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Cost of quality and quality optimization in manufacturing

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Abstract

This article looks to find the optimization between the quality of manufactured products and the components of the costs of quality, including prevention cost, appraisal cost, internal failure cost and external failure cost. The results for all products, such as automobiles, appliances and electronic devices can be used. Any serious attempts to improve quality must take into account the costs associated with achieving quality, since nowadays it does not suffice to meet customer requirements, it must be done at the lowest possible cost as well. In the current business environment, management accountants and designers need tools and to develop models for decision making and planning with the reduction in quality costs of the products to provide products with high quality in order to create value for an organization. In this paper, to improve (optimize) the quality and components of the costs of quality, a kind of ant colony algorithm under the title of minimum and maximum ants system has been implemented. The current study has at least one aspect of innovation. On the international level, no research has been done in regards to the relationship between quality and the costs of quality. It was found that from a product differentiation point of view and a cost leadership point of view what component of a product best leads to the optimization of the relationship between cost of quality and quality.

Keywords: Cost, Quality, Optimization, Manufacturing, Management Accounting.

Introduction

Improving quality of product and services is considered by entities to be the best way to improve customer satisfaction, to reduce manufacturing costs and to increase productivity. Any serious attempt to enhance quality must take into account the costs related with achieving quality. Not only quality does not suffice to just meet customer requirements but also it must be done at the lowest possible cost as well. Reducing cost and expenses can only happen by identifying and measuring the cost associated with improving quality (Schiffauerova and Thomson, 2006).There isn't any general agreement on a single broad definition ofcosts ofquality. Quality Cost is usually understood as the sum of conformance, the cost paid for prevention of poor quality (for example, quality appraisal andinspection), plus non-conformance costs, the cost of poor quality caused by service and product failure (for example, returns andrework) (Vaxevanidis and Petropoulos, 2008).

The broad concept of the ''economics of quality'' can be traced back to the early 1950s when the quality cost was first propounded in Juran's Quality Control Handbook and in Feigenbaum's Total Quality Control. Since then, many qualitycontrol experts have written about cost of quality systems and the importance of quality related costs has been more and more recognized. Costs related to theQuality represent a considerable amount of a company's total costs and sales (Vaxevanidis and Petropoulos, 2008).

No matter which quality costing approach is used, the main idea behind the cost of cost analysis is the linking of improvement activities with associated costs and customer expectations, thus allowing targeted action for reducing costs of quality and enhancing quality improvement benefits. Therefore, a realistic estimate of quality cost, which is the appropriate tradeoff among the levels of conformance and non-conformance costs, should be considered avery important element of any quality initiative and a critical matter for any top manager. These days, many organizations are seeking both theoretical advice and practical evidence about quality related costs and the implementation of cost of quality systems (Schiffauerova and Thomson, 2006). Almost

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all quality managers' consultants have cost of quality plans as an integral part of their repertoire (Campanella, 2003). When quality troubles are presented in the form of financial language, managers understand these problems and they can assist managers evaluate the importance of quality problems and also recognize opportunities for cost reduction (Rodchua, 2006). Monitoring and controlling costs of quality are becoming critical activities of quality improvement programs.

In this paper, a new ant colony algorithm has been developed for the optimization of a trade off between the Costs of Quality and the quality of the product. The algorithm will look to find the optimal combination of product quality versus cost for the various businesses that now recognize the importance of a quality cost control. This technique is helpful for both product designers and manufacturing managers who want to create value for the organizations.

Framework of Theory

Quality

Quality is a confusing term understood differently by different people. It is sometimes defined as activities designed to improve the organization and its services and also is known as achieving a pre-defined standard. It is also believed that quality is the characteristics of a service or product that bear on its ability to affect customers' buying decisions and satisfaction which is a determining factor influencing activities of entities (Rahnamayroodposhti, 2008). If a product fulfills the expectations of customers, the customer will be pleased and consider that the services and productsare of acceptable or even high quality. If his or her expectations are not fulfilled, the customer will consider that the services and products are of low quality. This means that the quality of a product or service may be defined as its ability to fulfill the customer's needs and expectations. Quality needs to be defined first in terms of characteristics orparameters, which vary from product to product. For example, for an electronic or mechanical product these are performance, reliability, safety and appearance. For pharmaceutical products, parameters such as chemical and physical characteristics, toxicity, medicinal effect, taste and shelf life may be important. For a food product they will include nutritional properties, taste, texture, and shelf life and so on (UNIDO, 2006). Customers seek for maximum quality and if they able to pay its price then it would tell that quality is free. Because of the trade-off between cost and quality, to maximize the profit this theory is not always true (Hilton *et al.*, 2008).

It is believed that quality is a factor affecting decision making and paying attention to it can make the decision economic. In other words, avoiding quality, as a worthwhile investment, is not economic. Quality is not an abstract, instrumental, luxurious and unnecessary characteristic of the business, but it is a culture, life style, paradigm and new approach to the managerial thinking. Giving serious attention to quality is found to be the main success factor of those organizations which are undisputed economic powers in today's world and have a high share of the global market (Rahnamayroodposhti, 2008). Quality management points to the strategic policies, methods and procedures assuring production of high quality products and services covering customers' demands. It should be noted that quality measurement indicators include the employer's level of satisfaction, quality of the finished product and the extent to which the customer's needs and demands are satisfied.

