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An instrument for quality performance measurement

A. De Toni*, G. Nassimbeni, S. Tonchia

Institute of Business Organization, University of Udine, Via delle Scienze-33100 Udine, Italy

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Abstract

An instrument for evaluating the quality performance measurement level and the quality performance results is presented. The instrument is based on the classification of quality in categories and classes; for each of them, the objects of the evaluation, the methodologies, techniques and indicators most useful and used for the quality measurement and control are described.

The instrument was tested in two large Italian manufacturing companies (Eaton Controls S.p.A. and Zanussi Elettrodomestici S.p.A.) and gave satisfactory results for the set up and improvement of the quality performance measurement and control system, and permitted a more effective benchmarking in relation to the quality performances.

1. Introduction

Nowadays quality is one of the best source of competitive advantage and high quality performance is becoming of crucial importance. Much has been said regarding quality management and practices [1], but very little exists in the literature concerning the measurement of the level of quality produced by a firm [2].

In this paper, an instrument for evaluating the quality performance measurement level and the quality performance results is presented. It analyses the quality measurement methodologies, techniques and indicators, and permits both the quality measurement level and the quality results obtained by a firm to be measured, in order to compare them in relation to the past ("self-evaluation") and to the best competitors ("benchmarking").

As illustrated in Fig. 1, the instrument is based on the classification of quality in three categories, which regard the overall aspects of quality and they should be measured separately, because they represent independent dimensions of the whole quality level of a firm:

- total quality offered,
- perceived quality and customer satisfaction,
- quality costs.

Top management, heads of the departments and workers are all responsible without particular distinctions; the results depend on management commitment, on investments and resource and operations management.

It is important to measure the level of total quality offered as a sole result of performance, but it is also relevant to measure the quality performance results of the single departments. So, the total quality offered becomes the result of the integration of several activities regarding the "value chain" (supplying and purchasing, production, sales and

* Corresponding author.

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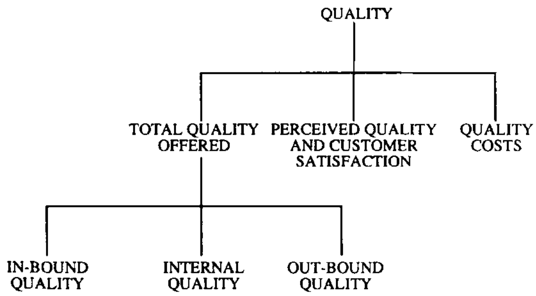

Fig. 1. Classification of quality for the measurement of quality performances.

TOTAL QUALITY OFFERED	IN-BOUND QUALITY	VENDOR QUALITY PERFORMANCE	
		VENDOR DELIVERY PERFORMANCE	
	INTERNAL QUALITY	PRODUCT DESIGN	Design Capability Design Performance
		PROCESS ENGINEERING	Process Capability Machine Availability
		MANUFACTURING	Conformance
	OUT-BOUND QUALITY	SALES & DISTRIBUTION QUALITY PERFORMANCES	Readiness Punctuality Reliability Serviceability

Fig. 2. Quality in relation to the value chain.

distribution). The quality in relation to the value chain (which we call "departmental quality") can be divided in three classes (Fig. 2):
- in-bound quality (vendor quality and delivery performance),
- internal quality (product design, process engineering, manufacturing quality performances),
- out-bound quality (sales and distribution quality performances).

2. Classification of quality

Now we will briefly describe the methodologies, techniques and indicators for measuring the above three categories and three classes of quality.

2.1. Total quality offered

It is measured by overall indicators such as the "modified productivity index":

$$\frac{(1 + p_1)/(1 + p_1 + p_2)}{(1 + p_1 r)} \cdot \frac{O}{I}$$

where O is the amount of output, I is the amount of input resources, p_1 is the output fraction that must be reworked, p_2 is the output fraction that is scrapped, r is the input consumption rate for an output unit reworking [3, 4].

The total quality is often evaluated according to the rules of some quality award (Malcom Baldrige National Quality Award, Deming Prize, European Quality Award, etc.).

2.2. Perceived quality and customer satisfaction

It is important to measure these because the total quality offered may not be entirely perceived by the customer or correspond to his expectations.

To evaluate this dimension of quality performance, the "snake charts" (importance and rank for each product characteristic), the "customer voice table" (complaints versus suggestions from the customer), the "quality map" (critical quality factors analysed on the Cartesian plane) [5] are valid instruments. Methodologies like QFD (Quality Function Deployment) [6], "servqual" (a service quality investigation framework) [7], and the "loss function" [8, 9] which is linked to a precise perceived quality target are also used. Two main ratios are usually calculated:
- perceived quality/expected quality,
- perceived quality/product price.

