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A Quality Performance Measurement Instrument

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1 - Introduction
High quality performance is becoming of crucial importance for companies operating on the international markets. Much has been said regarding quality management and practices [1], but though nowadays quality is one of the best source of competitive advantage [2], very little exists in the literature concerning the measurement of the level of the quality produced by a firm [3].

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 to measure both the quality measurement degree and the quality results obtained by a firm, in order to compare them for a self-evaluation in relation to the past, or with the degree and the results of the best competitors ("benchmarking").

The instrument is based on the classification of quality -fig.1- in three categories (or quality dimensions, which should be separately measured):

- total quality offered;
- perceived quality and customer satisfaction;
- quality costs;

with the distinction of the total quality offered in three classes, each of them contributes to the level of the total quality offered:

- in-bound quality (vendor quality performance and vendor delivery performance);
- internal quality (product design, process engineering and manufacturing quality performances);
- out-bound quality (sales & distribution performances).

For each category or class, the objects of the evaluation, the methodologies and techniques most useful and used for the quality measurement & control, and the relative quality indicators are described.

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

2 - A Quality Performance Measurement Instrument based upon the Integration of Methodologies, Techniques and Indicators for Quality Control
The quality performance measures can be divided into three categories regarding the overall aspects of quality (total quality offered, perceived quality & customer satisfaction, quality costs), which can be separately measured because they represent independent dimensions of the whole quality level of a firm.

The responsibility for these quality results is common: top management, heads of the department and workers are all responsible; the results depend on the management commitment, on the resource investments and resource management, on the operations
management. If it exists, the product manager has the role of coordinator of the activities in order to achieve the planned results.

The total quality offered, in detail, is the result of the integration of several activities regarding the "value chain" (supplying & purchasing, production, sales & distribution) [4]. While it is important to measure the level of total quality offered as a sole result of performance, it is relevant for the firm to measure the quality performance results of the single departments too.

We will first examine the measurement of the "value chain" quality; then the aspects of the overall quality (the total quality offered as a sole result of performance, the perceived quality & the customer satisfaction, the quality costs) will be discussed.

Fig.1 - A classification of quality for the measurement of quality performances

2.1 - The Value-Chain Quality

The quality in relation to the "value chain" is (fig.2):
- in-bound quality;
- internal quality;
- out-bound quality.

2.1.1 - The **in-bound quality** depends on the performance of the suppliers and on the effectiveness of the purchasing function in evaluating the suppliers themselves. The objects of evaluation are: the **vendor quality performances** and the **vendor delivery performances** [5]. Among the instruments utilized, let us mention as examples the Pareto diagrams (defects percentage for A-class, B-class etc. defects, where the class regards the importance of the defect) and the bar-charts (showing the lateness and the earliness of the deliveries, and the relative delivery variability) [6]. The purchasing function utilizes statistical sampling techniques for the evaluation of the suppliers [7].

The main in-bound quality indicators are: the number of A-class defects and the vendor quality rate. An example of vendor quality rate is given by the ratio:

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1 though, particularly, the marketing function has a great impact on the customer satisfaction: in fact the total quality could be very high and the customer could entirely perceive this high quality, but this does not correspond to his expectations.
\[ \frac{U_{\text{acc}}}{U_{\text{acc}} + 0.5 \times U_{R1} + U_{R2} + 3 \times U_{R3}} \]

where \( U_{\text{acc}} \) is the number of the accepted units, \( U_{R1} \) is the number of the units rejected for minor defects, \( U_{R2} \) is the number of the units rejected for more relevant defects and \( U_{R3} \) is the number of the units rejected for major defects.

### Table: Quality Performance

<table>
<thead>
<tr>
<th>TOTAL QUALITY OFFERED</th>
<th>IN-BOUND QUALITY</th>
<th>VENDOR QUALITY PERFORMANCE</th>
<th>VENDOR DELIVERY PERFORMANCE</th>
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<td>OUT-BOUND QUALITY</td>
<td>SALES &amp; DISTRIBUTION QUALITY PERFORMANCES</td>
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Fig.2 - The quality in relation to the value chain

2.1.2 - The internal quality depends on three entities: the product design, the process engineering and the manufacturing departments. Now we shall examine separately the quality performance of these departments.