A product specification is the minimum requirement according to which a service or producer provider makes and delivers the service and product to the customer. In setting specification limits, the following should be considered in order to gain marketing advantages: The user's and/or customer's needs, requirements relating to product safety and health hazards provided for in thestatutory and regulatory requirements, international and/or national standards, and the competitor's product specifications.In designing the product, the capacity of machines and processes should be kept inmind. It is also necessary to maintain a trade-off between value realization and cost. The drawings and specifications produced by the designer should show the quality standard demanded by the customer or marketplace in clear and precise terms. All dimensions should have realistic tolerances and other performance requirements should have precise limits of acceptability so that the production team can manufacture the product strictly according to drawings andspecification. To achieve good quality, those responsible for design, production and quality should be consulted from the sales negotiation phase onwards. The overall design of any productis made up of numerous individual characteristics. For example these may be dimensions, such as diameter, length, thickness or area; physical properties, such as volume, weight or strength; electrical properties, such as resistance, current orvoltage; appearance, such as finish, texture or color; functional qualities, such as output or kilometer per liter; effects on service, such as feel, taste or noise level. Manufacturing drawings and specifications are set by the designers and these should indicate to the production team precisely whatraw materials should be used andwhat quality is required. After the design, including the manufacturing drawings, has been reviewed and finalized, it is time to plan for manufacture. This will include deciding on the method of manufacture, providing the necessary plant, machines, tooling and other equipment, obtaining satisfactory raw materials, obtaining and training suitable operators, planning inspection and shop floor quality control.

Costs of Quality

Cost is traditionally known as price of making goods or doing the services by which cost accounting considers various approaches and in a new paradigm, management accounting deploys knowledge of cost management. There is a direct relationship between cost and organization efficiency. From this perspective, efficiency means the ability to convert input to the output with the lowest cost (Hilton *et al*, 2008). Cost management is an approach used to realize decisions made for planning, controlling and developing competitive strategies and it is noteworthy to say that making balance between this factor and other dimensions of competition such as quality and time is required to apply management on it aim to help maximize profits and value creation of the organization in current activities and future ones (Rahnamayroodposhti, 2008). Cost management is found to be a major tool to achieve strategic goals. Service or product costs include direct and indirect (overhead) costs. Cost is the result of resource consumption and actually is regarded as those resources sacrificed to gain value. To save resources and costs in the course of this process, it is necessary to remove those activities without value added and to strengthen and combine parallel activities seeking to create value. It should also be noted that those activities required to improve and complete the quality of services must be added to the organization's activities.

After revenue, cost is one of the main characteristics of any business. All organizationsare seeking to reduce their cost to finally be able to optimize wealth of shareholdersand to create value.The cost ofa given product or service is usually computed by enumerating its features. You can't reduce the cost without sacrificing features or deadlines. You can't increase features without incurring extra costs. Everyone likes to control the cost factor because it is the easiest to see the effect on bottom-line profitability.

The American Society for Quality's (ASQ) Quality Cost Committee, established in 1961, worked to formalize the quality and to promote its use (Bottorff, 1997). ASQ recognizes four categories of quality costs: (1) prevention cost (PC); (2) appraisal cost (AC); (3) internal failure cost (IFC); and (4) external failure cost (EFC) (Bemowski, 1992). These categories have been well accepted within the quality and accounting professions, and have been acknowledged internationally. However, in many companies quality cost is not calculated explicitly but are simply absorbed into other overheads (Shepherd, 2001). Cost of Prevention are the costs related to all activities to prevent defects from occurring and to keep appraisal and failure to a minimum. These costs include new product review, quality planning, supplier surveys, quality improvement teams, education and training, process reviews and other like costs. Appraisal costs are the costs incurred while performing measuring, evaluating, or auditing to assure the quality conformance. These costs include first time inspection, checking, process or service audits, testing, calibration of measuring and test equipment, receipt inspection, supplier surveillance and etc. Costs ofinternal failure are the costs that would disappear if no defects existed prior to shipment to the customer. These costs include rework, scrap, re-testing, re-inspection, redesign, material review, corrective action, material downgrades, vendor defects, and other like defects. Costs of external failure are the costs that would disappear if no defects existed in the product after shipment to the customer. These costs include processing customer complaints, warranty claims and repair costs, customer returns, product liability and product recalls. (Gary Zimak, 2000).

Literature Review

In the past few decades, different methods have been developed to optimize cost and quality of productions or services. Many economic and mathematical models have been developed to find the optimum cost of quality. The traditional model detailed by Brown and Kane (1984) (as cited by Kazaz *et al.*, 2005) has gotten widespread acceptance. According to this model there is an inverse relationship between prevention and appraisal effort and failure cost. The optimum conformance of quality or defect level is where the increasing costs of the prevention and appraisal curve converges with the curve of decreasing failure costs. Total quality costs are minimized to the point where the cost of prevention plus appraisal equals the cost of failure. The total cost of quality curve represents the sum of the other two curves, and the location of the minimum point on the total cost of quality curve, sometimes referred to as the optimum point (Kazaz *et al*, 2005).

