costly. Obviously if the early decision making lacks a clear understanding of the end products desired objectives or its related conceptual nature and industrialisation, then it is virtually impossible to distinguish and determine the right from the wrong decisions, since these decisions will be complicated, subjective and imprecise.

According to the previous statements it becomes apparent that the establishment of the customer's needs as early as possible will help the decision making process. However the main concerns and difficulties remain with the understanding and prioritisation of those data according to the needs of the customer. Arguably QFD's power is in its philosophy to enhance the early acquisition of these needs and provide an understanding of the end products targeted objective, especially when preliminary ideas both of the teamwork and the customer are not very well defined. In other words QFD provides consistent and coherent information of the customers needs. Moreover it enhances the understanding of how these needs interact functionally with the engineering and technical requirements of a product. Gaining this rigorous understanding of what the customers needs from the end product, a decision making in the early design stages can take place in order to establish the *end products targeted objectives (quantified SQC's)*.

One may conclude that QFD provides vital consistent and coherent information of the customers needs. Upon consideration of these needs a decision making can take place in order to establish the *end products targeted objectives (quantified SQC's)*. Starting with the *end products targeted objectives* acquired from the 1st QFD phase the product development team will deploy them in the next QFD phases where its design aspects and the means by which that objectives are to be achieved will be determined. It should be clear that the whole idea of the QFD's exercise is not necessarily to correspond to all of the customers needs but to weight the implications and the feasibility in responding to them. Hence from an operating viewpoint one can say that QFD accomplishes:

- 1) The definition of the product characteristics "whats" which agree with the customers voice.
- 2) The acquisition of all the necessary information needed to reach a reliable decision making without neglecting any available viewpoint, either gained from the customer or the product development team.
- 3) The supply of a supporting system for competitive benchmarking
- 4) The preservation of coherence between the products planning and manufacturing processes.
- 5) The provision of an audit from the manufacturing floor back to the customer demands
- 6) The auto - documentation of the product development process during its evolution.

Prior to the above QFD accomplishments one should consider the encountered barriers during its application as mentioned in previous chapters and the way these will affect its invaluable promised results. Obviously as it may become apparent to the reader from previous chapters one of the major barriers in QFD's implementation is the management's willingness to support the technique. There are a lot of excuses from companies and management to avoid QFD's proper implementation and there is no need to force them to apply it anyway. However there are a lot of legitimate barriers and complaints even when somebody has gained a good understanding and knowledge of the technique and he is willing to support its implementation (refer to Chapter 3).

In order to implement a technique such as QFD within a company the cost and effort associated with learning the technique and putting a system together have to

be justified. In chapter 2 the concept of QFD was described in a simple manner providing assurance in its clear understanding and purpose as well as an understanding in the way it can be implemented in the whole product development process. However to put together the described system, a computer program is required that can be quickly assimilated within the timescales available to those involved in the product development process. On the other hand this computer program needs to be sufficiently comprehensive in order to be able to retain the fundamental procedures carried out in the product design.

Over the last few years many institutions have produced such QFD computer programs. Most of them are procedural i.e. QFD/Capture or they are affiliated on another application usually from the area of total quality management. However all of them require an understanding of the fundamental operating and analytical principles on which they function. Some can run on independent personal computers but others require mainframe machines. On the other hand currently there are many computer programs which support organisational activities. These programs support the structural aspects of these activities and are able to process and manipulate information based on facts, experience, research and so on. The benefits arising from the computer programs are that they can be used for any sort of application with no cost implications. Among those computer programs are: databases, spreadsheets, word processors, activity planners etc..

The flexibility and user friendliness of spreadsheet packages are very important abilities which can be utilised in any QFD project. With the continuing development of spreadsheet programs it is foreseen that many of the tasks previously carried out by procedural programs could be more easily achieved using the new spreadsheet application packages. Their generality means that during QFD's implementation all those involved in the product development process will be familiar with their use from other areas i.e. laboratory tests, data analysis, numerical calculations and analysis, accounting, etc. Moreover all these people will have made the necessary investment in learning how to use the spreadsheets systems facilities. However the utilisation of a spreadsheet program in QFD's implementation appears to be the obvious choice.

Obviously the automation of the QFD process utilising a very well known and used computer program such as a spreadsheet will be of great help. The problem is

that the automation of the technique doesn't guarantee integrity and acceptance among those involved in the product development process. QFD is a continuous process of data gathering and decision making. To be able to respond in this multidiscipline QFD demand, the product development team has to be cross functional. Because of this multidisciplined structure, differences in opinions and judgements may arise at any point. Therefore diversity in the way data are collected and decisions are made is required.

In correspondence to the above issues the proposed methodology enables fuzzy logic principles to enter into the subjective information gathering and the collective individual decision making based on a fuzzy group decision model as a means to enhance and encourage team consensus. In the following paragraphs the details of the proposed methodology are explained.

5.1.1 - The prerequisites in QFD's implementation

The ability to implement QFD in the product development process and to gain its promising results is largely dependant on the people who populate the product development team. While QFD has the potential to accomplish the tasks stated in the previous paragraph, it will do it in an effective manner only if the structure and culture of the organisation allows and encourages participation and commitment of individuals who have the technical expertise, organisational awareness and authority to make informed decisions and implement recommended actions. Moreover one should consider that often the application and knowledge of the QFD application is based on gossip and not in real facts. Hence it is of paramount importance when one is thinking of implementing QFD or any other tool in the product development process to find out what the main properties of the tool are (refer to previous chapters). Once the main properties of QFD are known then a clear aim should be addressed for its effective use.

While the commitment and the understanding are prerequisites in QFD's implementation, they are not sufficient to guarantee its successful implementation. Acting on this tool alone is likely to produce only incremental results and as was stated in the second chapter, QFD relates to a series of other tools and techniques of equal importance. Therefore a thorough and clear understanding of those tools

(see in the Appendix “Useful TQM tools in QFD’s informational flow”) and the expectations one can have from their application would complete the prerequisites for its healthy and effective implementation.

5.1.2 - The planning steps in QFD’s implementation

The way in which QFD’s implementation will be conducted can have a significant bearing on its effectiveness in the product development process. Since the QFD process involves each member of the product development team and their particular function or discipline, the economical use of their time is an important consideration. As one may be aware QFD demands time from the participants in the product development process for such activities as data gathering and decision making. However in the planning of QFD’s implementation in the product development process an important consideration has to be placed on the above important activities.

QFD provides a control and support for all the activities related to the product development process in some known sequence. Therefore it allows people to work in more concurrent than sequential teams. The following figure 21 illustrates a sequential approach in the construction of the HoQ at the 1st phase of the QFD process. This is a suggested sequence and it is recommended to be followed as shown. Generally speaking these steps impose a discrete sequence of activities at which certain steps have to finish before proceeding with the next steps. It is very important that these steps are well understood before one proceeds with the implementation of the technique in the product development process.

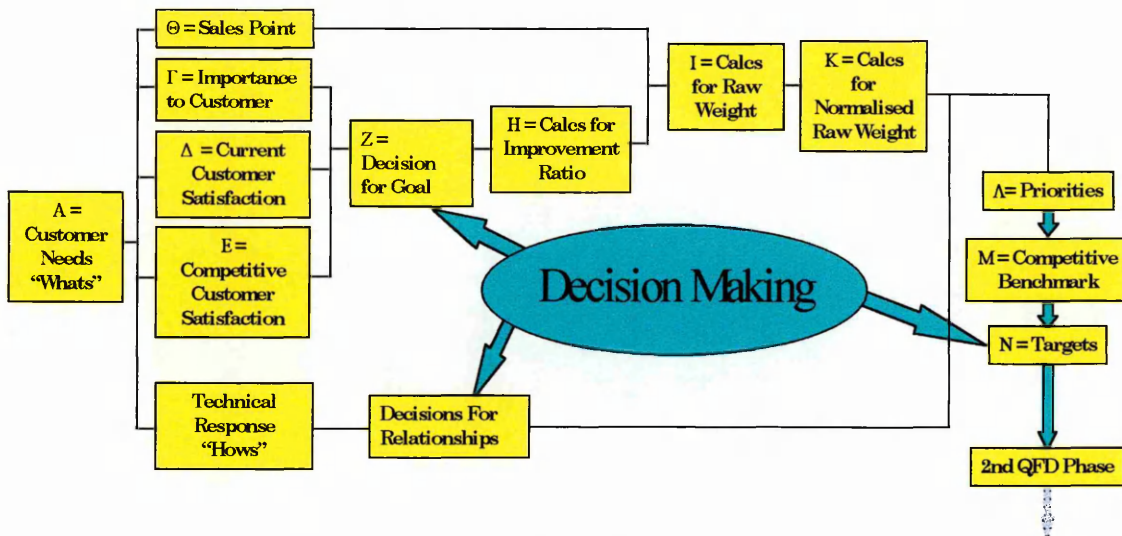


Figure 21

A sequential approach in the construction of the HoQ at its 1st phase

5.2 - Engaging fuzzy logic in human judgement and to the data acquisition

Each problem statement has its own unique set of circumstances, and each organisational element has unique relationships internally and externally. It is therefore impossible to specify a “procedure” in the acquisition of data relating to the suppliers ideas, participants decisions and customers needs, but it is possible to define a methodology in which the available data will be acquired and translated reliably and in such a manner as to gain a sensible meaning to every participant in the product development process.

Obviously QFD as an information and communication tool, involves human thinking and feeling with some comprehension. This comprehension involves the representation of our thinking and feeling in numerous forms such as pictures, images, daily language and value systems. If one considers that the power of human thinking and feeling is much higher than the power of a living language then it seems impossible to guarantee a one-to-one mapping of problems and systems in our imagination and in any logical model or methodology i.e. QFD. The acquisition of data that will be utilised in the technique is nothing more than a generalised way to proceed with its implementation. Providing that this generalisation represents human thinking and feeling in a reliable manner faithful

to the human style of processing information, then it can be said that QFD's implementation using this generalised input will produce accordingly a generalised output.

As mentioned in chapter 4 a popular mathematical way to model and handle this generalisation (vagueness) providing reliable results is the fuzzy set model. The ultimate goal of this model is to represent human thinking and feeling, as well as to provide a form amenable to computer manipulation. It can be viewed as a language that allows one to translate sophisticated statements from natural language into a mathematical formalism. With this mathematical form of knowledge we are able to collect ideas, preferences and opinions from numerous individuals i.e. suppliers ideas, participants decisions and customers needs. Therefore fuzzy logic enables us to model and mathematically calculate vagueness in data and relationships in a formal way.

A basic concept in fuzzy logic is linguistic variables, which is defined as a variable whose values are words or sentences in a natural or synthetic language i.e. 'Correlation' is a linguistic variable if its values are 'high', 'moderate', 'low', and so on. Each value of a linguistic variable represents a fuzzy number. Each fuzzy number represents a range of numbers. In this project TFN Triangle Fuzzy Number will be the only data representation. The following table (figure 22) provides a guide which can be used in this data representation and is organised under several headings. The table uses the normalised scale of 5 main discussion areas and it illustrates TFN relationships between vague linguistic statements.