2.1.2.1 - 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), the planning adherence (for example, the sum of days of delay divided by the number of days requested by the project), the design effectiveness (for example, the number of days spent for not-completed projects divided by working days of the design department) [8]. The design performance becomes evident in 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) [9].

2.1.2.2 - The process-engineering quality performances concern the process capability. There are two famous indicators, known as \( C_p \) and \( C_{pk} \) [10][11], which measure the process capability:

\( C_p \) 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 as a
specific value and the process width as -for example- ±3σ, where "σ" is the standard deviation of the process; also 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. \( C_{pk} \) is defined as: 
\[
C_{pk} = (1-k) \times Cp,
\]
with \( k = \frac{|D-M|}{S/2} \) correction factor or the ratio between the difference in absolute terms between the design centre (D) and the process mean (M), all divided by half the specification width (S).

There are other indicators which can indirectly measure the process capability: the machine MTBF and MTTR, the machine availability ratio (operating time / total time), the reworking rate (reworking time / operating time), the scrap rate (material scraps / total amount of materials worked).

2.1.2.3 - The manufacturing quality performances concern the quality level of the produced units. Given some product characteristics which must be controlled ("key variables") and the minimum requirement for conformance specified [12][13], the manufacturing quality performances can be measured by the number of conforming units on the number of produced units. Several instruments are utilized: from the simple bar-chart, the Pareto diagram and the "fishbone" diagram [14], to the more sophisticated single-variable control charts and multi-variable control charts.

Among the single-variable control charts, the most important and diffused are [15][16]:
- the p-chart (it controls the p-fraction of nonconforming units in a sample);
- the np-charts (similar to the p-chart but the sample has always the same dimension);
- the c-chart (it controls the c-fraction of nonconformities in a continuum);
- the u-chart (similar to the c-chart but the continuum controlled is not constant in length or width);
- the x-chart (it controls the mean of the statistical-samples means of a process variable);
- the R-chart (it verifies the validity of the variability range allowed for considering a process variable to be under control).

The latter two charts are economically advantageous because they control a process on the basis of some process variables instead of on the basis of the nonconforming units fraction [17].

The multi-variable control chart permits to control more than one process variable, in a single chart with specified upper and lower limits. They are used to monitor a process having several key variables which must be controlled [18][19].

2.1.3 - The out-bound quality depends on the performance of the sales & distribution department. It is the quality of the deliveries. Readiness, punctuality, reliability in terms of quantity and mix delivered, serviceability are the main performances. Some indicators are here listed: the D:P ratio (between the customer lead-time and the production lead-time), 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 indexes (sum of days between call and intervention / number of interventions; sum of repair-days / number of interventions) [20].

2.2 - The Overall Quality

The quality performances, regarding the overall quality, are: the total quality offered, the perceived quality with the customer satisfaction, and the costs of quality.
2.2.1 - The total quality is the result of integration of the in-bound, internal and out-bound quality. Each of these qualities is a condition for an overall high quality [21], which is measured by overall indicators such as the "modified productivity index":
\[
O\times(1+p_1)/(1+p_1+p_2)\times[I+r(1+p_1)]
\]
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 must be scrapped, "r" is the input consumption rate for an output unit reworking.

This type of indicator does not permit to individuate the single contribution of the departments. An alternative approach can be the measurement of the total quality level as a weighted summation of the department quality performances (for example: the in-bound quality, the out-bound quality and the internal quality splitted into product-design quality, process-engineering quality, manufacturing quality); nevertheless the choice of the most appropriate weights is not simple.

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

For the evaluation of the total quality, some methodologies and techniques are also used, even if they do not lead to specific quality indicators. The "value analysis" furnishes the contribution of each department in constructing the overall value-added to the product, after having separated its value components. The "regression curve" correlates the quality level offered with the market share [22][23][24].

