The Framework of Quality Measurement

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The paper describes general determinants of quality measurement. There are discussed four assumptions that have been formulated to develop the framework of quality measurement. The assumptions are: (1) quality is the degree to which a set of inherent characteristics fulfils requirements, (2) requirements and inherent characteristics create finite sets, (3) requirements may have both different importance and different values depending on who formulates them, and (4) requirements do not have to be constant in time. The article contains the framework of quality measurement based on above four assumptions. There are proposed notation on the quality measurement on booth synthetic and the analytical level. It also contains examples of selected distance metrics in m-dimensional space as well as examples of selected aggregate functions that may be used in quality measurement on synthetic level.

Key words: quality measurement, quality management, TQM

> I often say that when you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot express it in numbers your knowledge is a meagre and unsatisfactory kind – it may be the beginning of knowledge but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be.
>
> *Lord Kelvin*

Introduction

Much has been written about the importance of quality in any aspect of management and economy (Oakland 2014; Flynn, Schroeder, and Sakakibara 1995; Deming 1982; Juran and De Feo 2010; Juran 1999; Harrington 1991; Sousa and Voss 2002). There is no need to repeat generally known rules about significance of quality, but there is still a challenge how to measure the quality. As James Harrington had said: 'If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it' (Spitzer 2007, 19). Quality measurement methods are still being developed. There are specific methods for measuring the quality of a particular industry (Abbott 1999; Winkler and Mohandas 2008; Mor et al. 2003; Garvin et al. 2012; Alabaster and Lloyd 2013; Zoogman et al. 2011) but there is a need to develop a framework of quality measurement, which will set the standard of quality measurement.

To build the framework of quality measurement, it is essential to adopt certain assumptions about the essence of quality. Fundamental is the definition of quality.

The Assumptions About the Essence of Quality

The quality definition constitutes a basic assumption. There are many approaches to defining quality; most of authors quote categories of quality definition described by D. Garvin: the transcendent approach of philosophy, the product-based approach of economics, the user-based approach of economics, marketing, and operations management, and the manufacturing-based, value-based approaches of operations management (Garvin 1984; Sebastianelli and Tamimi 2002; Baker and Crompton 2000). Author of this article has adopted the definition of quality provided in clause 3.1.1 of the ISO 9000:2005, where the quality is defined as 'the degree to which a set of inherent characteristics fulfils requirements.' The authors of ISO 9000:2005 suggest the possibility of applying the notion of 'quality' with such adjectives as poor, good, excellent. According to the above-mentioned standard, 'inherent,' as opposed to 'assigned,' means existing in something, especially as a permanent characteristic. According to clause 3.1.2 of ISO 9000:2005, requirement is a 'need or expectation that is stated, generally implied or obligatory.' 'Generally implied' means that it is a custom or common practice for the organization, its customers and other interested parties, that the need or expectation under consideration is implied (note 1 to clause 3.1.2 of ISO 9000:2005).

The definition presented in the ISO standard is the most universal and, due to precise limitation of the notion of quality only to inherent characteristics and requirements, quality is clearly a measurable category. Use of the definition from the ISO standard enables also application of the framework of quality measurement in enterprises having a quality management system compliant with the ISO 9001 standard. Particularly, the proposed framework may be helpful in the fulfilment of the requirements described in items 7.3 (design and development) and 8.2.4 (product monitoring and measurement) of the EN ISO 9001 standard.

It has been assumed that *both formulated requirements and inherent characteristics may be of any number, but finite in both cases.* This does not mean that these sets must be equinumerous. A situation in which a series of inherent characteristics is responsible for fulfilment of the same requirement regarding the object cannot be excluded.

The Pareto principle, which states that 80% of the effects come from 20% of the causes, may be useful in the identification of both requirements and inherent characteristics. Translation of the Pareto principle directly into the quality measurement would mean that 20% inherent characteristics would affect the fulfilment of 80% of the requirements.

Another assumption allows the quality subjectivism; it means that *requirements may differ depending on who formulates them.* Particular requirements may differ with both their importance and desired target values. In particular, the most important thing for one type of stakeholder may be less important or generally unimportant for another stakeholder. Similarly, values of inherent characteristics can be completely different depending on who formulates the requirements. On the market are custom-delivered products and products addressed to a large amount of customers. The results of segmentation and analysis of values of particular segments determine whose requirements should be considered in a product.

