Chapter 1
Quality: A Big Canvas

1.1 Introduction

The history of Quality is as old as that of production. Whatever was produced—through a manufacturing process involving machines or simply through manual operations—had some level of Quality built into it, essentially in terms of skills in designing, producing and checking conformity with the design. This level in some cases was quite high and in some others pretty low. Taken somewhat simplistically as the collection of features of the product which could meet some use requirements or had some aesthetic or prestige value or had a long life or was user-friendly, a product and its quality were and are still now inseparable. Of course, with emphasis gradually growing on differentiation among products in terms of their quality, a 'quality product' has come to mean a product with a high level of quality.

The panorama of Quality has evolved through many paradigms (new ones not to be always branded as 'old wine put in a new bottle') encompassing the history of production, starting with those who produce (and obviously design) taking all care of quality in a phase referred to as 'operator Quality Control', through inspectors assessing quality subjectively though dispassionately (in a phase branded as 'inspector Quality Control'), Statistical Quality Control providing a more efficient anatomy of the production process, followed by Total Quality Control or Company-Wide Quality Control with a clarion call for involvement of all to boost quality, Total Quality Management throwing up a more humane but comprehensive and customer-oriented approach, to many other brands like right first time, zero-defect, Six Sigma, and what not.

The story of quality has been unfolded extremely rapidly in recent times in consonance with the amazingly fast developments in Science and Technology, society, economy and even polity. Now there are engineers, statisticians, management experts and similarly branded experts recognized as 'Quality Professionals'. Quantitative tools (essentially statistical)—often quite sophisticated—are being widely used for quality and reliability assessment as also improvement

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exercises. At the same time, roles of design engineering, of customer voice analysis and customer satisfaction measurement, of methods and practices to enhance people's involvement in quality efforts are also being accorded good priority.

Everyone talks about quality—about quality of diverse entities like food and fodder, safety locks and entertainment electronics, communication devices, health care, administration, primary education, banking services, news reporting, environment, and what not. Even an article submitted for possible publication in a peer-reviewed journal is assessed by the referee(s) for the quality of its content as well as of its presentation.

All of us are concerned about quality—at least in regard to goods and services consumed by us and environment for life and work given to us. If not, in relation to goods and services produced/rendered by us and environment created by us for others.

Any discussion on quality has to reckon with the fact no one can say the last word on quality. Perceptions about quality, standards bearing on quality, quality practices, and even quality ethics reveal a lot of diversity over the expanding spectrum of stakeholders and are changing fast, keeping pace with developments in Science and Technology. However, to our relief stand out certain realizations about quality shared by professionals and philosophers alike. A few of these are mentioned below.

Quality is not a goal—it is a march forward. Even zero-defect is not the ultimate to be achieved. Since we can always have a more stringent definition of defect, scope for improvement always remains—in materials, processes, procedures and systems.

Quality is not a freak—it is the outcome of a deliberate, planned and systematic effort. Such an effort has to be deliberately taken up by the producer. This will or, rather, zeal to produce goods of quality has to be translated into a policy (preferably documented). To put policy into action, a quality planning exercise has to be undertaken. Level of quality to be achieved and the way to achieve these should be clearly spelt out in necessary.

In a somewhat controversial article entitled 'Improved Quality Tactic', Budyansky (2009) argued that the definitions and simplified methodologies for quality articulated over the years have created a 'vague' situation. He mentions five principal 'vagueness factors', viz. (1) absence of a common and generally accepted definition of quality (2) absence of effective and well-defined rules of measurement and quality evaluation (3) absence of a methodology to go from physical parameters to quality parameters (4) absence of a of a methodologies for fulfilling a quasi-objective analysis and synthesis of quality and (5) absence of a common technology for quality assurance. He feels that the vagueness around quality is analogous to vagueness about concepts like' freedom' or 'democracy' or 'illness'.

The point to be remembered is that quality corresponds to a big canvas that combines richness with complexity and deserves a multi-pronged discussion, right from the philosophical angle to the mundane consideration of business interests.

1.2 Ubiquity of Quality

Quality is all pervasive, residing in all tangible and concrete forms and figures, processes and products. Quality has been a reflection of human civilization of progress in Science and Technology, of an ever-growing demand by human society for more of better goods and services, and a consequent effort to satisfy the demand. The quest or craving or passion for quality had a rather recent entry in the arena of industry or more generally the arena of organized human activities, though it had been too long an engagement in the field of fine arts and also in the behaviours and actions of even lower organisms.

Quality is associated with everything around us, judged in terms of features or characteristics or parameters of the particular entity that we consider. Thus, quality is often discussed in respect of the following entities.

