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D.S. Demidenko, E.A. Iakovleva

MANAGEMENT AND MODELS OF QUALITY COSTS

Д.С. Демиденко, Е.А. Яковлева

УПРАВЛЕНИЕ И МОДЕЛИ ЗАТРАТ НА КАЧЕСТВО*

The concept of quality cost is defined by standard ISO9004. Optimization of quality costs is understood by the enterprises in different ways and always in a practical sense. There is possibility to consider optimization of quality cost as a distributive problem of optimum enterprise costs planning. Anality control cost and failure cost are interrelated and interdependent. Perfection of control processes can lead to a decrease in quality control expenses. Losses from failure cost can also be reduced due to the realization of relevant projects in manufacturing. The implementation of all similar projects demands additional expenses in manufacturing. There are expenses for preventive maintenance and failure costs. The limited resources of prevention cost can be distributed between failure costs and quality control cost. Optimum distribution of prevention cost is presented as a model of optimum planning and distribution of resources in manufacturing. A method for taking the optimum decision is presented.

QUALITY MANAGEMENT. ECONOMIC THEORY. QUANTITY AND QUALITY OF CONSUMED PRODUCTS. PREVENTION COSTS. CONTROL COSTS. FAILURE COSTS. OPTIMIZATION MODEL.

Концепция управления затратами на качество определяется стандартами ISO9004. Существует возможность рассмотрения оптимизации затрат на качество как проблему оптимального распределения расходов предприятия при внутрикорпоративном планировании. При этом затраты на контроль качества и потери на брак взаимосвязаны и влияют друг на друга. Совершенствование процессов управления может привести к снижению расходов контроля качества. Потери от брака также могут быть сокращены за счет внедрения соответствующих проектов в производстве. Однако осуществление всех аналогичных проектов требует дополнительного финансирования в производство. Кроме того, существуют профилактические расходы на обслуживание процесса и предотвращения брака. Оптимальное распределение затрат на качество представлено в виде модели оптимального планирования и распределения ресурсов в производстве.

МЕНЕДЖМЕНТ КАЧЕСТВО. ЭКОНОМИЧЕСКАЯ ТЕОРИЯ. КОЛИЧЕСТВО И КАЧЕСТВО ПРОИЗВОДИМОЙ ПРОДУКЦИИ. ЗАТРАТЫ НА КОНТРОЛЬ И ПРЕДОТВРАЩЕНИЕ БРАКА. ОПТИМИЗАЦИОННАЯ МОДЕЛЬ.

Quality management problems have been widely covered in the domestic scientific and practical fields while quality economic issues and corresponding models have not been developed. There has been a gap between the economic theory (economic models of quality) and practice (quality management). Basic economic concepts and models used in decision-making by economic subjects are, as a rule, based on the interrelation of quantitative and financial (price) variables, whereas quality is usually considered ceteris paribus (invariable). Possible approaches to quantify quality classes and corresponding models of decision-making by the manufacturer concerning quality and a commodity price will be considered in the article.

Management and models of quality costs

At present, experts have started viewing quality as one of the fundamental economic variables, such as demand / supply of products, market prices of products and «the quality price», economic growth and quality. Scientists rarely take into consideration the following questions:

1. Does quality as one of the fundamental economic variables define contents of economic models?
2. How does quality influences rates of economic growth and economic equilibrium?
3. What are features of the investment analysis in the context of quality problems?

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4. How does quality influence project's investment appeal and investment and operating risks?

Problems of the economic theory are not generally considered in such a «coordinate system». In the economic theory there are neoclassical models of quality by Jean-Jacques Laffont. However, necessity of such an approach is becoming more and more obvious.

Models of quality costs optimisation

According to the fundamental concepts of the economic theory, a utility function of the customer is determined by two variable parameters – by the quantity of consumed products (q) and by their quality (k). Integrated utility under these conditions is expressed analytically: $U\ (q,\ k)$. Differential utility function or marginal utility function (MUF) depends on limiting (increment) values of variables ($u(\Delta q,\ \Delta k)$). Marginal utility function is assumed to have an additive and linear character. The given assumption is in contradiction with the fundamental neoclassical statements about the utility function (decreasing marginal utility as basically it does not agree with the linear character of utility function).

However, in our opinion, the assumption of linearity of utility function with little changes of variables is still acceptable. With these assumptions, the marginal utility function can be represented as:

$$u(\Delta q,\ \Delta k) = a_k \Delta q + a_k \Delta k, \qquad (1)$$

where $u(\Delta q,\ \Delta k)$ is the differential utility function; a_q, a_k – are marginal utility of a unit of quality and unit of quality; Δq, Δk – variation in the quantity of consumed products (q) and their quality (k).

