TOTAL QUALITY DESIGN [TQD]: ENGINEERS DESIGN WITH TOTAL QUALITY APPROACH

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ABSTRACT

Three important functions of an engineer are designing, making, and maintaining. Designing is the most important function among these three functions. It is said that one mistake in design may cause 10 fold problems while making, and 100 fold problems in maintenance. The way to avoid this is through the Total Quality approach in designing. This calls for designing a product, system or services by adopting a strategy of economically satisfying customers. Here, "customers" are both internal as well as external customers. "Satisfying" transcends beyond the static satisfaction level of the customer. It is at the level of "delighting" the customer, or even higher – at the "astonishing level". This is explained by the concepts of "time value of quality", "must be quality" and "attractive quality". "Economically" means adding attractive quality features in the product or service without making it costly by adopting the principle that quality is free. Total Quality Design is a new product development strategy of Total Quality Management (TQM) which, if adopted while designing, becomes very significant in building a sustainable system that benefits the whole society.
[Key words: Total Quality Management, Internal & External customers, Must-be-quality and Attractive quality, Time value of quality, Quality-cost relationship, Total quality design]

There are two actual creators in this universe – the almighty God and the engineers. God created this world with natural bounty such as the snowy mountains, hills, plain lands and oceans, and wonderful creatures like human beings, wildlife, butterflies and flies. On the other hand, engineers have created the great pyramid, the beautiful Taj Mahal, moving vehicles, airplanes, space satellite, war heads, nuclear bombs, electricity, telephones, mobile communications, television and computers. God created the nature, and engineers are exploring the natural science to use the knowledge to create products and services which are useful to mankind. Here, the word *"useful"* is worth noting – it is directed towards the society. Engineers work to create products for the society at large. Thus, we can say that all engineers are devoted to work for the society by designing, making[1] and maintaining the creation.

This paper attempts to redefine some terms such as quality, customers, needs of the customers, while discussing a new dimension of engineering that an engineer should adopt, and one that has the potentiality to address the societal needs. This is what I refer to as Total Quality Design.

Redefining Quality

As an engineer, we define quality as *"conformance to specification"*. If a product[2] satisfies the specifications spelled out in its design, then we say that the product is of good quality. While inspecting the product using 100% or sampling inspection plan, a quality inspector either rejects the product if it does not conform to its specification or approves it if it conforms to specification. This is a traditional way of looking at quality.

[1] In this paper, m*aking* is taken as a generic term for constructing, fabricating, assembling, operating, etc.
[2] In this paper, *product* means product as well as service

However, this raises the question – from whose perspective should quality be understood. The user's or the producer's?

Juran[3] probably was the first to define quality differently. According to him, quality is *"Fitness for use"*. This definition is from the perspective of users. Other quality gurus tried to further elaborate this perspective. Deming[4] described quality as *a predictable degree of uniformity and dependability, at low cost, and suited to the market.* To Crosby[5], quality is *"conformance to requirements"*. This is different from the original definition of "*conformance to specification*". This is more elaborative than what Juran and Deming said earlier. A product may be fit for use, but it does not qualify as good quality if it does not fulfill the requirements of the user. For example, a dress that fits quite well on a lady does not necessarily mean that she will be satisfied with its design. She will probably look for more appealing design to purchase. According to Crosby, quality should be fit for use as well as be able to fulfill the requirements or the needs of the users. In other words, a product can be said of good quality if it satisfies the stated and implied needs of the user.

Out of the three specific jobs of an engineer, that is, designing, making and maintaining, designing as the first process plays the most important role in servicing the users. One mistake in designing will give rise to 10-fold problems in the process of making and 100-fold problems during maintenance. Proper design assumes a prime role in controlling the source of problems and providing quality products to the users. A design engineer should, therefore, carefully and precisely understand the stated as well as implied needs of the users before actually designing the product.