More over *requirements do not have to be constant in time.* Usually, we observe the variability of requirements concerning their value, importance and number in time. Together with development of civilisation, standards expected from products and services may vary. Clear dynamics of changes in requirements may be observed on the market of modern technologies. For example, requirements regarding personal computer parameters from ten years ago or longer differ from the present-day standards. In addition, requirements concerning portable music players were different 20 years ago, and today the newer ones are valid. Many examples of changes in requirements in time may be provided. However, it is not a misapprehension that the discussed assumption has been formulated as a contradiction of the necessity of constancy of requirements in time, as it is possible to find such products and market segments where constancy of requirements is appreciated. For example, gastronomic services based on traditional meals are better assessed the closer they are to requirements posed many years, or even centuries, ago. On this market, quite a few producers boast of a recipe that has not changed for centuries.

Conceptualization of the Framework of Quality Measurement

In highly competitive market the quality management in organizations become critical, as well as the need of quality measurement. There were many attempts to develop quality measurement method. Most famous are Six Sigma, Servqual, and Servperf. There are also many conceptual models, for example: technical and functional quality model (Grönroos 1984), GAP model (Parasuraman, Zeithaml, and Berry 1985), attribute service quality model (Haywood-Farmer 1988), synthesised model of service quality (Brogowicz, Delene, and Lyth 1990), performance only model (Cronin and Taylor 1992), ideal value model of service quality (Mattsson 1992), evaluated performance and normed quality model (Teas 1993), evaluated performance (EP) framework (Teas 1993), normed quality model (Mattsson 1992), IT alignment model (Berkley and Gupta 1994), attribute and overall affect model (Dabholkar 1996), PCP attribute model (Philip and Hazlett 1997), retail service quality and perceived value model (Sweeney, Soutar, and Johnson 1997), service quality, customer value and customer satisfaction model (Oh 1999), antecedents and mediator model (Dabholkar et al. 2000), internal service quality model (Frost and Kumar 2000), internal service quality DEA model (Soteriou and Stavrinides 2000), framework for measuring service quality (Sureshchandar, Rajendran, and Kamalanabhan 2001), model of e-service quality (Santos 2003). Most of mentioned models are well described by Seth, Deshmukh, and Vrat (2005). There are opinions about Six Sigma that 'its focus on processes and variation is central to what is historically thought of as "quality control" and can be found in works by W. Edwards Deming and Walter A. Shewhart.' (Klefsjö, Wiklund, and Edgeman 2001). B. Morris had written, 'one of the chief problems of Six Sigma, say Holland and other critics, is that it is narrowly designed to fix an existing process, allowing little room for new ideas or an entirely different approach. All that talent – all those best and brightest – were devoted to, say, driving defects down to 3.4 per million and not on coming up with new products or disruptive technologies (Morris 2006).

In my opinion, all above mentioned methods and models are very specific and their authors omit the generic assumptions on the essence of quality. They especially omits assumption 3 (requirements may have both different importance and different values depending on who formulates them) and 4 (requirements do not have to be constant in time). On the operational level, authors of mentioned methods seem to ignore the phenomenon of limited substitution between inherent characteristic.

Quality measurement may be conducted on two levels: analytical and synthetic. On the analytical level, an n-dimensional vector of values of inherent characteristics describing the object's qualitative condition constitutes a measurement result. On the synthetic level, a measurement result is constituted by a dimensionless scale within the range $< 0, 1 >$, where 1 means full compliance of inherent characteristics with the requirements, while 0 means a complete lack of compliance, all other values represent partial compliance with the requirements, the higher degree to which a set of inherent characteristics fulfils requirements the closer the result of measurement is to 1. To interpret a measurement result on the analytical level, additional knowledge about identified requirements and inherent characteristics (particularly their importance and accepted ranges of variability) is necessary. Moreover, it is assumed that a recipient of measurement results knows the character of particular inherent characteristics (stimulant – the larger the better, destimulant – the smaller the better, nominee – nominal the best) and their impact on a degree of fulfilment of requirements. A requirement for additional knowledge means that the quality measurement results from an analytical level is addressed to individuals having expert competencies within the scope of a sector from which the tested object comes. On the synthetic level, a measurement result is much simpler for interpretation and more useful to compare the quality of objects by those who do not have expert knowledge within the scope of inherent characteristics of the object and identified requirements. On the synthetic level, measurement enables quality optimisation within a much larger scope than a measurement on the analytical level.

