A General Approach of Quality Cost Management Suitable for Effective Implementation in Software Systems

Stelian BRAD
Technical University of Cluj-Napoca, Romania
stelian.brad@staff.utcluj.ro

Investments in quality are best quantified by implementing and managing quality cost systems. A review of various opinions coming from practitioners and researchers about the existent quality cost models reveals a set of drawbacks (e.g. too theoretical and too close to ideal cases; too academic, with less practical impact; too much personalized to particular business processes, with difficulties in extrapolating to other cases; not comprising all dimensions of a business system). Using concepts and tools in quality management theory and practice and algorithms of innovative problem solving, this paper formulates a novel approach to improve practical usability, comprehensiveness, flexibility and customizability of a quality cost management system (QCMS) when implementing it in a specific software application. Conclusions arising from the implementation in real industrial cases are also highlighted.

Keywords: *Quality Costs, Performance Planning and Monitoring, Quality Management, Quality Cost Software*

1 Introduction

Recent surveys have revealed that approximately two thirds of the market value of a company is not accounted by the official value statement [18]. This means that most of the intangible assets in a company are not visible. Considering the characteristics of today's business environment, this issue becomes of high importance. Thus, a good strategy is to quantify value-added activities within the business system of the company for revealing this valuable information.

To minimize losses within the processes of a business system, an important step is to develop capabilities for monitoring and controlling the costs related to value-added activities. A well-designed quality cost management system (QCMS) is a reliable tool for achieving this goal. Quality cost management systems refer to the management of costs for achieving good quality (CGQ) and costs of poor-quality (CPQ) [9], [26], as well as hidden costs of quality (HQC) [10]. Costs for achieving good quality comprise prevention costs (PC) and appraisal costs (AC) [26]. Poor-quality costs are constituted from internal failure costs (IFC) and external failure costs (EFC) [26]. For preventing failure occurrence, as well as for assessing quality performances, various actions are undertaken. They involve costs. If the prevention and/or the appraisal activities are inadequately performed, they automatically lead to losses; that is to poor-quality costs. Besides the direct costs of performing these activities, supplementary losses could occur. In addition, if the corrective actions for removing various internal and external failures are not properly performed, supplementary losses are also generated. All these costs belong to the group of hidden quality costs [7], [17]. Solutions to increase the visibility of hidden quality costs are reported by [7], [17], [27], etc.

Because quality cost management systems play an important role in motivating organizations to improve their quality performances, researches have been done around this subject. The classical quality cost models are well-described in [9]. The same work highlights the evolutions of poor-quality costs models, too. However, later works, like [21], criticize the classical models and propose improved variants. It is the merit of [6] to show that the classical, well-known models which describe quality costs have limited practical value, they representing only particular cases which neglect the dynamism of continuous improvement. Beyond this, in [6] it is demonstrated that quality cost models are not adequate for determining an economically optimal quality level. Researches on optimizing quality costs are reported in [25], where the analysis is done for the particular case of a production process, as well as in [14], which develops a concept and a model for determining the level of quality that maximizes both customer's satisfaction and firm's profit. In the same spirit, [3] proposes a quality cost model that takes into account both the traditional prevention-appraisal-failure expenses and hidden-opportunity quality loss of costs. The model has some limitations due to the fact it is mainly focused on production processes. In the same attempt, [37] proposes a revised model for the costs of quality. The model incorporates two cost functions: one dealing with quality-related costs incurred while maintaining a stable level of operation and the other one dealing with the costs of process improvement. The two functions are assembled by means of incremental economics and an economic criterion is used to evaluate improvement alternatives. New dimensions in handling inconsistencies of quality cost models are revealed in [20], with a focus on external failure costs. Searching for answers in the same area, [16] observed that what it is known as quality costs is being applied under different guises and different names.

In the work [32], a structured framework to implement and sustain a QCMS based on process cost modelling, but with application only in process industries is proposed. It attaches fuzziness to the notion of quality and quality cost determination. The information obtained after fuzzy synthesis is used to set up priorities with respect to the processes where organization has to invest effort in reducing the cost of non-conformances. The fuzzy concepts are also explored in [2] to evaluate quality improvement alternatives based on quality cost information. The work in [34] examines various quality cost models and explains the misallocation of quality investment by firms. This work also shows that quality initiatives undertaken by a firm are generally consistent with corporate goals and strategy, the maturity level of a firm and management commitment. A survey is done in [31] on published literature about various quality costing approaches and reports of their success. This survey provides a better understanding of quality cost methods. The survey shows that even if the subject is of high interest for the academic community, a mature quality cost approach is not utilized in most quality management programs. It also reveals the fact that where quality costs are taken into account in practice, there are various models implemented, depending on the particular cases. However, according to the same authors the classical prevention-appraisal-failure model is commonly implemented [31]. Specific characteristics of quality cost models and systems from various industrial sectors are well-described by [8], [11], [13], [19], [24], [29], [33], [36]. These researches show that successful quality cost models and approaches require deep customization, both related to the industrial sector and to the specificity of firms within the same sector.

The importance which IT plays in quality management for enhancing quality awareness, improving product quality and reducing quality-related costs is demonstrated by [22]. Interviews and questionnaires are used to support findings in [22]. The work [5] comes up to the same conclusion and demonstrates the necessity of a knowledge management approach to support quality costing. Moreover, for improving its practical use, a quality cost model should comprise several key attributes, like: comprehensiveness, flexibility, customizability, intelligence, as well as easiness to be implemented in a software tool.