2.2.2 - The perceived quality and customer satisfaction are evaluated in several ways [25]. They can be expressed by the ratio: perceived quality / expected quality; each of these two qualities are measured by a weighted summation (a rank for each product characteristic or functionality, weighted by an importance coefficient). The "snake" charts (importance and rank for each product characteristic), the "customer voice" table (complaints versus suggestions from the customer), the price-quality curve, the "quality map" (critical quality factors analysed on the Cartesian plane) are valid instruments [26][27] as well as methodologies like QFD (Quality Function Deployment) [28], the "servqual" questionnaire, and the Taguchi "loss function" [29], which is linked to a precise perceived-quality target [30].

2.2.3 - Finally, the quality costs must be evaluated. These ones can be classified as [31][32][33]:
- quality-maintenance costs (for the supplier evaluation and the 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 conditions).

Several ratios can be constructed, linking together these costs with other types of cost [34]:
- quality control costs / total labour costs;
- reworking and scraps and rejected-products-before-sales costs / total production costs;
- rejected-products-after-sales costs and warranty repair-intervention costs / amount of sales [35][36].

3 - Case Studies
Two significant case-studies are here briefly presented, in order to describe how the generalized instrument proposed can be applied. Its application permits to measure both the firm quality measurement degree and the quality results obtained by each firm, and then it is possible to compare ("benchmark") them with those of the best competitors of the firm, or with those of their own 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 client 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 - Ohio) and having the tasks of quality engineering and measurement.

Quality engineering consists of studies and research to improve the process quality level; furthermore it updates the firm quality system, certified according to the ISO 9000 standards [37].

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

The in-bound quality is measured by a special empirically-based vendor quality rate (VQR):

\[
VQR = 101 - \frac{(L_{\text{acc}} + L_{\text{res}} + 30 + L_{\text{rej}} + 100)}{L_{\text{tot}}}
\]

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

VQR is good if it is included between the values 96 and 100.

There is a statistical control in receiving materials, though all the suppliers are selected. The standard is the American 105 D Military Standard [38].

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

Time-to-market and product reliability are the main dimensions of evaluation for the design & engineering department. Weibull analysis is employed during the beginning of the components life-cycle, while useful life is tested in order to certify the finished products [39]. FMEA (Failure Mode Effect Analysis) is a methodology [40] used to calculate the so called "risk priority index", which is -for Eaton Controls S.p.A.- the product of three different ranks: the failure occurrence probability, the failure severity and the failure detection probability.

Process capability is automatically checked (daily and monthly) both for components, sub-assemblies and finished products. The mean \( \text{C}_{pk} \) and the maximum and minimum \( \text{C}_{pk} \) are data diffused to the people involved. The target value is 1.33. Others indicators utilized are: the ratio between the dollarized amount of scrap and the sold-product cost; the ratio between the reworking hours and the total hours worked; the machine utilization percentage; the total amount of hours in materials starving. Bar-charts, Pareto diagrams and the x- and the R- control charts are the methods adopted for showing 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 as the results obtained in the Eaton Quality Award world competition. The results are summarized in a 7-ray diagram: each ray correspond to the relative examination category of the Malcom Baldrige Quality Award which the Eaton Award is based on [41]. The Eaton Quality Institute also compiles a Quality

2 Leadership, Information and Analysis, Strategic Quality Planning, Human Resources Development and Management, Management of Process Quality, Quality and Operational Results, Customer Focus and Satisfaction.
Improvement Plan Matrix, with six levels for the several 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 un conforming units returned by the buyers (about 500-1500 p.p.m.). The in-warranty returns are revealed too (0.3-1.4%).

The quality costs are evaluated and classified in four types: internal un conformity costs (i.e. before sales), external un conformity 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 & Control staff. From 1990, the Total Quality Project exists, due to the awareness that quality is not a task for only one function but it is the result of the integration of the different objectives (productivity, cost reduction, customer satisfaction etc.) of the different departments. So now the Quality Assurance & Control staff acts as a coordinator of quality improvement actions, as a divulger of the "language" and instruments for quality (including problem-solving sessions [42], "kaizen" meetings [43] and permanent training programmes for all the employees), as the body responsible for the quality procedures and the measurement of the quality performances.

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

The internal quality is measured by several un conformity indicators. The defects are classified into four types: critical (C), or dangerous for the user, primary (P), or causing product un working, secondary (S), that however permit the product to work, tertiary (T), or aesthetic ones.