Having regard to adopted assumptions, each quality measurement is designated by the time of its occurrence and a subject formulating requirements. An individual unit (e.g. human being, organisation) or a group of units may constitute this subject. Both on the analytical and synthetic level, identification of requirements are done in order to determine the quality pattern of a desired object. *Quality pattern* contains list of inherent characteristics with a desired target value, importance and type (stimulant, destimulant, nominants). Depending on the size of the research population and the budget allocated to establish the requirements might be applied:

- study of all individuals,
- random sampling,

- stratified sampling,
- study of individuals regarded as pattern for appointed segments,
- determine the quality pattern by experts.

In the event of a group of units where full compliance of requirements does not occur, it is important to conduct a segmentation process where segments of similar requirements regarding an object shall be appointed. Such a division of subject where differences within a segment are minimised and differences between various segments are maximised constitutes the main principle of segmentation. Among the advantages of segmentation, McDonald and Dunbar (2010, 40) mention:

- recognising customer' differences is the key to successful marketing, as it can lead to a closer matching of customers' needs with the company's products or services;
- segmentation can lead to niche marketing, where appropriate, where the company can meet the needs of customers in that niche segment resulting in segment domination, something which is often not possible in the total market;
- segmentation can lead to the concentration of resources in markets where competitive advantage is greatest and returns are high;
- segmentation can be used to gain competitive advantage by enabling you to consider the market in different ways from your competitors;
- by means of segmentation, you can market your company as a specialist in your chosen segments, with a better understanding of the customers' needs, thus giving your products or services advantages over those of your competitors.

Development of a quality pattern includes three stages:

- Identification of requirements.
- Segmentation of requirements.
- Conversion the requirements of selected segments into values of inherent characteristics and determination of accepted ranges of variability for each characteristic.

In this paper, specific designations shall be adopted for the needs of framework of quality measurement. Ω shall designate a set of n vectors δ^n, where δ^n constitutes p-dimensional vectors of the following components $(\delta_1;\gamma_1), (\delta_2;\gamma_2), (\delta_3;\gamma_3), \ldots, (\delta_p;\gamma_p)$. Parameter p itself may have values from 1 to k, where k is the maximum number of identified requirements in relation to an object, which quality is measured. δ_i for $i = 1 \ldots p$ means the i-th requirement formulated by a unit in relation to the object, γ_i means importance of the i-th requirement on the interval scale $0 \ldots m$. For example, a very simplified set Ω of the number 2 for a passenger car might look as follows:

- δ^1 =< (δ_1 = fuel consumption (E95 petrol) below five litres per 100 km, $\gamma_1 = 7$ on the 10-point scale), (δ_2 = safety assurance in the event of head-on collision, $\gamma_2 = 10$ on the 10-point scale), (δ_3 = green car frame, $\gamma_3 = 3$ on the 10-point scale) >,
- δ^2 =< (δ_1 = fuel consumption (E95 petrol) below six litres per 100 km, $\gamma_1 = 6$ on the 10-point scale), (δ_2 = safety assurance in the event of head-on collision, $\gamma_2 = 10$ on the 10-point scale), (δ_3 = green car frame, $\gamma_3 = 0$ on the 10-point scale)>.

After completion of the segmentation process, the next stage is constituted by the exchange of a set of homogenous requirements (Ω_S segment), being Ω subset, into k-dimensional vector $\vec{X}$ of model values of the object's inherent characteristics. $\vec{X}$ vector includes k following components ($x_k; x_{k\_min}; x_{k\_max}; \beta_k$), where x_k is an optimal value of the k-th value, x_{k_min} is a minimal acceptable value of the k-th value, x_{k_max} is a maximal acceptable value of the k-th value, and β_k – is a coefficient defining importance of the k-th value on the interval scale $1 \ldots r$.