* *Raw Materials*—like coal raised from mines, water flowing along a river, air that we inhale, fruits that are plucked from trees and plants. We even talk about quality of soft materials like raw data arising from a given source. In the case of coal, quality is judged in terms of properties like dust content or useful heat value; water quality is assessed in terms of dissolved oxygen, total dissolved solids, pH value, coliform count, ratio between biological oxygen demand to chemical oxygen demand and a few other parameters. Adequacy, accuracy, timeliness, etc. could characterize quality of data.
* *Processes* (*including process technologies*)—like machining of a metal, calibration of measuring equipment, auditing, developing a quality plan, communication of a message, etc. Quality of any such process can be judged in terms of rotation per minute of a machine, feed rate of input materials, duration of a conversion operation, yield and the like—all compared against specified norms or standards.
* *Processed Materials*—like washed coal, treated water, boiled fruits, spun fibre, alloy steel, tabulated data, etc. For spun fibre, we may use tensile strength as an important quality parameter. In many cases, change in quality parameters of corresponding raw materials during the process provide good ideas about quality of processed materials.
* *Products* (*including augmented and extended products*)—like a lathe machine, an item of furniture, cooked food, a steel utensil, a data-based report, and the like. Quality parameters are given out in terms of fitness for use requirements, value derived by the user against the price paid, manufacturing cost, costs of usage, maintenance, disposal and similar other features.
* *Services* (*loaded with products to varying extents*)—like transportation, marketing, health care, recreation or entertainment, education, security, etc. Quality is judged in terms of both measurable properties as also subjective perceptions.

[Products and processed materials have to be carefully distinguished in terms of use, viz. a product for final consumption and a processed material for as an intermediate. Further, services may be heavily loaded with products, the product

content may be moderate or the service may not involve much of a product content.]
* *Work Environment*—like the physical facilities for work, security, safety, hygiene, etc. where the most important quality parameter could be adequacy and availability.
* *Environment*—covering humans, flora and fauna, natural resources. Here diversity and abundance are quite important to discuss quality. Aspects like pollution, natural resource depletion or conservation become relevant in this context.

We also started talking about quality of life covering various aspects of individual and public life. We speak of quality of measurements, of information, of communication and many other entities. In an interesting article entitled 'The Golden Integral Quality Approach from Management of Quality to Quality of Management' Galetto (1999) wrote about quality of management in terms of intellectual honesty, holistic cooperation, quality integrity and scientific approach to decision-making.

Concerns for quality have been felt and expressed even in spheres far removed from the world of goods and services. Among the six plenary talks in the 2017 Stu Hunter Research Conference in Denmark attended by 60 participants from 18 countries in America, Europe and Asia, one was on *Quality and Statistical Thinking in a Parliament and Beyond by P. Saraiva*. The speaker and the three discussants considered such matters as choice of issues taken up by the legislators for discussion and debate, the use of facts and figures, the credibility of figures rolled out, the use of logical reasoning and the outcomes of discussions.

Except for the case of raw materials, where quality is being continuously altered by anthropogenic activities which affect ecology, quality is the outcome of a planned, deliberate and systematic effort put up by an individual or an organization.

1.3 Quality Variously Perceived

It is only expected that quality will be perceived differently by different persons from different angles or perspectives. Such perceptions vary widely from abstract, philosophical ones to concrete, quantifiable ones. We can possibly start from *Quality is beautility* to imply that quality combines beauty with utility—beauty that is eulogized and utility that is demanded. We are reminded of what a great poet wrote, viz. a thing of beauty is a joy forever. If we look at a pendulum clock once adorning the courtroom of a royal family and now kept in a museum or even a well-crafted jewelled wristwatch, we appreciate this statement.

By quality, we tend to identify and assess certain characteristics or properties which contribute to the value of a product. Value of a product or service is something that is created through some effort, is appreciated by the customers and can justify a higher than usual price. This concept of value includes (a) use or functional value (b) esteem or prestige value and (c) exchange or re-usability value. While all these are quite important as value contributions of a product or service, their relative importance would vary depending on the nature of the product. For a household decorative item, prestige or esteem value is more important, consideration of use value may not arise no one bothers about exchange value. On the other hand, for a household device like a ceiling fan use value dominates over esteem value and exchange value may be trivial.

It will be quite rational to look upon quality as a value addition and to argue that customers want value for money to acquire the product This value can be influenced by the quality of design as also by quality due to product support. In this connection, one may note that product augmentation and product extension can definitely enhance value addition and the nature and extent of these two should be incorporated right in the product design phase. Augmentation in terms of packing and packaging of the product and extension in terms user guide/manual, provision maintenance support and of spares and accessories, etc. do influence customer-perceived quality.

Quality is also perceived as the degree of excellence in

1. material or process or product;
2. service, procured or delivered;
3. work environment and;
4. performance, individual or collective.

This excellence is expected to yield a certain amount of satisfaction—to both the producer and the consumer—and results in a certain extent of profit to a business. In fact, excellence is one desideratum to judge the situation in a higher education system, besides access and equity.

Several other perceptions about quality may be considered to get an idea about the diversity in perceptions about quality.

The ultimate state of quality is not the ‘absolute best’, since quality is strongly related to market, to technology and to cost.

Quality is not static, goes on diminishing in relation to continuously increasing customer expectations.

Quality is not characterized by a single dimension. At least has two important dimensions to be taken into account for assessing the quality effort of an enterprise, viz. value addition and cost differential.

Quality has several different aspects to be taken care of by different groups of people within and outside the enterprise.

Quality Management is meant eventually to improve organizational performance. Improvement calls for measurement of quality—existing and desired—and has to be planned for.