In order to improve product quality an organization should take into account the costs associated with achieving quality since the objective of continuous improvement programs is not only to meet customer requirements, but also to do it at the lowest cost (Vaxevanidis and Petropoulos, 2008). Reporting product and service quality system activities and effectiveness in financial terms is an increasingly important approach to linking continual improvement of the quality system to performance improvement of the organization and is a keystone of the Six Sigma approach to quality. Total costs quality have been estimated by Kent (2005) at 5-15 percent of turnover for organizations in Great Britain, by Crosby (1984) at 20-35 percent of sales for service and manufacturing organizations in the USA, and by Feigenbaum (2001) at 10 percent of revenues. That the most conservative of these estimates might exceed an organization's net profit highlights the potential importance of cost of quality.

When costs of quality are not visible, managers are unable to use this information of quality in their decisionmaking processes. In their experimental study, Viger and Anandarajan (1999) showed that managers who have access to cost of quality data make different decisions than managers who do not have cost of quality data available. Tsai (1998) introduced or mentioned some approach to measuring quality cost included Prevention-Appraisal-Failure (PAF), costof quality elements, economics of quality related activities, drawbacks of the Prevention-Appraisal-Failure approach, alternatives to the Prevention-Appraisal-Failure approach, quantitative approach to measuring costs of quality, pictorial approach and activity base costing. Drawing on construal level theory, Yan and Sengupta (2011) proposed that consumers' reliance on price (vs. feature-specific product attributes) for making quality inferences will be enhanced when the judgment is psychologically distant (vs. close). For example, the impact of price (attributes) on quality inferences should increase (decrease) when these inferences are made with regard to another person rather than oneself. A series of experiments provides support for this thesis. In addition, they (a) documented a theoretically derived reversal of the core pattern, (b) reconciled the current findings with seemingly opposed results in the construal literature, and (c) ruled outseveral alternative explanations for the obtained effects. The insights obtained in this work enrich their understanding of three different areas of research: the price-quality link, construal level theory, and the self-other distinction.

Boronico and Panayides (2001) focused on a service provider who, faced with competition, must determine the optimal price and level of service quality to provide in order to maximize profits. They believeservice quality and price are assumed to impact jointly on demand for services. Both demand and service quality impact on the cost of providing services. While considerable literature exists on the impact of servicequality on demand or cost, less work has focused on the explicit impact of service quality jointly on both demand for and the cost of providing services. A service quality constraint is appended to the formulation in order to guarantee that a declared service standard is met. Conditions are developed which characterize optimal solutions, together with comparative static. They developed a model through which both price and quality of service may be determined, in addition to other variables more operational in nature, such as capacity. The model developed (1) assumes that service quality impacts on both demand for service as well as costs and (2) unifies both marketing and operations oriented system components.

Sower *et al.* (2007) did a research on cost of quality usage and its relationship to quality system maturity. The purposes of this study were to examine the relationship between the distribution of quality costs and the level of maturity of an organization's quality system, to assess the extent to which effective COQ systems and maturing quality systems affect organization performance, and to determine why some organizations do not utilize COQ systems. According to their research external failure costs were found to decline as a percentage of total cost of quality (COQ) as an organization's quality system matures. Total COQ was found to increase as an organization moved from a very low level of quality system maturity to a higher level. Sales and profit growth were not significantly correlated with the presence of a quality cost system or with the level of maturity of the quality system. Lack of management support was found to be the most common reason why organizations do not systematically track quality costs.

At the other hand, numerous studies have been done on time-cost optimization and multi-objective optimization of time-cost-quality in case of construction projects. Feng *et al.* (1997) and Burns *et al.* (1996) have suggested a standard technical construction projects sample for optimizing time and cost and the solved it and tried to calculate the objective function. They used a Hybrid LP/IP programming method. A same optimization research has been done by Zheng *et al.* (2004) using Genetic algorithm to optimize these two factors. Using Ant Colony Algorithm, Xiong and Kuang (2008) aimed to solve the problem of optimizing time and cost too. Hallak and Sivadasan (2009) develop a two-factor heterogeneous-firm model. They introduce a factor, which they call caliber, affecting the fixed costs of the product quality. They derive the cutoff function showing the minimum level of caliber for a given productivity necessary to survive in the market. On the plain of caliber and productivity, the cutoff functionis a downward-sloping curve. By introducing fixed cost of exports and iceberg transport cost, they show the cutoff function of exporter. They show that two kinds of exporters, with low-productivity, high-caliber and high-productivity, low-caliber, may exist.