Customers' requirements do not have to be synonymous with values of inherent characteristics. Often, a subject formulating requirements does not acquire appropriate knowledge about the technology of the object performance and cannot define model values of inherent characteristics on its own. The part of the QFD method which concerns obtaining target values for technical parameters (field VIII in the QFD 'House of Quality'), may be used to exchange requirements into values of inherent characteristics. In addition, a result obtained through the QFD method should be completed with acceptable ranges of variability for each characteristic. Subsequent specification of requirements and inherent characteristics responsible for their fulfilment creates a precise documentation of the quality model expressed in units of inherent characteristics.

As regards the measuring abstractions Early and Coletti (2010, 123) claim that 'Some quality features seem to stand apart from the world of physical things. Quality of service often includes courtesy as a significant quality feature. Even in the case of physical goods, we have quality features, such as beauty, taste, aroma, feel, or sound. The challenge is to establish units of measure for such abstractions.'

TABLE 1 Scale of relative states

Classes of quality states	Class discriminant	State
0	0.95	Superb
1	0.85	Distinguished
2	0.75	Profitable*
3	0.65	Convenient*
4	0.55	Moderate
5	0.45	Intermediate
6	0.35	Inconvenient
7	0.25	Unfavourable
8	0.15	Critical
9	0.05	Bad

NOTES * Normal. Adapted from Kolman (2009, 38) and Dudek-Burlikowska and Szewieczek (2008).

In order to measure quality on the analytical level, it is necessary to define which inherent characteristics should be measured, in what units and with what accuracy. The framework of the object's quality measurement on the analytical level may be written in accordance with the formula:

$$Q(O, W_{in}, t) = < I_1, I_2 \ldots I_n >, \tag{1}$$

where O is the object of the quality measurement, t is the time of conducting the quality measurement, W_{in} is the type and number of inherent characteristics describing identified requirements together with units and accuracy of measurement, and $I_1, I_2 \ldots I_n$ are the values of subsequent inherent characteristics together with units of measurement.

The steps of the framework of the object's quality measurement on the analytical level are as follow:

1. Identify the requirements at a fixed time.
2. Find type and number of inherent characteristics describing identified requirements.
3. For each inherent characteristic establish unit and accuracy of measurement.
4. For each inherent characteristic provide the value expressed in established unit with established accuracy of measurement.

$$x'_i = \left(\frac{x_i - A}{B}\right)^p, \tag{2}$$

where x'_i is normalized value of x_i, x_i is the value of xi, A, B, p are the

TABLE 2 Selected aggregate functions (F), where β_i is the weight of the i-th standardised inherent characteristic (N_i)

$$F = \prod_i \beta_i N_i \tag{3}$$

$$F = \prod_i N_i^{\beta_i} \tag{4}$$

$$F = \left[\prod_i N_i^{\beta_i}\right]^{\frac{1}{\sum_i \beta_i}} \tag{5}$$

$$F = \sum_i \beta_i N_i \tag{6}$$

$$F = \frac{\sum_i \beta_i N_i}{\sum_i \beta_i} \tag{7}$$

$$F = \frac{\sum_i \beta_i}{\sum_i \frac{\beta_i}{N_i}} \tag{8}$$

$$F = 1 - \sqrt{\frac{\sum_i \beta_i (N_i - 1)^2}{\sum_i \beta_i}} \tag{9}$$

NOTES Adapted from Borys (1991) and Kolman (1973).

parameters, for $p = 1$ it is a linear transformation and for other values of p ($p <> 0$) is a non-linear transformation. A parameter is used to change the range of the features. Most appear on one of the following values: 0, $\overline{x}$, x_{min}, x_{max}. Parameter B serves as a scaling factor (deprives feature of unit) frequently takes on one of the following values: $\overline{x}$, x_{min}, x_{max}, $x_{max} - x_{min}$, S_x, $\sum_{i=1}^{n} x_i$.