1.4 Dimensions of Quality

In an article in Harvard Business Review, November–December, 1987, pages 101–109, David A. Garvin listed eight dimensions of quality and these have been clearly and concisely stated by Cathal Brugha (in a private communication to the author), with illustrations drawn from a Personal Computer.

Dimension 1. Performance—A product's primary operating characteristics. Clock speed, RAM, hard drive size, etc.
Dimension 2. Features—Characteristics that supplement basic functioning like wireless mouse, flat-screen monitor, DVD-RW, etc.
Dimension 3. Reliability—Probability that the product will not malfunction before a specified time period. Meantime between failures.
Dimension 4. Conformance—Degree to which the product's design and operating characteristics meet established standards. Underwriter laboratories labelled, mouse, monitor, keyboard included with CPU.
Dimension 5. Durability—Expected product life. Time to technical obsolescence, rated life of monitor.
Serviceability—Speed, courtesy, competence and ease of repair. Warranty conditions, availability of customer service and replacement parts.
Aesthetics—How does a product look, or feel, or sound, or taste or smell (depending on the nature of the product). Computer housing colour scheme. Keyboard touch, etc.
Perceived quality—Reputation and other indirect measures of quality like previous experience of self or others. Brand name, advertising.

While different dimensions of quality of a product may have different appeals to different persons or groups, we also talk about several Aspects of Quality which are of interest to different groups of people in different contexts. Some of these aspects are:

1. FundamentalAL: Quality of design (specifications/standards/grades)
2. Measurable: Quality of conformance
3. Consumer (marketable): fitness for use, life, performance, price, availability, delivery
4. Operational: Quality of management, system and operations, minimum waste and cost
5. Conservational: Optimum use of resources—materials and energy
6. Environmental: Safe waste, tolerable noise, etc. minimum air and water pollution and
7. Human: Quality of working life

Aspects 1, 4 and 5 should be great concern to the producer in particular; aspects 2 and 3 affect the customer, aspect 6 should be a common concern for all and aspect 7 affect the people engaged in the producer–provider organization.

From the point of industry or business, three broad dimensions of quality stand out prominently in the supplier–customer transactions. These are

Physical (technical) in terms of product features (including features of the augmented product) that can be quantitatively assessed or qualitatively judged at the time of product–service delivery.
Functional (interactive) in terms of features (including features of the extended product) which are revealed during product use/deployment.
Corporate in terms of features of the supplier–provider organization that influence customer perceptions about product quality over continued use as also their expectations about quality of a product to be acquired.

1.5 Approaches to Defining Quality

We all agree that quality is multi-dimensional and is comprehended in different ways by different individuals or groups in the light of different concerns and demands. Thus, we all agree that quality is not expected to have a unique or even a consensus definition among all interested individuals who are concerned with quality in a great diversity of situations. The question that arises in our minds is 'how badly do we need to have a formal definition of quality to appreciate good quality or deprecate poor quality, to pay for quality, to assess or compare quality in terms of some standard? Notwithstanding the validity of such a question, we may proceed with alternative definitions which have come up from time to time in a bid to find out some broad consensus. There is no need to consider these definitions chronologically, though some pattern could emerge if that exercise is taken up.

Anyone interested or involved in the quality profession will come across a plethora of definitions of Quality offered by eminent exponents. This led Garvin (1988) to suggest the following five approaches to defining quality.

* *Transcendent Approach*—This approach relates to 'a condition of excellence implying fine quality as distinct from poor quality and achieving or reaching for the highest standard against being satisfied with the sloppy or the fraudulent'.
Examples of fine quality that meet this approach are present in arts and literature. The sculptures in the caves of Ajanta and Ellora, Beethoven's symphonies and Leonardo Da Vinci's 'Mona Lisa' are all examples of 'achieving or reaching for the highest standard'. This approach, however, lacks objectivity in the form of an absolute standard of performance which is equally acceptable to all. It is not much relevant to business and industry. It does not enable a worker to claim with certainty that his product is of the highest standard.
* *Product-based Approach*—It focuses on certain features or attributes that indicate higher quality. Leather upholstery on a sofa set, for example, is deemed to have higher quality than cotton. The disadvantage of this approach is that it implies the

presence of leather as the criterion to define higher quality and does not pay attention to its colour or finish.
* *User-based Approach*—It is defined by Juran as 'fitness for use'. Here the user determines the level of quality. The product–service that fulfils his requirements is of higher quality. In this approach, the producer or service provider must know how the customer intends to use the product–service and for which purpose and act accordingly. Customer satisfaction levels reflect levels of quality. This approach is most suited to modern competitive market. This approach needs to identify the target market and its requirements, and then design, develop and deliver the appropriate product–service to the customers. Here cross-functional teams should be in place to contribute to the product–service quality. This approach emphasizes on better brand image and increased market share. This approach may require the producer or service provider to create quality consciousness among the customers about the wide variety of benefits that may arise from the use of the product–service. This will help the customer to know about the potentials of the product–service and thus help him develop a better idea the versatility and quality of the product–service.
* *Manufacturing-based Approach*—According to Crosby (1996), this approach focuses on 'conformance to requirements'. Engineers specify the characteristics of a product. The more closely manufacturing conforms to these requirements; the better is the quality of the product. Conformance within a smaller range is better than conformance within a larger range.