Engineers experience many frustrating situations. One of my architect friends narrated me one such experience which probably many of us can relate to. According to him, he goes through a lot of trouble to understand the owners' view before designing the houses, but after preparing the comprehensive designs, 90% of the owners change them during construction. This is indeed quite frustrating for an engineer who has spent a lot of time and effort in designing. This is a common phenomenon in the construction sector whether they be in building, water supply, dams, irrigation, roads, bridges, or in the manufacturing sector or in utility services like electricity supply, telecommunication, etc. Design engineers design but somehow it does not satisfy the users.

It is worth citing an example to understand the problems generally felt by design engineers. During the late 1970s and early 1980s, Nigro[6] administered hundreds of U.S. navy construction contracts designed by civil engineering firms. He found that half of the thousands of negotiated change orders were due to coordination errors that could have been avoided during design phase. Some of the errors were as follows:

- *Civil site plans that have underground utilities (such as water line, sewerage, storm lines) interfering with locations of electrical substations, power poles, or underground conduit, duct banks, or storage tanks.*
- *Landscape drawings with trees in the same locations as sewer lines, or in the middle of drainage swales shown on civil drawings.*
- *Structural drawings with column locations and grid lines that conflict with architectural locations.*

[3] Joseph. M. Juran's *Planning for Quality*, Free Press
[4] Dr. Edward Deming's *Out of the crisis*, MIT Press
[5] Philip Crosby's *Quality without tears*, McGraw Hill
[6] A report by consultant William T.Nigro, AIA, REDICHECK *Interdisciplinary Coordination*, The REDICHECK Firm, Peachtree City, GA 30269. Copyright © 1987

- *Architectural floor plans that do not match other discipline floor plans.*
- *Plumbing drawings with riser diagrams that do not match plumbing fixtures on architectural floor plans.*
- *Mechanical drawings that read "see structural drawings for additional roof supports" while structural drawings do not indicate such supports.*
- *Electrical drawings that indicate items of equipment with horsepower ratings, voltages, and phases different from those shown on mechanical drawings and/or in specifications.*
- *Specification sections referring to other sections that do not exist or that asks to install something "as indicated" or "where indicated" when there is no indication of the item on the contract drawings.*

Even without any empirical research, we know that such design problems definitely exist in different construction contracts in our country too. Some research is required to make engineers as well as the public aware of the extent the society is paying for such design problems.

The Total Quality Management approach can help minimize these problems. Total Quality school defines quality as *economically satisfying customers*.[7] The three words in this definition – customers, satisfaction and economy – are very important to understand the quality concept.

Identifying Customers

Who are customers of engineers, or more specifically, design engineers? Who uses the outputs of design engineers? It is necessary to identify them so that engineers can try to satisfy them. Traditionally, a customer is seen as one who pays for the service or the product he/she receives.

Let us take a simple example. A mother buys a toy for her child. Who is the customer – the mother or the child? The child uses the toy while the mother pays for it. Both the mother and the child should be satisfied. Obviously, both of them are customers. The analogy may be extended further to understand the relationship between an engineer and his/her customers. The engineer designs a toy which is manufactured in a factory. The manufactured product, i.e., the toy is distributed to the departmental store where the mother comes and purchases it for her child. Now, the question arises – whom does the design engineer need to satisfy? Who are the users of his design? First, the manufacturer uses his design. So the manufacturing company should be satisfied. There should not be any problem for the manufacturer to produce the designed toy. Secondly, the distributor distributes the toy to various shops and departmental stores. The distributing company should be satisfied, and not face any problems. Thirdly, the departmental store has to maintain some stock of the toy as well as showcase it to attract customers. The store should be satisfied. In the end, the mother buys the toy which the child uses. Thus, in the sequence of processes, each should be able to satisfy the requirement of the user without having to face any problem. For the design engineer who designs the toy, the customers are all the players in the process, i.e., the manufacturing company, the distributing company, the departmental store, the mother and the child. The design has to satisfy all of them. If one is dissatisfied, the process will not be completed successfully.

[7] Hitoshi Kume, *Management by Quality*, 3 A Corporation, Tokyo, 1995

"Next process is customer" is one important concept of the school of Total Quality.[8] It defines two types of customers – internal and external. Internal customers are the stages identified during the process of reaching to the end users. The end users are the external customers. Some times there is confusion about whom to satisfy – the internal customers or the external customers. Obviously, we have to satisfy both. Otherwise the total process will not be successful.