Although Rodchua (2006) believes that companies can lose money because they fail to use significant opportunities to reduce their costs of quality. Her study identified important factors and measures contributing to a successful quality cost program implementation and developed an empirically based model for quality costs in the manufacturing environment. Also the study presented the cause and effect diagram of difficulty that industrial professionals experienced in their program implementation. Rodchua's survey instrument collected descriptive data from manufacturing and industrial professionals. She found the primary factors that aided the success of a quality cost program were management support, effective application and system, cooperation from other departments, and understanding the concepts of the cost of quality. As an innovative research, the present study, in line with other related studies, aims to optimize Costs of Quality and Quality using ACO algorithm. The technical sample (table 1) used in this research and its results will launch a new course of research in this field.

Methodology

In terms of its results, the present research is an applied survey whose findings may be helpful in developing management accounting techniques and employing engineering techniques to improve the performance of organizations and maximize the profit. Regarding implementation process, it is a quantitative research whose data are processed using Ant Colony Optimization algorithm (henceforth, ACO). No study already has been carried out about optimization of Cost of Quality and quality. The present research, developing a new method in writing code for ACO algorithm, tries to solve optimization problem. As a case study, the goal of this research is to help management accountants, product designers and productionengineersto design the best component of a product or service in such a way that the balance among different kinds of quality costs and quality are optimized. In terms of logic, this study enjoys the deductive approach.

To make a product, there are several options for each component to assemble. Some of different componentsare compatible and some of them are incompatible with each other. Each of these compatible components of a product, as a solution for optimization problem, involves their characteristics, costs of quality and quality. It is interesting to say that the same situation can be proposed for all products. Each component has different cost of quality and has special impact of total quality of the product. To produce an automobile, for example, one can use different pieces with various quality and costs of quality. It is noteworthy to say that various production methods may result in various production qualities as well as various delivery times.

It should be noted that such data in table 1, may be helpful in comparing findings of various reliable methods adopted in different studies and providing opportunity for many researches to compete with each other using new technologies and methods. So, the critical stages of this study appear in coding of the algorithm done with respect to the objective and restrictive functions. Therefore, this research is seeking to answer the following questions:

1. What component of a product best leads to the optimization of the relationship between cost of quality and quality?
2. From a product differentiation point of view, what component of a product best leads to the optimization of the relationship between cost of quality and quality, where the quality is above 90%?
3. From a cost leadership point of view, what component of a product best leads to the optimization of the relationship between cost of quality and quality in cases where the cost was at most $22,000?

Review of Ant Colony Optimization Algorithms

ACO is therefore metaheuristic in the sense that the absolute optimum solution is not found, but good solutions practically close enough to the optimum are found. Real ants coordinate their activities through stigmergy, which is a form of indirect communication (Dorigo, 1992). Specifically, in the search for food, ants deposit chemicals along the path they travel which is recognized by other ants, and will increase the probability of the path being traveled by other ants of the colony. The chemical is called Pheromone (Stutzle, 1999). The fundamental components of ACO can be briefly categorized as:

Table 1. The technical sample

Process or Component	Alternative No.	Incompatible With Alternative No.	PC ($)	AC ($)	IFC ($)	EFC ($)	Effective Weight (%)	Quality (%)
1	1-1	4-1,8-3	1000	300	200	300	5	70
	1-2	2-2, 4-2,	1200	250	180	280		85
	1-3	4-2,7,2	1600	240	150	240		98
2	2-1	3-3, 6-3	4500	450	300	870	25	80
	2-2	1-2,5-1,	5000	440	280	860		85
	2-3	3-1, 9-2	7000	400	200	830		98
3	3-1	2-3, 8-2	600	130	350	190	8	80
	3-2	6-1, 5-3	700	110	290	180		90
	3-3	2-1, 5-2	900	100	280	140		99
4	4-1	1-1, 5,1	400	85	200	150	5	75
	4-2	1-2,1-3	480	80	190	130		85
	4-3	6-2, 5- 2	600	90	180	115		95
5	5-1	2-2,4-1	1900	230	300	300	15	75
	5-2	3-3, 4-3	2100	250	250	200		87
	5-3	3-2,	3500	260	200	150		97
6	6-1	3-2, 7-1	1600	190	300	120	12	80
	6-2	4-3, 7-2	1700	150	350	90		85
	6-3	2-1, 7-3	3500	160	360	70		95
7	7-1	6-1	1100	185	390	120	15	65
	7-2	1-3, 6-2	1300	190	380	100		85
	7-3	6-3, 8-1	1700	200	330	80		96
8	8-1	7-3, 9-1	900	30	450	120	10	75
	8-2	3-1	1000	50	400	95		84
	8-3	1-1	1300	60	360	80		96
9	9-1	8-1	600	230	310	200	5	80
	9-2	2-3	700	280	280	180		90
	9-3	-	1000	385	250	100		99

I- Construct a graph of the problem. The resulting graph will have *m* columns, and each column has *n* nodes.

II- Define the objective function and the restrictions. The number of ants and the number of attempts for solving the problem are also specified in this step.