In this respect, a section of this paper focuses on defining a novel model of QCMS to increase its comprehensiveness and degree of generality, seeing that current models are so much personalized that hardly can be transposed from one sector or firm to another sector or firm. An approach that makes a QCMS more accessible for non-specialists is also introduced in the paper, together with a modality to adapt a standard version of the QCMS to the dynamics of process improvement and to the dynamics of the business system where it is implemented. These innovations, together with a novel analysis methodology, have been used to work out the model of an intelligent agent with the purpose of analysing data in the QCMS and automatically revealing the highest priority areas of intervention for a given state of the business system in the attempt of minimizing quality losses with maximum efficiency. This model is also revealed in the paper. Paper ends with aspects about implementing the intelligent agent in a software tool, as well as discussions around its effectiveness. Conclusions and remarks on the limitations of the proposed model are also included.

2 Innovations to Facilitate Computation of a QCMS

Approach to enhance the application area of a QCMS: Practice has proved that, the most important success factor in any initiative of continuous quality improvement is the leadership [26]. In many cases, managers have a poor understanding on how investments in quality are reflected in the financial results of the business. Studies have shown that, when continuous quality improvement projects are described in terms of return on investment (ROI), the involvement of the top management immediately occurs [10]. The use of a quality tool which is able to speak the money language is crucial for bringing the support and commitment of the top management within the continuous quality improvement initiatives. Such quality tool is represented by a comprehensive QCMS; that is, a QCMS able to cover all activities that bring value within the business system of an organization. To achieve this goal, it is here proposed a quality cost structure that follows the structure of the business system itself. In this respect, the EFQM model is taken as reference [23]. This means, the quality cost structure shows like a tree-structure, with quality cost items distributed on affinity groups. The tree-structure starts with a set of 9 blocks, as in the case of EFQM model: (1) leadership (LDP); (2) strategy-policy-marketing (SPM); (3) personnel management (PMT); (4) resource management (RMT); (5) core processes (CPS); (6) employee satisfaction (ESN); (7) customer satisfaction (CSN); (8) society satisfaction (SSN); (9) business performances (BPS). Each block includes a set of standard main processes (MP). Within each main process, a set of standard activity-modules (AM) are further formulated. To the level of each standard activity-module, a set of standard value-added elementary activities (EA) are defined.

Quality costs are collected to the level of elementary activities. Each cost item is assigned to one of the four categories of quality costs: PC, AC, IFC or EFC. Researches done by the author led to a standard tree-structure of quality costs consisting of: 92 standard main processes, 227 standard activity-modules and 512 elementary activities. To have a better image around the size of the standard database, a listing of elementary activities covers over 100 pages, A4 format. A generous reservoir of information and resource of education is stored within this standard database, because it represents a compilation of huge amounts of data about business models and quality cost systems from various structured and unstructured sources. It is not the purpose in this paper to move into more details around this issue.

The standard database of quality costs follows a natural way of connecting the quality cost system to the business system and provides the essential information for customizing the quality cost system. A company has the possibility to adapt, enhance, reduce and adjust the standard database to its specific needs in a friendly manner and from any point of the tree-structure, as long as the "language" is of managers, not of accountants. In other words, one can add, delete, freeze/unfreeze activity-modules, elementary activities and quality cost items. Figure 1 illustrates a fragment of representing the tree-structure of the standard database for easy implementation in a software application (the highlights in figure 1 are on the leadership block, which includes 14 standard main processes, where the first main process includes 6 standard activity-modules and where the first activity-module includes 2 standard elementary activities). The concept of the standard database, as well as the quantity and the content of information which the database incorporates, represent, all together, the key issue for fast and facile design of a customizable QCMS for any given business system, independently of its maturity, profile and specificity in time and space.

Fig. 1. Fragment of the business process oriented tree-structure of the quality cost system

This concept significantly facilitates the development of a generalized software-based QCMS, with obvious practical advantages in terms of versatility, efficiency, etc. And there is something much more important here for the practical success of the initiative in managing quality costs: the business system-oriented quality cost structure permits, once implemented in a web-based software tool, to distribute the tasks for data collection to almost every person in the company. Thus, time, costs and accuracy of data collection is significantly improved. This represents a relevant step forward, as long as classical QCMSs usually lead to an increase with 50% of the staff within the financial department [9] and do not bring every people in the organization enough close to quality cost and quality loss problems.

Approach to improve practicality of a QCMS: Countless analyses and surveys upon various sources in the last 50 years, as well as the analyses done by [26] and [28], reveal the fact that quality-related costs represent between 5% and 40% from the business revenues. On the other side, the profit of most companies varies between 3% and 20% [18], [26], [27], etc. It is observed that the level of quality-related costs is of the same magnitude as the level of profit with respect to company's turnover. This aspect induces the idea that companies could increase their profit on medium and long term by reducing the quality-related costs. The modality of assessing the global performance of the business processes by comparing the total quality-related costs with the revenues over the monitoring period is very motivating for managers in setting up quality improvement programs. From this perspective, this paper proposes in figure 2 a graphical visualisation of quality costs with higher practical impact. According to figure 2, company should firstly work out a curve representing the relationship between price of the unit sold (P_u) and the level of quality (Q).