Taking this Total Quality concept, let us re-examine and identify the customers of a solid waste management (SWM) system. Figure 1 depicts a simple schematic process of SWM system.

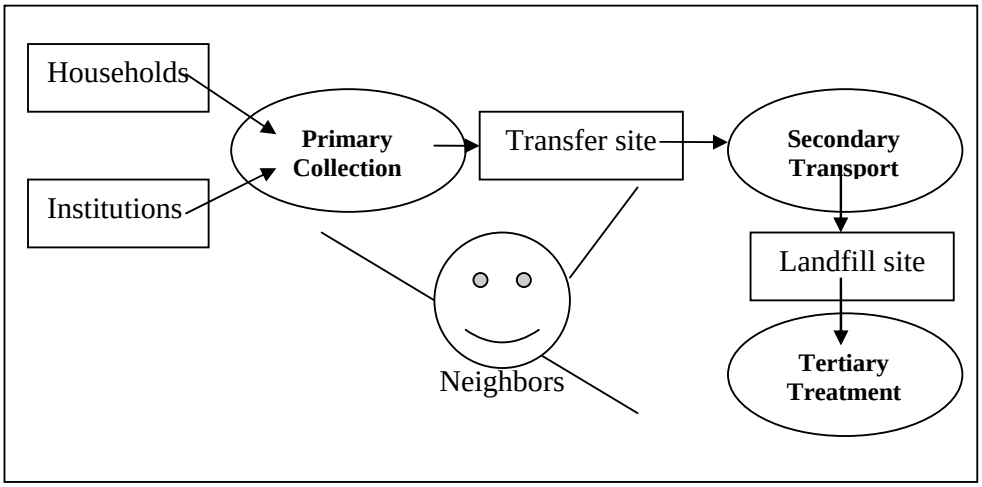

Figure 1: Solid Waste Management System

Looking at the process itself, one can identify the customers of different processes or actors involved in the system. The concern is how an engineer can design a system that satisfies all customers related to the system, namely the internal customers who are within the process and the external customers who are the ultimate beneficiaries of the system.

Main Process or actors	**Customers**
Households	Primary collection system, neighbors
Institutions	Primary collection system, neighbors
Primary collection	Households, institutions, transfer site, human and vehicular traffic
Transfer site management	Neighbors, secondary transport system
Secondary transport	Landfill site, human and vehicular traffic
Landfill site management	Tertiary treatment system, neighbors
Tertiary treatment	Neighbors, aquatic lives

Table 1: The SWM Process and its customers

[8] For more explanation on this issue refer to an article *"UNDERSTANDING CUSTOMRS: The TQM Way"* by Dinesh P. Chapagain published in Business Vision, Kathmandu University School of Management, 2000

In this system, the external customers are the urban households for whom the SWM system is designed. However, there are a number of internal customers within the system whom the design engineer should take into consideration to make a successful and sustainable system.

Understanding Satisfaction Level

Human beings, by nature, are selfish and ambitious creatures. It is difficult to satisfy a person, and even more to satisfy him/her every time. The first time we receive an unusual and pleasant service, we become quite happy. Once we start getting the same service repeatedly, its charm starts eroding, and then we begin to want something more. Human beings are thus an insatiable creation of the God. They are never satisfied. This prime reason has led engineers to strive for and bring about continuous development in the world. The following experiences allude to this perpetual endeavor to enhance our satisfaction.

- We were so excited to have black and white television in the 50's. Then came the colour TV. After that remote controlled TV entered our room. Today, we have TVs in which numerous channels can be viewed. Today there are multi-system multi-function and multi-featured TVs in the market.
- We were excited to get a real photograph with a simple camera in the 20's. Then flash, an artificial light, was added to have control over natural light. After that came the auto focus camera. Then came a light single unit camera having auto focus and auto flash. Now digital camera has come to the market.
- We were excited to have a telephone to talk to someone from one place to another in the early 20th century. Then came the cordless phone, and then the mobile phone which can be used globally. Now mobile phone with picture has come in the market and enables us to talk and view our nearest and dearest ones staying on the other side of the globe.