The advantages of this approach are

(1) objectively measurable quality standards and
(2) reduction in cost of quality.

Conformance to requirements brings about substantial reduction in costs such as rework, scrap, re-inspections and returns from the customer. A major disadvantage is its lack of concern for the requirements of the customer. Product–service characteristics specified by the manufacturer or service provider may not in alignment with what the customers need. The underlying assumption is that customer satisfaction has a direct relationship with the fulfilment of the given specifications of a product.

- *Value-based Approach*—This approach to quality introduces the elements of price and cost. According to Broh (1982) 'quality is the degree of excellence at an acceptable price and the control of variability (resulting in uniformity) at an acceptable cost.' The degree of excellence at an acceptable price is decided by the customer, and the manufacturer decides on control of variability at an acceptable cost. The purchase decision of the customer is based on a trade-off between quality and price. This approach is not effective in providing objective quality criteria since many of the quality attributes could be subjective in nature.

1.6 The Deluge of Definitions

Many definitions of quality have emerged over the years and some of these are worth a perusal. There is—as is expected—a large communality among these. At the same time, each definition claims some individuality. Some definitions are conformity-based, while some others are oriented towards excellence. Some consider the set or totality or composite of features and characteristics—of the product as such or of associated functions such as design, manufacture, use, maintenance and even reuse as constituting quality of the product. On the other hand, quality is looked upon as an ability to meet certain requirements. Of course, the former emphasizes on what determines the latter. Let us look at some of the definitions that may serve the purpose of revealing this diversity in definitions. Some definitions apply directly to individual units (products or work items) while some others emphasize on uniformity or consistency among units in a suitably defined population or aggregate. Some definitions facilitate development of measures of quality, while such measures are difficult to arise from some definitions which stress on abstract or latent features or properties of the units. Some definitions tend to highlight the role of the designer–producer of a product or service to state that 'Quality is a way of Life'. Such definitions need not be debated for their meaningfulness, but since we cannot measure quality defined in such a manner, we cannot adopt such a definition for the purpose of comparison, control and improvement.

Let us look at definitions proposed by some eminent exponents of quality who have guided the quality movement over the decades beyond the Second World War.

Quality is the 'Level of Usefulness to the Consumer' Or
Quality is Fitness for (intended) Use—Juran (1988)

This fitness is generally assessed in terms of quality attributes or characteristics used as surrogates or constituents or, better, determinants of 'fitness'. Requirements for the latter entities are often mutually agreed upon between the producer–supplier and the customer–user and sometimes given out by the producer only or even dictated by the customer–user and accepted by the producer–supplier, and thus is justified a second definition, viz.

Quality is conformance to requirements or specifications—Crosby (1979). Another important definition attributed to Deming, though not explicitly stated this way by him runs as

'Quality is predictable degree of uniformity and dependability at low cost and suited to the market.'

This definition refers to uniformity (among different units or items in respect of quality attributes) and dependability (during use—a concept that can apply to even an individual item or unit), rather than conformity to requirements or specifications directly. It also harps on 'low cost' and suitability to the market, keeping in mind needs, expectations and purchasing power of the people visiting the market. Thus, this definition differs from those suggested by Juran or Crosby.

Alternatively, quality is the totality of features and characteristics of a product or–service that bear on its ability to satisfy given needs—ANSI–ASQC Standard A3 (1978). This definition leads us to consider several functions that precede and follow manufacturing, as was indicated by A. V. Fiegenbaum in taking quality as 'the total composite of product and service characteristics of marketing, engineering, manufacturing and maintenance through which the product or service in use meet the expectations of the customer.' It is presumed that marketing and engineering together should be able to incorporate those features in the product which are expected (might not be so stated) by the customers.

Galetto (1999) defines quality in terms of 'the set of characteristics of a system that makes it able to satisfy the needs of the customer, of the user and of the Society.'

The user's point of view is also reflected in the definition of Quality as the 'Quotient between what the user receives and what he expected to receive' (green). Accepting this definition, we are reminded of the fact that quality of a product or service is not something static and that in the context of increasing customer expectations (motivated by knowledge about technological advances, development of new and better materials and entry of new producers), the numerator has also to increase proportionately in order that quality as is perceived by the customer does not decrease over time. This calls for product quality improvement through innovation and updation of production processes.

The International Organisation for Standardisation (ISO) had first offered the definition 'Quality is the totality of features and characteristics of a product that bear on its ability to satisfied stated or implied needs' (1994). Later, this definition has been modified to indicate the outcome as 'Quality is the degree to which a set of inherent characteristics meet requirements.' (2005). One wonders if one should read too much into the ISO definition that does command some respect in some quarters. This definition takes Quality as something relative and not absolute—relative to 'requirements' (explicitly stated or just tacitly implied). If one argues that requirements may be circumscribed by purchasing power or access or even by individual attitudes and lifestyles, we may then justify different degrees of the same product to meet differing requirements or assign different labels of quality to it. It may not be out of place to mention that even now—as also earlier—we get the same product in different variants some marked as 'export quality', implicitly better than those not so marked.