Likelihood	Usuality	Judgement / Statement	Relation / Relevance	Quantification	TFN (Triangle Fuzzy Number)
Certain	Always	Excellent	Most	All	0.8,0.9,1
More than Likely	Very Frequently	Very Good	Great	Most off	0.7,0.8,0.9
Likely	Frequently	Good	Strong	Three Quarters	0.6,0.7,0.8
Not So Likely	Often	Fairly Good	More	More than half	0.5,0.6,0.7
Uncertain	Quite Often	Medium	Moderate	half	0.4,0.5,0.6
A Bit Unlikely	Occasionally	Fairly Poor	Less	Less than half	0.3,0.4,0.5
Unlikely	Rarely	Poor	Weak	A Quarter	0.2,0.3,0.4
More Than Unlikely	Very Rarely	Very Poor	Small	few	0.1,0.2,0.3
Certainly Not	Never	Bad	Least	Nothing	0,0.1,0.2

Figure 22

A Recommended Example of Translating Linguistic Variables into the Corresponding TFN Variables

So far the vagueness in data acquisition has been discussed and a methodology to tackle this issue explained. However this is one side of the story since these may represent data of relative importance (data relative to another opinion or attribute) or absolute importance. It is highly recommended to the reader when acquiring and importing data into the HoQ to clarify the situation whether this data refers to an absolute or relative importance metric (see 2.5.1). Note that any negligence in this section will create completely wrong results.

5.3 - Achieving team consensus during the group decision making process

Decision making is fundamentally one of the basic human activities. Every day we are faced with a variety of alternatives and in some instances we have to decide which of the available alternatives are right for us. The current literature on decision making is based largely on theories and methods based on various studies regarding methods of election, social choice, group decision making etc. Decision making on its own is a very rich field of study. As its name suggests it deals with the way decisions are made and in this study it is perceived as the outcome of an individuals or a groups opinion and judgement, produced as a result of using their knowledge and expertise when considering an existing set of data.

The QFD process is a process of decision making for aspect involved in the product development process. To be able to correspond to any aspect the QFD group is cross functional. Because of this multidiscipline structure of the QFD group, differences in opinions and judgements may arise. These differences need to be accommodated, a proposed methodology is provided in 5.3.1. A flexible technique is required in order to support individuals opinions and ideas and to retain an efficient and balanced group decision making. In other words a technique to achieve team consensus during group decision making is required

In our democratic society group decisions are the result of discussion and vote. Obviously one should note that the primary value behind this method of discussing and voting is to ensure that no individual involved in the product development process forgoes personal rights and that every opinion is equally considered. By introducing more perspectives, ideas and professional experience in the decision making it can only be beneficial. Since team decision making is better than individual. The reason is that a team decision will help the team members to pool their knowledge and develop a creative synergy hence they can choose the best alternative using the diverse perspectives and information available. In other words team decision making is highly effective process in the product development cycle, whereby each individual may find themselves equally compromised and yet equally fulfilled with the knowledge that their own ideas have helped to create the final decision.

5.3.1 - Functional description of the proposed group decision making process

As mentioned earlier the whole QFD exercise and implementation undertaking has as its ultimate goal the acquisition of SQC target values. Now these target values are dependent upon a series of matrices which make use of the *collective individual* decision making and lead to a *team* decision making therefore the team consensus. To ensure team consensus a compromised group decision making has to be reached. This can be achieved by the fuzzy group decision model proposed in this thesis which translates the individual fuzzy decisions into a crisp team consensus decision. Here each member of the *n individual decision makers* is giving his preference order. A "social choice" or the simple majority vote *S* is then acquired by summing the relative popularity of all the alternatives x_n and dividing

them with n participant decision makers. However the assumptions that are made are that any TFN $[A (a_1,a_2,a_3)]$ will be translated in the following crisp form $(a_1+2*a_2+a_3)/4$.

Hence: $S = \text{Sum } x_{1..n}/(4*n)$

So lets consider the Goal matrix in the HoQ and a technical development team of 4 for a case study. Lets say that their names are: **TD1, TD2, TD3, TD4** and their individual decision making for product goal about each individual customer need; GA,GB,GC,GD,GE are in the following table in figure 23. (Note that their decisions are significantly different, however it is difficult to find which decision will provide the team consensus).

	TD1	TD2	TD3	TD4
GA	least	small	least	less
GB	most	more	great	strong
GC	more	weak	small	strong
GD	less	weak	least	less
GE	great	strong	more	most
GA	0,0.1,0.2	0.1,0.2,0.3	0,0.1,0.2	0.3,0.4,0.5
GB	0.8,0.9,1	0.5,0.6,0.7	0.7,0.8,0.9	0.6,0.7,0.8
GC	0.5,0.6,0.7	0.2,0.3,0.4	0.1,0.2,0.3	0.6,0.7,0.8
GD	0.3,0.4,0.5	0.2,0.3,0.4	0,0.1,0.2	0.3,0.4,0.5
GE	0.7,0.8,0.9	0.6,0.7,0.8	0.5,0.6,0.7	0.8,0.9,1

Figure 23
Case study of a collective individual decision making

The overall purpose is to reach a common, acceptable decision. To deal with the multiplicity of opinion evidenced in the group, the social preference S for GA,GB,GC,GD,GE may be defined:

$$S_{G4} = \frac{(1*0+2*0.1+1*0.2)+(1*0.1+2*0.2+1*0.3)+(1*0+2*0.1+1*0.2)+(1*0.3+2*0.4+1*0.5)}{4*4} = 0.2$$

$$S_{G8} = \frac{(1*0.8+2*0.9+1*1)+(1*0.5+2*0.6+1*0.7)+(1*0.7+2*0.8+1*0.9)+(1*0.6+2*0.7+1*0.8)}{4*4} = 0.75$$

equally $S_{GC}=0.45$ & $S_{GD}=0.3$ & $S_{GE}=0.75$

The above described calculations are repeated where group decision making is needed in the HoQ and upon completion of the described process crisp quantified values are acquired.

(Note that so far Figure 23 symmetric TFN's are used in order to describe the technique in a basic simple manner. However the technique is designed for a broader computer application and it will calculate reliably asymmetric TFN's.)

5.4 - General description of the overall computerised QFD implementation

As previously stated there are a lot of computer programs available to an organisation nowadays. Among these computer programs are spreadsheets. The benefit of a spreadsheet QFD implementation suggests the development of a spreadsheet structure where all the procedural as well as the informational data are included.

QFD is a series of matrices where elements of each one of the matrices correspond to a specific technical correspondence "how" or customer need "what". The principal requirement for a spreadsheet program is to define exactly what needs to be accomplished by using its application. In other words a specific spreadsheet environment has to be created. The requirements of this spreadsheet environment that would be necessary to implement QFD are:

- 1) A means whereby a hierarchy of entities can be effectively represented.
- 2) The basic units of representation should be capable of handling factual and procedural information in a coherent body (since both are required for any analysis).
- 3) Means of representation for the economy of expression.

The problem is how to divide the available data into tables. It is very important for a spreadsheet program to demand good planning in the tables development, since the tables make up the foundation of QFD's application. If their structure is weak, the whole application will be weak. In fact it will be impossible to create the QFD's application without the right set of tables and relationships. The principle requirement of QFD's implementation is the layout of its tables. Obviously we consider that the spreadsheet software has the ability of multiple sheets (modules). Figure 24 illustrates the modules with their details required for the initial 1st QFD phase of the product development process. The chosen arrangement is similar to that used in other procedural programs which means it can be easily controlled. Note that this is a suggested modular order and one may do the same work with less modules or a different layout.

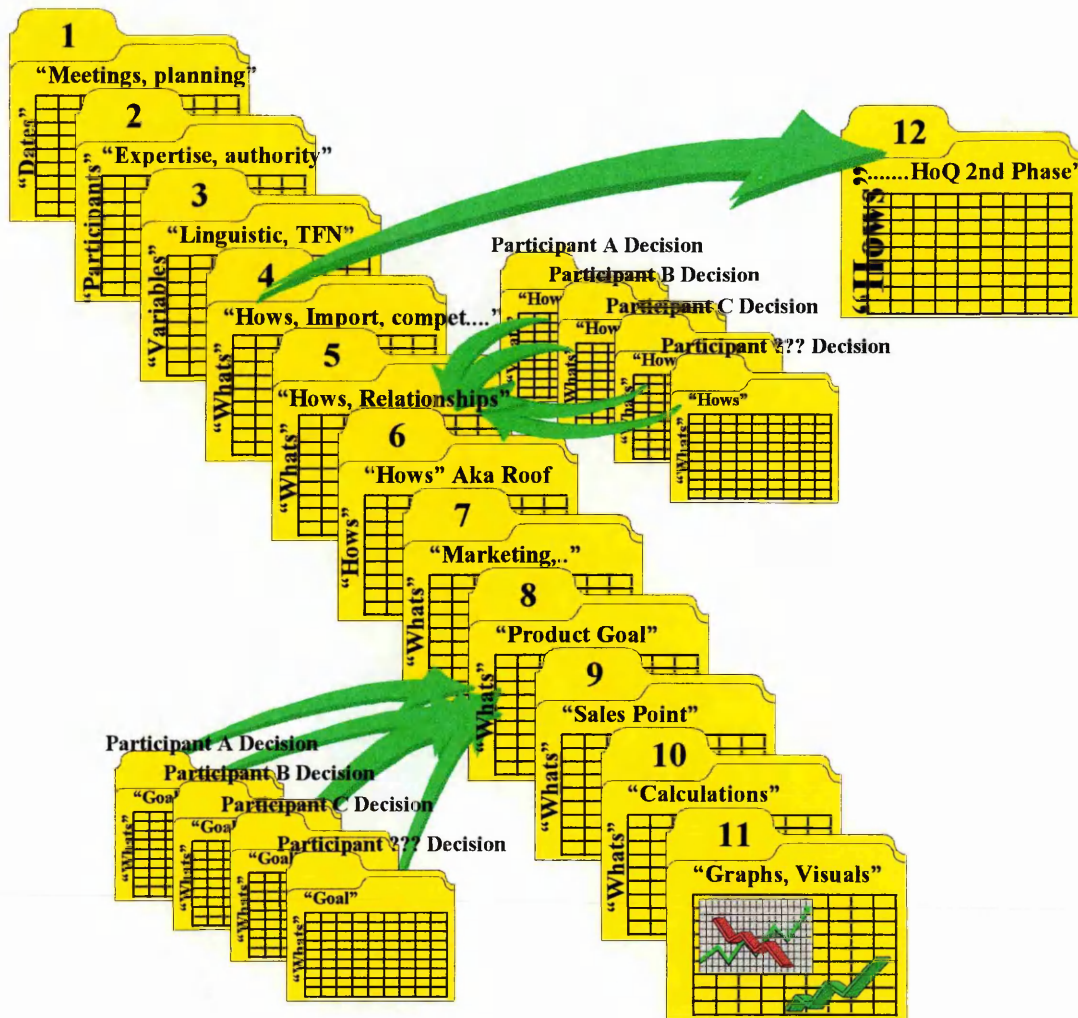


Figure 24

The suggested arrangement of the spreadsheet modules for the 1st QFD phase

Hence the modules which are suggested are:

- 1) **General**; This module contains all of the data related to the product development planning, group meetings, development budget, electronic communication dates and outcome etc.
- 2) **Participants**; This module includes all of the team participants, their expertise, where their input is crucial and where their input is negligible, their authoritative status etc.
- 3) **Linguistic two TFN**; This module includes the table of the translation between linguistic variables and TFN variables. See (5.2)

- 4) HoQ (1st Phase);** This module includes all of the HoQ matrices explained in Chapter 2 without the AKA roof. This module is to acquire and update the latest results which affect the HoQ. Moreover it is the module where a meeting should take place in order to finalise SQC targets (obviously in the case that agreement cannot be reached one can use the previously recommended group decision making methodology). Finally this module will be the one to be linked with the 2nd QFD phase.
- 5) Individual or Group Decision Making for Relationships;** This module has all the group decision for relationships between “Whats” and “Hows”. One may include into it equal amount of modules as the participants and hence be able to capture individuals opinion (Figure 24). Moreover it can calculate the collective compromised team decision making (see 5.3.1)
- 6) Decision Making for AKA Roof;** This module has the outcome of teams judgements for relationships between “Hows” and “Hows” (see 2.8).
- 7) Marketing (Customer importance, Customer Satisfaction Performance, Competitive Satisfaction Performance);** This module has all the data published from the marketing sector and these data include; the customer importance against each individual “What”, the satisfaction of our customer from the current product against each individual “What” and the competitors customers satisfaction performance against each individual “What” (For further information see 2.5.1, 2.5.2, 2.5.3)
- 8) Individual or Group Decision Making for Product Goal;** This module is similar to the one for Relationships and it has all the group decision for product goal. One may include into it equal amount of modules as the participants and hence be able to capture individuals opinion (Figure 24). Moreover it can calculate the collective compromised team decision making (see 5.3.1)
- 9) Sales Point;** This module has all the data published from the sales sector and these data include the impact of sales of a product according to each individual “What” (see 2.5.6).
- 10) Calculations for Raw Weight and Normalised Raw Weight;** This module contains all of the calculated values for each individual “What” (see 2.5.7, 2.5.8).
- 11) Visualisations;** This module includes the graphs which may help to achieve a clear decision making. These graphs may use data linked from any module provided in this spreadsheet program or other source of information.

12)HoQ (2nd Phase.....); This will be the next phase module where all the HoQ matrices for the 2nd QFD phase will be included. (For more information see 2.9) obviously this matrix will be decomposed to other matrices and so on.

5.5 - Guidelines of QFD's informational access and implementation

The recommended methodology of QFD's application within a general purpose spreadsheet program offers the possibility of conducting QFD studies more conveniently and with more flexibility than any traditional special - purpose program. The philosophy of this methodology demands that QFD data structures should be dynamically available during the design process and be concurrently available to all sites at which design activities take place. Moreover the QFD partially changes from a centralised meeting to computer conferences. Interconnected PC stations provide concurrent working. Each participant can concentrate on the task he is responsible for. It has to be established which part of the QFD process is well suited for (asynchronous) computer conferencing and which part is better performed using the classical face to face meeting style.

The networked PC support environment provides both a uniform concurrent environment and a means to retain independence and individuality. Moreover it allows individual knowledge to be shared among the members of the product development team. The advantage of which is that at the major face to face meetings, all the participants will be able to discuss the 'commonly shared information' from each members input in the computer environment this decreases the 'surprise' element whereby new ideas brought up in a meeting may be ruled out without sufficient thought by others. The reason is that team members feel that shared information is more reliable because it is confirmed by everyone else in the group. Unshared information on the other hand cannot be verified during the meeting, particularly if it is known by only one member.

QFD implementation involves group members co-operating with one another to achieve an agreed goal, but not necessarily carrying out the task in a synchronised manner or in 'real time'. This approach provides an ability to implement the QFD methodology and retain local autonomy in the conduct of work. Each participant can inject their own ideas into the "spreadsheet software" at any agreed time slot.

This type of approach would provide a valuable source of information within the specified time constraints. Moreover it enhances 'democracy' each participant has equal access to the available information during any stage of the product development process.

So far the basic achievements that one can have when implementing the proposed methodology in a spreadsheet software have been explained. As one may be aware there is no real limitation to what a spreadsheet can provide to those who want to take the proposed methodology a bit further. The spreadsheet can be programmed using simple computational procedures, to check or suggest relationships or rules according to previous similar QFD studies. Moreover it can be programmed using equally simple computational procedures to examine different scenarios providing invaluable clues to how ones decisions can affect the product development process.

Spreadsheet technology enables us to create a remarkable variety of digital images and displays which given the right conditions effectively enrich communication capabilities. A variety of graphs will project the participants in the product development process and probably the customer into an interactive environment which can go to such a level as CAD's parametric product representation and so on. A key consideration in favour of this proposed visual representation is that it can be a cost effective way of getting people in different capacities to work together without the need for long explanations.

5.6 - Anticipated results from its implementation in the product development process

The proposed QFD methodology promotes thinking in a systems manner. In this approach an abstract representation of subsystems (modules) can be acquired as well as their interactions in the overall product development process. This abstract representation promotes conceptual thinking and creativity. It also maintains the design quality leverage. The approach also promotes a rational structuring and scheduling of decision making. Decisions are not made individually or on an ad hoc basis but in the context of the decisions relationship to the system. This approach is important from another viewpoint, by developing a system that does not rely on expensive high end hardware but on very basic hardware, it makes it friendly and

easily accessible, hence the people involved can concentrate on the QFD technique for managing decisions and their interactions.

With the proposed QFD methodology knowledge can be preserved in one place, in contrast to unruly design standards manuals. The matrices and charts prepared during the QFD procedure create a working document that can be easily referenced and learnt from. The QFD knowledge base holds great promise for future product development efforts. It holds the answers to questions concerning what decisions were made and why-and can simplify similar decision making endeavours. Concurrently it helps prevent problems that have occurred in the past from recurring in the future. In addition QFD can be used to train entry level engineers. By reviewing the results of a successful QFD project, entry level engineers begin higher up on the learning curve. The process also offers potential for continuing education of employees across departmental lines.

QFD provides a database for design engineering of future products. While QFD may initially consume more man-hours, from an engineering-talent standpoint the hours required for the same level of product quality on similar, subsequent products will be much less. The net result? A significant reduction of time from product conception to introduction into the field. In other words QFD lays the foundations for future work so that one; *"doesn't have to reinvent the wheel or wonder how a product was developed last time"*. It also provides a needed discipline, much like a pilot's checklist. A guy may have flown 300 missions, but he still checks off every instrument when he gets into that cockpit."

Other advantages of the recommended method are that the whole technique encompasses greater flexibility gained from the computer environment, and greater participation since professional experience is translated into a mathematical formalism faithful to the human style of processing information. In addition this numerical quantification achieves greater understanding of the impact each participants job has on the customers satisfaction. The implementation of QFD in a PC platform enables all the participants to create remarkable numerical displays, which when given the right conditions will enrich communication capabilities.

The structured process imposed in the proposed methodology forces the development of a strong logic behind each decision. Documented reasoning provide several benefits. Not only does it aid others in understanding the original reasoning, but it also makes updating the analysis easy. Instead of redoing the entire analysis, selected decisions can be revised when the reason changes. With documented reasoning the results can be modified and adjusted based on new overlooked facts or ideas. It can be done quickly and efficiently as situations change.

Chapter Six

**Discussions, Conclusions and future
work**

6 - Discussions, Conclusions and future work

6.1 - Discussions

The aim of this thesis was to simplify QFD's documentation, to research its benefits and its limitations when applying the technique to the European Automotive Industry. Following consideration of the limitations, a methodology had to be developed in order to enhance QFD's integrity and acceptance in the European Automotive Industry.

The basic construction or design of the QFD concept was completed in the early 1970's in Japan. Officially it made its appearance in Europe in the early 90's. Therefore published work concerning the technique may be found from that date onwards. Although textbooks exist they lack a consistent and coherent representation of the technique. Moreover the textbooks which maintain a coherent explanation manage to confuse the reader through lengthy discussions and analysis of the technique's basic components. The existing papers concerning the technique debate its basis and principles, but very rarely question its vague and unclear documentation. This problem is enhanced from the fact that existing information and paradigms which could help in its understanding are contained within a proprietary context.

QFD is dealing primarily with the design aspects of a product by starting with the end objective and then determining the means by which that objective is to be achieved. QFD joins the voice of the customer with the combined perspective of the product development process. Therefore it becomes a sort of translator between customers language and any language within the product development context i.e. financial, design, mechanical, manufacturing etc.

If a system is too complicated, then there may be some mistake in its basic concept. This could be justified through the use of an analogy; the motion of the planets in the Solar System is explained with a combination of 40 ~ 50 circles in the Ptolemaic theory or the geocentric theory, but it can be explained with only seven circles in the Copernican or heliocentric theory.

On consideration of the above analogy and the mechanics of QFD one will notice that numerous papers and articles will debate and attempt to offer solutions in a

statistical or purely academic context. In other words the published papers concentrate too intensely on the mechanics of the technique rather than its philosophy. This is quite similar to the geocentric theory in astronomy, which simply added supplementary circles in order to explain new observations. As a result QFD becomes unnecessarily complicated and more difficult to understand and it is consequently difficult to implement to cope with the demands of present times. What we should be working on is a reliable but simple version of the technique, so that it can be more user friendly, easier to understand and implement.

In response to the above statements this thesis achieved the mathematical simplification as well as the reliability in the data acquisition through the use of fuzzy logic principles. Utilising this mathematical formalism in the QFD context, it provided us with a way to model generality previously done by statistical mathematics. Moreover since QFD engages human judgement which inevitably is subjective, it manages to capture this subjectivity and come up with a way to express it, model it and mathematically manipulate it. This approximate mathematical description in human judgement and opinion has been utilised by the proposed methodology within the group decision making. As one may see in chapter five group decision making is vital to the correct implementation of the technique. More importantly group decision making has to maintain team consensus. The proposed group decision making model accomplishes that by the acquisition of a computed collective decision which equally compromises but equally fulfils all of the team members.