The list can go on and on. There are millions of such examples in products and services where new features are constantly being added to astonish the never satisfying instinct of human beings.

The traditional definitions of quality such as conformance to specification, fitness for use, and conformance to requirements simply looks at quality in a very straight forward manner, that is, as customer satisfaction. However, today's satisfied customer may not be satisfied tomorrow. So, simply satisfying is not enough. We have to strive hard to delight the customer or even astonish the customer and that, too, continuously.

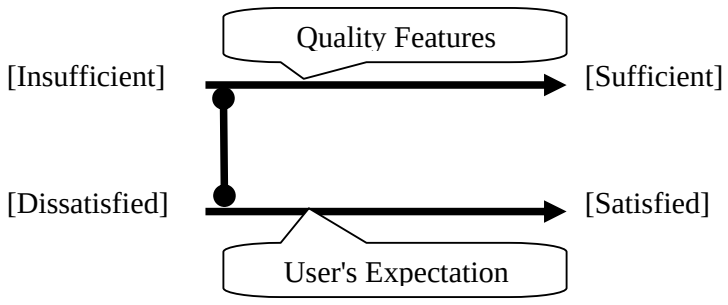

Figure 2: One-dimensional Quality Model

For this, a continuous improvement in quality is necessary. A model shown in Figure 2 explains quality in a dynamic situation. This one dimensional quality model states that if we can continuously improve the quality features of our products or services, the satisfaction level of the users will also increase. This means, the expectation of the users that is related to the satisfaction level of the customers is directly proportional to the sufficient quality features of the products or services. A simple linear relationship between a satisfied customer's expectation vis-à-vis improvements in quality features of the product exists.

Prof. Noriaki Kano[9] gave a new insight to the satisfaction level of a customer and quality. He introduced a two-dimensional model to conceptualize the term quality. The linear relationship between quality features and customers expectation (shown in Figure 2) can be plotted in a two-dimensional model. See Figure 3.

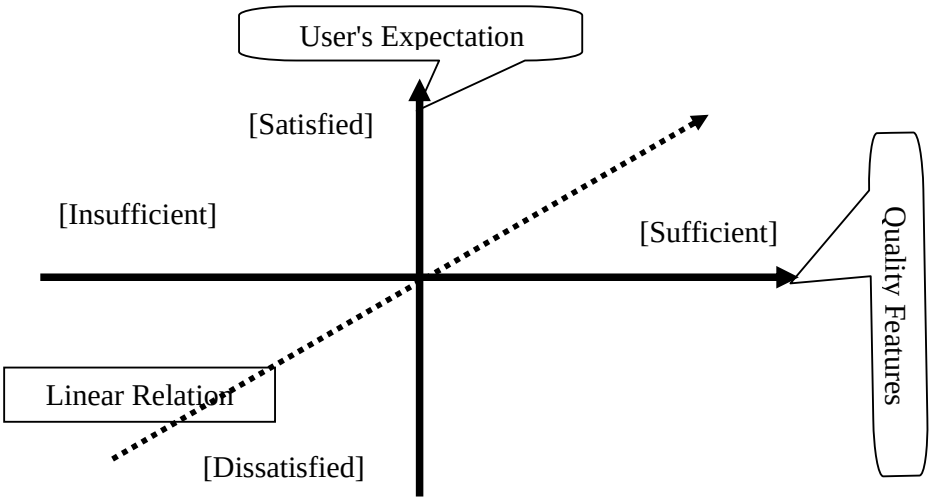

Figure 3: Two-dimensional Quality Model of Linear Relationship

Kano says that this simple understanding of linear relationship between user expectation and quality features does not really reflect the actual situation. He introduced two additional quality states which are very integral to any service or product. These are:

- ♥ Must-be-quality, and
- ♥ Attractive or creative quality

Must-be-quality is a state of products or services which is essential for customers' usage, and customers pay for this quality because they really need it. Television producing pictures and sound, cameras which can produce photographs, flight connections which transmit passengers from one place to another are all examples of must-be-quality. Nobody will buy a television which cannot produce a good quality picture and sound, and nobody will buy a camera which can not create a good quality photograph, even if they are available at very low prices. Similarly, nobody would like to pay for water supply if it does not supply required amount of water. These are only some examples of the must-be-quality state.