Budyansky (2009) recognizes five vagueness factors associated with quality, viz. absence of a generally accepted definition of Quality, absence of effective and well-defined rules of measurement and quality evaluation, absence of a methodology allowing a transition from physical parameters to quality parameters, absence of a methodology to carry out a quasi-objective analysis and synthesis of quality and lastly the absence of a common technology for quality assurance. He argues that the distinction between procedure-oriented and result-related definitions should not be obliterated and that the universal definition of Quality should be 'Quality is a degree of compatibility of an obtained result with an objective'. He goes on to say that 'compatibility' theory is applicable to situations characterized by vagueness like fuzziness as in systems engineering or fuzzy set theory. He advocates three possible definitions, viz.

- Quality is the degree of achievement of a formulated objective.
- Quality is the degree of achievement of progress under certain conditions.
- Quality is the degree of 'wishing' satisfaction into a realistic environment.

He provides a somewhat complicated procedure to get at the 'compatibility' measure.

An Unconventional definition

Quality is a situation in which a product once sold does not come back (with a complaint or a request for repair or replenishment or recall), but the customer does (Margaret Thatcher, former Prime Minister of UK.). This definition does make a lot of sense in business and needs an appropriate context-specific interpretation.

All these definitions apply directly to products, but are also relevant to services (which involve products to varying extents).

1.7 The Longest Definition

It is worth recalling the almost prophetic words of a great visionary P. V. Donkelaar, President, Outward Marines, Antwerp, Belgium (1978) uttered some 40 years back that can be accepted as an early pointer to various exercises taken later on to broaden the concept of Quality, taking due account of concerns expressed (or felt, though not always explicitly stated) by different stakeholders. This definition—probably the longest one cited in the literature—and a quite debatable one in the context of modern industrial practice, runs as

> A product is of good quality if and only if at a minimum life-cycle cost it provides a maximum contribution to the health and happiness of all people engaged in its manufacture, distribution, use, maintenance and even recycling with a minimum use of energy and other resources and with an acceptable impact on Society and on Environment.

This comprehensive understanding of quality goes much beyond the current concerns with 'customer satisfaction' or 'customer delight' in two ways. It talks about 'happiness' and 'happiness' in social sciences is something tat implies but is not necessarily implied by 'satisfaction or delight'. It goes further to take care of 'health' and, that way, of 'safety'. Secondly, it does not speak of customers only, but goes on to embrace all others engaged in the entire life-cycle of the product from design to disposal.

It will be apparent from this definition itself that Quality Management involves decision-making using multiple criteria by different persons (person groups) with mutually opposed interests in different quality-related activities to achieve several different objectives. To minimize consumption of energy and other resources and, at the same time, to ensure solidity of product life and to provide a maximum contribution to the health and happiness of all people concerned at various stages with the product is an extremely difficult optimization exercise. Consumption of energy and resources is a concern to the producer while life-cycle cost is a matter of concern for the customer or the user.

This definition puts an emphasis on the impact of the product and its use on the society and the environment. And it is worth noting that these latter aspects are now being considered as important concerns of Quality Management.

A much bigger conflict that this definition begets concerns the fact business particularly in consumer goods as also of capital goods grows in recent times under a veiled policy of 'planned obsolescence' so that items of consumption become obsolete or out of fashion or difficult to maintain in order that new brands or even new variants or new products are introduced into the market to take over the still-operating or functional items or product units.

Thus, Quality Management today involves multiple stakeholders not all directly related to products and services that are traded between the producer or provider and the customer or the consumer, Custodians of public interest including regulatory bodies as also public interest activists have a say and Management—taken broadly as Quality Management here—can no longer brush aside their objections and suggestions. Of course, some may argue that such issues are too big for 'Quality Management' in usual parlance.

This definition has not escaped criticisms from the consumer goods industry, where emphasis is placed on the product's appeal to the customers in terms of user-friendliness, conformity to changing customer tastes and likes or dislikes, esteem or prestige value and similar other features without a direct reference to the concerns about consumption of energy and materials and the impact on environment.

1.8 Quality Through the Life Cycle

Quality as an attribute of a product or a process or a service is not a static concept. Before proceeding further, we may note that whatever is produced can be generally taken as a product. This way we need not differentiate between a product and a service. The life history (or better, life cycle) of a product can be comprehended in four phases and each phase some processes are involved. In fact, processes are inseparably associated with a product. The following different phases encompass a product's life cycle, viz.

1. Concept or Mission: developed prior to the design of a product, meant to capture the intentions behind designing and manufacturing the product by stating the desired or intended functions. To this end, we usually bring in some performance parameters or functional characteristics, some of which can be conveniently quantified while some others could be just qualitative. An automobile's intended performance may be stated in terms of some performance parameters like average speed or maximum attainable speed, fuel consumption per mile,

safety features, comfort feeling, etc. While such a list could be pretty long, some of these could be critical in describing the expected functioning and requirements on these critical parameter are taken as critical events, like

Maximum speed attainable (S) $\geq$ 150 mph., miles per litre of fuel (FE) $\geq$ 22.

For a household electric lamp of a given wattage, the mission requirements could be

$L \geq 1000$ and $I \geq i_0$ where L is the length of life in hours, and I is the intensity of light emitted.