III- Move artificial ants on the graph in order to construct admissible solutions to the problem: In this step, artificial ants placed on the initial point start moving, randomly selecting a node on each consecutive column in order to build incremental solutions to the problem under consideration. The more ants placed on the graph, the more cross sections produced, and the higher the chances are that the best solution is approached. In selecting the nodes of a column to move to, the probability of an ant selecting the *j-th* node of the *i-th* column is described by the following relation:

$$p_{i,j} = \frac{\tau_{i,j}^{\alpha}}{\sum \tau_{i,j}^{\alpha}} \qquad (1)$$

In Eq.1, $\tau_{i,j}$ is the sum of the pheromone placed on node (*i*,*j*) from previous attempts. In the first attempt, all nodes have an equal pheromone of τ_0, and therefore in the first attempt, all nodes have an equal chance of being selected by the ants.

IV- Evaluate the solutions obtained by each ant in the first attempt: Once all the ants complete the first attempt, the objective function *f* is calculated for each ant. Next, pheromone is deposited along the trail which each ant has chosen in forming an incremental solution.

The amount of pheromone deposited on each node is reversely related to the objective function of the path being considered, i.e.,$t_{=}\ {}^{1}/f$. As the rule states, the lower the objective function of a path, the more pheromone will be deposited on the components of the path.

V- Update the pheromone value of each node in the graph: After calculating the pheromone value of every node for the present attempt, the updated pheromone value of each node is obtained through the following relation:

$$\tau_{i,j}(t+1)=(1-p)\tau_{i,j}(t)+\Delta\tau_{i,j}(t) \tag{2}$$

In Eq.2, $\Delta\tau_{i,j}$ is the difference between the deposited pheromone in the present attempt and the previous attempt, $\tau_{i,j}$ is the updated pheromone value, and r is the evaporation index which takes a value between zero and one. Pheromone evaporation is a useful form of forgetting, preventing the algorithm from rapidly converging towards local optima. The term (1-r) thus determines how much of the pheromone accumulated from previous attempts is evaporated.

VI- Repeat steps III through IV in the next attempts in order to reach the optimum solution: in the next attempt, the decision making process of the artificial ants is no longer completely by chance; as stated by Eq.1, nodes with more pheromone have a higher chance of being selected by the ants. After each attempt, pheromone values are updated and some pheromone is evaporated. The combined action of pheromone deposit and evaporation enables a constant exploration of the search space towards a global optimum in ACO.

The above mentioned steps form the fundamental framework of the ACO algorithm. Various improvements have been introduced to the original algorithm in recent years, aiming to make the search algorithm both more effective and more efficient. Accordingly, in addition to the ants system (AS) algorithm discussed above, three other algorithms have been more successful, and have been used in the present study: ranked ant system (AS_{rank}), elite ant system (AS_{elite}), maximum-minimum ant system (MMAS). The principle features of AS and MMAS which are applied in this research and elite ant system and ranked ant system are briefly discussed herein.

Ants System (AS): This is the simplest form of ACO first introduced by Dorigo *et al.* (1991). In AS, artificial ants choose their path according to the following probabilistic relation:

$$\rho_{ij}(k,t)=\frac{\left[\tau_{i,j}(k,t)\right]^{\alpha}\left[\eta_{i,j}(k,t)\right]^{\beta}}{\sum_{j=1}^{J}\left[\tau_{i,j}(k,t)\right]^{\alpha}\left[\eta_{i,j}(k,t)\right]^{\beta}} \tag{3}$$

In which $\rho_{i,j}(k,t)$ is the probability of selecting i-th node of the j-th column, by the k-th ant in the t-th attempt. $\eta_{i,j}(k,t)$ in Eq.3 represents the heuristic information and the determication of its value is problem-specific. In some problems, the value of $\eta_{i,j}(k,t)$ is hard to determine, and is therefore omitted from equation. a and b in Eq.3 are constants which determine the role of pheromone and heuristic information in the artificial ants' decision making process. If $a>b$, the role of pheromone is emphasized and heuristic information has less effect on the decision of the ants. Adversely, $a<b$, means that the ants decide which node to move to based on the heuristic information, paying less attention to the pheromone deposited from previous attempts. Another important characteristic of ant colony algorithms is the way that pheromone update is defined in these algorithms. $\Delta\tau_{i,j}$ that is used in Eq.2, is determined as:

$$\Delta\tau_{i,j}(t)=\sum_{k=1}^{m}\frac{Q}{f\left(s_{k}(t)\right)}I_{S_{K}(t)}\{(i,j)\} \tag{4}$$

In which m is the number of artificial ants, or the number of solutions produced; Q is a constant named the pheromone return index and its value depends on the amount of pheromone deposited; $S_k(t)$ represents all the nodes which the k-*th* ant has chosen on the t-*th* attempt; $I_{Sk(t)}\{(i,j)\}$ is a coefficient which is either zero or one, depending respectively on whether the k-th ant has chosen the node (i, j) or not. In other words, $I_{Sk(t)}$ ensures that only the nodes on which the k-*th* ant has moved to will be considered in depositing pheromone. It can be deduced from Eq.4 that in AS, solutions with a lower objective function will have more pheromone deposited, and vice versa.