To define marginal utility function, marginal utilities of units of quality and units of quantity should be known and expressed in the identical measurement. A company strives for marginal utility function maximization under the existing resource restrictions and restrictions on the minimum admissible degree of quality and quantity of the products.

The problem of marginal utility optimization can be presented as following:

$$\begin{aligned} & u(\Delta q,\ \Delta k) \to \max \\ & r_q q + r_k k \le R \\ & q \ge \bar{q} \\ & k \ge \bar{k} \\ & q,\ k \ge 0 \end{aligned} \qquad (2)$$

or after its transformation according to maximization requirements:

$$\begin{aligned} & u(\Delta q,\ \Delta k) \to \max \\ & r_q q + r_k k \le R \\ & -q \le -\bar{q} \\ & -k \le -\bar{k} \\ & q,\ k \ge 0. \end{aligned} \qquad (3)$$

Here R – available resources; $\bar{q}$ – minimal requirements for the quantity of products; $\bar{k}$ – minimal requirements for the quality of products; r_q, r_k – norms of consumption of some generalized limited resource on production of a unit of quantity and a unit of quality.

The formulated optimization problem is, in its essence, an optimum plan of consumption for a company at existing limitations. As it has a linear character, a dual problem can be formulated and its substantial interpretation can be given:

$$\begin{aligned} & -P_k \bar{k} - P_q \bar{q} + Re \to \min, \\ & -P_k + r_k e \ge a_k, \\ & -P_q + r_q e \ge a_q, \end{aligned} \qquad (4)$$

here P_k, P_q, e – dual variables – the prices of products and resources.

Once again we reformulate the problem, now presenting it as a maximization condition:

$$\begin{aligned} & P_k \bar{k} + P_q \bar{q} - Re \to \max, \\ & P_k - r_k e \le -a_k, \\ & P_q - r_q e \le -a_q. \end{aligned} \qquad (5)$$

The dual problem represents conditions for manufacturing products. The criterion function, in this case, characterizes the criterion of the production efficiency – the added economic value. If the solution of a «direct» problem allows defining the optimum consumer plan, the solution of the «dual» problem allows defining the objective estimations of this plan, i. e. the prices. Dual variables express quantitative estimations of variables of «the quantity prices», «the quality prices» and the prices of resources in an optimum consumption plan. These are the prices of products and resources in the optimum plan. In this particular case, «products» are the quantity and the quality of manufactured goods.

The solution of the dual problem results in notional prices according to which the «exchange» is made, i. e. the quantity and the quality of manufactured goods are coordinated in a comparable way. The substantial meaning of the dual problem restrictions implies that neither quality of production, nor its quantity are given to a company «free of charge». The manufacturer pays for the «production» of the quantity and the quality of products with the reduction of its utility. Thus, the added economic value should not exceed decrease in utility – otherwise quantity and quality reproduction would make no sense. The obtained conditional calculative prices are coefficients for the recalculation of quantity and quality in a comparable way. The solution to the dual problem results in the prices according to which the quantity and quality are «exchanged».

One of the problems connected with the formation of a quality economic model directly depends on the nature of a quality category which, by definition, is difficult to quantify, as well as it duality from the point of view of the manufacturer and consumer as participants in the deal. On the one hand, the buyer sees the quantitative expression of quality as a bid price. At the same time, the buyer makes a decision concerning quality, namely, the decision to buy a product at a determined price, being based on incomplete information.

Since the consumer cannot define categorically all quality components when buying the product, his decision-making is based on «an adverse selection» principle, i. e. he understates «expected» evaluation concerning implicated quality parameters. A priori, it is possible to name this buyer's quality evaluation as consumer quality evaluation. After the product has been consumed, the consumer can generate the final quality evaluation a posteriori which can be either above, and below the initial price. On the other hand, the direct quantitative function of quality of the goods for the manufacturer is the amount of production costs. It is obvious that the basic stimulus for the manufacturer in decision-making on quality is to minimize costs.

Therefore the manufacturer, in general, will not be interested to improve quality of goods over aprioristic «skeptical» quality evaluation by the consumer. It concerns, first of all, «implicit» factors of quality which cannot be evaluated by the consumer when buying, for example, the reliability of durable goods.