2.3. Quality costs

They can be classified as [10, 11]:
- quality maintenance costs (for supplier evaluation and internal procedure management),
- quality appraisal costs (for product sampling and testing),

- non-quality costs (due to reworking, scraps and rejected products, both before and after sales, and warranty repairs).

Several ratios can be constructed, linking together these and other types of costs [12]; for example:
- quality control costs/total labour costs,
- reworking and scraps and rejected-products-before-sale costs/total production costs,
- rejected-products-after-sale costs and warranty repair costs/amount of sales.

2.4. *In-bound quality*

This depends on the performance of the suppliers and on the effectiveness of the purchasing function in the evaluation of the suppliers. The objects of evaluation are the vendor quality and delivery performances. Among the instruments utilized, let us mention as examples the Pareto diagrams (percentage of defects in class-A, class-B etc., where class regards the graveness of the defects) and the barcharts (showing the lateness and the earliness of the deliveries). The purchasing function utilizes statistical sampling techniques [13, 14].

The main in-bound quality indicator is the Vendor Quality Rate (VQR); for example,

$$\mathrm{VQR} = \frac{U_{\mathrm{acc}}}{U_{\mathrm{acc}} + w_1 U_{r_1} + w_2 U_{r_2} + w_3 U_{r_3}}$$

where U_{acc} is the number of the accepted units, U_{r_1} is the number of the units rejected for minor defects, U_{r_2} is the number of the units rejected for more relevant defects, U_{r_3} is the number of the units rejected for major defects, w_1, w_2, w_3 are weights of importance (for example, respectively: 0.5, 1, 3).

2.5. *Internal quality*

This depends on (1) product design, (2) process engineering and (3) manufacturing.

2.5.1. *Product design*

The product design quality performances concern:

(a) the design capability,

(b) the design performance.

The design capability is measured by
- time-to-market (number of new products or important changes in a specified interval of time),
- planning adherence (for example, the sum of days of delay divided by the number of days requested by all the projects),
- design effectiveness (for example, the number of days spent on not-completed projects divided by working days) [15].

The design performance refers to two characteristics of the product: its reliability and its maintainability, measured, respectively, by indicators such as product MTBF (Mean Time Between Failures) and product MTTR (Mean Time To Repair).

2.5.2. *Process engineering*

The process engineering quality performances concern process capability (measured by the indicators known as C_p and C_{p_k}) [16, 17] and machine availability (measured by the machine MTBF and MTTR and by ratios such as: operating time/total time; reworking time/operating time).

C_p is defined as the ratio between the specification width (S) and the process width (P). In probabilistic terms, we can say that there is a C_p-chance that items produced will meet the product specification requirements, given the specification width and the process width (for example: $\pm 3\sigma$, where σ is the standard deviation of the process);

C_{p_k} considers the non-centring of the distribution, that is if the process mean does not correspond to the design centre: in this case we must take into account both spread and non-centring. C_{p_k} is defined as: $C_{p_k} = (1 - k) * C_p$, with $k = |D - M|/(S/2)$ where D is the design centre, M the process mean, S the specification width.

2.5.3. *Manufacturing*

Given some product characteristics which must be controlled and the minimum requirements for conformance, the manufacturing quality performances can be measured by the number of conforming units divided by the number of produced units [18, 19]. Several instruments are utilized: from the simple bar-chart and the Pareto diagram, to the more sophisticated single-variable control charts and multi-variable control charts.

Among the single-variable control charts, the most important and widespread are [20, 21]:
- the p-chart (controls the p-fraction of unconforming units in a sample),
- the np-charts (similar to the p-chart but the sample has always the same dimension),
- the c-chart (controls the c-fraction of unconformities in a continuum),
- the u-chart (similar to the c-chart but the continuum controlled is not constant in length or width),
- the $\bar{x}$-chart (controls the mean of the statistical samples means of a process variable),
- the R-chart (verifies the validity of the variability range allowed so that a process variable can be considered under control).

The latter two charts are economically advantageous because they control a process on the basis of some variables instead of on the fraction of unconforming units [22].

The multi-variable control chart permits more than one process variable to be checked in a single chart. It is used to monitor a process having several key variables which must be controlled [23, 24].