[9] Prof. Noriaki Kano's seminar on Total Quality Management at Hotel Blue Star Katmandu in 1999

Kano explains this level of customer satisfaction as the relationship of customer's expectation and quality features in the state of must-be-quality of any products in the two-dimensional model as shown in Figure 4.

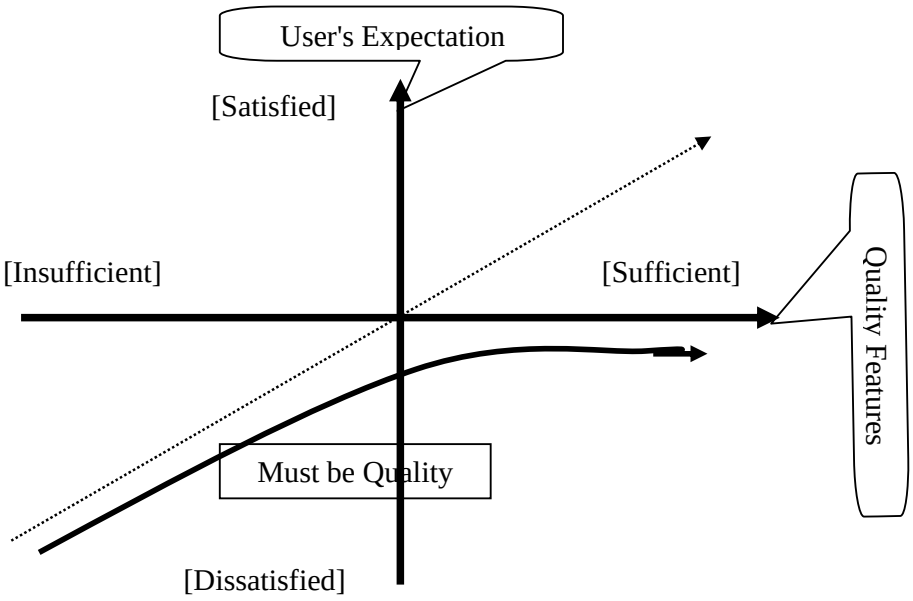

Figure 4: Two-dimensional Quality Model of Must-be-quality State

If the producer concentrates only on the must-be-quality state, with increased quality features, customers' satisfaction will also increase. However, the level of satisfaction of customers will at the most be equal to their expectation. Prof. Kano explains another concept of quality, termed as attractive or creative quality, which is necessary to increase the level of satisfaction of the customers continuously. Attractive quality is a state in which the customers will be attracted towards the product and be willing to pay more or give more value for their satisfaction.

If a designer improves the quality by adding some special features in a product, customers tend to be attracted towards it. A good picture television with remote control, a camera with flash and auto focus facilities, smooth and swift flight connection are examples of attractive quality. Generally, the customers cannot perceive before hand what will excite them or the features of attractive quality that will excite them to pay more. A design engineer has to be creative, be able to identify such attractive features and offer them proactively. In other words, customers do not realize what their expectations are before the engineers offer them the special and attractive features. Kano explains this level of customer satisfaction and its relationships in a two-dimensional model as shown in Figure 5. He explains the satisfaction levels of the customer as the relationship of customer's expectation and quality features at the linear-related quality, must-be quality and attractive quality state.[10]

[10] For detail explanation refer to an article "*Adopt Kano's Two-dimensional Quality Model and Improve Productivity"* published in Productivity and Development, National Productivity and Economic Development Centre, 2000