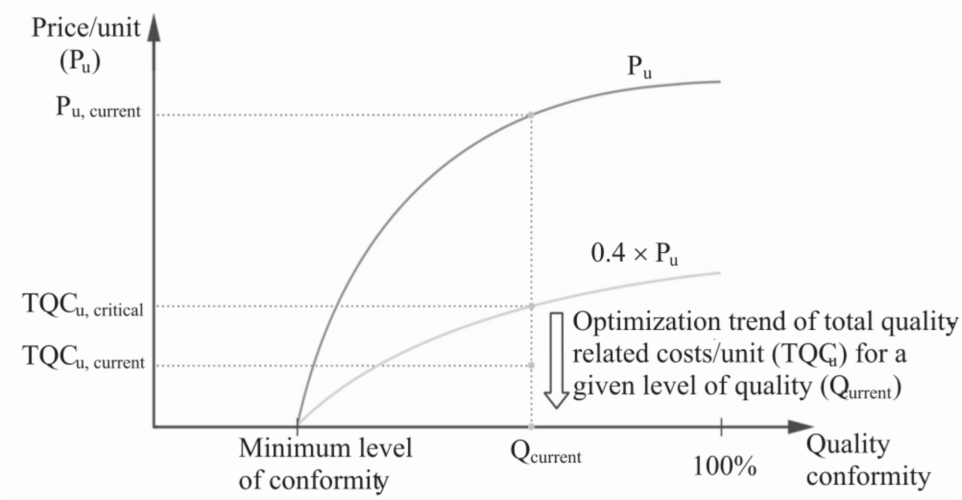

Fig. 2. Company's profitability from the perspective of quality-related costs

This automatically involves definition of metrics for quantifying quality, related units of measurement, ideal values (100% quality conformity), minimum quality conformity level, as well as market surveys to define the price policy with respect to the delivered quality. This simple approach, even taken alone, changes the view of managers about quality problems. Once the curve P_u versus Q is elaborated, a new curve, resulted by multiplying P_u with 0.4, is further constructed. The new curve actually represents the upper limit (the critical level) for the total quality-related costs per unit sold (TQC_u). For a given quality level ($Q_{current}$), $TQC_{u,current}$ should be lower than $TQC_{u,critical}$ (see figure 2) such as the organization to be enough profitable. However, for a given level of quality $Q_{current}$, the trend should be towards reducing the value of $TQC_{u,current}$ (see figure 2). Comprising various countless and formal opinions [1], [6], [10], [26], [28], [31], etc., this paper proposes a classification of quality performances from an economic perspective (see table 1).

The global assessment of organizational performances by means of the model "TQC as percentage from revenues" can be applied only when the QCMS monitors all activities that bring value-added within organization. If some activities (especially those which involve high costs) are omitted (accidentally or intentionally) from the monitoring program it is possible to get attractive results, while the reality is opposite. According to figure 2, for a given level of quality, various programs to improve efficiency and effectiveness of the business processes could be applied such as to increase profitability. However, a better policy is the one in which, by means of continuous improvement programs, the goal is both the increase of quality level and the reduction of total quality-related costs.

Table 1. Ranking quality performances from an economic perspective

No.	Level according to 6σ model	TQC as % from total revenues	Level of competitiveness
1	1σ	>40%	Non-competitive: majority of the key processes have an extremely low maturity (unacceptable, with extremely high risks in terms of company's survival), with extremely low levels of efficiency and effectiveness
2	2σ	35-40%	Non-competitive: majority of the key processes have a very low maturity (unacceptable, with very high risks in terms of company's survival), with very low levels of efficiency and effectiveness
3	2σ	30-35%	Non-competitive: majority of the key processes have a low maturity (unacceptable, with relative high risks in terms of company's survival), with low levels of efficiency and effectiveness
4	3σ	25-30%	At the limit of competitiveness: majority of the key processes have a relative low maturity (at the lower limit of acceptance), with relative low levels of efficiency and effectiveness
5	3σ	20-25%	At the limit of competitiveness: many of the key processes have a relative low maturity and relative low levels of efficiency and effectiveness
6	4σ	15-20%	Medium level of competitiveness: the key processes are relative mature, with good levels of efficiency and effectiveness
7	5σ	10-15%	High level of competitiveness: innovative key processes, with high levels of efficiency and effectiveness
8	6σ	5-10%	Very high level of competitiveness: highly innovative key processes, with very high levels of efficiency and effectiveness
9	6σ	<5%	Extremely high level of competitiveness: radical innovative key processes, with extremely high levels of efficiency and effectiveness

Figure 3 illustrates the appropriate evolution of the pair "Q;TCQ_u" when a competitive program of process performance improvement is applied. A major role in getting evolution-curves "Q;TCQ_u" like the one in figure 3 is played by continuous innovation both to the level of product or service and to the level of the organizational processes. Product innovation leads to simpler and higher performance products, with more functions incorporated in fewer components, with lower technological requirements, etc.