Another aspect in the implementation of QFD was the utilisation of fuzzy logic in the translation of linguistic variables into mathematical variables. The proposed process of translating linguistic variables into a mathematical formalism serves two main reasons, the first reason is that it can model the vagueness in the meaning of a judgement and the second is that this vagueness will be calculated reliably, in order to provide indications for an appropriate course of action i.e. decision for product goal and decision for relationships between what's and how's and so on.

Another aspect in the implementation of QFD in this thesis is the feasibility of activities and knowledge across perspectives. The proposed method enhances communication between developers of different views. Its main philosophy implemented in a typical PC spreadsheet software provides numerous benefits to

the implementation of the technique. Among the important benefits is that the technique may be implemented on an individual or congregational basis. It becomes more convenient to convince or gain constructive arguments for any opinion involved in the process. In addition its utilisation in a spreadsheet software, becomes a convenient way to handle the mechanics of the technique. With this computerised version communication is enhanced as well as the re-examination process of the product development cycle. Moreover group dynamics are enhanced since every individuals opinion is considered. In other words by implementing the whole methodology in a spreadsheet program it automatically encompasses all the functionality's and abilities of the computer spreadsheet environment i.e. visual representation of the data in the form of graphs, ability to mathematically analyse individual or group decisions, ability to construct different scenarios for different inputs etc. Hence the overall product development process gains flexibility and traceability.

Although the proposed methodology has not been fully evaluated, due to time restrictions, it appears to show a strength in its theoretical sense which is perhaps not observable in other studies encountered during this research. As it may be obvious from chapter 3, launching and conducting QFD projects may encounter barriers and limitations derived from its mechanics or its constitutional behavioural aspect.

Being involved in QFD's implementation in the product development process and in particular launching a QFD project for a new generation product, has meant that the author has gained invaluable practical experience. Even though this is an ongoing project and the proposed methodology hasn't been fully implemented as yet, the author would like to share some of his early findings or practical tips in the following paragraphs.

One of the main barriers the author had to face was peoples resilience to QFD's implementation. However this resilience was perceived not as an action against his proposed methodology but an instinctic reaction created from their fear to the unknown. Obviously noone wants to talk about things they are not fully aware of or don't understand. Moreover it should be acknowledged that QFD is a powerful technique and by its own nature may offend all those involved in the product development process, since it keeps track of all of the contributing factors to a decision which makes it easier to pinpoint mistakes, negligence or professional incapacibilities. On the other hand one should realise that these people have

natural skills and as a matter of fact these skills make them useful to the business, hence if a new technique comes onto the horizon, people want to know how their new role will change and if they will be better off.

To resolve the above issues the author proceeded with three distinct activities. These are:

- Work and plan an easy way to educate people about the technique.
- Reassure all those involved in the process that QFD is not a method to police and penalise their decisions and activities but its a way to correct them by making them aware.
- Present visuals on each individuals current role and expertise and how these will be embraced with the techniques implementation.

Upon the completion of the previously mentioned activities the ground was friendlier and fertile enough to introduce the technique in a new project. At this point the author was fully aware that any mistake in the techniques implementation will become a barrier to its evolution. However the chosen option was the one of clarity and constitutional responsibility for its success, (see in previous chapters, fuzzy logic, team decision making and a friendly accessibility within a known spreadsheet package). As a result of the chosen options participants became more willing to learn the technique and become comfortable enough with its existence in the product development process. All of these indications are perceived as very promising for the methodology's success.

From the above statements one may expect to see final results in the form of a case study , to prove the validity of the technique. Since the whole technique is very subjective by its nature, a specific case study would not really prove its integrity regarding the structure of the methodology and in its method of data acquisition and implementation. The reason is that when we talk about a product design that discussion will be very subjective and imprecise. Until now numerous methodologies utilising mathematical language had to be right or wrong. Their validity was easier assessed in a typical case example. On consideration that the proposed methodology utilises fuzzy logic principles this kind of approach would contradict the ultimate goal and philosophy of this mathematical formalism. Although the author maintains a keen interest in the implementation of this methodology by the industry itself, he acknowledges that failure or success of the technique would be impossible to be accredited solely to

this method. A number of case studies would be required to fully value the technique. This was not possible in the project due to time constraints.

Finally it needs to be mentioned that the author did publish one conference paper. The conference paper was published in ISATA's proceedings in Florence in order to initiate and encourage discussions and comments for the proposed methodology. The acquired comments were taken into consideration and improvements did take place upon the original ideas. The methodology proposed and described in this thesis include these considerations and improvements.

6.2 - Conclusion

A simplification of QFD's documentation has been achieved. A methodology which considered QFD's limitations has been developed. The ultimate goal of which was to create a solid structure in QFD's implementation and approach, as well as achieving enhancement of its integrity and purpose. This was accomplished by the engagement of fuzzy logic principles in the data acquisition related to human judgements, collective group decision making derived from a calculated mathematical model orientated to achieve team consensus and the automation of the whole project within a PC spreadsheet program.

Knowing that this project breaks new ground it is proposed that this methodology is put into practice. The work illustrated within this thesis has accomplished the description of the QFD technique in a simple and reliable way with negligible cost implications. Due to the vast area that this project covers and its subjective status as well as the lack of a suitable paradigm, has not been fully evaluated in a real product development process. It is to be hoped that such a complete evaluation of the methodology will be realised in the near future.

6.3 - Future work

Taking into account the above conclusions it is recommended for future work that the described QFD methodology be implemented in as many cases as possible.

Other further work that the author would see as a natural extension of this project is the area of extensive computerisation with the QFD module as the centre of the decision making evaluation (refer 2.10 QFD's informational flow). This means that the QFD spreadsheet implementation can be part of a company's existing computerised engineering database system where all the product specifications and previous history will be used and make sense within the QFD area.

Another area for future work using the proposed methodology is in the CAD systems with parametric design capabilities. A CAD system with this sort of ability would provide the product development team and the customer with a visual impact derived from individual or collective decisions. Arguably this type of implementation would not be feasible for all the products considered in the automotive industry but it can be implemented in the vast majority of them, since mathematical and computer simulation of the automotive products is quite common.

Other areas of considerations are quality, safety, standards, product or manufacturers specifications etc. These areas can be translated in a fuzzy mathematical formalism and become a series of "Whats", ie Customers importance etc. Hence they will be able to prevent, affect or give advice to participants judgements and decisions related to the final end product and its product development process.

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Appendix

Useful TQM tools in QFD's informational flow

Appendix

Useful TQM tools in QFD's informational flow

Brainstorming or Idea Generation

Brainstorming is an idea generation technique that stimulates creativity, encourages team participation and minimises premature critiquing and evaluation of ideas. Participants are encouraged to think opposites, and add wild ideas and think “out of the box” since all ideas are recorded. During this team activity there is no criticism of ideas - the idea is to open up as many possibilities as possible, and break down preconceptions about the limits of the problem. Once this has been done the results of the brainstorming session can be analysed and the best solutions can be explored either using further brainstorming or more conventional solutions.

The steps to retain a successful brainstorm session are:

- Define a clear problem to be solved with any criteria which should be met.
- Encourage everyone to participate and to be creative.
- Generate a large number of ideas.
- Keep on subject and steer the generated ideas towards the development of some practical solutions.
- Invite participants from a wide range of disciplines with as broad a range of experience as possible.
- Welcome all the generated ideas from the practical to the wild impractical ones.
- Do not criticise ideas since it creates a risk to prevent the participants from putting forward their ideas.
- It is advisable to keep a good record of the ideas so that in later stages they can be studied for evaluation.

Flow Chart

A flow chart provides a visualisation of a process by the graphical representation of actions, activities or situations. It can be defined as the mapping of the sequence of steps required for the completion of an activity. There are numerous symbols which can be used in order to represent certain processes or activities. These symbols are used to enhance its graphical illustration and are connected with 'links' in order to show the flow of information in the represented process. Figure A1 displays a typical example of a flow chart which describes the simple process for getting a cup of coffee and some typical flow chart symbols.

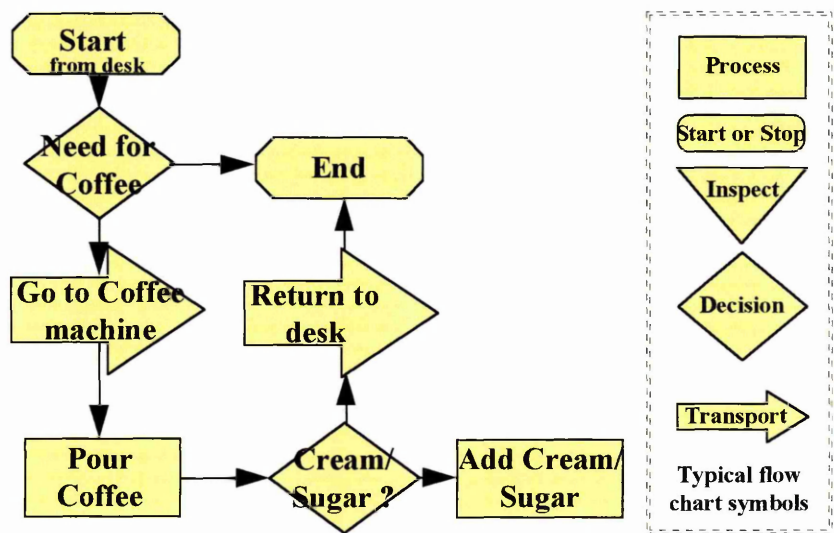


Figure A1

A typical Flowchart example of the process for getting a cup of coffee and some typical flow chart symbols

Histogram

A Histogram is a chart that displays the frequency distribution of the characteristic data from a process. It is generally used to display the patterns of

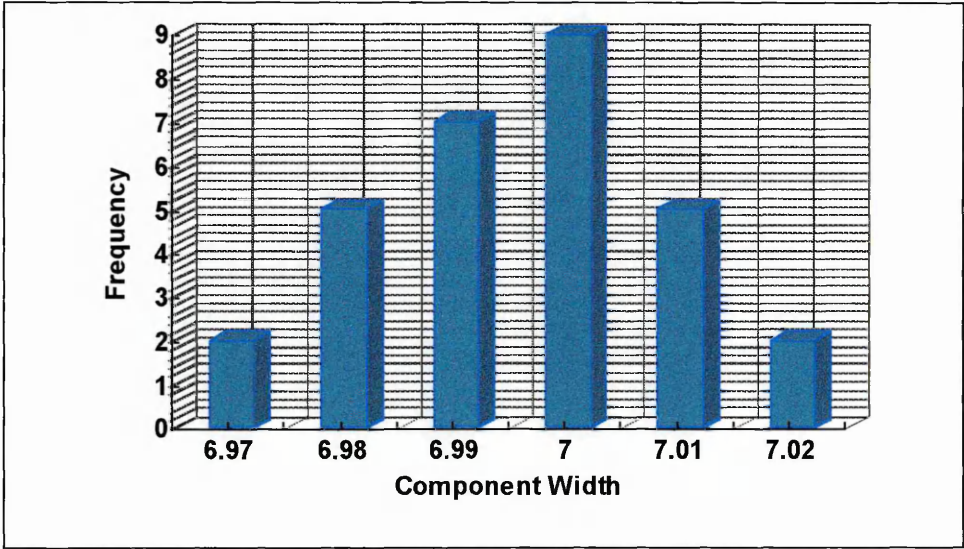


Figure A2

A typical histogram acquired from the measurements of a components width of a part manufactured on an automated lathe. variation of either discrete or continuous interval data. Figure A2 shows a typical histogram. Histograms provide an excellent visualisation tool for stochastically varying data. Consider tabulating a set of data (Figure A3) acquired from the measurements of a components width of a part manufactured on an automated lathe.