In order to apply a measurement on the synthetic level, each inherent characteristic from the X set of values of the object's inherent characteristics (quality pattern) should be additionally completed with a function transforming absolute values to an established range of relative values. In this paper, the scale of relative states by R. Kolman with values from 0 to 1 shall be adopted as an established range of relative values (see table 1). Transformed values shall be designated as x_n. A form of transforming function (N_k) may be expressed with the formula 2. However, this formula has some limitations, as it assumes finite ranges of variability of inherent characteristics. If required, instead of a function equal to formula 2, in order to transform inherent values, one may use a function where the domain is constituted by an infinite set and co-domain by a finite set (e.g. logistic function). Figure 1 presents an example of a function transforming a range (W_{min}; W_{max}) of accepted variability of the object's inherent characteristic. It should be noted that in the given example the limited range of variability of inherent characteristics has caused limitation of the set of values of the transforming function.

In order to obtain a synthetic metric of the object quality, it is

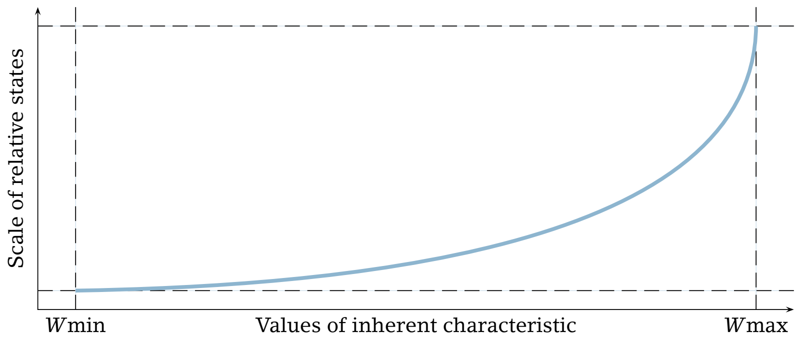

FIGURE 1 Example of a function (N) standardising a range ($Wmin; Wmax$) of accepted variability of inherent characteristic of an object

necessary to apply an appropriate function aggregating partial measurements of inherent characteristics on the relative scale. Table 2 presents selected aggregate functions. The quality of a perfect object on a relative scale may be achieved only when all normalized inherent characteristics equal 1. While using this fact, one may develop a series of aggregate functions based on metrics defining distances in finite-dimensional spaces. To this end, one should deduct from 1 (perfect quality) a distance between the point which subsequent coordinates designate inherent characteristics normalized to the scale of relative states, and the point which subsequent coordinates equal 1. Table 3 presents selected distance metrics in m-dimensional space. Such approach in similarities and dissimilarity measures is not new, for example it was applied in clustering (Gan and Wu 2007, 71–76).

The framework of the object's quality measurement on the synthetic level may be written in accordance with the formula below:

$$\begin{aligned} Q(O, W_j, t) = F[&(N_1(x_1; x_{1\_min}; x_{1\_max}); \beta_1), \\ &(N_2(x_2; x_{2\_min}; x_{2\_max}); \beta_2) \ldots \\ &(N_k(x_k; x_{k\_min}; x_{k\_max}); \beta_k)], \end{aligned} \tag{17}$$

where W_j is the quality pattern, O is the object of the quality measurement, t is the time of conducting the quality measurement, $N_k(x_k; x_{k\_min}; x_{k\_max})$ is the k-th function normalizing results of measurement on the analytical level to the dimensionless scale within the range $< 0, 1 >$, $F((N_1(x_1; x_{1\_min}; x_{1\_max}); \beta_1), (N_2(x_2; x_{2\_min}; x_{2\_max}); \beta_1) \ldots (N_k(x_k; x_{k\_min}; x_{k\_max}); \beta_k))$ is the function aggregating k normalised inherent characteristics $N_k(x_{k\_min}; x_{k\_max})$ with consideration of weight β_k. The formula of the F function should consider a

TABLE 3 Selected distance metrics in m-dimensional space, where $d_{i,k}$ is a distance of point x_j and x_k, $p > 0$