The "quality index" is defined as: 1000*P/N, where N is the number of products tested (one working cycle); the "confidence index" considers P after 6 working cycles, and the "reliability index" considers P after 60 working cycles. The "mean quality index", taken daily, is defined as: 1000*(a*P+b*S+c*T)/N, with a, b, c normally equal to 1.0, 0.5, 0.1 and P referred to only one working cycle.

The processes are controlled by the x- and the R- control charts.

The out-bound quality and the perceived quality / customer satisfaction are very important because the products are consumer products. 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 being 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 diffusion of the quality performance results is wide: there is an internal journal ("The Quality Letter") and huge coloured tables are set up near each productive line (bar-charts etc.), showing the results obtained. There is also a box to collect suggestions regarding possible quality improvements.

3.3 - The Quality Performance Presentation

It is possible to represent in four 3-ray diagrams the evaluation of the quality performances as the consequence of the application of the instrument proposed. The 3-ray diagrams concern:
Quality measurement degree and quality performances in relation to the targets

A) the utilization of methodologies, techniques and indicators for the overall-quality measurement (total quality offered, perceived quality & customer satisfaction, quality as a cost) among those available at the state-of-the-art level;

B) the utilization of methodologies, techniques and indicators for the departmental-quality measurement (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.

The utilization of methodologies, techniques and indicators [(A) (B)] is measured by a
ratio having as a numerator a weighted summation of ranks regarding the utilization by
the firm, and as a denominator the weighted summation resulting from the hypothetic full
utilization of all the methodologies etc. available at the level of the state-of-the-art³. In this
way, the ratio has a maximum value of one. The instrument furnishes a complete list of
methodologies etc. for each category/class of quality (some of these presented -for the
sake of brevity- in the 2nd paragraph). The utilization ranks vary from 0 to 4 (from "no
utilization" to "strongly utilized"); the weights, which concern the relative importance of
each methodology etc., can be varied by each firm in relation to its dimension, industry,
type of product or other particular situation.

The effective achievement of quality performances [(C) (D)] is measured by a ratio
having as a numerator a weighted summation of the results obtained (values of the quality
performance indicators used), and as a denominator the weighted summation of the
results planned ("target indicators"). In this way, the ratio can have a value that is more or
less than one. The instrument furnishes a complete list of indicators for each
category/class of quality (some of these presented -for the sake of brevity- in the 2nd
paragraph). The values of the quality indicators are normalized to ten, so the possible
values become comprised between 0.0 and 10.0 (from "very bad result" to "excellent
result") in order to have homogeneous ranks to sum together. In the summations there are
also indicator-importance weights, which vary from 1 to 5 (from "not very important" to
"extremely important"); moreover the weights can be varied by each firm in relation to its
dimension, industry, type of product or other particular situation.

In other words, the diagrams illustrate the quality-performance measurement degree
and the quality-performance results obtained. These four diagrams can be compared with
past diagrams (self-evaluation) or with the diagrams of the best competitors
(benchmarking).

The quality performances of Eaton Controls S.p.A. and Zanussi Elettrodomestici
are presented, according to the four 3-ray diagrams, in fig.3.; a comparison between the
respective quality 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.

4 - Conclusions

In this paper, an instrument for the evaluation of the quality-performance
measurement degree 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 and
about single techniques 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 & customer
satisfaction, costs, with common responsibilities among top management and heads of
department. The "value chain" quality, with its department-performances results and
responsibilities, are also described. The proper methodologies and techniques for the
measurement of the quality level for each type of quality are indicated; reference is made
to the literature, and then they are integrated in a unitary framework.

³ If alternative or similar methodologies etc. exist, the more effective one is considered for the utilization
at the-state-of-the-art level; the other ones will have minor relative importance coefficients.
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 degree and the quality results obtained by each firm can be measured, if respectively compared 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 the self-evaluation. Both the self-evaluation and benchmarking furnish interesting information for quality improvement, quality measurement system set-up, competitive advantage acquisition.

References
[41] Bush D., Dooley K., The Deming Prize and Baldrige Award: How They Compare, Quality Progress, no.1, 1990