Quality costs. Nowadays, difficulties in the development and the application of economic quality models are caused by deficiency of some fundamental economic concepts. The development of market processes leads to the reconsideration of the existing approaches to the economic problems one of which is the so-called «problem of quality costs». It has been formulated in the 1970s when quality management methods were rapidly developing all over the world, including Russia. The formulation of the economic model of quality costs is attributed to A. Fejgenbaum, a famous American expert in the field of quality systems. In its essence, it was a management model, based on the use of economic criteria. Quality costs in quality management system, according to this approach, should be considered as an element of this system and as a corresponding tool of economic management for the manufacturer. This tool of economic management, under market conditions, is aimed at achieving an internal balance by the manufacturer and gaining maximum profit. The model assumed that there was a separate group of production costs in the company which was caused by the level of quality of manufactured goods and necessity to maintain the determined quality in production. This group of costs has been named «quality costs». An approximate structure of costs and prospective influence of some expenses on the other ones were identified in the model. So the interrelation between the elements of costs in the quality management process has been formulated. The ways to minimize quality costs based on the effect of mutual influence of costs have been considered. Since economic management methods were not developed enough in our country in those years, scientists and experts did not find it interesting to study the interrelation and the mutual influence of elements of quality costs.

At the same time, much attention was paid to the issue of the cost structure and classification, as well as to philosophical aspects (what is interrelationship between quantity and quality; what are the expenses for quantity, if expenses for quality exist etc.). The economic side of the problem was definitely underestimated, manipulations with the classification and the definition of cost structure deformed its economic contents and true criterion function of management – quality cost reduction or achievement of the required quality with least costs. The market conditions epmhasised the hopelessness of the strategy «quality at any cost» both from the point of view of achievement of required quality (this approach cannot ensure quality anyway), and of production efficiency (there must be more effective areas to use operating resources at such approach). We include here the main provisions of the model of industrial quality costs just for historical information.

Quality costs (QC) are the total costs of the three above-named groups of expenses (prevention costs, control costs, failure costs) and criterion function of quality maintenance economic model is profit maximization of the company from minimization (economy) of quality costs which is ensured by the mechanism of mutual influence of expenses (Fig.1).

Fig. 1 shows that preventive expenses of the 1st group (quality preventive costs (QC_p)) are «managing directors» in management process and influence other costs. In the economic model, these expenses play a role of external variable, constant in relation to other variables and, consequently, they are not included into criterion function of model of management.

The traditional costs classification, included into existing the standards of the quality management system, comprises the following groupings of costs:

1. Prevention costs (QC_p) – expenses of quality preventive maintenance (revealing and eliminating causes of poor quality of producing) and also on perfection of production quality monitoring and quality evaluation of the product and production process.

2. Control costs (QC_c) – expenses of revealing inappropriate quality or on the control and quality evaluation of goods and production process.

3. Failure costs (QC_f) – expenses (costs, losses) of the production of inappropriate quality. These expenses can be divided into two groups: internal production costs (losses) of the manufacturer from inappropriate quality of the product and external expenses (losses) of both the manufacturer and the consumer because of inappropriate quality. In practice, when the system of the quality assuarance is developed and losses are compensated, consumer's expenses (losses) because of goods of inappropriate quality become internal expenses of the manufacturer, i. e. expenses of this group are mutually converted.

Under the influence of the preventive costs, the quality control costs will diminish provided:

1. The amount of the preventive costs is fixed according to the production plan of appropriate goods quality;

2. Production quality control is one hundred percent, including the goods of inappropriate quality;

3. Goods of inappropriate quality are not subject to correction or processing, according to the accepted definition of the target use of quality costs.

This decrease is caused by the direct reduction of controlled goods quantity due to the measures taken to eradicate the causes of poor quality. Consequently, the quantity of poor-quality goods decreases and the output of good quality goods increases. As a result, the total quantity of input decreases to produce the required amount of the good quality goods. This quantity of suitable goods is exposed to quality assurance, which, accordingly, leads to the reduction of quality assurance costs. Therefore there is a direct influence on the amount of specific expenses on quality assurance of goods which decrease due to the corresponding preventive measures directed, in a broad sense, at an in increase on the productivity of quality assurance processes. Under the influence of the preventive costs the quantity of poor-quality goods also diminishes as actions to eliminate the causes of discrepancy of quality to the established standards are taken. As a result, quality costs shrink since cost of poor-quality goods is part of it.