Minkowski distance	$d_{i,k} = \sqrt[p]{\sum_{j=1}^{m} \lvert x_{i,j} - x_{k,j} \rvert^p}$	(10)
Arched distance	$d_{i,k} = \sqrt{\frac{1 - \sum_{j=1}^{m}(x_{i,j} \cdot x_{k,j})}{\sqrt{\sum_{j=1}^{m} x_{i,j}^2 \sum_{j=1}^{m} x_{k,j}^2}}}$	(11)
Squared chord distance	$d_{i,k} = \frac{1}{m}\sum_{j=1}^{m}(\sqrt{x_{i,j}} - \sqrt{x_{k,j}})$	(12)
Bray-Curtis distance	$d_{i,k} = \frac{\sum_{j=1}^{m} \lvert x_{i,j} - x_{k,j} \rvert}{\sum_{j=1}^{m} \lvert x_{i,j} + x_{k,j} \rvert}$	(13)
Canberr distance	$d_{i,k} = \frac{1}{m}\sum_{j=1}^{m}\frac{\lvert x_{i,j} - x_{k,j} \rvert}{\lvert x_{i,j} + x_{k,j} \rvert}$	(14)
Clark distance	$d_{i,k} = \sqrt{\frac{1}{m}\sum_{j=1}^{m}\left(\frac{x_{i,j} - x_{k,j}}{x_{i,j} + x_{k,j}}\right)^2}$	(15)
Angular distance	$d_{i,k} = \arccos\frac{\sum_{j=1}^{m}(x_{i,j} \cdot x_{k,j})}{\sqrt{\sum_{j=1}^{m}(x_{i,j})^2 \sum_{j=1}^{m}(x_{k,j})^2}}$	(16)

NOTES Adapted from Gan and Wu (2007), Schmidt and Hollensen (2006), and Siarry and Michalewicz (2007).

limited substitution of inherent characteristics phenomena. Range $< 0, 1 >$ constitutes a set of values of function F.

The steps of the framework of the object's quality measurement on the on the synthetic level are as follow:

1. Develop a quality pattern at a fixed time.
2. Identify the requirements.
3. Perform segmentation of requirements.
4. Convert the requirements of selected segments into values of inherent characteristics and determine accepted ranges of variability for each characteristic.
5. For each inherent characteristic establish a function normalizing results of measurement on the analytical level to the dimensionless scale within the range $< 0, 1 >$,
6. Select a function aggregating all normalized inherent characteristics. The formula of the function should consider a limited substitution of inherent characteristics phenomena. Range $< 0, 1 >$ constitutes a set of values of selected function.

The adoption of $< 0; 1 >$ scale in the quality measurement on the synthetic level may cause some doubts. What happen when inherent characteristic level is in practice 'better' than requirement? What in practice means 0 on the adopted scale? Referring to the first problem, we need to define what and for whom 'better' level of inherent characteristic mean. Assuming that for stimulant it would be larger than required value, for destimulant it would be smaller than required value and for nominee it would be equal to required value, the result of quality measurement would be still 1. Based on formula (18) and assumption (4) it must be noted that quality measurement on the synthetic level is made with fixed quality pattern (established on the basis of segmented requirements formulated by some units in relation to the object), fixed time of conducting the measurement and assumption that requirements do not have to be constant in time. Let us consider quality measurement on the synthetic level in situation where in some time $(t+1)$ consumer (from segment to whom quality pattern was established in time t) was offered an object with inherent characteristic level 'better' than requirement established in quality pattern (fixed in time t). In this case there may be two option, firstly: 'better' inherent characteristic level may be irrelevant from the point of view of the consumer, secondly: requirements have changed therefore quality pattern become outdated and to measure the quality properly new quality pattern is needed.

Referring to the second problem, based on and assumption (3) (requirements may have both different importance and different values depending on who formulates them) quality measurement equal 0 made for the selected segment does not exclude the situation that for a different segment the same object would have higher quality as well as there may be situation that it is the product of different category and even for the same segment but different quality pattern would get higher quality value.

Conclusions

In light of the foregoing considerations, to accept that the quality measurement is a concept so obvious that it does not need to be systematized can not be considered as correct. The use of the framework of quality measurement can help to avoid many mistakes and misunderstandings resulting from the desire to measure the quality without clarifying fundamental assumptions. The adoption of the methodology proposed in this paper allows systematizing quality measurement booth on analytical and synthetic level. Based on the definition of quality contained in the widespread ISO 9000, the proposed methodology for measuring the quality can also be used to interpret the results of other quality measurements. For example, wherever in the results of quality measurement a large variance is observed there may be presumed that there was not properly executed segmentation process.

