Beyond Taguchi's Concept of the Quality Loss Function

Atul Dev, Pankaj Jha

Abstract—Dr. Genichi Taguchi looked at quality in a broader term and gave an excellent definition of quality in terms of loss to society. However the scope of this definition is limited to the losses imparted by a poor quality product to the customer only and are considered during the useful life of the product and further in a certain situation this loss can even be zero. In this paper, it has been proposed that the scope of quality of a product shall be further enhanced by considering the losses imparted by a poor quality product to society at large, due to associated environmental and safety related factors, over the complete life cycle of the product. Moreover, though these losses can be further minimized with the use of techno-safety interventions, the net losses to society however can never be made zero. This paper proposes an entirely new approach towards defining product quality and is based on Taguchi's definition of quality.

Keywords—Existing concept, goal post philosophy, life cycle, proposed concept, quality loss function.

I. Introduction

IN the present day era of competitive manufacturing, quality has become the basic qualifier. Over time, different quality gurus have given different definitions of quality; the scope of quality has moved from just conformance of specification and customer satisfaction to broader terms like delighting all stakeholders and sustainable development. In this scenario, Dr Genichi Taguchi's definition of quality appears to be the most appropriate one, which states that if a quality characteristic deviates from the target value, it results in losses to the customer. Taguchi has limited these losses to the monetary losses only which a customer may have to incur in terms of the repair of a poor quality product [1]. He gave a mathematical equation to quantify these losses. His definition of quality is one of the most comprehensive, as it aims far beyond the traditional concept of conformance to specifications. But one of the main limitations of Taguchi's approach is that his concept of loss to society is limited only to the useful life cycle of the product [2], [3]. In view of ever growing concern for the environment and safety, as well as continually emerging technological capabilities, the same concept of quality, as advocated by Taguchi, can be further enhanced and improvised.

Atul Dev is with the Defence Electronics Applications Laboratory (DEAL), Defence Research and Development Organisation (DRDO), Govt of India, Dehradun-248001, India (phone: 91-135-2781426 (O), 91-135-2788788 (R), 91-9837022246 (M), fax: 91-135-2787265, e-mail: atuldevji@yahoo.co.uk).

Pankaj Jha, is with the Department of Management Studies, Graphic Era University, Dehradun-248001, India. At present he is on deputation at Department of Statistics, College of Computing and Informatics, Haramaya University, Harar, Ethiopia (e-mail: pankajkjha75@gmail.com).

II. Existing Concept of Taguchi Loss Function

Genichi Taguchi devised the concept of Quality Loss Function which states that whenever there is a deviation of a product dimension with reference to the nominal value i.e. the design value, there is some associated loss of quality of the product and this loss of quality is basically a loss to society. Societal losses include failure to meet customer requirements, failure to meet ideal performance and harmful side effects. Taguchi has defined quality as the loss imparted to society from the time a product is shipped [5]. As per this concept, to minimize the losses to society, irrespective of allowable design tolerances, manufactured dimensions should be as close to the nominal dimensions as possible.

As per the conventional philosophy, or say American philosophy, advocated by Crosby [6], loss due to poor quality is depicted by Fig. 1 [4], [7].
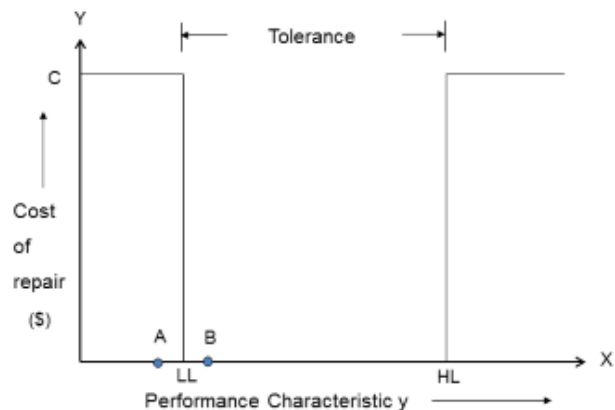