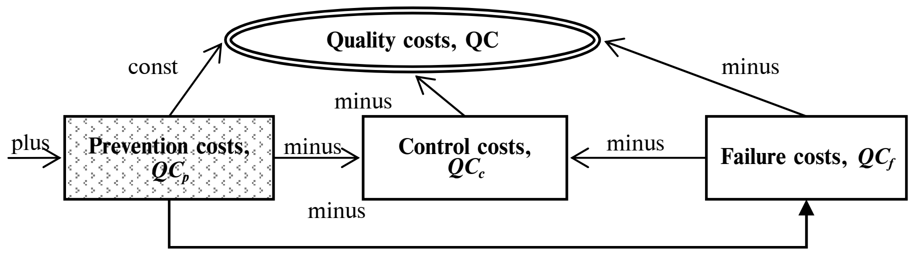

Fig. 1 The mechanism of mutual influence of expenses on quality

In a more comprehensive sense, the formulation of a problem of quality expenses is not anything else but an attempt to find application for the classical problem of optimum economic management in the field of quality management. It means that the quality management is considered as an economic problem and corresponding approaches and methods should be used to solve it. From this point of view, the minimization of quality costs can be allocated limiting (additional) expenses (costs) of the company for production perfection in directions: to increase quantity of manufactured products; to decrease direct industrial costs on manufacturing of a unit of goods (except quality costs); to take measures to decrease or indemnify factors of discrepancy of quality of goods to the established standards or direct industrial costs of an increase in the output of suitable goods (hereinafter these are expenses of production process improvement); to take measures to decrease current production costs of control and quality evaluation processes. Expenses are expressed in shares of the allocated limit of resources. Let us review control and quality evaluation expenses. The assumption (not quite realistic) is that the direction of all allocated resources can ensure zero level of these expenses.

Let's assume that the transformation of additional production costs of production into perfection into required results is described by a number of production functions. Production function reflects the transformation of additional production costs of production perfection into required result in the form of reduced quantity of goods which do not correspond to the established quality standards (increase in the output suitable). It is obvious, that if funds for process perfection are not allocated, quality of the process remains at the same level and, if all funds of the allocated limit are spent in the given direction, production improvement quality will be the greatest possible.

The following formulas are suggested to calculate actual quality expenses:

$$QC_f = Q\left(\frac{1}{y+kx} - 1\right),$$

$$QC_c = \frac{Q}{y+kx} a(1-x),$$

$$QC = QC_f + QC_c. \qquad (6)$$

$Q(X)$ – production function (in its classical understanding), reflects the quantity of manufactured goods depending on expenses of production factors, at the set planned output should be $X = 0$, $Q(X) = Q = \text{const.}$ – it is set by the plan, a – reduction in expenditure marginal level on the control and quality evaluation at allocation of one additional unit of resources.

Abbreviations and numerical values for a considered settlement example are given in the Tab. 1.

Table 1

Real quality costs

Indicator, amendment unit	The Designation.	Numerical significance
Quantity of goods according to plan (unit)	Q	1
Output suitable without improvements (a share unit)	y	0,7
Expenses of the control of a unit of goods (a share monetary unit)	a	0,4
The multiplicator of an output suitable (unit shares / additional monetary unit)	k	0,3

Here the allocated size of expenses of improvements (x) «runs» all values with the accepted numerical interval from 0 to the size of the allocated limit. The optimizing problem of minimization of quality costs is reduced to optimum distribution of the restricted limit of the allocated resources of expenses of production improvement among all quality expenses.

The definition of the minimum size of total quality costs ($QC = QC_f + QC_c$). With numerical values of parameters $QC_f = f_1(x)$ and $QC_c = f_2(x)$, we receive:

$$f_1(x) = \frac{3(1-x)}{7+3x};$$

$$f_2(x) = \frac{4(1-x)}{7+3x} = \frac{4}{3} f_1(x). \qquad (7)$$

Thus, we come to the following statement of the problem. Entering function $f(x) = \frac{3(1-x)}{7+3x}$, it is required to find the least value of function of two variables: $F(x, y) = f(x) + \frac{4}{3} f(y)$ in the area: $0 \le x \le 1$, $0 \le y \le 1 - x$.

Table 2

Calculation of real components of quality costs.

x		0,000	0,100	0,200	0,300	0,400	0,500	0,600	0,700	0,800	0,900	1,000
	3k/36	0,571	0,493	0,421	0,354	0,293	0,235	0,182	0,132	0,085	0,041	0,000
0,000	0,429	1,000	0,922	0,850	0,783	0,722	0,664	0,611	0,561	0,514	0,470	0,429
0,100	0,370	0,941	0,863	0,791	0,724	0,663	0,605	0,552	0,502	0,455	0,411	
0,200	0,316	0,887	0,809	0,737	0,670	0,609	0,551	0,498	0,448	0,401		
0,300	0,266	0,837	0,759	0,687	0,620	0,559	0,501	0,448	0,398			
0,400	0,220	0,791	0,713	0,641	0,574	0,513	0,455	0,402				
0,500	0,176	0,747	0,669	0,597	0,530	0,469	0,411					
0,600	0,136	0,707	0,629	0,557	0,490	0,429						
0,700	0,099	0,670	0,592	0,520	0,453							
0,800	0,064	0,635	0,557	0,485								
0,900	0,031	0,602	0,524									
1,000	0,000	0,571										
QC optimum		1,000	0,922	0,850	0,783	0,722	0,663	0,597	0,551	0,498	0,448	0,398