It seems that the problem of inherent values normalization has been sufficiently described in the literature. The challenge for measuring the quality is still to determine the appropriate aggregate function at the synthetic level of measurement. According to the author of this article may be assumed that there is a whole class of aggregate functions that may be appropriate depending on the type of the object being measured. Moreover, it can be assumed that through the use of scale of relative states, quality measurement results will be widely used in computer information systems.

References

Abbott, J. A. 1999. 'Quality Measurement of Fruits and Vegetables.' *Postharvest Biology and Technology* 15 (3): 207–25.

Alabaster, J. S., and R. S. Lloyd. 2013. *Water Quality Criteria for Freshwater Fish.* 2nd ed. London: Butterworth-Heinemann.

Baker, D. A., and J. L. Crompton. 2000. 'Quality, Satisfaction and Behavioral Intentions.' *Annals of Tourism Research* 27 (3): 785–804.

Berkley, B. J., and A. Gupta. 1994. 'Improving Service Quality with Information Technology.' *International Journal of Information Management* 14:109–21.

Borys T. 1991. *Kwalimetria, teoria i zastosowania.* Cracow: Akademia Ekonomiczna w Krakowie.

Brogowicz, A. A., L. M. Delene, and D. M. Lyth. 1990. 'A Synthesised Service Quality Model with Managerial Implications.' *International Journal of Service Industry Management* 1 (1): 27–44.

Cronin, J. J., and S. A. Taylor. 1992. 'Measuring Service Quality: A Reexamination and Extension.' *Journal of Marketing* 56 (3): 55–68.

Dabholkar, P. A. 1996. 'Consumer Evaluations of New Technology-Based Self-Service Operations: An Investigation of Alternative Models.' *International Journal of Research in Marketing* 13 (1): 29–51.

Deming, W. E. 1982. *Quality, Productivity, and Competitive Position.* Boston, MA: Massachusetts Institute of Technology Center for Advanced Engineering Study.

Dudek-Burlikowska, M., and D. Szewieczek. 2008. 'The Modern Quality Control of Preproduction Sphere in a Company.' *Journal of Achievements in Materials and Manufacturing Engineering* 30 (1): 79–86.

McDonald, M., and I. Dunbar. 2010. *Market Segmentation: How to Do It, How to Profit from It.* Berkeley, CA: Goodfellow.

Early, J. F., and O. J. Coletti. 2010. 'The Quality Planning Process.' In *Juran's Quality Handbook,* edited by J. M. Juran and J. A. De Feo, 3.1–3.50. New York: McGraw Hill.

Flynn, B. B., R. G. Schroeder, and S. Sakakibara, S. 1995. 'The Impact of Quality Management Practices on Performance and Competitive Advantage.' *Decision Sciences* 26 (5): 659–91.

Frost, F. A., and M. Kumar. 2000. 'INTSERVQUAL: An Internal Adaptation of the GAP Model in a Large Service Organization.' *Journal of Services Marketing* 14 (5): 358–77.

Gan, G., C. Ma, and J. Wu. 2007. *Data Clustering: Theory, Algorithms, and Applications.* ASA-SIAM Series on Statistics and Applied Mathematics 20. Philadelphia, PA: SIAM.

Garvin, D. A. 1984. 'What Does Product Quality Really Mean.' *Sloan Management Review* 26 (1): 25–43.

Garvin, J. H., S. L. DuVall, B. R. South, B. E. Bray, D. Bolton, J. Heavirland, and M. K. Goldstein. 2012. 'Automated Extraction of Ejection Fraction for Quality Measurement Using Regular Expressions in Unstructured Information Management Architecture (UIMA) for Heart Failure.' *Journal of the American Medical Informatics Association* 19 (5): 859–66.

Grönroos, C. 1984. 'A Service Quality Model and Its Marketing Implications.' *European Journal of Marketing* 18 (4): 36–44.

Harrington, H. J. 1991. *Business Process Improvement: The Breakthrough Strategy for Total Quality, Productivity, and Competitiveness.* Vol. 1. New York: McGraw-Hill.

Haywood-Farmer, J. 1988. 'A Conceptual Model of Service Quality.' *International Journal of Operations and Production Management* 8 (6): 19–29.