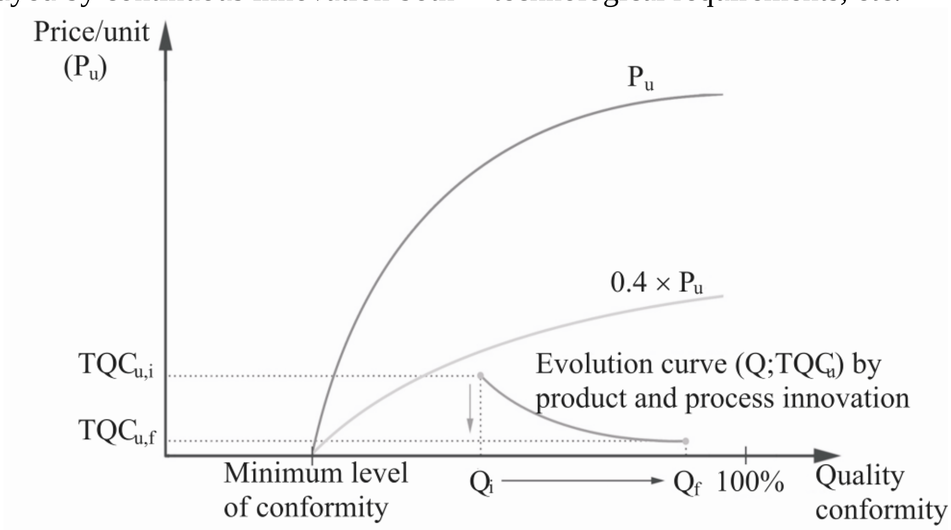

Fig. 3. Competitiveness curve from the perspective of quality-related costs

Process innovation leads to fewer operations, to more accurate and secure technologies, to higher efficiency, etc. All these elements lead to reduction of cases that facilitate failure occurrence; and from here, to reduction of prevention, appraisal and remediation costs.
In order to work out a diagram like the one in figure 3, a deep knowledge of quality requirements and their degree of importance from beneficiary point of view, as well as very good knowledge about the level of achievement of each requirement should be realized. In this respect, all quality requirements have to be measurable and have to have clear defined target values. This goal can be achieved by means of product quality planning activities within the quality management system, where product life-cycle issues have to be taken into account (e.g. using the QFD method [4]). Moreover, this way of representing a QCMS highly facilitates the implementation in a specialized software application for quality cost assessment.
Approach to improve flexibility and customizability of a QCMS: Both flexibility and customizability of a QCMS come up from several directions. The first direction emerges automatically from the concept of defining and structuring quality-related costs, as it was already highlighted. Mapping the quality cost system over the structure of the business system represents a reliable way of increasing flexibility and customizability of a QCMS. The structure proposed in the first part of this section is very flexible for adding, freezing, removing “branches” on the quality cost tree-structure, up to the level of activity-modules and bottom to the level of quality cost items. This model is highly compatible with the classical way in which information is structured within a software application.
The second direction occurs once the QCMS is implemented within a software tool that incorporates features for distributed task allocation (e.g. specific quality cost data to be collected by the most appropriate person in the network).
The third direction is materialized from the solution which defines the quality cost items. If quality cost items are defined in a specialized language (understandable only by accountants) the flexibility of the QMCS is very much affected. In this respect, quality cost items should be defined in a natural language, easy understandable by any person in the company (e.g. from white collars to blue collars).
This paper proposes that quality cost items related to any value-added elementary activity (EA) to be structured in three groups: cost items associated with human resources (CHR), cost items associated with material resources (CMR) and cost items of other kind (COK) (e.g. R&D sub-contracting, consultancy, training, technology transfer, licensing, investment in specific software, investment in technology, etc.). Considering an elementary activity EA characterized by n cost items of CHR-type, m cost items of CMR-type and p cost items of COK-type, this paper proposes a very simple way of defining the total quality costs QC_{EA} related to the elementary activity EA:

$$QC_{\mathrm{EA}} = \sum_{i=1}^{n} T_i \cdot CH_i + \sum_{j=1}^{m} K_j \cdot CM_j + \sum_{k=1}^{p} CO_k \ . \qquad (1)$$

In the relationship (1) T_i, $i = 1, \ldots, n$, represents the time spent to perform the task i, $i = 1, ..., n$, CH_i, $i = 1, ..., n,$ is the total cost per unit time with the human resource involved to perform the task i, $i = 1, ..., n$, K_j, $j = 1, \ldots, m$, represents the quantity of material resource j, $j = 1, \ldots, m$, in the framework of elementary activity EA, CM_j, $j = 1, \ldots, m$, is the unitary cost of the material resource j, $j = 1, \ldots, m$, in the framework of elementary activity EA, CO_k, $k = 1, \ldots, p$, is the cost of the special task k, calculated as strict contribution in the framework of the elementary activity EA.
The simplistic way in which quality cost items are formulated in this paper ensures a

high degree of flexibility when quality cost system's dynamics is taken into account. This simple, almost "elementary" way of quality cost formulation is the result of discussions with representatives from 56 SMEs. The focus group came up to the conclusion that a QCMS is efficient in a web-based software tool, where all relevant people from the company can be involved in data collection. At one end, in terms of costs, any kind of quality-related elementary activity can be condensed to what it is proposed in relationship (1). This form of representation allows within a software tool to add or cut cost items in a very simple way, any time, according to quality cost system's dynamics and experience accumulated by the company during QCMS implementation. If some activities require special mathematical formulas to calculate the related cost items (especially for those belonging to the group COK), the software tool should allow adding comments for explaining the respective mathematical formula, as well as adding explanations to any data which is introduced in the QCMS.

Practice has proved that it is less relevant for performance analysis which is the formula of calculating a certain cost item. If the analysis shows that for a certain activity the costs exceed the expectations, an improvement project is normally generated and within this project, the critical issues are identified. In other words, the message about this is the following: not the QCMS is the one which solves drawbacks; it only signals them. Moreover, it is the role of process improvement mechanisms to solve the problems.

Beyond this, flexibility should be ensured also in terms of data collection. A very detailed and particular formula for every cost item is actually a barrier in implementing a QCMS considering time issues, organizational issues, system's dynamics issues, etc. Many times, and especially in the first stages of QCMS implementation, some data are collected using informal channels and sometimes fuzzy approaches (e.g. in the acceptable limit of ± 5% accuracy) [3], [26]. The goal of a QCMS is not to identify values with 0.01, 0.1 or unit accuracy since it is mainly a tool for supporting and motivating continuous improvement and innovation. It should be a clear balance between accuracy and effort (of time and money) related to data collection [3].

Beyond the above mentioned arguments, the solution proposed in relationship (1) permits development of a quality-related cost software tool with a high level of generality and openness towards customizability. In addition, combining the cost structure proposed in relationship (1) with the tree-structure proposed in the first part of this section, the degree of flexibility and usability of a QCMS is further increased in terms of report generation. The top management can easily have various combinations of data about quality-related costs: relative to material resources, relative to human resources, relative to other kind of resources, for the whole business system, for some particular processes, for a certain block, for a specific sub-process and many-many other combinations.