In Elitist Ants System this algorithm, more attention is focused on the elite ant of the colony. The elite ant is the one which has produced the best answer in all previous attempts. Specifically, in AS_{elite} extra pheromone is deposited on the path which the elite ant has produced. The ants decide which node to move to using Eq.3. The pheromone update rule in AS_{elite} is:

$$\tau_{i,j}(t+1)=(1-p)\tau_{i,j}(t)+\Delta\tau_{i,j}(t)+\sigma\Delta\tau_{i,j}^{gb}(t) \tag{5}$$

Wheres $\Delta\tau_{i,j}^{gb}(t)$ is the extra pheromone deposited by the elite ant, and$s$ is the weight of the extra pheromone. AS_{elite} is an attempt to balance between exploration and exploitation in the algorithm. And in ranked ants system algorithm, unlike the AS$_{elite}$ in which all ants participate in the pheromone update process, only*s-1*elite ants which have created better solutions are chosen to update the pheromone of the paths they have chosen. In AS$_{rank}$, following each attempt, the ants are lined up according to the solutions they have obtained, and pheromone update values are assigned to each ant, the most pheromone being assigned to the best solution and decreasing thereafter to the last ant in the line. Thus, the pheromone update rule in AS$_{rank}$ can be stated as:

$$\Delta\tau^{rank}{}_{i,j}(t)=\sum_{k=1}^{\sigma-1}(\sigma-k)\frac{Q}{f(S_k(t))}I_{s_k(t)}\{(i,j)\} \quad (6)$$

Minimum-Maximum Ants System (MMAS): Stutzle and Hoos (2000) first reported the MMAS algorithm in a successful attempt to improve the efficiency of AS. The general structure of MMAS is similar to AS. However, only the path with the best solution in each attempt is chosen to deposit pheromone on its trail. In this way, the solution rapidly converges to the optimum. The danger always exists that the ants quickly move towards the first optimum solution achieved, before having the chance to explore other possibly better solutions in the search space. In order to prevent this from occurring, a restriction is placed on the minimum and maximum allowable net pheromone deposit on the trails, i.e., the deposited pheromone value is limited to [τ_{min}, τ_{max}]. Following each pheromone deposition step, all pheromone values are controlled to fit within the mentioned limit, and any node for which the pheromone value exceeds the limits is adjusted to the allowable limit. This is a way to promote the ants to explore new solutions in the search space. The maximum and minimum allowable pheromone values of the *t-th* attempt are calculated as:

$$\tau_{\max}(t)=\frac{1}{1-\rho}\frac{Q}{f\left(s^{gb}(t)\right)} \quad (7)$$

$$\tau_{\min}(t)=\frac{\tau_{\max}(t)\left(1-\sqrt[n]{p_{best}}\right)}{\left(NO_{avg}-1\right)\sqrt[n]{p_{best}}} \quad (8)$$

Where $f(S^{gb}(t))$ is the value of the objective function up to the *t-th* attempt, P_{best} is the probability of the ants choosing the best solution once again, NO_{avg} is the average of the number of decision choices in the decision points. It is noteworthy to mention that the initial pheromone value associated with the nodes, τ_0 is $\tau_{\max}(t)$. Objective function is defined according to Eq.9:

$$F(x)=\frac{TCOQ-TCOQ_{\min}}{TCOQ_{\max}-TCOQ_{\min}}+\frac{Q_{\max}-Q}{Q_{\max}-Q_{\min}} \quad (9)$$

Where *TCOQ* is the total cost of quality and *Q* is quality of each resource option for activities. Because the cost of quality and the quality have different module, by Eq.8 they become normalize. Now they can be comparable, added or subtracted. In this case study minimum cost of quality ($TCOQ_{min}$) is \$19,905, maximum cost ($TCOQ_{max}$) is \$26,770, minimum quality (Q_{min}) 79.95 and maximum quality (Q_{max}) is 95.32. The total cost of quality for each option for compatible alternatives is calculated according to Eq.10:

$$TCOQ=\sum_{n=1}^{9}PC_n+\sum_{n=1}^{9}AC_n+\sum_{n=1}^{9}IFC_n+\sum_{n=1}^{9}EFC_n \quad (10)$$

Where PC_n is the prevention cost of each option for compatible alternatives, AC_n is the appraisal cost of each option for compatible alternatives; IFC_n is the internal failure cost of each option for compatible alternatives and EFC_n is the external failure cost of each option for compatible alternatives. Finally, the total quality for each option for compatible alternatives is calculated according to Eq.11:

$$Q=\sum_{n=1}^{9}EW_n\times Q_n \quad (11)$$

Where EW_n is the effective weight of each component or part of a product, Q_n is quality of each option for compatible alternatives. After run the program the results were obtained as follow.