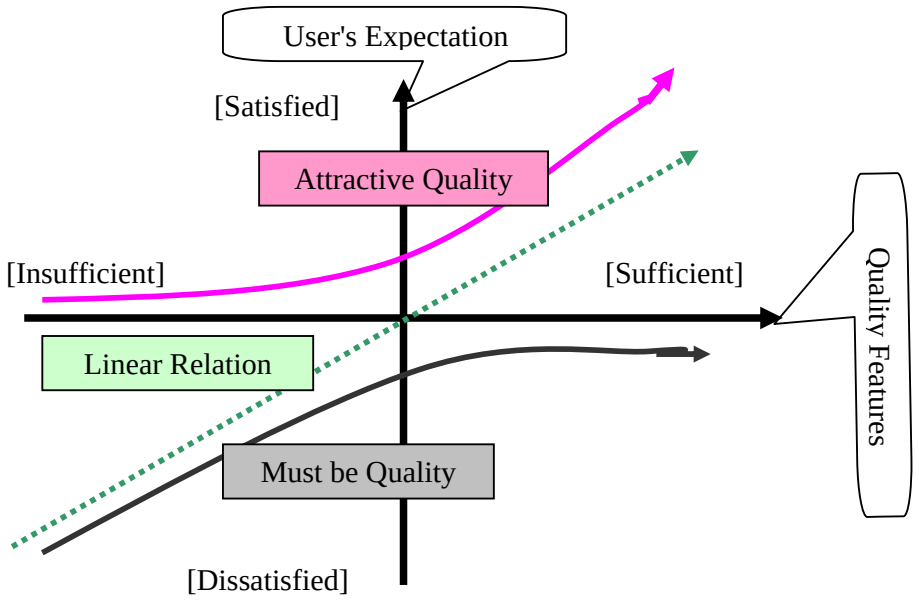

Figure 5: Kano's Two-dimensional Quality Model

Customers are excited at every invention of technology. But if the designer cannot integrate these technologies with the motive of exciting customers by creating attractive quality they will always lose. It will then be difficult to make and maintain a sustainable product. Customers satisfied today by a product will not be satisfied tomorrow by the same product. Customers demand more and more as time passes. In Total Quality concept, this is termed as "*Time Value of Quality (TVQ)*".[11]

Designing and Producing Economically

Most people believe that improving quality of product would entail increase in cost. Engineers, therefore, tend to take precautionary measures not to add any quality features. It is a popular misconception that if more quality features added to a product, customers will not like it as it will make the product costlier. Uneconomic products will definitely not attract customers. The Total Quality emphasizes on designing and producing economical products. No doubt, the traditional thinking about the relationship between cost and quality has a direct allusion to increased quality as increased cost.

The Total Quality school defines the relationship other way round. According to this, as quality increases, cost decreases, making the relationship between them inverse. Let us take an example to illustrate this. In recent times, many quality features have been regularly added in electronic products like computer, television, mobile telephone, and so on. However, the cost of production is reported to be decreasing sharply. In 1970s, when Philip Crosby[12], the living charismatic quality guru, wrote a book entitled *Quality is Free*, a huge hue and cry was raised by quality professionals and engineers. Presently, this book is rated as one of the best selling books among quality professionals although many are

[11] Dinesh P. Chapagain's paper "*Astonish Customers Always by understanding the Time Value of Quality Concept*" in the Third International Quality Control Convention, Mauritius, 2000.
[12] Philip Crosby's best selling books "*Quality is Free*" and "*Quality without Tears*"

not yet convinced with this notion. We have to look at the cost of quality in two stages – quality of design and quality of conformance.

At the time of design, with value analysis and value engineering techniques integrating with customer's needs assessment, the engineer identifies the primary functions and secondary functions in a product. The primary function serves the main purpose of the product and which is a quality that customers will demand and appreciate. The secondary function simply supports the primary function. To understand these two functions, let us take an example of a pair of spectacles. The glasses are for the primary function of the spectacles, whereas the spectacle frame serves the secondary function. The designer concentrates on the primary function, improves its features and tries to reduce the involvement of secondary functions. If an engineer adopts this philosophy of quality with focus on the customer perspective, then with increased quality, the cost will decrease.