Fig. 1 Loss to the customer as per Goal Post Philosophy

As depicted in Fig. 1, performance characteristic y has been plotted on the X-axis, on which LL represents a lower specification limit and HL represents a higher specification limit and the gap between LL and HL represents the tolerance given by the designer on the performance characteristic. Associated losses due to the poor quality of the product have been plotted on Y-axis. Now, consider a situation where the value of performance characteristic y is within specification, say it is at point B on X-axis, the associated loss is $0, and when it is outside the lower specification limit (LL), say at point A, the associated loss is $C. In this case, though the difference between the values of performance characteristic y at point A and point B is marginal, the difference between their associated losses however is quite significant. This concept of quality is also known as 'Goal Post Philosophy',

since this concept has a similarity with respect to the goal scored in the game of football or hockey, where a goal is counted one irrespective of the location of the ball hitting the goal-post. Crosby supports the position that a product made according to the print, within permitted tolerance, is of high quality [6], [7]. In contrast to this, Taguchi proposed that loss occurs as soon as the performance characteristic y departs from the target value m, which is the center value of allowable tolerance given on nominal value by designer. This revolutionary concept of quality, given by Taguchi, is depicted graphically in Fig. 2. This concept was in total contrast with the traditional 'Goal Post Philosophy' concept. As shown in Fig. 2, if the value of performance characteristic y is nearer to the target value m, say it is at B', the corresponding loss is $B; whereas if the value of performance characteristic is away from the target value m, say it is at A', the corresponding loss is $A, which is far more than $B. As per this concept, the farther the performance characteristic (y) is from the target value (m), the more it will be the associated losses and these losses increase with the increasing rate.

Taguchi measured quality as the variation from the target value of a design specification and then translated that variation into an economic 'loss function' that expresses the cost of variation in monetary terms. The economic loss applies to both goods and services. Taguchi assumed that losses can be approximated by a quadratic function so that larger deviations from target cause increasingly larger losses [8].

Taguchi further emphasized that, though it is the responsibility of the manufacturer to maintain performance of characteristic (y) as close as possible to the target value (m), yet the associated variability with the performance characteristic can be minimized by choosing the correct value of input parameters. Here, one thing may be noted that the losses are zero if the value of performance characteristic (y) is exactly same as of the target value (m). The loss to society is composed of the costs incurred in the production process as well as the costs encountered during use by the customer (repair, lost business etc.) [7].

Quality characteristic can have three types of forms, which are lower-is-better, higher-is-better and nominal-is-best. Fig. 2 describes the Taguchi's concept of quality loss function for the nominal-is-best kind of situation.

If m is the target value, i.e. centre of upper specification limit and lower specification limit and y is the achieved value of the performance characteristic then as per Taguchi's Quality Loss Function, loss will be proportional to the square of difference between 'achieved value' and 'target value'. This can be written as (1) [5], [7]:

$$L = k\,(y - m)^2 \qquad (1)$$

Here, L = Cost incurred by the customer as quality feature i.e. performance characteristic deviates from the target, y = Achieved value of performance characteristic, m = Target value given by designer, k = Quality loss coefficient, which depends upon the repair cost and the width of the specifications.

It can be noted here that the imparted losses would be zero if the value of performance characteristic y is same as of the target value m. From (1) L = 0, if y = m.
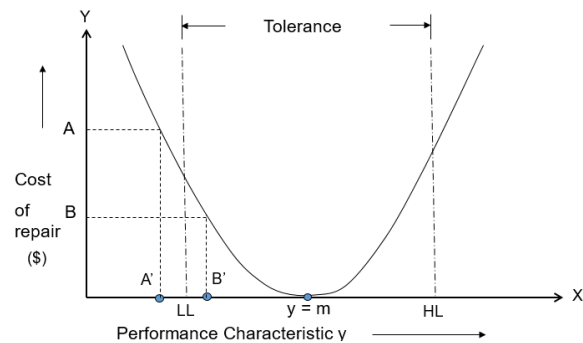

Fig. 2 Loss to the customer as per Taguchi's Loss Function [7]

Equation (1) depicts the case of the single unit. For large numbers of parts, the average loss can be given by (2):

$$\bar{L} = k[\,S^2 + (\bar{y} - m)^2\,] \qquad (2)$$

Here, $\bar{L}$ = Average loss (repair cost) to the customer, S^2 is the variance associated with the performance characteristic (y), $\bar{y}$ is the average achieved value of performance characteristic, $(\bar{y} - m$) is the offset of the group average from the nominal value, and k = Quality loss coefficient.

Average loss can be lowered by first reducing the variation, S, and then adjusting the average $\bar{y}$, to bring it on target m. In this case, even if the average of performance characteristic $\bar{y}$ coincides with the target value m, the associated losses will not be zero as the associated variability of individual y values i.e. S^2 cannot be zero.