Juran, J. M. 1999. *Quality and Income.* New York: McGraw-Hill.

Juran, J. M., and J. A. De Feo. 2010. *Juran's Quality Handbook: The Complete Guide to Performance Excellence.* New York: McGraw Hill.

Klefsjö, B., H. Wiklund, and R. L. Edgeman. 2001. 'Six Sigma Seen As a Methodology for Total Quality Management.' *Measuring Business Excellence* 5 (1): 31–5.

Kolman, R. 1973. *Ilościowe określanie jakości.* Warszaw: PWE.

Mattsson, J. 1992. 'A Service Quality Model Based on Ideal Value Standard.' *International Journal of Service Industry Management* 3 (3): 18–33.

Mor, V., K. Berg, J. Angelelli, D. Gifford, J. Morris, and T. Moore. 2003. 'The Quality of Quality Measurement in US Nursing Homes.' *The Gerontologist* 43 (S2): 37–46.

Morris, B. 2006. 'New Rule: Look out, Not in.' *Fortune,* 11 July.

Oakland, J. S. 2014. *Total Quality Management: Text With Cases 4e.* London: Routledge.

Oh, H. 1999. 'Service Quality, Customer Satisfaction and Customer Value: A Holistic Perspective.' *International Journal of Hospitality Management* 18:67–82.

Parasuraman, A., V. A. Zeithaml, and L. L. Berry. 1985. 'A Conceptual Model of Service Quality and Its Implications for Future Research.' *Journal of Marketing* 49 (3): 41–50.

Philip, G., and S. A. Hazlett. 1997. 'The Measurement of Service Quality: A New P–C–P Attributes Model.' *International Journal of Quality and Reliability Management* 14 (3): 260–86.

Santos, J. 2003. 'E-Service Quality: A Model of Virtual Service Quality Dimensions.' *Managing Service Quality* 13 (3): 233–46.

Schmidt, M. J., and S. Hollensen. 2006. *Marketing Research: An International Approach.* New York: Pearson Education.

Sebastianelli, R., and N. Tamimi. 2002. 'How Product Quality Dimensions Relate to Defining Quality.' *International Journal of Quality and Reliability Management* 19 (4): 442–53.

Seth, N., S. G. Deshmukh, and P. Vrat. 2005. 'Service Quality Models: A Review.' *International Journal of Quality and Reliability Management* 22 (9): 913–49.

Siarry, P., and Z. Michalewicz, eds. 2007. *Advances in Metaheuristics for Hard Optimization.* New York: Springer.

Soteriou, A. C., and Y. Stavrinides. 2000. 'An Internal Customer Service Quality Data Envelope Analysis Model for Bank Branches.' *International Journal of Bank Marketing* 18 (5): 246–52.

Sousa, R., and C. A. Voss. 2002. 'Quality Management Re-Visited: A Reflective Review and Agenda for Future Research.' *Journal of Operations Management* 20 (1): 109–91.

Spitzer, D. R. 2007. *Transforming Performance Measurement: Rethinking the Way We Measure and Drive Organizational Success.* New York: AMACOM.

Sureshchandar, G. S., C. Rajendran, and T. J. Kamalanabhan. 2001. 'Customer Perceptions of Service Quality: A critique.' *Total Quality Management* 12 (1): 111–24.

Sweeney, J. C., G. N. Soutar, and L. W. Johnson. 1997. 'Retail Service Quality and Perceived Value.' *Journal of Consumer Services* 4 (1): 39–48.

Teas, K. R. 1993. 'Expectations, Performance Evaluation, and Consumers' Perceptions of Quality.' *Journal of Marketing* 57 (4): 18–34.

Winkler, S., and P. Mohandas. 2008. 'The Evolution of Video Quality Measurement: From PSNR to Hybrid Metrics.' IEEE *Transactions on Broadcasting* 54 (3): 660–8.

Zoogman, P., D. J. Jacob, K. Chance, L. Zhang, P. Le Sager, A. M. Fiore, and S. S. Kulawik. 2011. 'Ozone Air Quality Measurement Requirements for a Geostationary Satellite Mission.' *Atmospheric Environment* 45 (39): 7143–50.