2.6. *Out-bound quality*

This depends on the performance of the sales and distribution department. Readiness, punctuality, reliability in terms of good quantity and mix delivered, and serviceability are the main performances of this quality dimension. Some indicators are listed here:
- the delivery reliability index (number of on-time complete orders/number of dispatched orders),
- the return rate (units returned/units sold),
- the call rate (service calls/units sold or the time interval),
- the serviceability indices (sum of days between call and intervention/number of interventions; sum of repair days/number of interventions).

3. Case studies

Two significant case studies are briefly presented here, in order to describe how the proposed generalized instrument can be used. Its application permits both the quality measurement level and the quality results obtained by a firm ("self-evaluation") to be evaluated. Then it is possible to compare ("benchmark") them with those of the best competitors or with those of the customers/suppliers to verify the mutual operative integration. In our case, Eaton Controls is an important supplier for Zanussi Elettrodomestici and Zanussi Elettrodomestici is an important customer for Eaton Controls.

3.1. *Eaton Controls S.p.A.*

Eaton Controls S.p.A. belongs to the Eaton Corporation, a group operating in 22 different countries and with a world quality award (the Eaton Quality Award) which entitles the winners to take part in the Malcom Baldrige Quality Award competition. Eaton Controls S.p.A. produces timers for domestic appliances, serving Zanussi, Whirlpool and Thompson.

Eaton Controls S.p.A. has a quality assurance staff, employed by the Eaton Quality Institute (Cleveland, OH), with the task of quality engineering and measurement.

Quality engineering consists in studies and research to improve the quality level of the production processes; furthermore it updates the firm quality system, certified according to the ISO 9000 standards [25].

Quality measurement is very advanced, based on the Eaton BPCS information system (the first established in Europe).

The *in-bound quality* is measured by a special empirically based Vendor Quality Rate (VQR):

$$\text{VQR} = 101 - (L_{\text{acc}} + L_{\text{res}} * 30 + L_{\text{rej}} * 100)/L_{\text{tot}}$$

with

L_{acc} = accepted lots,
L_{res} = lots accepted with reserve,
L_{rej} = rejected lots,
$L_{\text{tot}} = L_{\text{acc}} + L_{\text{res}} + L_{\text{rej}}$.

A good value is between 96 and 100.

There is a statistical control of the materials received, though all the suppliers are selected. The standard is the American 105 D Military Standard [26].

The *internal quality* is measured both for the design and engineering, and the manufacturing.

Time-to-market and product reliability are the main dimensions used to evaluate the design and engineering department. Weibull analysis [27] is employed during the beginning of the components life-cycle, while useful life is tested in order to certify the finished products. FMEA (Failure Mode Effect Analysis) [28] is a methodology used to calculate the so called "risk priority index", which is the product of three different scores: the failure occurrence probability, the failure severity and the failure detection probability.

Process capability is automatically checked (daily and monthly) both for components, subassemblies and finished products. The mean, maximum and minimum values of the process capability index C_{p_k} are widely diffused. The target value is 1.33.

Others indicators utilized are:

- the ratio between the value of scraps and the sold product cost,
- the ratio between the reworking hours and the total hours worked,
- the machine utilization.

Bar-charts, Pareto diagrams and the $\bar{x}$- and the R-control charts show the obtained quality performances.

The *out-bound quality* is measured in a simple way, because of the type of the product sold.

The *total quality* is measured according to the Eaton Quality Award. The results are summarized in a 7-ray diagram: each ray corresponds to the relative examination category of the Malcom Baldrige Quality Award on which the award is based [29].[1] The Eaton Quality Institute also compiles a Quality Improvement Plan Matrix, with six levels for the different areas involved in quality improvement (for each area, the actual and the target levels are highlighted).

The *perceived quality and customer satisfaction* are revealed as unconforming units returned by the buyers. The in-warranty returns are revealed too.

The *quality costs* are evaluated and classified in four types:

- internal unconformance costs (i.e. before sales),
- external unconformance costs (i.e. after sales),
- prevention costs,
- appraisal costs.

3.2. Zanussi Elettrodomestici S.p.A.

Zanussi Elettrodomestici S.p.A., a company of the Swedish Electrolux holding, is the biggest European producer of domestic appliances (with four product divisions and five main factories). The first quality project goes back to 1986 with the constitution of the Quality Assurance and Control staff. The Total Quality Project has existed since 1990, because of the awareness that quality is not a task for only one function but is the result of the integration of the different objectives (productivity, cost reduction, customer satisfaction, etc.) of different departments. Now the Quality Assurance and Control staff acts as a coordinator of improvement actions, as a divulger of the "language" and instruments (including problem-solving sessions [30], "kaizen" meetings [31] and permanent training programmes for all the employees), as the body responsible for the procedures and the measurement of the quality performances.