In general, if $Y_1, Y_2, \ldots, Y_k$ stand for k critical parameters in the mission and for satisfactory performance of the product $Y_i \in S_i\, i = 1, 2, \ldots, k$ where S_i denotes the one-sided or two-sided interval in which Y_i should lie to ensure satisfactory performance. These inequalities should be satisfied in a prescribed sequence by a product during use and define what is called a mission plan or mission profile. Requirements on critical parameters are recognized as critical events which may or may not take place in the life of a particular unit of the product, in the context of a population of units to be turned out.

2. Design: developed in terms of requirements or specifications on physical or chemical or even biological parameters, generally referred to as quality parameters of materials, processes, checks and tests, controls, etc. which should be met during manufacture. Knowledge about the functional requirements and of their dependence on these quality parameters as also domain knowledge about the process(es) involved will yield the Design as $\{X_j \in I_j\, j = 1, 2, \ldots, 1\}$ where X's are the quality parameters that influence performance and I' s are the corresponding intervals within which these quality parameters are allowed to vary. Thus, for the case of a lamp, there could be design requirements like $T \geq 1800$ °F where T stands for the melting point of the filament used. The design would also specify the firmness of soldering of the cap on the bulb. Take, further, the case of a missile meant to hit and harm a target. The mission plan can be stated in terms of several critical events taking place in a given sequence, viz. the missile takes off from its launching pad or base almost immediately after being fired, should hit a point very close to the target and release some destructive energy. The following would be the critical events: T (take-off time) $\leq$ 2 s, D (distance between the target and the point hit) $\leq$ 3 m and E (energy released on hitting a point) $\geq e_0$.

In fact, design should and does specify requirements about process parameters like the feed rate of an in-process material into a machine or the alignment between the jaws of a machine or time during which a certain treatment should take place, etc. Design also specifies checks to be carried out at various stages and control to be exercised on the basis of the results of such checks.

Design as a comprehensive set of requirements should be developed keeping in mind the mission plan or profile.

3. Manufacturing: p) in terms of operations or activities to turn the initial input along with inputs at intermediate stages into the final product. Most often this is a multi-state process where the output at the end of any stage depends on the output of some previous stage(s). It is expected that the process plan takes care of the design requirements along with equipment performance. That way, manufacture or production has a big interface with procurement, engineering, inspection and quality control and related functions.
4. Use or deployment of the final product in environments which may or may not have been foreseen and accounted for during the design phase and for purposes which might not had been envisaged in the mission phase. All this may lead to malfunction or failure. The actual performance of the product gets revealed as we use it—at a point or over an interval, depending on the mission. More often than not, performance is noted by way of its converse, viz. failure and we may note the time-to-failure or, in case of a repairable product, time between consecutive failure or time to repair, etc. Functional or field-performance parameters noted during use or deployment are included directly or otherwise in the mission plan.

From the last phase, having noted the actual performance of a product in relation to the performance expected in the mission and targeted in the design, we like to revisit even the mission to find out if we were too ambitious in the sense of an expected performance that could hardly be achieved or if we could do better and achieve something more what we intended modestly. Either would lead to some design modification that would have to be accommodated during manufacture. Finally we would get to know the changed performance. And thus the cycle goes on.

The term 'Quality' has different implications during different phases of this life cycle. In fact, all the implications take the mission as granted and then proceeds to identify and quantify quality for each of the remaining three phases. Thus, the three different determinants of quality of a manufactured product are relative to a given mission and will change from one mission to another. And this mission usually takes care of technology, market and cost (of production).

The primary determinant of product quality should be the ability of a design to meet mission requirements and this ability is recognized as quality of design (sometimes referred to as design reliability). Second comes the ability of a manufacturing process to meet design requirements and this is accepted as process capability, also referred to as quality of conformance. Quality of design coupled with quality of conformance will imply that a product during use will meet mission requirements. And this ability as directly concerns the customer and the user is recognized as quality of performance, also known as product reliability. We thus come to the fundamental quality equation to be stated as

$$\text{Quality of Performance} = \text{Quality of Design} * \text{Quality of Conformance} \quad (1.1)$$

where the symbol * denotes 'composite of.'

A fourth determinant of quality for a repeated-use product is provided by quality due to product support by way of customer education to enable proper use and maintenance, etc. Thus, quality due to product support enhances quality of performance.