Measuremen t Number	Measurement Value (Width)
2	6.97
2	7.02
5	6.98
5	7.01
7	6.99
9	7.00

Figure A3

A tabulated set of data measuring repeatedly the width of a component

After tabulation of a set of data, the highest and lowest bounds of the data can be determined and a series of bins or cells created into which counts of the number of occurrences of measured values are placed. For example, consider for the repeated measurement in the above example that the highest value measured is 7.02 and the lowest is 6.97. A series of bins could be constructed for each .01 increment along a scale from perhaps 6.97 to 7.02, a total of 6 bins. Then each number in the list of measurements would fall inside one of the bins. For example, (Figure A4)

6.97	6.98	6.99	7.00	7.01	7.02
x	x	x	x	x	x
x	x	x	x	x	x
	x	x	x	x	
	x	x	x	x	
	x	x	x	x	
		x	x		
		x	x		
			x		
			x		

Figure A4

A series of bins of the repeated measurement of the components width

The histogram is then just a plot of the number of occurrences in the bins. The utility of histograms is to gain a rapid look at how the data collected from a process is distributed. A normally distributed histogram has the appearance of the chart in the histogram (Figure A2) and is called a normal histogram. Many other distributions are well known and mathematically characterised. Also, inspection of histograms can give rapid clues to problems in sampling the data, or if problems are present in the process.

The Pareto Diagram

Pareto diagrams are named after Vilfredo Pareto (1848-1923), an Italian sociologist and economist, who invented this method of information presentation toward the end of the 19th century. It helps to identify causes of a problem by analysing the frequency of their occurrence. Figure A5 shows a typical example of a Pareto diagram. The chart appears much the same as a histogram or bar chart, except that the bars are arranged in decreasing order from left to right along the base (x-axis). Usually is accompanied by a cumulative percentage line that depicts the cumulative frequency of items, starting with the most frequent category and adding remaining categories until 100% is reached.

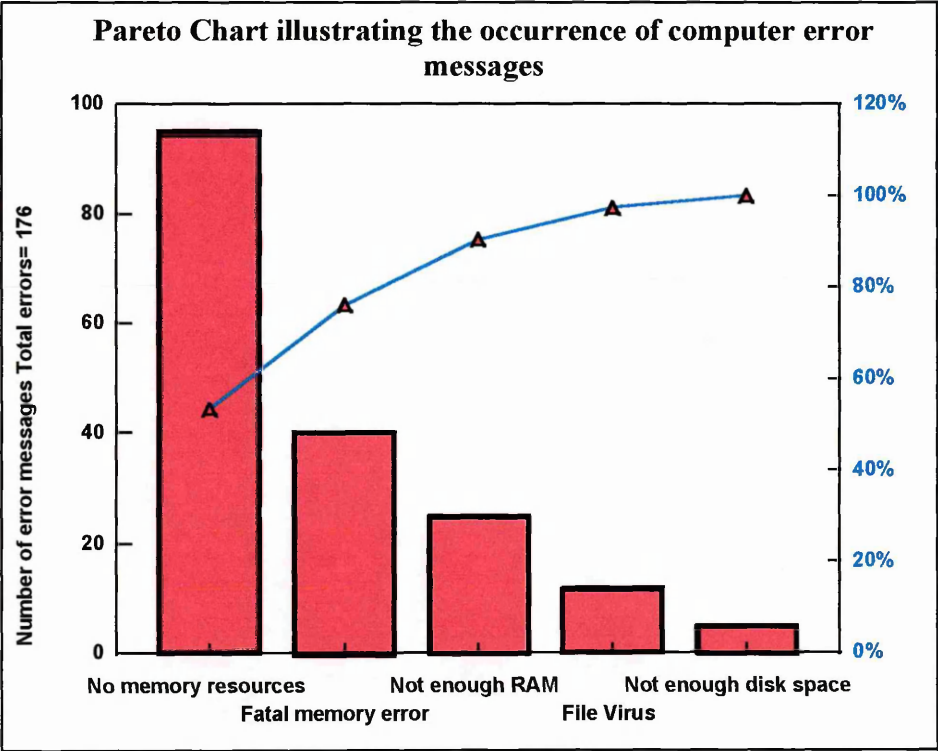


Figure A5
Typical example of a Pareto Diagram

The Pareto Chart, let us quickly see which problems need to be tackled first. Typically used to prioritise competing or conflicting "problems" so that resources are allocated to the most significant areas. In general, though, they can be used to determine which of several classifications have the most "count" or cost associated with them. Often 20% of the items contribute to the 80% of the effects; hence the "80-20" popular Pareto rule. For example, Figure A5 shows the number of

occurrences of a computer error type during a certain period. The graph indicates that 76.14% of the computer errors are due to its memory allocation (memory error and resources) . Obviously, we should place a higher priority into correcting the causes of these two errors, as these two problems if corrected, would have the highest return.

Ishikawa Diagram or (Fishbone, Cause and Effect Diagram)

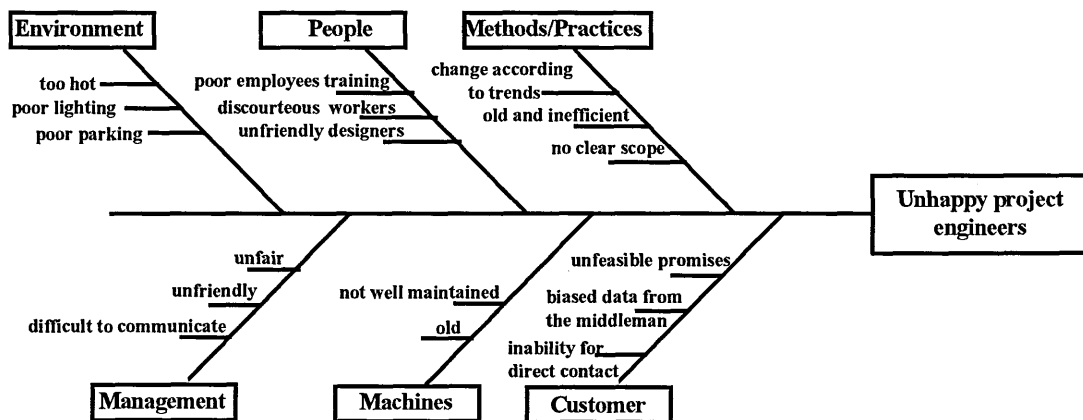


Figure A6

A typical Ishikawa Cause and effect diagram: Causes of unhappy project engineers in an Automotive business

An Ishikawa diagram, Cause and Effect or Fishbone Diagram is a visualisation and knowledge organisational tool. It collects and organises the ideas of a group in a systematic way facilitating the understanding and ultimate diagnosis of a particular *problem of interest*. As one may note there are several names referring to the same tool. The first name is after the inventor of the tool - K. Ishikawa (1969) who first used the technique in the 1960s. Cause and Effect describes the tool, since the tool is used to capture the causes of a particular effect and the relationships between cause and effect. The term Fishbone is used to describe the look of the diagram on paper. Figure A6 shows a typical Ishikawa or Cause and Effect diagram.

It is a tool which helps to identify and relate possible causes with effects. It consists of the "basic problem", *problem of interest* which is entered at the right of the

diagram at the end of the main 'bone'. At an angle to this main bone there are typically three to six sub-bones which are the general causes to the problem under consideration. Associated with each of the sub-bones are the causes which are responsible for the problem designated. This subdivision into ever increasing specificity continues as long as the problem areas can be further subdivided. The maximum practical depth of this tree is usually about four or five levels. When the fishbone is complete, one has a complete picture of the possible root causes for the designated problem.

The Ishikawa diagram can be improved by computer automation. There are several computer packages in the PC market today which elaborate and maintain the integrity of the technique.

Control Chart

The control chart is probably the best known and best understood quality tool. Its purpose is to classify a variation in a process. It helps to determine if this variation is operating between expected boundaries or if something has happened that has caused the process to go 'out-of-control'. Figure A7 illustrates a typical Control Chart example, it is based on histograms so that the reader can get some means of comparison between the two techniques. Again the measurements of the components width of a part manufactured on an automated lathe, produces a stream of values that vary slightly. How can one know if the variation is simply part of inherent variations in the process, or if something has changed, for example in the lathe tool sharpness, which requires readjustment? The concept of the control chart is to measure a variation, taking repeated samples, and calculate control limits (upper and lower). If any point exceeds these limits, there may be cause to consider making an adjustment (or at least watching the process more closely).

There are several major types of control charts, even though all have the same basic structure. One basic type of control chart is the attribute control chart, which deals with tracking attribute data such as percentage of a process variations. Charting the proportion of these variations results in the capability of observing whether this variations are in-control or out-of-control. The second major chart

type is the variables control chart in which actual variables are used, rather than a percentage of a process variations. Explanation of these chart types and their characteristics requires considerable space; however the reader can refer to a numerous bibliography which exhaustively examines control charts and the way they work.