A very good example of this is the modern cars that Japanese are producing. Earlier, the German, American, Swedish and other European car makers used to manufacture long lasting robust cars because the body itself was designed to be strong. However, the body of a car only has a secondary function. Car owners relate the model of cars as fashion and prefer new models. Although western cars are considered to be good quality due to their robustness, customers started rejecting them. They did not like to stick to a car for life long. Rather they preferred to change to good looking ones according to their aesthetic mood. The Japanese, who entered the automobile industry quite later, understood this desire of car owners and designed, made and marketed economic and customer-friendly cars. Designing carefully by concentrating on the primary functions and eliminating unnecessary secondary functions reduce costs significantly. The Total Quality approach postulates this inverse quality-cost relationship.

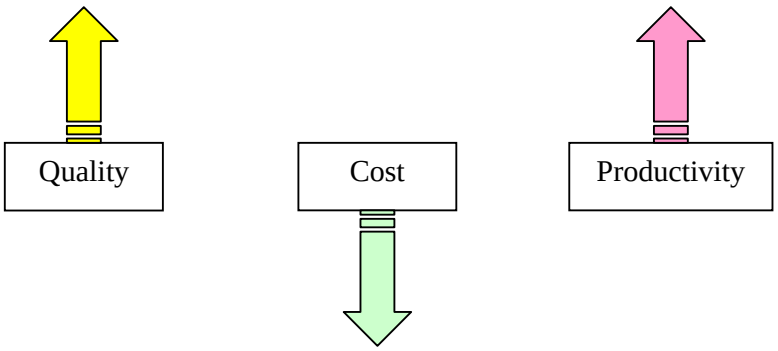

Figure 6: Quality, Cost and Productivity Relationship

Quality increases and the cost decreases also at the making stage or at the quality of conformance stage. This is illustrated by the simple fact that when defect rate at the making stage decreases, or rework, scrap and rejection decreases, the cost also automatically decreases. The product becomes more economical. Quality improvement at this stage means improving productivity and so customers can get a product economically. *Refer Figure 6.*

Thus, at both stages, i.e., the quality of design stage or the quality of conformance stage, as the quality of a product increases the cost of the product decreases. The productivity also invariably increases. This is the Total Quality philosophy.

Total Quality Design

The key phrase of the Total Quality Management (TQM) is *economically satisfying customers*. A design engineer whose design quality is the determinant of major qualification requirement in serving the society, should be very careful in developing concepts and designing the product.

This holds true in all engineering fields. Civil engineers, water resource engineers, architects, irrigation engineers, environmental engineers, transport engineers and others who design various types of public and private utilities like water supply systems, buildings, dams, irrigation systems, roads and bridges for governmental or societal use are responsible for developing these sustainable public utility products. Mechanical engineers, industrial engineers, food engineers, aeronautical engineers, automobile engineers, chemical engineers and others who design various types of institutional and consumer products like machines, packed foods, paper and paper products, cement and cement products, chemicals, airplanes, automobiles, electronic products for private, public or institutional use are responsible for developing sustainable industrial markets. Electrical engineers, electronics engineers, computer engineers, system engineers who design various types of utility, hardware, software products and services for public and private consumers and institutions are responsible for developing sustainable and reliable products and utilities. If engineers whose major function is designing adopt the Total Quality Management approach of economically satisfying customers, their products will be highly sustainable. This is the underlying concept of Total Quality Design.

Total Quality Design requires engineers to follow the following procedures to design their products before applying their specialized engineering techniques and tools.

- **Identify customers:** After identifying the whole process from initial suppliers to final customers with input-output systems, prepare a customer network and customer mapping. This way, all internal customers and external customers will be identified.
- **Identify customer satisfaction level:** Conduct customer survey to identify the must-be-quality and attractive quality states of all identified customers – internal as well as external. Before designing a product it is necessary to understand the time value of quality of the product for both types of customers.
- **Identify the primary and secondary functions of the product:** Before using the technical procedure for designing the product conduct value analysis and other similar techniques to understand the primary creative quality features that should be incorporated in the design, and identify the supporting secondary functions which can be reduced in the product. This will assist in designing an economical product.
- **Design the product:** After mapping the internal and external customers, and understanding each customer's attractive quality states and identifying the primary and secondary functions of the product, initiate the engineering design. This will help in developing a product which will economically satisfy customers. The customers are of course the society who uses these products.