In such a case, if $\bar{y} = m$, $\bar{L} = k\,S^2$. Here, S^2 is the variance of performance characteristic y and k is the quality loss coefficient.

III. PROPOSED CONCEPT OF TAGUCHI LOSS FUNCTION

Taguchi gave a wonderful concept of defining quality in broader terms; however, this concept can be further improvised in the following two ways:

A. Consider Losses over Complete Life Cycle

As per Taguchi's concept, a truly high quality product will have a minimal loss to society as it goes through its life cycle. If a product does not perform as expected, the customer senses some loss. The loss to society is imparted by a product from the time of its shipment, because it is the point at which the producer can do nothing more to the product [7]. Whereas in view of the growing environmental and safety concerns, this loss to society shall be seen over the total life cycle of the product and should not be limited only to the useful life cycle of the product. This loss to society shall be seen from even before the time of the processing of raw materials and even after the disposal of the product as waste. Loss should not be seen only in terms of loss to the customer, but also it should be seen in terms of the harmful effects a product imparts to the

environment and to the safety of living beings, because ultimately, any loss to the environment or to the living beings is loss to all society. Excessive consumption of resources in making a product is also a loss to society. This can be easily understood with the help of an example. Suppose there are two products, A and B, both are manufactured having exactly same specifications and cost, and thus, both are capable of giving exactly same kind of satisfaction to the customer; hence, according to Taguchi's definition of quality, both products will impart same loss to society, which may be even zero in case their performance characteristic matches with the target value. But, consider a situation where, as compared to product B, product A has been manufactured consuming less energy and is made of a material which is bio-degradable; then considering the overall life cycle of the product, product A will be considered as a product of much higher quality as compared to product B, because the total losses imparted to society by the product A would be much less than those imparted by product B.

Another example can be taken up related to the safety aspect. Suppose there are two products C and D, both are made with the same specifications, same material and same cost; thus according to Taguchi's definition of quality, they impart the same loss to society, but while manufacturing product D, proper safety measures have not been taken and the health of people who have worked on its production have been put at risk, whereas, the safety aspects of workers have been taken care of in the manufacture of product C, then obviously product C is having a better quality than product D.

B. Societal Losses Cannot be Zero

In line with Taguchi's concept of quality, the losses to society can be zero if the performance characteristic y matches with the target value m (refer to (1)). This statement does not hold good if we consider the losses imparted by a product during its complete life cycle because sooner or later better technology would be available to further minimize the losses to society. Here it may be noted that we are talking about the losses to 'society' and not the losses to the 'customer' only. Society, at large, is a stakeholder in the quality of the product because society suffers some losses during all the three phases of a product, and these three phases are:

1. Before Shipment

For example, losses due to excessive consumption of energy, excessive use of raw materials, unsafe and unhealthy working conditions for the workforce etc. Think of a situation where cheap raw material and cheap energy is available and the manufacturer uses these things in a wasteful manner that too without any concern for worker's safety, meets the desired specifications and sells at a lower price. In such a scenario, losses to the 'customer' may be zero and his satisfaction level may be very high, but the losses to 'society' are huge.

2. After Shipment

For example, losses due to poor quality of the product. Think of a situation, where in such a case the customer is provided with a free replacement instantly; the losses suffered by a customer may again be zero or minimal, but the loss to society is huge as the poor quality product has consumed precious resources like raw materials, energy etc., which are societal property, and hence, such products impart huge loss to society. Moreover, there may be some situations where a product may jeopardize the safety of a third party, again, the losses for customer are zero but not for society.

3. After Disposal

For example, losses due to the use of non-environment friendly materials. Think of a situation, where performance-wise two products are exactly identical and are sold at the same cost, however, one of the products is made of bio-degradable material and the other one is made of non bio-degradable material. It is very obvious that, though the losses perceived by a customer are same in both the cases, the loss to society is much less in the case of the one which is made of bio-degradable material. Losses to society will be again even greater if the disposed product is harmful to the safety and health of living beings.