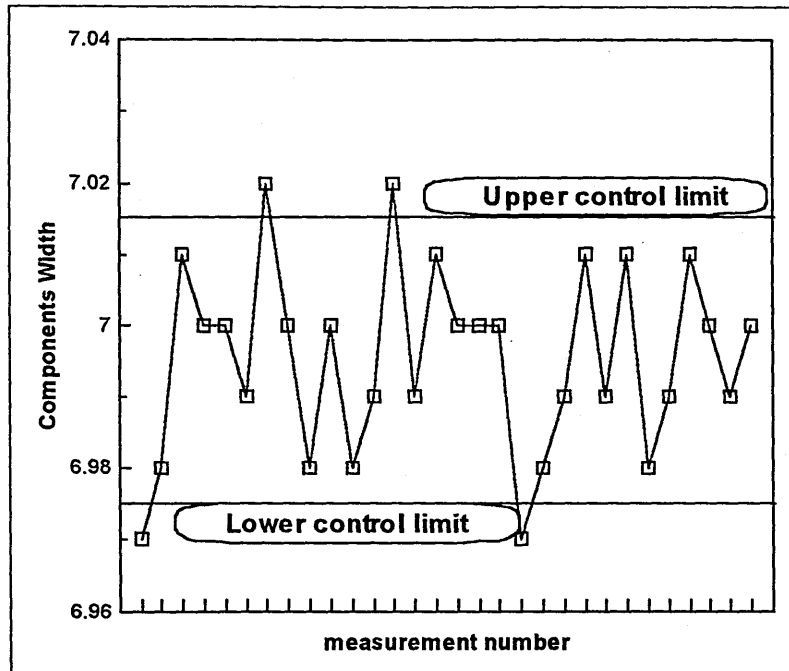


Figure A7
A typical Control Chart

Scatter Diagram

A scatter diagram is a representation of two or more variables plotted against each other. Typically the data included is interval data. The acquired graph can range from a shotgun pattern to a near perfect line of data points indicating the strength of the relationship between the two variables. The existence of the relationship

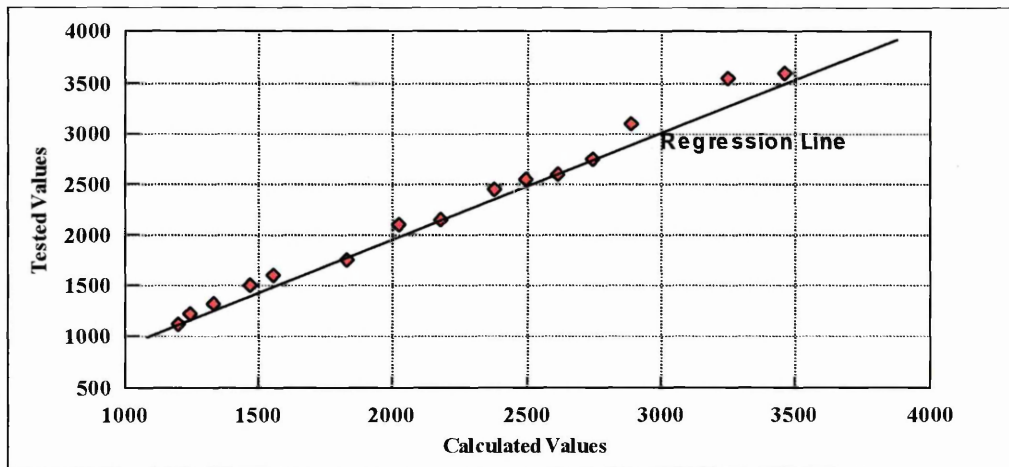


Figure A8

A typical Scatter Diagram between calculated and tested values from an engineering test process

does not infer a “cause and effect” relationship, since another third variable may be the causal factor. The relationships can be either positive (i.e. both variables increase together) or negative (i.e. one variable increases while the other decreases) and linear or non linear. Figure A8 shows a plot of two variables, in this example, calculated values versus tested values from an engineering test process. As shown, the predicted value increases, so does the actual measured value. These variables are said to be positively linear correlated. The line plotted is a *regression line* which shows the average linear relationship between the variables. When no regression line can be plotted and the scatter plot appears to simply be a ball of diffuse points, then the relationship between the variables are said to be uncorrelated.

Affinity Diagram

The affinity diagram is a brainstorming tool which is very useful in structuring and organising verbal data through analysis and simplification (Mizuno S, 1988) says that the affinity diagram method clarifies important but unresolved problems by collecting verbal data from disordered and confused situations and analysing that data by mutual affinity. Its origin is traced to the KJ method, developed in the 1960's by the Japanese anthropologist Kawakita Jiro. It provides invaluable help for new discoveries and breakthroughs in the traditional patterns and concepts. The way these are achieved is by the hierarchical structuring of the acquired unresolved data. The hierarchy is built from the bottom up, and the relationships between the ideas are based on the intuition of the team creating the diagram. Therefore the participants perception and ways of thinking is directed to a more visual and logical means helping them to reach a team consensus.

Typically the affinity diagram is represented as nested squared ellipses called concepts, which have smaller and smaller subgroupings of concepts. Figure A9 shows an example of the structure of an affinity diagram. The name of the problem considered is displayed at the top of the diagram and subproblems are grouped internal to the main problem. The basic idea is for the team participants to suggest at random areas of concern, then arrange these concerns in groupings and name the groupings. The benefit from the technique, like all the tools, is the enhanced visualisation.

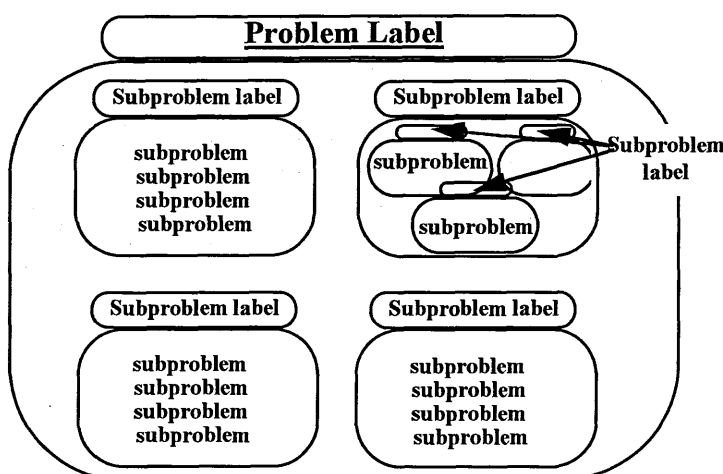


Figure A9
Affinity Diagram

When in use with QFD the used factual verbal data consists of phrases directly taken from the customer. This is evident since these verbal data are direct evidence of the customers needs. Now this verbal data normally comes from direct interviews with the customer at the preparation process of QFD.

The steps in constructing an affinity diagram proposed by (Mizuno S, 1988) are:

- Select a theme.
Select the issue or problem topic of this brainstorming activity. State the problem "as is" in neutral and plane terms.
- Collect narrative data.
Brainstorm ideas for the stated problem. Encourage every participant to think of ideas and write them, as short statements of a noun and a verb, on index cards, sticky notes, or have a recorder. .
- Collect and arrange the cards or notes.
Collect the cards or sticky notes, mix them up and spread them out (or stick them) on a flat surface (e.g., desk or wall). Clarify all the card statements without discussion or evaluation. At this point do not place them in a specific order
- Sort the cards into related, natural or logical groups.
Arrange the cards or sticky notes into related, natural or logical groups. Since this activity is based on the participants gut feelings, allow them to pick out cards that list related ideas and set them aside until all cards are grouped.
- Get everybody's agreement for the cards groupings.
It is vital to get team consensus among participants. Therefore discuss and get agreement on the final cards groupings.
- Label the cards of each group.
Create a title or heading for each grouping that best describes the theme of each group of cards. Separate large groups into subgroups and create subheadings.
- Draw the diagram.
Draw a line around each grouping to indicate affinity with the titles of the headers or subheaders.
- Compare results.

Compare the acquired results from this activity with the original issues and customers factual verbal data.

- Confirm teams consensus.

It is vital at these primary QFD preparation and implementation steps to have teams consensus. If the participants cannot agree on this simple straightforward activity, how one can expect them to agree at later more complicated activities.

The affinity diagram can be improved by computer automation. Currently there are techniques available on the PC market which encourage participants involvement into this process and they can retain anonymity until the team consensus is reached.

Relations or Interrelationship Diagram

The Relations Diagram or Interrelationship Diagram is a visual representation used to determine the relationships between a given issue or a problem and the factors that may cause it. More specifically, it is used to map and analyse problems where causes of the problem have complex interrelationships. While still a creative tool it formulates the logical connections that the affinity diagram surfaces. In contrast to the Ishikawa diagram in which all causes of a problem are assumed to be hierarchically decomposable, the relations diagram promotes discovery of relationship among causes. In other words a single thing may influence two or more other things, a situation that cannot be easily shown in a fishbone diagram.

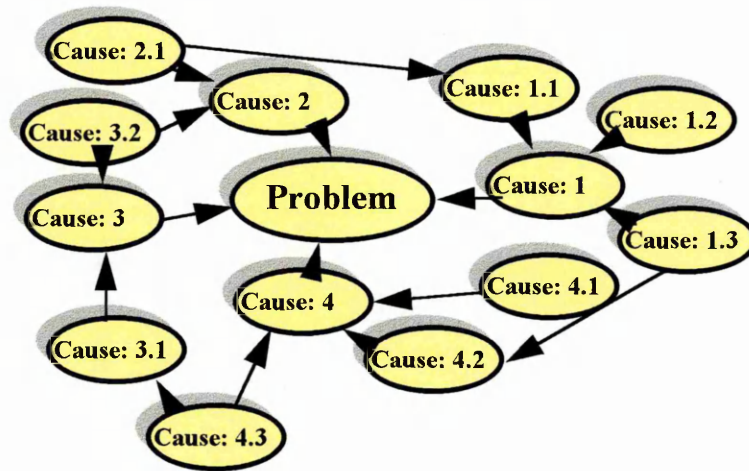


Figure A10

A typical Relations or Interrelationship Diagram

The relations Diagram is recommended when a problem or issue is complex and its root causes are difficult to determine. Figure A10 shows a typical relations diagram. Note that in this diagram key factors are allocated in order to map all possible relationships.

Systematic or Tree / Systems Diagram

Tree diagrams help teams or individuals think systematically about how to achieve a goal. Whilst the affinity diagram assists in identifying a problem, relations

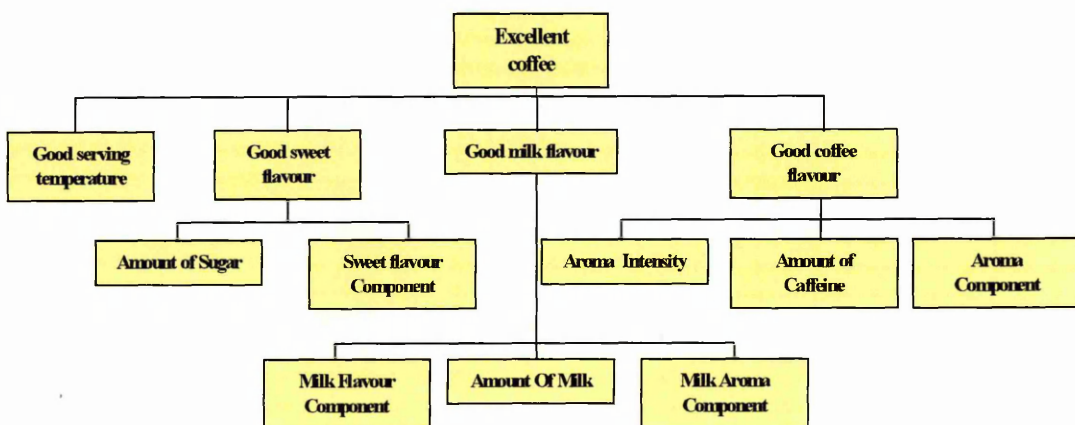


Figure A11

A general form of a tree diagram for an excellent cup of coffee

diagrams help to figure out what is related to a problem, tree diagrams organise

the aspects of the solution of the problem. It is used to detail the full range of paths and tasks that need to be accomplished in order to achieve a goal or a subgoal. Figure A11 shows a general form of a tree diagram for an excellent cup of coffee, note the structure for assisting in breaking a goal down into subgoals. Subgoals in this case can become sets of methods and plans which assist in achieving the subsequent goal. Another way to use the tree diagram is to decompose components or physical processes into their subparts. This type of hierarchy is sometimes known as a whole-part hierarchy, in reference to breaking the whole into its constituent parts.