3 A Model-Based Reflex Intelligent Agent to Support the Decision-Making Process

Once cost data are collected over the scheduled period of time, analyses are performed and, where necessary, improvement programs are proposed. This is simple in saying, but difficulties occur in practice when priorities must be established and resources must be allocated such as the curve of competitiveness to follow a similar trend like the one illustrated in figure 3. As it happens in most of the cases, a multitude of problems are identified and resources are never enough to meet the needs. Imagine the case of a QCMS having hundreds or even more, thousands of value-added elementary activities. In such complex systems, the decision-making process required for establishing priorities and for handling conflicting problems becomes very "painful". In addition, there are cases when actions must be taken outside of what is currently monitored within the QCMS; that is, new activities must be considered in the business system and new value-added elementary activities must be monitored with a higher priority such as the competitiveness curve to follow attractive paths (see Figure 3). This paper proposes an innovative solution to support the decision-making process taking into account the before presented aspects. A software-based "intelligent agent" that generates automatic recommendations about priority areas of intervention is further introduced. According to [15], there are various definitions of intelligent agents. The work [30] groups intelligent agents into five classes based on their "intelligence" capacities. In this respect, a class of intelligent agents is the one called "model-based reflex agents" [30]. A model-based reflex agent keeps track on the current state of the environment using an internal model. It is able to handle a partially observable environment. The internal model describes that zone of the environment which is not "visible (tangible)". Additional information describing environment's behaviours are introduced in the system by means of some mechanisms (e.g. human operator introduces data in the system). This additional information completes the model. Based on a "condition-action" rule, the agent chooses an action to be performed.

Model-based reflex intelligent agents work very well for supporting the decision-making process in a quality cost management system. The relationships between processes within the business system define the internal model of the intelligent agent. Data about the current state of the environment (i.e. quality costs to the level of the overall organizational process) are introduced by people logged into the system. These data are connected to the internal model. Some condition-action rules define the agent function (e.g. ranking areas of intervention based on their impact upon business profitability). Thus, priority-directions of intervention are automatically generated by the intelligent agent (e.g. which areas to be monitored into more details, which new areas to be further monitored, which areas are the most critical ones, etc.).

To elaborate the concept of the intelligent agent for the problem under consideration in this paper, I-TRIZ innovation framework has been applied [12]. Major criteria taken into account for defining the concept of the intelligent agent are focused on concept's flexibility and reliability to facilitate customization of the quality-related cost tree-structure (i.e. add, delete, freeze items from any point of the tree-structure). Considering various useful functions (e.g. existence of ranking methods) and harmful functions (e.g. variability of business processes, technical barriers in customization), as well as their interactions, the application of I-TRIZ algorithm finally led to a set of twenty two guiding principles in formulating the algorithm of the model-based reflex intelligent agent. After a careful analysis, eight principles have been finally selected. They are further presented, together with the concrete solutions generated from these principles:

- Guiding principle: Introduce one or more added stable states. Solution: The first layer of the main processes (MP) will be defined enough generic and exhaustive to cover all aspects of a generic business system; the next layers (activity-modules (AM) and elementary activities (EA)) will be defined enough exhaustive but with possibilities to add, delete items.
- Guiding principle: The degree of freedom of a system can be increased by dividing the system into parts that can move relative to each other. Solution: Use a tree-structure for the quality cost system.
- Guiding principle: The inner dynamics of a system can be increased by introducing mobile objects into the system. Solution: QFD relationship-type matrices can be used to rank items against a set of input criteria [4]. The absolute value weight related to each ranked item is not affected when new columns within matrices are inserted.
- Guiding principle: Make the system or process more universal by providing it with a set of elements that can be exchanged each other as the system or process operates. Solution: Cost items are inserted only on the very bottom layer of the tree-structure, thus increasing the flexibility and universality of the quality cost system.

- Guiding principle: Set up the elements required by the system or process, then program the sequence in which the elements are brought into play. Solution: Formulation of the initial tree-structure, freeze it within a project over the monitoring period and apply the algorithm of the intelligent agent related to the frozen project.
- Guiding principle: Provide the system or process with the ability to perform programmed changes in the shape and/or properties of its elements. Solution: When a new item is introduced in the tree-structure of the quality cost system, the user will be forced to pass the same steps in defining and ranking the new item as it happened with the standard, initial tree-structure.
- Guiding principle: A system function can be enhanced by adding another field or by adding a substance that "contains" a field. Solution: At each layer of the tree-structure properties of each item have to be identified. Relevant for the algorithm are the correlations between the main processes, the impact of each main process, activity-module and elementary activity upon business performance and difficulty to solve properly each main process, each activity-module and each elementary activity such as to minimize the business risks.
- Guiding principle: Fields (forces, effects, actions) that lack ordered structure should be replaced with fields that have definite, ordered structure. Solution: Tree-structure of the quality cost system.
- Guiding principle: Consider introducing a mediator. Solution: Unitary assessment criteria for all new cost items (the same used to set up the initial tree-structure).

Using the guiding principles and the corresponding solutions above presented, the intelligent agent is formulated. Some notations are considered to support algorithm's formulation. It is denoted with α the number of MP, with β the number of AM, with γ the number of EA, with β_i, $i = 1, \ldots, \alpha$, $\beta_1 + \ldots + \beta_\alpha = \beta$ the number of AM within the i-th MP, $i = 1, \ldots, \alpha$, with γ_j, $j = 1, \ldots, \beta$, $\gamma_1 + \ldots + \gamma_\beta = \gamma$ the number of EA within the j-th AM, $j = 1, \ldots, \beta$, with MP_i, $i = 1, \ldots, \alpha$, the i-th MP, with $AM_j(MP_i)$, $j = 1, \ldots, \beta_i$, $i = 1, \ldots, \alpha$, the j-th AM belonging to the i-th MP, with $EA_k((AM_j(MP_i))$, $k = 1, \ldots, \gamma_j$, $j = 1, \ldots, \beta_i$, $i = 1, \ldots, \alpha$, the k-th EA belonging to the j-th AM belonging to the i-th MP.