In view of the ever evolving technologies and considering the losses to society over a product's complete life cycle, losses to society can never be zero because we must consider losses to society in terms of the energy and natural resources consumed in making a particular product, the safety of living beings as well as its disposal after its useful life. Depending upon the present day technology, we can only minimize the losses, but can never make them zero. As technology advances, we may develop better ways to produce a product by using less energy, fewer raw materials, following better safety standards and by using environment friendly materials. This means that the loss function curve should never touch the X-axis and it should be depicted as shown in Fig. 3.
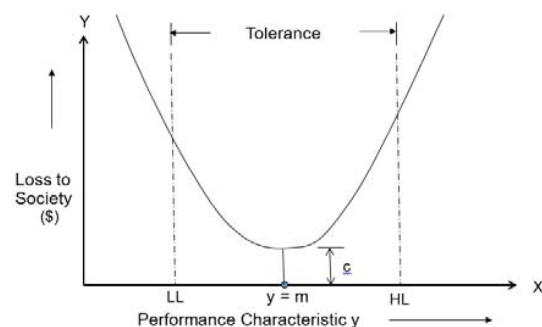

Fig. 3 Loss to the customer as per the Proposed Quality Loss Function

In Fig. 3, it can be noted that the loss function curve is not touching X – axis, means while manufacturing a product, losses to society will never be zero, they can only be minimized. Depending upon present day technology and safety measures, a certain amount of loss will always be there, which can be further reduced (but can never be made zero) with the advancements in techno-safety measures. For example, if we can produce a product using less energy, fewer raw materials, with better safety measures for the workers,

using environment friendly material etc., the losses to society can be further reduced. For a single product, this situation can be expressed by (3):

$$L = c + k \, (y - m)^2 \qquad (3)$$

where, 'c' is a constant

Here c can be termed as a 'Techno-Safety Coefficient', which is a function of present day technology (used in producing the product) as well as the safety measures taken for producing the product and is inversely proportional to the level of technology and level of safety measures, i.e. the lesser (inferior) the technology and fewer the safety measures, the higher will be the value of constant 'c'. Here, present day technology means, technology used for realizing the product. The value of 'c' can never be zero, as technology and safety measures can never be infinite; this means there is always some chance to improve the production process and make it more environment friendly and more safe for workers. Hence $c = f \, (T_c, S_f)$ where, T_c indicates the technological level used for realizing the product and S_f indicates the level of safety measures taken. And $c \, \alpha \, 1 / (T_c, S_f)$ and $c \neq 0$ as T_c & $S_f \neq \infty$. Here, it may also be noted that in Fig. 2, the Y axis has been shown as a 'Cost of Repair' [7]; whereas in Fig. 3, the Y axis has been shown as a 'Loss to Society', because as per the proposed concept, 'Loss to Society' is not just limited to the repair cost incurred by the customer, it is a cost that shall be considered in terms of the losses imparted by the product to the whole of society over its complete life cycle.

Technology Coefficient 'c' is a function of many technology and safety dependent parameters used in the production process; e.g. process efficiency in terms of man, machine, material and energy, judicious selection and use of raw materials, safety of manpower involved, disposal of waste generated, use of environment friendly materials, disposability of a product after its useful life from environment and living being's safety point of view and so on. In other words, it can also be said that T_c will depend upon the total 'carbon foot print' of a particular product. Hence, $T_c = f$ (Carbon Footprint of a Product during its complete life cycle), S_f will depend upon the safety measures taken for the workforce involved in the manufacturing of a product right from the stage of the procuring raw materials for it, the safety of its handlers, the safety of its customer, the safety of any third party to whom the product can pose a threat, and the safety of all the living beings etc. Hence, $S_f = f$ (Safety of all living beings affected by a product during its complete life cycle)

It is believed that the use of higher technology will result in a smaller carbon foot print and better safety of all living beings, and thus, fewer losses to society i.e. a smaller value of constant c in (3).

In the case of multiple numbers of products, average loss can be calculated from (4):

$$\bar{L} = c + k[\, S^2 + (\bar{y} - m\,)^2 \,] \qquad (4)$$

When process offset is zero, i.e. $\bar{y} = m$, average losses to the society will be:

$$\bar{L} = c + k \, S^2 \qquad (5)$$

From (5), it can be seen that average losses to society imparted by products depends on two things, i.e. the 'Techno-Safety Coefficient' c and 'Variance multiplied by Quality Loss Coefficient' i.e. $k \, S^2$. Here, the first component, i.e. Techno-Safety Coefficient c is linked with the losses imparted by a product to the whole of society, whereas the second component i.e. the 'Variance multiplied by Quality Loss Coefficient' depends on losses imparted by a product to the customer only. Since the variance of a process can never be zero and always there will be some scope to improve the techno-safety features to minimize societal losses, the overall loss can never be zero.