The *in-bound quality* is not a problem for Zanussi Elettrodomestici S.p.A., due to its advanced comakership policy (long-term collaborative programs exist) and the E.D.I. (Electronic Data Interchange) with its suppliers.

The *internal quality* is measured by indicators of unconformance. The defects are classified into four types:

(1) "Critical" (C) — defects dangerous for the user,
(2) "Primary" (P) — defects causing product unworking,
(3) "Secondary" (S) — defects that however permit the product to work,
(4) "Tertiary" (T) — aesthetic defects.

[1] Leadership, information and analysis, strategic quality planning, human resources development and management, management of process quality, quality and operational results, customer focus and satisfaction.

The indicators of unconformance are (the exemplum is referred to the machine-washers):

- the Safety Index S.I. is $1000 \times C/N$, where C is the number of critical defects after 6 working cycle of the product, and N is the number of products tested,
- the Quality Index Q.I. is $1000 \times P/N$, where P is the number of primary defects after one working cycle of the product, and N is the number of products tested,
- the Confidence Index C.I. is similar to the preceding index but the defects P are counted after 6 working cycles,
- the Reliability Index R.I. is similar to the preceding index but the defects P are counted after 60 working cycles,
- the Mean Quality Index M.Q.I., taken daily, is defined as $1000 * (P + 0.5 \times S + 0.1 \times T)/N$, with P referred to only one working cycle.

The processes are controlled by the $\bar{x}$ and the R-control charts.

The *out-bound quality* and the *perceived quality and customer satisfaction* are very important because the products are consumer products (machine-washers, dish-washers, fridges and freezers, cookers). The main indicator are: the call rate (calculated by model, component causing failure, productive line) and the fidelity index (brand re-buying percentage).

The *total quality* level is evaluated in relation to the product targets planned for each step of the Total Quality Project, at present still in progress.

Scraps and reworks are also measured and they constitute, with the rejected finished products (before and after sales) and the assistance service costs, the *cost of non-quality*.

In Zanussi Elettrodomestici S.p.A. the quality performance results are communicated to everybody: there is an internal journal (The Quality Letter) and huge coloured tables are set up near each productive line (bar-charts, etc.). There is also a box to collect suggestions regarding possible quality improvements.

4. The application of the instrument

The quality measurement and performances of Eaton Controls S.p.A. and Zanussi Elettrodomestici S.p.A. are presented, according to the scheme of Fig. 3 (for the sake of reserve, true values have been altered), which consists of four 3-ray diagrams; a comparison between the respective quality measurement and performances is illustrated: in fact one firm is respectively supplier and customer of the other, so an analysis of the tuning in the different quality performances could be very interesting.

The application of the instrument is shown in four 3-ray diagrams:

(A) the utilization of methodologies, techniques and indicators *for the measurement of the overall quality* (i.e. total quality offered, perceived quality and customer satisfaction, quality costs) among those available at the state-of-the-art level,

(B) the utilization of methodologies, techniques and indicators *for the measurement of the departmental quality* (i.e. in-bound, internal and out-bound quality) among those available at the state-of-the-art level,

(C) the *overall quality results* obtained in relation to the targets, in other words the level of effectiveness in achieving overall quality performances objectives,

(D) the *departmental quality results* obtained in relation to the targets, in other words the level of effectiveness in achieving departmental quality performances objectives.

These four diagrams can be compared with past diagrams (self-evaluation) and with the diagrams of the best competitors (benchmarking).

4.1. Calculation of the quality measurement (QM) level

The quality measurement level is calculated (for each type of quality: total quality offered, perceived quality and customer satisfaction, quality costs, in-bound quality, internal quality, out-bound quality) by the ratio

$$\mathrm{QM} = \sum_i w_i u_i \Big/ 4 \sum_i w_i$$

where w_i is the "importance weight" of the i-methodology, technique or indicator and u_i is the "utilization rank" by the firm.