It is denoted with k_{hg}, $h, g = 1, \ldots, \alpha$, $h \neq g$, the influence coefficient of the h-th MP on the g-th MP (it should be mentioned that the influence of MP_h to MP_g might be different than the one of MP_g to MP_h). The influence coefficient k_{hg}, $h, g = 1, \ldots, \alpha$, $h \neq g$ belongs to the set: {0: no influence, 1: very weak influence, 3: weak influence, 9: medium influence, 27: strong influence, 81: very strong influence}.

There are considered x criteria $IM_1, \ldots, IM_x$ to assess the impact of MP, AM and EA against business performances and there are denoted with R_l, $l = 1, \ldots, x$, their degrees of importance. The author of this paper worked with seven impact criteria. They are presented in Table 2. The degrees of importance have been established with the AHP method [4] and with the mediation of a focus group of twenty people belonging to potential beneficiaries.

Table 2. Impact criteria and their importance

No.	Criterion	Importance
1	Effect on product quality	16.4
2	Effect on production and delivery times	10.4
3	Effect on total production costs	16.4
4	Effect on people motivation / control	11.3
5	Effect on process capability / reliability	16.1
6	Effect on logistic and administrative costs	12.8
7	Effect on robustness with respect to internal and external noise factors	16.5

There are considered y criteria $DI_1, \dots, DI_y$ to assess the difficulty in solving properly MP, AM and EA and there are denoted with G_f, $f = 1, \dots, y$, their degrees of importance. The author of this paper worked with seven difficulty-related criteria. They are presented in Table 3. Their degrees of importance have been established as for the case of impact criteria.

Table 3. Difficulty criteria and their importance

No.	Criterion	Importance
1	Financial difficulty to support the task (process, activity, etc.)	18.3
2	Technological difficulty to support activities	14.7
3	Organizational difficulty to support activities	12.7
4	Scientific / knowledge-related difficulty to support activities	18.4
5	Severity when a failure occur within the task	12.8
6	Detection and easiness of failure removal within the task	11.8
7	Task complexity	11.2

To support the algorithm, further notations are required. They refer to the relationship coefficients between $IM_1, \dots, IM_x$ and MP, AM and EA, respectively between $DI_1, \dots, DI_y$ and MP, AM and EA. In this context, it is denoted with imp_{1ij}, $i = 1, \dots, x$, $j = 1, \dots, \alpha$, the relationship coefficient between IM_x, $i = 1, \dots, x$ and MP_j, $j = 1, \dots, \alpha$. It is denoted with dif_{1ij}, $i = 1, \dots, y$, $j = 1, \dots, \alpha$, the relationship coefficient between DI_y, $i = 1, \dots, y$ and MP_j, $j = 1, \dots, \alpha$.
It is denoted with imp_{2ijk}, $i = 1, \dots, x$, $j = 1, \dots, \beta_k$, $k = 1, \dots, \alpha$, the relationship coefficient between IM_x, $i = 1, \dots, x$ and $AM_j(MP_k)$, $j = 1, \dots, \beta_k$, $k = 1, \dots, \alpha$. It is denoted with dif_{2ijk}, $i = 1, \dots, y$, $j = 1, \dots, \beta_k$, $k = 1, \dots, \alpha$, the relationship coefficient between DI_y, $i = 1, \dots, y$ and $AM_j(MP_k)$, $j = 1, \dots, \beta_k$, $k = 1, \dots, \alpha$.
It is denoted with imp_{3ijkh}, $i = 1, \dots, x$, $j = 1, \dots, \gamma_k$, $k = 1, \dots, \beta_h$, $h = 1, \dots, \alpha$, the relationship coefficient between IM_x, $i = 1, \dots, x$ and $EA_j((AM_k(MP_h))$, $j = 1, \dots, \gamma_k$, $k = 1, \dots, \beta_h$, $h = 1, \dots, \alpha$. It is denoted with dif_{3ijkh}, $i = 1, \dots, y$, $j = 1, \dots, \gamma_k$, $k = 1, \dots, \beta_h$, $h = 1, \dots, \alpha$, the relationship coefficient between DI_y, $i = 1, \dots, y$ and $EA_j((AM_k(MP_h))$, $j = 1, \dots, \gamma_k$, $k = 1, \dots, \beta_h$, $h = 1, \dots, \alpha$. The relationship coefficients belong to the following set: {0: no relationship, 1: very weak relationship, 3: weak relationship, 9: medium relationship, 27: strong relationship, 81: very strong relationship}. The following steps define the algorithm of the intelligent agent.
Step 1: Calculation of the influence level CC_i, $i = 1, \dots, \alpha$ of each MP_i, $i = 1, \dots, \alpha$ upon the other MPs, with the formula:

$$CC_i = \sum_{\substack{j=1 \\ j \neq i}}^{\alpha} k_{ij}, \quad i = \overline{1, \alpha}\,. \tag{2}$$

Step 2: Calculation of the impact level W_{1j}, $j = 1, \dots, \alpha$ and difficulty level D_{1j}, $j = 1, \dots, \alpha$ of each MP_j, $j = 1, \dots, \alpha$, with the formulas:

$$W_{1j} = \sum_{i=1}^{x} imp_{1ij} \cdot R_i, \quad j = \overline{1, \alpha}\,, \tag{3}$$

$$D_{1j} = \sum_{i=1}^{y} dif_{1ij} \cdot G_i, \quad j = \overline{1, \alpha}\,. \tag{4}$$