Data analysis

The algorithm used in this study is pioneer in coding it in more than one thousand lines of program using MATLAB soft ware. The input data are taken from technical sample shown in Table 1 and after running program, its results are presented in Table 2, table 3 and Table 4. As it can be seen in Table 2, the optimization of the costs of quality and quality based on MMAS algorithm is 3,2,2,1,2,2,3,3,2 in which the total cost of quality is \$21,565, at 0.8885 level of quality and the objective function is 0.6628. These options for compatible alternatives are the answer of the first research question and their costs and quality are calculated as follow:

Prevention Cost (3,2,2,1,2,2,3,3,2): 1,600+5,000+700+400+2,100+1,700+1,700+1,300+700=15,200
Appraisal Cost (3,2,2,1,2,2,3,3,2): 240+440+110+85+250+150+200+60+280=1,815
Internal Failure Cost (3,2,2,1,2,2,3,3,2): 150+280+290+200+250+350+330+360+280=2,490
External Failure Cost (3,2,2,1,2,2,3,3,2): 240+860+180+150+200+90+80+80+180=2,060
Total Cost of Quality: 15,200+1,815+2,490+2,060=21,565
Quality: (0.05×0.98)+(0.25×0.85)+(0.08×0.90)+(0.05×0.70)+(0.15×0.87)+(0.12×0.85)+(0.15×0.96)+ +(0.10×0.96)+(0.05×0.90)=0.8885

$$F(x)=\frac{21,565-19,905}{26,770-19,905}+\frac{0.9532-0.8885}{0.9532-0.7995}=0.6628$$

The optimization of the costs of quality and quality and the other options for compatible alternatives which are close to optimum solutions, are shown in table 2.

Table 2. Sample of Costs of Quality and Quality Optimization Solutions

No.	Objective Function	PC ($)	AC ($)	IFC ($)	EFC ($)	Total COQ ($)	Total Quality (%)	Option for Compatible Alternatives								
								1	2	3	4	5	6	7	8	9
1	*0.6628	15,200	1,815	2,490	2,060	21,565	88.85	3	2	2	1	2	2	3	3	2
2	0.6728	14,300	1,835	2,540	2,110	20,785	86.95	2	1	2	1	2	2	3	3	2
3	0.6764	15,500	1,920	2,460	1,980	21,860	89.30	3	2	2	1	2	2	3	3	3
4	0.6807	15,100	1,765	2,520	2,080	21,465	88.35	3	2	2	1	2	2	3	3	1
5	0.6864	14,600	1,940	2,510	2,030	21,080	87.40	2	1	2	1	2	2	3	3	3
6	0.6907	14,200	1,785	2,570	2,130	20,685	86.45	2	1	2	1	2	2	3	3	1
7	0.7137	16,900	1,860	2,360	1,965	23,085	91.47	3	2	3	3	3	1	3	3	2
8	0.7270	15,400	1,940	2,520	1,990	21,850	88.50	3	2	1	1	2	2	3	3	3
9	0.7274	17,200	1,965	2,330	1,885	23,380	91.92	3	2	3	3	3	1	3	3	3

*- Optimal Situation

To answer the second research question, as shown in table 3, the researchers should like to state that as product differentiation point of view, the option 3,2,3,3,3,1,3,3,2 which the total cost of quality is $23,085 dollars, at 0.9147 level of quality and the objective function is 0.7137, is the optimum solution:

Prevention Cost (3,2,3,3,3,1,3,3,2): 1,600+5,000+900+600+3,500+1,600+1,700+1,300+700=16,900
Appraisal Cost (3,2,3,3,3,1,3,3,2): 240+440+100+90+260+190+200+60+280=1,860
Internal Failure Cost (3,2,3,3,3,1,3,3,2): 150+280+280+180+200+300+330+360+280=2,360
External Failure Cost (3,2,3,3,3,1,3,3,2): 240+860+140+115+150+120+80+80+180=1,965
Total Cost of Quality: 16,900+1,860+2,360+1,965=23,085
Quality: (0.05×0.98)+(0.25×0.85)+(0.08×0.99)+(0.05×0.95)+(0.15×0.97)+(0.12×0.80)+(0.15×0.96)+ +(0.10×0.96)+(0.05×0.90)=0.9147

$$F(x)=\frac{23,085-19,905}{26,770-19,905}+\frac{0.9532-0.09147}{0.9532-0.7995}=0.7137$$

According to table 3, it should be mentioned that the cheapest option which has more than 0.90 quality is 3,2,3,3,3,1,3,2,2. In this option, the total cost of quality is $22,830, at 0.9027 level of quality and the objective function is 0.7546. If the option is 3,2,1,1,3,2,3,3,3, the quality will be exactly 0.90 with $23,160 dollars cost of quality.