Matrix Diagram

The Matrix Diagram emphasises multi-dimensional thinking, by analysing the relationships between two or more variables. Many of these relationships are between independent and dependent variables, i.e. cause and effect. It permits organisation of knowledge so that relationships between factors, causes, objectives, (or any thing that one wants to show) can be shown. In other words the Matrix Diagram helps in expediting the problem solving process and in clarifying problematic areas.

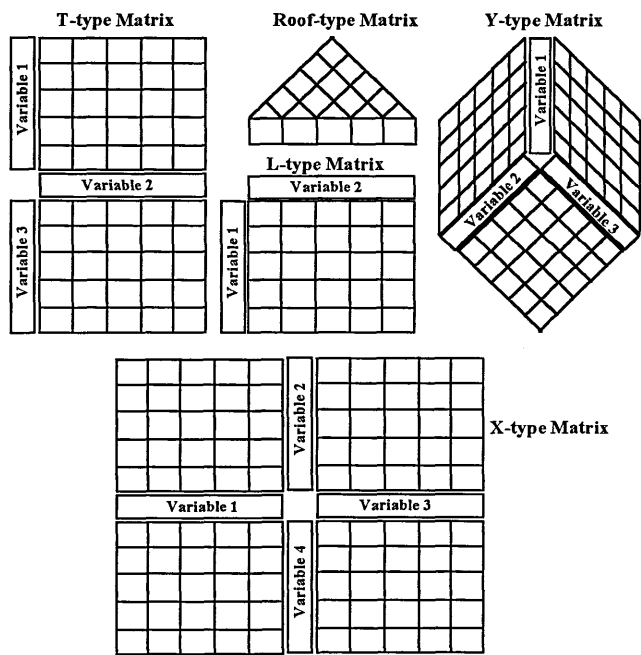


Figure A12
Several basic forms of matrix types

Obviously the QFD approach relies heavily on the use of matrices to record and propagate information. Matrices have rows and columns with intersecting cells that can be filled with information that describes the relation between the items located in the rows and columns. Several basic forms of matrix- related tools (Figure A12) have been developed including, an L-type matrix, a T-type matrix, Y-type matrices, X-type matrices, and roof type matrix. The L-type matrix is just a two dimensional table that places contrasting elements in the rows and columns of the matrix. The L term is used to describe the upside-down shape of the labels of the row and columns. The T-type matrix forms the labels in the form of a T adding

an additional matrix above the top of the matrix. X and Y-type matrices are simply composed of multiple L and T matrices. Finally the roof type matrix shows the relationship or degree of strength in correlation between the same type of elements or factors.

Process Decision Program Chart

The Process Decision Program Charts is used to map every event and contingency that can occur when progressing from a problem statement to its solution. It helps in the selection of the best processes to be used to accomplish a desired task. It is used where complex tasks are being implemented for the first time and the cost of failure is high. While the method has many variations, the most simple explanation is that it shows the possible tasks, sequences of a process and all of their relevant alternatives.

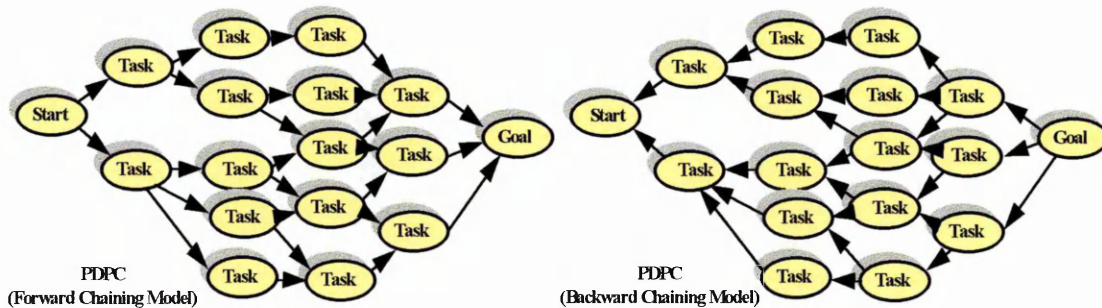


Figure A13

The two major ways to undertake the Process Decision Program Charts (PDPCs)

A PDPC recognises that all activities towards a goal or objective must deal with an uncertain environment. In other words it provides a low cost method of testing the process capability, because it is a simulated trial of expected tasks. It differs from the Tree Diagram because in the Tree Diagram the characteristics of an issue are deployed to its components from a top-down approach. PDPC starts from the lowest level of detail, normally the output of a Tree Diagram, following a bottom up approach by guessing the outcomes of an occurrence. Because of this potential it can be used as basis for another popular technique the FMEA (Failure Mode and Effects Analysis see end of appendix).

Figure A13 shows two major alternatives to undertake PDPCs, the forward planning and the backward planning. The forward planning method begins at the start node and works towards the goal node, attempting to select the best path as one moves forward. In contrast, backward planning starts at the end node and moves toward the start.

Arrow Diagram

Arrow diagrams or Critical Path Method (CPM) display information about the operation of a process by using arrows and nodes (junctions). It is used primarily in the process of planning and scheduling. It establishes the most suitable detailed plan to accomplish a task and monitors its progress. Moreover it permits an explicit visualisation of the bottleneck problems that will occur. The arrow diagram can be thought of as a way to understand the operation of a process using time, cost, or other metrics.

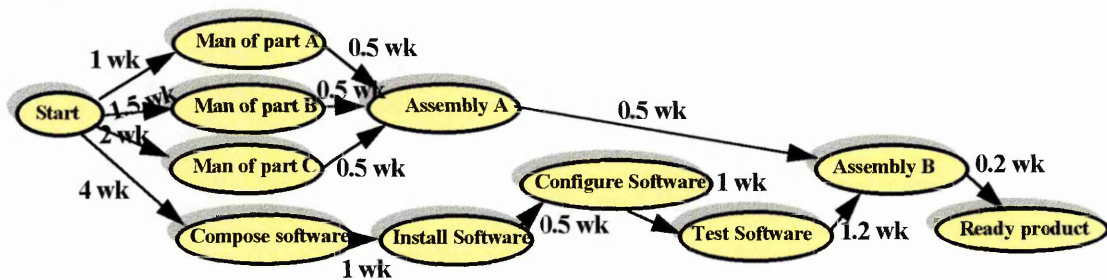


Figure A14

Arrow Diagram of the manufacturing process for a new product

Figure A14 displays a simplified process of creating a new product. In this very simple diagram, two paths are shown, the top path for creating the hardware component of the product and the bottom path, the software component. Each link (i.e., arrow) has a numerical label on it which designates the time required to proceed from one node to the next. As one may notice the time required for completing the initial software for this product is much longer than the time required for the hardware.

Taguchi Methods

For some time the manufacturing industries in Europe have worked on the basis of tolerance. This tends to suggest that a product would be perceived as acceptable if its quality was within the specified tolerance range (Figure A15). Obviously product design and development concepts make use of this tolerance basis. Dr. Genichi Taguchi's (Taguchi G., Elsayed E. and Hsiang T., 1989) response differs from this European philosophy. His methods are working on the principle that when designing a product it should be designed with minimum loss, that is the relative product being designed as close to the optimum value as is feasibly possible. Therefore the result would be a product designed and manufactured in regards to its life cycle and its customer satisfaction.

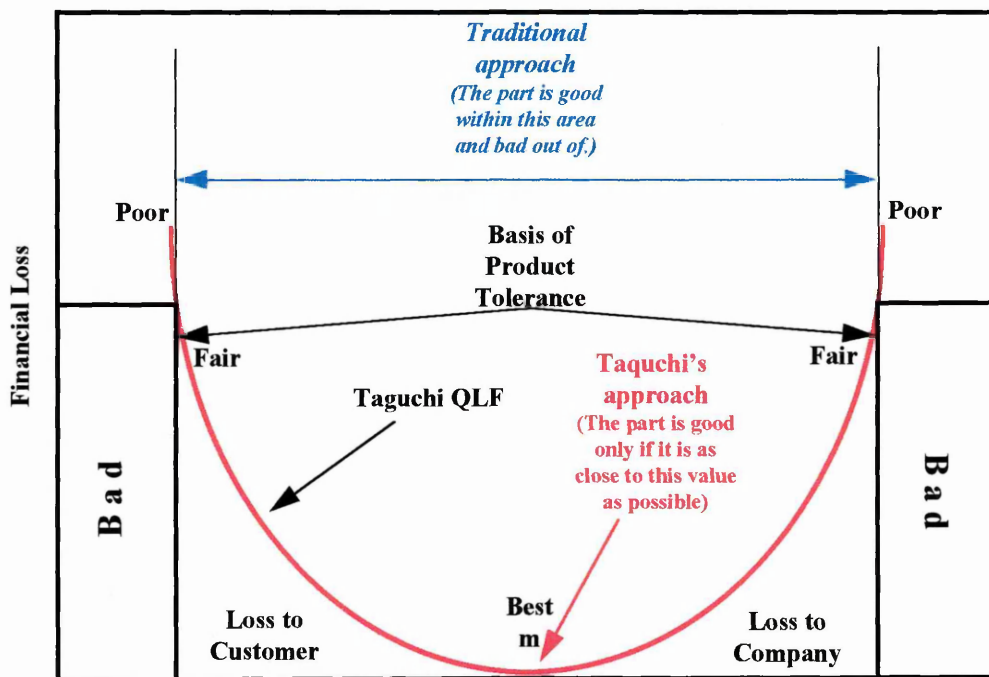


Figure A15

A target value defined in a product characteristic based on a tolerance range and on Taguchi's QLF (Quality Loss Function)

Taguchi defines quality in terms of a loss function which assesses the loss to society for not having a high quality product. Hence, the higher the quality of the product, the lower the loss. The basic idea is that variables which influence a product can be varied to determine the performance of the product in various

situations. It might be thought of as a statistical conceptional design. The Taguchi methods assess variation in a matrix formulation, which varies each significant variable around an operating point, keeping track of the products output for each variation captured in the matrix. While QFD can help in the identification of key product or process concerns with respect to the VOC, Taguchi methods can help identify what product or process relationships truly exist, their relative strengths and the nature of the relationship (Sriraman, Vedaraman, Tosirisuk, Phadhana, Chu, Hsing Wei, 1990). Therefore it can be said that Taguchi's methods are complementary in nature to the QFD methods (Ryan, N. ed, 1989) and (Ross P.J,1988). Moreover they can be used to desensitise the output of uncontrollable inputs, resulting to a reduced variation in the end product performance.