Step 3: Calculation of the impact level W_{2jk}, $j = 1, …, \beta_k$, $k = 1, …, \alpha$ and difficulty level D_{2jk}, $j = 1, …, \beta_k$, $k = 1, …, \alpha$, of each $AM_j(MP_k)$, $j = 1, …, \beta_k$, $k = 1, …, \alpha$, with the formulas:

$$W_{2jk} = \sum_{i=1}^{x} imp_{2ijk} \cdot R_i,\ \ j = \overline{1, \beta_k},\ \ k = \overline{1, \alpha}\ , \tag{5}$$

$$D_{2jk} = \sum_{i=1}^{x} dif_{2ijk} \cdot G_i,\ \ j = \overline{1, \beta_k},\ \ k = \overline{1, \alpha}\ . \tag{6}$$

Step 4: Calculation of the impact level W_{3jkh}, $j = 1, …, \gamma_k$, $k = 1, …, \beta_h$, $h = 1, …, \alpha$ and difficulty level D_{3jkh}, $j = 1, …, \gamma_k$, $k = 1, …, \beta_h$, $h = 1, …, \alpha$, of each $EA_j((AM_k(MP_h))$, $j = 1, …, \gamma_k$, $k = 1, …, \beta_h$, $h = 1, …, \alpha$, with the formulas:

$$W_{3jkh} = \sum_{i=1}^{x} imp_{3ijkh} \cdot R_i,\ \ j = \overline{1, \gamma_k},\ \ k = \overline{1, \beta_h},\ \ h = \overline{1, \alpha}\ , \tag{7}$$

$$D_{3jkh} = \sum_{i=1}^{x} dif_{3ijkh} \cdot G_i,\ \ j = \overline{1, \gamma_k},\ \ k = \overline{1, \beta_h},\ \ h = \overline{1, \alpha}\ . \tag{8}$$

Step 5: Two intermediary indicators are calculated for each EA. The first one is called impact-related index P_{jkh}, $j = 1, …, \gamma_k$, $k = 1, …, \beta_h$, $h = 1, …, \alpha$ and the second one is called difficulty-related index I_{jkh}, $j = 1, …, \gamma_k$, $k = 1, …, \beta_h$, $h = 1, …, \alpha$. Their formulas are:

$$P_{jkh} = CC_h \cdot W_{1h} \cdot W_{2kh} \cdot W_{3jkh},\ \ j = \overline{1, \gamma_k},\ \ k = \overline{1, \beta_h},\ \ h = \overline{1, \alpha}\ , \tag{9}$$

$$I_{jkh} = \frac{P_{jkh}}{D_{1h} \cdot D_{2kh} \cdot D_{3jkh}},\ \ j = \overline{1, \gamma_k},\ \ k = \overline{1, \beta_h},\ \ h = \overline{1, \alpha}\ . \tag{10}$$

Step 6: Each EA has associated an attribute that shows the quality cost category where the respective EA belongs: CPQ or CGQ (see section 1). It is denoted with $QC_{EA\,[CPQ]}$ the quality costs over the monitoring period for an EA that belongs to category CPQ and with $QC_{EA\,[CGQ]}$ the quality costs over the monitoring period for an EA that belongs to category CGQ. To simplify the mathematical representation, it is supposed that λ elementary activities belong to the category CPQ $\{EA_{g\,[CPQ]},\ g = 1, …, \lambda,\ \lambda < \gamma\}$ and $\delta = \gamma - \lambda$ elementary activities belong to the category CGQ $\{EA_{g\,[CGQ]},\ g = 1, …, \delta,\ \delta < \gamma\}$. For each EA belonging to the category CPQ a priority index Q_{1g}, g = 1, …, λ is calculated:

$$Q_{1g} = P_g \cdot QC_{EA_g\,[CPQ]},\ \ g = \overline{1, \lambda}\ . \tag{11}$$

Step 7: When priorities are brought into equation, practice recommends operating with 80-20 rule [26]; that is to consider the minimum set of items that brings the maximum contribution to a certain problem. In this respect, from the sub-set of $EA_{g\,[CPQ]}$, g = 1, …, λ, $\lambda < \gamma$, the first 20% elements will be extracted, considering the priority index Q_{1g}, g = 1, …, λ, starting with the highest one. A new sub-set is thus generated: $\{EA_{20\%g\,[CPQ]},\ g = 1, …, \sigma,\ \sigma < \lambda < \gamma\}$.

Step 8: For each EA belonging to the last sub-set, a technical priority index $Q_{20\%g}$, g = 1, …, σ, is calculated:

$$Q_{20\%g} = I_{20\%g} \cdot QC_{\mathrm{EA}_{20\%}g\,[\mathrm{CPQ}]},\ g = \overline{1,\sigma}\,. \tag{12}$$