Thus $f'(x) = \frac{30}{(7+3x)^2} < 0$. This function $f(x)$ monotonously decreases. It means that it reaches the least value on the right end of an interval. Therefore the least value of function $F(x, y)$ cannot be reached in a triangle or on its legs of a triangle. It will be reached on its hypotenuse $y = 1 - x$.

Hence, it is required to find a function minimum: $g(x) = f(x) + \frac{4}{3} f(1-x)$, $0 \le x \le 1$. Write the equation to find a minimum point:

$$g'(x) = f'(x) - \frac{4}{3} f'(1-x) = \\ = \frac{40}{(10-3x)^2} - \frac{30}{(7-3x)^2} = 0.$$

This equation is reduced to a quadratic and also has a positive root $x \approx 0{,}2966$. Thus, the least value required $9x^2 + 348x - 104 = 0$ and $F_{\min} = g(0{,}2966) \approx 0{,}3977$.

The given size is expressed in cost units.

The solution is presented in the calculation Tab. 2.

In the given example, quality cost optimization, i. e. the minimum size of accumulated costs of the control and losses from poor quality is considered at various (allocated) values of expenses of prevention of defects that have been set in advance, as the table shows (the minimum value on each of diagonals). The total minimum value of quality costs corresponds to the minimum value on that diagonal of the calculation table which corresponds to a certain value of the allocated resources in the realization of preventive maintenance of quality (prevention cost). The size of preventive costs run all values from 0 to 1 with the chosen interval of change. Minimum costs corresponding to these values on quality are shown in the bottom line of the calculation table. From it, it is obvious that the more resources are allocated for preventive maintenance, the lower are accumulated quality costs. Economy has to be paid for! Note. Direct quality costs, i. e. direct costs of operating resources or production factors on manufacturing, according to the norms and in correspondence with the requirements to the applied engineering procedures are hereinafter considered. Costs or expenses of resources which, at the same time, constitute a significant share of quality costs are not considered, being indirect or constant in relation to the production volume. The reason is that economic models of production optimization are developing by neoclassical principles of marginal economic analysis which does not consider fixed costs when analyzing current production costs (marginal fixed costs are equal to 0). Fixed costs can be considered in the investment analysis at performance evaluation of the capital investment projects used to improve managerial processes in quality systems. However, the problem of quality costs minimalization is traditionally considered as a problem of current production costs management. Here we stick to this rule.

Conclusions. Quality costs are the total sum of prevention costs, control costs, failure costs and criterion function of economic model of quality maintenance which is profit maximization of the company from minimization (economy) of quality costs. There is a possibility to consider the optimization of quality cost as a distributive problem of optimum enterprise costs planning. Cost control and failure cost are interconnected and influence each other. Optimum distribution of prevention cost is presented as a model of optimum planning and distribution of resources in manufacturing. Financial management methods (formation of an additional profit through costs reduction owing to efficient management through investments and disinvestments into company's assets and quality management model which is self-balanced) are used to describe the influence of quality costs in the enterprise management system.

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DEMIDENKO Daniil S. – St. Petersburg State Polytechnical University.
195251. Politekhnicheskaya str. 29. St. Petersburg. Russia. E-mail: demidenko11@rambler.ru

ДЕМИДЕНКО Даниил Семенович – профессор кафедры «Финансы и денежное обращение» Санкт-Петербургского государственного политехнического университета, доктор экономических наук, профессор.
195251, ул. Политехническая, д. 29, Санкт-Петербург, Россия. E-mail: demidenko11@rambler.ru

IAKOVLEVA Elena A. – St. Petersburg State Polytechnical University.
195251. Politekhnicheskaya str. 29. St. Petersburg. Russia. E-mail: helen812@pochta.ru

ЯКОВЛЕВА Елена Анатольевна – профессор кафедры «Финансы и денежное обращение» Санкт-Петербургского государственного политехнического университета, доктор экономических наук, профессор.
195251, ул. Политехническая, д. 29, Санкт-Петербург, Россия. E-mail: helen812@pochta.ru