For the purpose of quantification, each of the above abilities can be viewed as obtained as a ‘probability’ which can be estimated from relevant data. Thus, quality of design is the conditional probability that products (turned out by a process that meets requirements of the design fully) meet mission requirements as can be estimated from field-use data on performance parameters compared with the mission-required values. Similarly, quality of conformance is an unconditional probability that design requirements are met during the production–manufacturing process that can be estimated from inspection data—covering incoming materials, work-in-progress items and finished goods—compared with corresponding values prescribed in the design. And product reliability is now a joint probability that both design and mission requirements are met, as can be estimated by considering use data. These probabilities can now be stated in terms of parameters X and Y as

$$\begin{aligned}
\text{Quality of Design} &= \text{Prob.}\left[Y_i \in S_i,\quad i = 1, 2, \ldots, k / X_j \in I_j,\quad j = 1, 2, \ldots, L\right] \\
\text{Quality of Conformance} &= \text{Prob.}\left[X_j \in I_j,\quad j = 1, 2, \ldots, L\right] \text{ and} \\
\text{Quality of Performance} &= \text{Prob.}\left[Y_i \in S_i,\quad i = 1, 2, \ldots, k\right]
\end{aligned}$$

Defined as probabilities, these determinants of quality yields the modified quality equation

$$\text{Quality of Performance} = \text{Quality of Design} \times \text{Quality of Conformance} \tag{1.2}$$

1.9 Quality of a Process

Quality of a process to transform some input—hard or soft—into some output (which also could be hard or soft) as distinct from the quality of input is comprehended indirectly in terms of the quality of the output. For this purpose, a process is segmented into work items each of which may have a specified intermediate output or a specified start or finish time. This way, there are seven generic ways to measure quality of a process (taken as a collection of work items) besides the Cost of Quality, viz.

1. Defect, i.e. deviation from the relevant specification given in the process plan regarding any observable feature(s) of some items or elements in the process
2. Rework—when the deviation can be corrected by repeating some work item(s)
3. Reject or Scrap—when the deviation cannot be corrected
4. Late Delivery—in terms of the work output arriving late for the next work item or process

5. Work Behind Schedule—may be caused by the delayed completion of the preceding work item or otherwise
6. Lost Items—when the output of some work item(s) was not properly preserved or saved and could not be retrieved when required
7. Items Not Required—in terms of some work item (s) not relevant in the process or are redundant.
   [Items mean work items or elements]

We can apply these quality measures only when a comprehensive process plan has been in place, identifying the features of the process—may be in the different work items or elements—and specifying limits for these features. Features of a process may include feed rate of some in-process material into a machine, time during which an operation like heating or cooling should be carried out, temperature to be maintained during an operation like calcination of raw petroleum coke within a calcinator, etc.

The above measurements apply to office outputs or outputs of some service operation as well as to outputs of production–laboratory–warehouse processes.

Regarding the output, the process plan should specify the target and we can speak of the following levels or values of the output before or after the process is completed.

1. Target—the level of performance to be achieved (in terms of performance parameters related to the different work elements of the process).
2. Forecast—the level of performance which may be better or worse than the target depending on current business situation. The target also shows when the target will be reached, if at all it can be reached.
3. Actual—the level of performance achieved till date.

We can add two more entities here to be noted and acted upon by process management, viz.

4. Problem—the gap between the actual and the target levels, when the actual is worse than the target
5. Opportunity—for improving quality when the actual is better than the target, at no extra cost.

1.10 Measures of Quality

For any item—a product as the output of a manufacturing process or a processed material or a work-in-progress unit—it may be difficult to measure quality. One possibility is to relate this measure to different parameters or characteristics of the item that influence its quality defined in a particular manner and to compare accrual or realized values or levels of the parameters for the given item with intended or targeted or specified values or levels.

Sometimes it is easier to measure quality inversely, viz. in terms of deviations from the above values or levels from those specified (may be in the design). Such a deviation in one parameter may or may not imply that the product will fail to satisfy some 'use' requirements—for use in some subsequent production stage or by the customer or the user. A deviation that renders the product unfit for use or for satisfactory functioning is usually referred to as a 'defect'. The presence of at least one defect will render the product 'defective'. An inverse measure of item quality could then be a count of defects. One has to note that such a defect may arise whenever a parameter is assessed through inspection. Thus, any property or parameter that is inspected corresponds to an 'opportunity' for a defect to arise. Of course, there could remain properties or parameters which are not inspected, because of complacency leading to a conviction that there would not be a defect even if this property was inspected or because it is inconvenient or difficult or too expensive to inspect the property. Such a property is regarded as a passive opportunity for a defect to arise. Thus, considering an item or product unit with many active opportunities for defects, a count of defects should be related to the number of opportunities rather than the number of items inspected. Since product quality has been improving almost everywhere, defects per opportunity may turn out to be pretty small and may rather consider 'defects per million opportunities' of DPMO as a measure of quality, not for a single product unit but for a sample of units taken out of a process. An analogous measure could have been the total number of defects in the sample or in case the sample size varies and measures of quality across samples need to be compared, one could better take the proportion or fraction defective as the sample quality measure.

Measures like 'defects per unit' or DPU and 'defects per million opportunities', i.e. DPMO, are applicable to manufactured articles as also for office or administration work outputs. For example, a purchase order to be forwarded to a vendor for supply of a material may be inspected for its accuracy, adequacy as well timeliness. The communication could have an incorrect or incomplete address of the vendor, a wrong material or a wrong quantity of material to be delivered, a wrong delivery date or a wrong specification attached or an incorrect statement of financial terms, etc. Each one is an opportunity for a defect. If, say, 20 such orders are inspected and in each 25 elements are checked before the orders are passed on to vendors, the total number of opportunities would be $20 \times 25 = 500$ and if a total of, say, three defects are come across, DPU would be $3/20 = 0.15$ and DPMO would be $(3/500) \times 2000 = 12$.