The Fundamental Taguchi Concepts

The definition of quality given by the Taguchi methodology is customer orientated. Taguchi defines quality in a negative manner - "Quality is the loss imparted to society from the time the product is shipped"(A.V. Feigenbaum, 1991). This "loss" would include the cost of customer dissatisfaction that leads to loss of company reputation. This differs greatly from the traditional producer-orientated definition which includes the cost of re-work, scrap, warranty and service costs as a measure of quality. The customer is the most important part of the process line, as quality products and services ensure the future return of the customer and hence improved reputation and increased market share. In general, there are four quality concepts devised by Taguchi :

- 1) **Quality should be designed into the product from the start, not by inspection and screening.** Quality improvements should occur during the design stages of a product or process, and continue through to the production phase. According to Taguchi, no amount of inspection can put quality back into a product; it merely treats the symptom. Quality concepts should therefore be developed by the philosophy of prevention ; problems are tackled at the source and not down stream. Taguchi emphasises that quality is something that is designed into a product, to make it robust and immune to the uncontrollable environmental factors in the manufacturing phase.

- 2) **Quality is best achieved by minimising the deviation from the target, not a failure to conform to specifications.** The product should be designed so that it is robust or immune to uncontrollable environmental factors - e.g. noise, temperature and humidity. This concept mainly deals with actual methods of effecting quality. Reducing variation is the key to improving quality. By specifying a target value for critical parameters, and ensuring the manufacturing meets the target value with little deviation, the quality may be greatly improved.
- 3) **Quality should not be based on the performance, features or characteristics of the product.** Adding features to a product is not a way of improving quality, but only of varying its price and the market it is aimed at. The performance and characteristics of a product, can be related to quality, but should not be the basis of quality. Instead, performance is a measure of product capability.
- 4) **The cost of quality should be measured as a function of product performance variation and the losses measured system-wide.** From given design parameters, the deviations from a target are measured in terms of the overall life cycle cost of the product. This includes costs or re-work, inspection, warranty servicing, returns and product replacement. It is these costs that provide some guidance as to which major parameters need controlling.

Taguchi Terms

In general the following terms are applicable to Taguchi Methods:

- ***Confirmation Experiment***

An experiment that is taking place under optimal conditions defined from previous experiment. As its term imposes it is used to verify experimental predictions.

- ***Linear Graph***

A graphical representation of the assignment of factors to specific columns of an orthogonal array. Each linear graph is associated with one orthogonal array. A given array though can have several linear graphs

- **Noise**

A quantified representation of the uncontrollable factors influencing product quality. In general there are three kinds of noise: *the external* (noise due to external causes i.e. vibration humidity.), *the internal* (noise due to internal causes i.e. material creep, deterioration wear.) and *the product to product* (noise due to part to part variation).

- **Orthogonal Array**

As mentioned in previous chapters a product should be designed based on a set of specifications demanded by the customer. Each specification can be quantified according to the VOC in order to finalise target values. As previously stated Taguchi's methods are focused to minimise variation around those target values. However employees design experiments using specially constructed tables known as Orthogonal Arrays in order to build product quality from the design phase. These are a special set of matrices containing a series of numbers. Each row in the matrix represents the state of the factors in a given experiment. Each column represents a specific factor or condition that can be changed in each different test. The results obtained from these arrays are then analysed in order to estimate the contribution of the individual quality influencing factors in the product design stage. Moreover these results will indicate the optimum conditions for a process and their approximate influence on the product design parameters.

- **Parameter design**

It is the second design stage where nominal values of critical dimensions and characteristics are established to optimise performance at low cost.

- **Signal to Noise (S/N) Ratio**

A quantified characteristic representing the influence of noise factors on the end product result. In other words it measures the stability a quality characteristic has and its performance when influenced by certain (noise) factors. The larger the S/N ratio the more robust the end product against noise factors.

- **Quality Loss Function (QLF)**

As previously stated Taguchi's definition for quality is "Quality is the loss imparted to society from the time the product is shipped" (A.V. Feigenbaum, 1991). However from this statement one can say that quality is related to monetary loss and not to any other factors or conditions. Even though the actual loss maybe the loss of functionality to the product, or other losses such as pollution, time, noise, etc., the

overall effect is a financial loss. It can also be expanded to include the development, and manufacturing phases of a product.

The conventional method of computing the cost of quality is based on the number of parts rejected and reworked. This method of quality evaluation is incapable of distinguishing between two samples, that are both within the specification limits, but with different distributions of targeted properties. Therefore Taguchi proposed a parabolic approximation of the quality loss that occurs when a given design parameter deviates from its target value (Figure A15). This parameter may be the critical dimension, colour of the product, surface finish or any other characteristics that contribute to the customer's conception of quality.

This quality loss takes the following basic quadratic form: $L(x) = k(x - m)^2$

Where L is the financial loss, m is the point at the which the characteristic should be set, x is where the characteristic is actually set, and k is a constant that depends on the magnitude of the characteristic and the monetary unit involved. This basic loss function is used if no other function based on data is available. However, when no market research data is available, the next best option is to use the quadratic loss function.

A case study example on Taguchi methods

In order to clarify the above description on Taguchi methods a case example is provided. Lets consider the once again coffee example. As mentioned before a number of factors affect the coffee product. Now lets consider that these factors could be: the coffee beans, the amount of coffee, and the amount of water. These factors can be perceived as the control factors for the coffee product. Obviously the purity of water is hard to control unless pure water is always used. However this can be perceived as a noise factor.

The application of Taguchi methods in this example would result in a low cost and good tasting coffee product for a variety of water types. However the process could be started with the parameter design, where control factors minimise the noise factor effects, (hence reduce variation) are selected (Figure A16). The goal is to find the combination of materials, processes and specifications that will lead to a stable and reliable performance in the coffee production at the lowest cost.

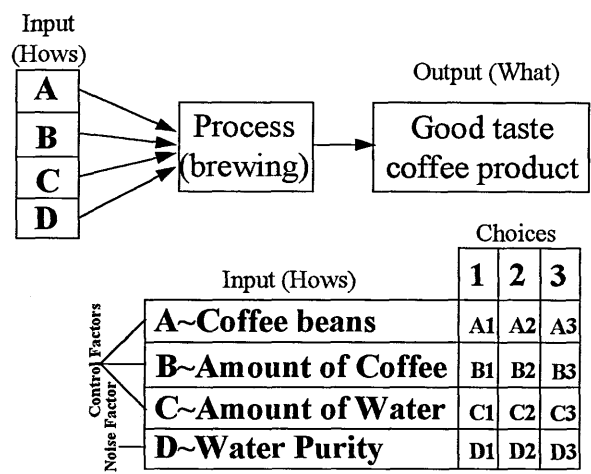


Figure A16

Taguchi Methods: Case example on a coffee product using parameter design

This can be accomplished by maximising the signal to noise ratio (S/N Ratio). As mentioned earlier S/N ratio measures the stability a quality characteristic has in its performance when influenced by certain factors. QLF is then used to evaluate the effect of that stability in monetary values.

Once the parameter design is over, confirmation experiments are recommended in order to verify the results. Taguchi methods utilise a form of experimental design employing orthogonal arrays and linear graphs. Linear graphs are used in order to assist different numbers of test settings to factors. The arrays then focus on an average effect that occurs as other conditions are changed. The level of each factor in the orthogonal arrays occurs the same number of times (Figure A17). This minimises the number of required experimental runs and ensures reproducibility of results.

Test Run No	A=Coffee Bean	B=Amount of Coffee	C=Amount of Water	D=Water Purity (Noise factor)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Figure A17

Taguchi Methods: Case example on a coffee product using Orthogonal Array

Failure Mode Effect Analysis “FMEA”

Failure Mode and Effect Analysis (FMEA) is a structured approach to improving the design, manufacturing, assembly and service of a product (Figure A18). It is a technique where all possible failures in a system design are documented. FMEA's are utilised primarily as a means to consider assure and address potential failure modes and their associated causes/mechanisms in the design process. As the mission and design requirements are becoming more specific the FMEA can consecutively expand to greater level of detail. Arguably FMEA's are performed intuitively by the experienced and good engineers without using a structured approach. However today's products are so complex, and their parts and systems so inter-related that an unstructured approach to failure analysis is no longer adequate. The reason is that some items may not be detected until tests are underway or manufacturing and assembly has started, and sometimes even worse after the product is in the field. Therefore the result will be a costly rework of prototype parts, recalls and more important a commercial embarrassment.

Product Customer		Part No. Issue Date	Design Failure Mode & Effect Analysis Design Engineer Industrial Engineer Quality Engineer Purchase Existing Conditions					Occurrence Severity Detection Ro Rs Rd			LEVEL 1 - COMPONENTS Resulting Conditions		
Part Name/No.	Function	Failure Mode	Effect(s) of Failure	Cause of Failure	Current Controls	R _o	R _s	R _d	RPN	Recom Action	Action Taken	RPN	
RETENTION PLATE	RETAIN SLATCH TOODON	STRIPPED THREADS		INCORRECT THREAD FORM SPECIFIED WATERPUMP TOO BRITTLE/TOFT	STRENGTH TESTING AT 10 PREVIOUS EXPERIENCE WITH SAME THICKNESS MATERIAL	1	4	2	8	STRENGTH TESTS			

Figure A18

A typical FMEA Failure Mode and Effect Analysis Chart

Obviously on consideration of the previous facts one may realise the importance of a structured and disciplined approach such as FMEA's. However FMEA's prevents (given that proper steps are followed) all the potential failure modes, by the identification and quantification in the seriousness in their occurrence. A typical FMEA study can be described through the following steps:

- Definition of the products mission/function and expected performance.
- Construction of Block Diagrams; these may be functional, reliable, flow diagrams and they are enhancing the traceability through all the levels of detail.
- Identification of all potential items and interface failures and their consequences. This is identified in two stages; the FMA (Failure Mode Analysis) and the FEA (Failure Effects Analysis).

FMA identifies the predictable failure modes for each level of the system and FEA examines the consequence of each assumed failure mode.

Finally upon completion of the analysis a risk priority number (RPN) can be identified. That is a number which is formulated from the rating of the likely occurrence, severity and detection of a potential failure mode. Hence the RPN number is: $RPN = R_o R_s R_d$

Where R_o is the risk of occurrence, R_s is its likely severity and R_d is the chance of detection.(Figure A18)