To answer the third research question, as shown in table 4, it should be stated that as cost leading point of view, the option 3,2,2,1,2,2,3,3,3, which the total cost of quality is $21,860, at 0.8930 level of quality and the objective function is 0.6764, is the optimum solution. If the designers want to have less than $22,000 cost, this option will enjoy the most quality level:

Table 3. Sample of Quality Costs and Quality Optimization Solutions, as Product Differentiation Point of View

No.	Objective Function	PC ($)	AC ($)	IFC ($)	EFC ($)	Total COQ ($)	Total Quality (%)	Option for Compatible Alternatives								
								1	2	3	4	5	6	7	8	9
1	*0.7137	16,900	1,860	2,360	1,965	23,085	91,47	3	2	3	3	3	1	3	3	2
2	0.7274	17,200	1,965	2,330	1,885	23,380	91,92	3	2	3	3	3	1	3	3	3
3	0.7317	16,800	1,810	2.390	1,985	22,985	90.97	3	2	3	3	3	1	3	3	1
4	0.7475	16,700	1,765	2,460	1,990	22,915	90.57	3	2	3	1	3	2	3	3	1
5	0.7546	16,600	1,850	2,400	1.980	22,830	90.27	3	2	3	3	3	1	3	2	2
6	0.7683	16,900	1,955	2,370	1,900	23,125	90.72	3	2	3	3	3	1	3	2	3
7	0.7842	16,800	1,910	2,440	1,905	23,055	90.32	3	2	3	1	3	2	3	2	3
8	0.8203	16,800	1,950	2,470	1,940	23,160	90	3	2	1	1	3	2	3	3	3

*- Optimal Situation

Prevention Cost (3,2,2,1,2,2,3,3,3): 1,600+5,000+700+400+2,100+1,700+1,700+1,300+1,000=15,500
Appraisal Cost (3,2,2,1,2,2,3,3,3): 240+440+110+85+250+150+200+60+385=1,920
Internal Failure Cost (3,2,2,1,2,2,3,3,3): 150+280+290+200+250+350+330+360+250=2,460
External Failure Cost (3,2,2,1,2,2,3,3,3): 240+860+180+150+200+90+80+80+100=1,980
Total Cost of Quality: 15,500+1,920+2,460+1,980= 21,860
Quality: (0.05×0.98)+(0.25×0.85)+(0.08×0.90)+(0.05×0.70)+(0.15×0.87)+(0.12×0.85)+(0.15×0.96)+ +(0.10×0.96)+(0.05×0.99)=0.8930

$$F(x)=\frac{21{,}860-19{,}905}{26{,}770-19{,}905}+\frac{0.9532-0.8930}{0.9532-0.7995}=0.6764$$

Table 4. Sample of Costs of Quality and Quality Optimization Solutions, as Cost Leading Point of View

No.	Objective Function	PC ($)	AC ($)	IFC ($)	EFC ($)	Total COQ ($)	Total Quality (%)	Option for Compatible Alternatives								
								1	2	3	4	5	6	7	8	9
1	*0.6764	15,500	1,920	2,460	1,980	21,860	89.30	3	2	2	1	2	2	3	3	3
2	0.6628	15,200	1,815	2,490	2,060	21,565	88.85	3	2	2	1	2	2	3	3	2
3	0.7414	14,900	1,950	2,540	2,000	21,390	87.25	3	1	1	1	2	2	3	3	3
4	0.7270	15,400	1,940	2,520	1,990	21,850	88.50	3	2	1	1	2	2	3	3	3
5	0.8586	15,300	1,900	2,530	2,085	21,815	86.40	2	1	1	3	3	1	2	3	2
6	0.9652	15,200	1,975	2,590	2,045	21,810	84.75	2	1	1	3	3	1	2	1	3
7	0.8765	15,200	1,850	2,560	2,105	21,715	85,50	2	1	1	3	3	1	2	3	1
8	0.8589	15,500	1,850	2,530	2,080	21,960	86,72	1	2	3	3	3	1	2	2	1

*- Optimal Situation

If the most qualified product is requested, the option 3,3,3,3,3,3,2,3,3 with $26,770 cost of quality and0.9532 quality should be chosen. This option incurs $26,770 cost of quality which is the most expensive option. Also, the cheapest option which has the lowest quality is 1,1,2,2,2,2,1,1,1. This Option for Compatible Alternatives incurs$26,770 cost of quality and 0.7995 qualities.

Conclusions

Today's developing business environment resulted from globalization and competitive conflicts; an organization survival depends on paying attention to value creation management and establishing optimum relationship between optimal cost and customer satisfaction and optimal value for organization. Furthermore, it was declared that the two classic design objectives are quality and costs of quality. Quality of a product is defined as its ability to fulfill the customer's needs and expectations. On the other hand, it was recognized that there are at least four categories of quality costs such as prevention cost, appraisal cost, internal failure cost, and external failure cost. It is known that improving quality is considered by many to be the best way to enhance customer satisfaction, to reduce manufacturing costs and to increase productivity. Any serious attempt to improve quality must take into account the costs associated with achieving quality, since nowadays it does not suffice to meet customer requirements, it must be done at the lowest possible cost as well.

In this paper, to optimize the quality and components of the costs of quality, we used a kind of ant colony algorithm under the title of minimum and maximum ants system. It has been developed for the optimization of Costs of Quality and Quality as a trade-off problem. It will look for to find the optimal combination of a product which has the optimum trade-off between the costs of quality and quality. This technique is helpful for product designers and manufacturing managers who want to create value for the organizations and the results for all products, such as automobiles, appliances and electronic devices etc. can be used. Also, the result of this research will help the organizations which are now seeking both theoretical advice and practical evidence about quality related costs and the implementation of quality costing systems.

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