As has been pointed out in an earlier section, we need to develop two types of measures, viz. (1) a measure for an individual item or unit and (2) a collective measure that applies to some aggregate of items or units defined to suit some context. It is just obvious that the second type of measures will be appropriate and effective summary of individual quality measures for the individual items or units constituting the aggregate of interest. Thus, dealing with on-line process control activities where the outputs of the process under consideration are distinct items or units, we may either examine selected items or units or consider sub-groups of several consecutively produced items or units. In the latter case we need a sub-group quality measure. Similarly, dealing with the problem of sampling inspection from lots of discrete units or items, we need to speak of a lot quality measure as also a sample quality measure.

Number of defects in an item and total number of defects in a sample or sub-group illustrate the two types of measures. The number of defectives in a sample or the fraction defective is collective measures of quality. To make such measures more effective for the purpose of control and improvement, we may classify defects and defectives into several categories, associate suitable weights for the different categories and consider weighted totals as the collective measures of quality. In cases of quantitative quality measures for individual items or units, sample statistics like the mean, the range or the standard deviation could be taken as collective measures. Defects and defectives can be defined conveniently for both qualitative and quantitative quality measures for individual items or units. More sophisticated measures of sample quality like the trimmed mean dropping outliers, progressive averages, moving averages, exponentially weighted moving averages or cumulative totals or cumulative means and comparable measures of variability or dispersion are also being used increasingly, since we now wield great computational power and it is of little concern which measure do we use.

1.11 Quality–Reliability Interrelationship

'Quality' or 'reliability' of an entity (a material or process or product or service) cannot be defined uniquely, and even definitions offered by standards organizations (including ISO) change over time.

In fact, the latest ISO definition (2005) of quality is quite broad, and in some sense, subsumes Reliability as one aspect of quality. This definition runs as:

Quality is the degree to which a set of inherent characteristics meets requirements.

There are three noticeable features of this definition. Quality has to be assessed only in relation to some requirements. Quality is built into the entity through a set of characteristics which are incorporated in the entity during the design and manufacturing phases, and quality is measurable, though the measure could be ordinal as also cardinal.

Amplifying this definition, it has been generally appreciated that there are four dimensions or even determinants of quality, viz. quality of design, quality of conformance, quality of performance and quality due to product support. In fact, quality in the usual sense (as accepted in SPC) is just quality of conformance to design requirements.

Assuming that the design requirements truly reflect all relevant aspects regarding materials, processes, checks and modifications which have a bearing on the quality of the output, quality of conformance does imply the desired quality, quality of conformance can be checked a pre-, during and post-production (at the finished goods stage).

Quality of performance is the most important dimension of quality that concerns the customer or user. And this dimension can be assessed only during use of the Output. This dimension along with quality due to product support (specially in cases of intermittent-duty and continuous-duty products) really determine the ability of the product to carry out the required functions during use of the product throughout its life cycle.

Product reliability is the composite of quality of design and quality of conformance (as also of quality due to product support, wherever necessary). With this explanation, reliability goes beyond quality of conformance. Sometimes, we argue that reliability is an extension of quality to 'to use of deployment' phase or reliability concerns begin where quality concerns end.

Whatever be the views adopted, it is well appreciated that quality and reliability are definitely related closely. In a bid to establish some differences between quality and reliability, we should go by the conventional definition of quality which can be assessed in terms of physical, chemical, biological and other relevant properties (known to influence the quality of output) which are either explicitly stated or just implied or even meant to be commonly in place, which are specified in the design and which can be checked at the incoming materials stage or during different stages of manufacture or during inspection of final output.

On the other hand, reliability can be assessed in terms of functional or performance parameters like time-to-failure or time between consecutive failures or time to repair or even values or levels of performance parameters (like luminosity or energy or load, etc.) that determine the ability of the product to function as desired. Quite of ten the requirements about performance parameters are not clearly stated and some of these parameters are not easily or conveniently measurable.

1.12 Concluding Remarks

Quality is enigmatic; it is elusive. No one can say the last word on any aspect of quality. Some critics of modern Quality Management with its emphasis on formal and rigid systems, regimented workers and alluring rigmaroles argue that products of days long gone by when none of the above aspects of Quality Management were present had generally better quality than the products offered in the markets today. This, of course, does not mean that we can afford to neglect all that have been developed over the recent years to comprehend quality in all relevant details and to improve quality in products and services, leading to a better quality of living. We can hardly ignore the fact the nature of production processes and the variety as well as volume of products and services have dramatically changed over the years at an exponentially increasing rate.

We should note that users in recent times insist on better and better quality in newer and newer products and more and more reliable services. The ever-increasing quantity and variety of goods and services with the growing demand for better quality is not felt only in the areas of manufactured items—as was the situation earlier—but also in all services that constitute a large segment of the consumption basket today. Thus, the need to start with a comprehensive understanding of quality in all its facets and in all spheres of human activity is just a bad necessity nowadays.

Quality considerations embrace both soft philosophical approaches as also hard scientific and technological approaches. To strike a balance is a difficult task. However, taking care of both the approaches along with their merits and limitations is highly desirable in any discourse on quality and Quality Management.

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