From the above discussion it is clear that an average loss imparted by a product has two components, which can be written as follows:

Average Loss = Loss to the Society + Loss to the Customer

A true high quality product must have lower losses to society as well as to the individual customer.

IV. Conclusion

The Quality Loss Function concept given by Genichi Taguchi is an excellent concept, but it was limited to the losses imparted to the customer only. In modern times, when our concern for the environment and safety is growing, a product's quality has to be evaluated over its complete life cycle, and hence, slight improvisation in this concept is necessary. Losses to society shall not be evaluated only on the basis of the useful life of the product and shall not be limited to the 'Cost of Repair' only, but shall be evaluated over the complete life cycle of the product and include the overall societal losses imparted by a product, which may be done in terms of the overall carbon footprint of a product as well as the adherence to best possible safety practices during the production process; and for that, it has been proposed to introduce a constant which depends on the techno-safety features used for realizing that product. The advances in the technology used and the safety measures taken to realize a product can further minimize the losses imparted to society; it is an ongoing perpetual process.

References

[1] James R. Evans, William M. Lindsay, *Managing for Quality and Performance Excellence*, Cengage Learning, USA, 2016, cp. 7.

[2] G. Taguchi, *Introduction to Quality Engineering: Designing Quality Into Products and Processes*, Asian Productivity Organisation, Tokyo, 1986.

[3] Jeh-Nan Pan, Jianbiao Pan, A Comparative Study of Various Loss Functions in the Economic Tolerance Design, *IEEE International Conference on Management of Innovation and Technology*, 2006, pp 783-787.

[4] Naresh K. Sharma, Elizabeth A. Cudney, Quality Loss Function – A Common Methodology for Three Cases, *Journal of Industrial and Systems Engineering*, Vol. 1, No. 3, pp 218-234, 2007.

[5] Dale H. Besterfield, *Total Quality Management*, Addison Wesley Longman Publishers: Singapore, First Indian Reprint, 2001, cp 14.

[6] Philip B, Crosby, *Quality is Free*, McGraw Hill Publishers: New York, 1979.

[7] Phillip J, Ross, *Taguchi Techniques for Quality Engineering*, McGraw-Hill Book Company, 1988, cp. 1.

[8] David A. Collier, James R. Evans, *Operations Management*, Cengage Learning, USA, 2009, pp 99.

Atul Dev, born at Bareilly, Uttar Pradesh, India on 25th Jan 1971, did B.Tech (Mechanical Engineering) from GB Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India in 1991, Master of Science in Quality Management from Birla Institute of Technology and Science, Pilani, Rajasthan, India in 2004, Certified Quality Engineer from Indian Institute of Quality Management, Jaipur, India in 2001 and Lean Six Sigma Black Belt from Benchmark, India in 2015.

He is working as Scientist and Group Head, Centre for Advance Mechanical Engineering (CAME) with Defence Research and Development Organisation (DRDO), Gov't of India at one of its laboratory Defence Electronics Applications Laboratory (DEAL) at Dehradun, India. He is working in the field of Dimensional Metrology and Precision Machining of Electro-Mechanical Components. His specialization includes Taguchi Optimisation Techniques and Six Sigma problem solving techniques. He has written more than seven research papers in International / National conferences on Dimensional Metrology, Uncertainty Calculation, Statistical Quality Control and Taguchi Design of Experiments.

Mr Dev is a Member of Institution of Engineer (India) and Metrology Society of India.

Pankaj Kumar Jha is presently working as an Associate Professor in the department of Faculty of Management Studies at the Graphic Era University, Dehradun, India. He received the Bachelor of Science (Statistics) degree from Delhi University, Delhi in 1995. He received M. Sc. (Statistics) from Delhi University, Delhi in 1997 and Ph.D (Statistics) degrees from H.N.B.Garhwal (central) University in 2009.

He has published seven papers in international journals and many more in various international and national conferences. He worked in India as a faculty member for around 19 years and has taught several core courses like Research Methodology, Quantitative Technique, Statistics, CBNST, Industrial Management Statistical and scientific Computing etc. His research area is Inventory Control and the topic is "Optimum replenishment policies of some inventory models under partial backlogging".

Dr Jha has written a book on Statistics "Quantitative Analysis', Anand Publication, Meerut. He has done two International projects under CV Raman Fellowship for African Researchers sponsored by DST, Gov't of India and FICCI.