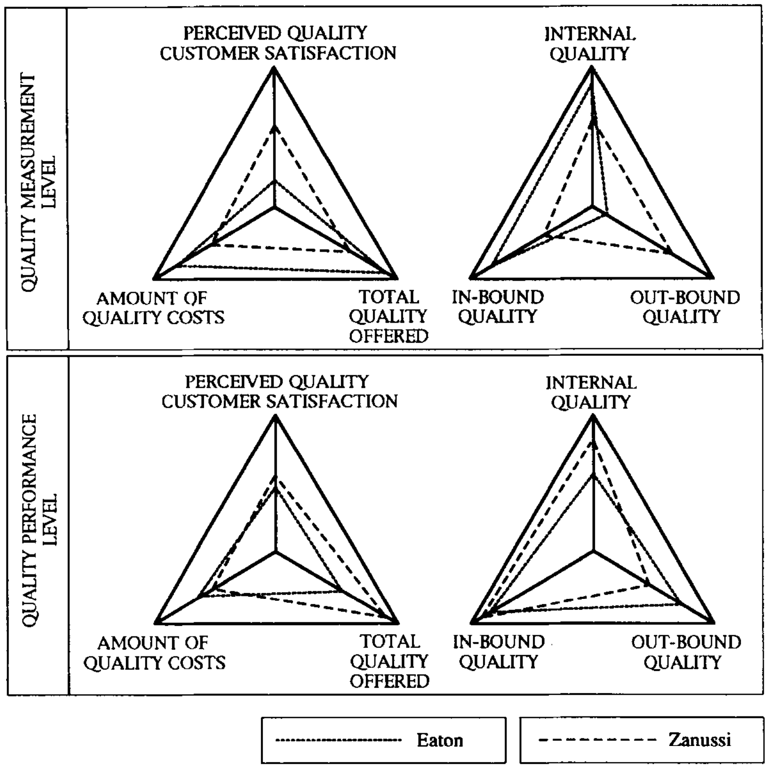

Fig. 3. Quality measurement level and quality performance level.

The utilization ranks vary from 0 to 4 (from "no utilization" to "strongly utilized"). In the denominator, the utilization ranks of all the methodologies, techniques and indicators has the value of 4, because it is hypothesized that there is a strong utilization of all at the level of the state-of-the-art.

The importance weights, which concern the relative importance of each methodology, technique and indicator, can be varied by each firm in relation to its dimension, industry, type of product or other particular situation. The importance weights for each methodology, technique and indicator are the same in the numerator and in the denominator.

The instrument furnishes a complete list of methodologies, techniques and indicators for each type of quality (some of these presented – for the sake of brevity – in section 2).

4.2. Calculation of the quality performance (QP) level

The quality performance level is calculated (for each type of quality: total quality offered, perceived quality and customer satisfaction, quality costs, in-bound quality, internal quality, out-bound quality) by the ratio

$$\mathrm{QP} = \sum_i w_i p_i \Big/ \sum_i w_i t_i$$

where w_i is the "importance weight" of the i-methodology, technique or indicator, p_i is the related "performance value" (the value of the indicator, or the value derived from the application of the methodology or technique for quality measurement), t_i is the related "target value" (or expected value of performance).

The performance and target values are normalized to ten, in order to have homogeneous values to sum together. So the possible values become comprised between 0.0 and 10.0 (from "very bad result" to "excellent result").

The importance weights vary from 1 to 5 (from "not very important" to "extremely important"); these weights are defined by each firm in relation to its dimension, industry, type of product or other particular situation.

The methodologies, techniques and indicators utilized are the same for the calculation of the quality measurement level.

5. Conclusions

In this paper, an instrument for the evaluation of the quality performance measurement level and the quality performance results obtained (in relation to the targets) is presented.

Although the literature in regard to themes of quality management and practices is plentiful, very little exists concerning quality performance measurement in detail and as an integrated system, so the proposed instrument can be considered a contribution in this sense.

The instrument is based on the classification of quality into different types, regarding the overall quality in terms of quality offered, quality perceived and customer satisfaction, costs (with common responsibilities among top management and heads of department). The "departmental" or "value chain" quality, with its departmental performance results and responsibilities, is also described. The proper methodologies, techniques and indicators for quality measurement regarding each type of quality are indicated; reference is made to the literature and they are integrated into a unitary framework.

Two significant case-studies are briefly described, in order to demonstrate the use of the instrument proposed, which has a general validity, in real situations.

The quality measurement level and the quality result level of each firm can be measured, if compared, respectively, with the state-of-the-art methodologies, techniques and indicators, and with the firm quality targets.

Using the same instrument, a benchmarking analysis of the quality performances can be made after self-evaluation.

Both self-evaluation and benchmarking furnish interesting information for quality improvement, quality measurement system set-up, competitive advantage acquisition.

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