Step 9: The elementary activities from step 7 will be further prioritized according to the value of $Q_{20\%g}$, g = 1, …, σ, starting with the highest one. This sub-set of ordered elementary activities actually comprises the first group of key areas of intervention where the top management should define improvement projects.
Step 10: Define the sub-set of elementary activities from the category CGQ characterized by the fact that each elementary activity from this sub-set respects at least one of the following properties: 1) the main process where it belongs is influenced by at least other main process that includes at least one of the elementary activities defined at step 7 (the influence should not necessarily happen in the opposite sense); 2) there is at least one elementary activity from the sub-set defined at step 7 that belongs to the same main process. This sub-set is denoted with $\{\mathrm{EA}^{*}_{z\,[\mathrm{CGQ}]},\ z = 1, \ldots, \varepsilon,\ \varepsilon \le \delta\}$.
Step 11: All main processes that do not incorporate at least one elementary activity from the sub-set defined at step 7 or at step 10 are removed. For the remaining set it is recalculated a new influence coefficient $CC_{\mathrm{new}\,i}$, $i = 1, \ldots, \theta,\ \theta \le \alpha$, where θ expresses the size of the new set of main processes. $CC_{\mathrm{new}\,i}$, $i = 1, \ldots, \theta,\ \theta \le \alpha$, is calculated with a similar formula as in relationship (2).
Step 12: For each elementary activity determined at step 10 the indexes from step 5 are calculated, where the coefficient CC_{new} determined at step 11 will be considered instead of the coefficient CC. They will be denoted with P_{new} and I_{new}. The results are further used to calculate a priority index $Q_{1\mathrm{new}}$ with formula (11), where P_{new} and $QC_{\mathrm{EA}\,[\mathrm{CGQ}]}$ are considered. The first 20% elementary activities from the sub-set determined at step 10 will be extracted, considering the priority index $Q_{1\mathrm{new}}$, as in the case of step 6. The new sub-set will be ordered afterwards by means of the same algorithm as in steps 8 and 9, where I_{new} will be actually considered in formula (12). This sub-set of ordered elementary activities actually comprises the second group of key areas of intervention where the top management should define improvement projects.
Step 13: The whole philosophy from step 1 to step 12 is taken once again for the standard quality cost tree-structure (defined in section 2.1), but here every $QC_{\mathrm{EA}\,[\mathrm{CPQ}]}$ and $QC_{\mathrm{EA}\,[\mathrm{CGQ}]}$ will be set to 1. At the end, a sub-set of elementary activities from the standard quality cost tree-structure will be selected. There will be removed from this sub-set all elementary activities that already exist in the sub-sets from step 9 and step 12. The remaining elementary activities reveal some possible areas of intervention, where the top management should perform analyses and, if opportune, define additional improvement projects. They might contain areas that are not actually monitored within the current QCMS.
The areas of intervention automatically recommended by the algorithm should not be taken into account mechanically, without any supplementary analysis, because no computer-based expert system can compensate the common sense and human expertise, as well as no computer-based expert system can take into account all unexpected noise factors that act upon the business system and all variations in the dynamics and structure of the business system and external environment. However, with all these natural limitations, the intelligent agent contributes in a relevant manner to the decision-making process, because it quantifies, makes tangible, some of the most opportune areas of intervention.

4 Implementation

Each particular business requires customization of the standard tree-structure of quality costs to the specific needs (e.g. freezing some activity-modules and elementary activities from the standard structure, adding new activity-modules and elementary activities). It is obvious that, for an effective use, a quality cost management system, including the model described in section 3, has to be implemented in a software application. Implementation of the model from section 3 in a software tool requires a preliminary work to generate the input data for the standard tree-structure according to steps 1, 2, 3 and 4 of the algorithm. This work has to be done manually by experts, which are able to define the right levels for the influence coefficients *k* (see step 1 of the algorithm from section 3), as well as for the relationship coefficients imp_1, imp_2, imp_3, dif_1, dif_2, dif_3 (see steps 2, 3 and 4 of the algorithm from section 3). Because the standard tree-structure includes 92 standard main processes, 227 standard activity-modules and 512 elementary activities, the effort required to perform this preliminary task is significant and the amount of information worked out at the end of this process is quite large. However, this work is done a single time by experts, during the development phase of the software application, just to feed the knowledge base of the system. Thus, this information is stored in the knowledge base of the standard system. Once the software application is installed and set up in a company, the knowledge base is effectively used in every quality-cost project during the analysis phase of the results collected within the respective project, according to the formalism required by steps 5, …, 13 of the algorithm described in section 3.

When new activity-modules and/or elementary activities are introduced within the quality cost system (as a consequence of customization and/or adaptation of the quality cost system to the dynamics of the particular business), they have to be initially assessed with respect to the same set of criteria (see tables 2 and 3), using the same scale and assessment methodology as for the construction of the standard quality cost tree-structure. Therefore, the software tool must facilitate this feature. This information completes the knowledge base of the system, being added to the standard information delivered with the software application. The quality cost model, including the algorithm from section 3, has been effectively implemented in a software tool, within an R&D project of 1500 man-day work effort.

5 Discussions

The effectiveness of the model-based reflex intelligent agent proposed in this paper for planning improvement projects within the business processes of an organization based on QCMSs depends on several aspects which are in strong relation with the human factor involved in setting up the system. They are further highlighted:

- The set-up phase of the intelligent agent requires formulation of correlation levels between processes, as well as relationship levels of processes, modules and activities with respect to various categories of criteria. This work is performed by a group of experts, which act as analysts during the development phase of the software application. The accuracy of defining the correlation and relationship coefficients will crucially determine the effectiveness of the intelligent agent. The analysis criteria (see table 2 and table 3) proposed in this paper have been carefully selected to minimize confusions and misunderstandings during the analysis process, thus contributing positively to failure minimization. Moreover, the numerical values selected to express the relationship levels (1, 3, 9, 27 and 81) increase the robustness of analysis.
- The decision-making indicators within the model which describes the intelligent agent take into account inputs from the real environment (e.g. cost data, customization of the tree-structure, etc.). The accuracy of input data will strongly influence the effectiveness of the algorithm. To avoid failures in this direction, an adequate guidance is required during the initial phases of implementation. In other words, one should see that performance of a quality cost management system is ensured only when a well-balanced product-service system is put in place.

The intelligent agent acts in a living environment. The quality cost system is reshaped from the current project to the next one according to data collected in the current project. In this respect, priority areas could be changed from project to project, according to the current evolution of the system. Also, new monitoring areas could be required for being introduced in the system and some other areas could proof to be less relevant for being further monitored.

Moreover, priorities come from several directions – see poor quality costs and costs to achieve good quality, extracted both from the monitored system (the foreground system), as well as from the background system (the system comprising activity-modules and elementary activities that are frozen in the current system). For example, in the hypothetical case study, 14 elementary activities were not monitored in the current system.

Based on the collected cost data in the current project, as well as on the logic of the algorithm, a number of four elementary activities from the background system are proposed for being monitored in the future project.

The model has been effectively implemented within a large chemical enterprise. Feedback coming from the pilot project revealed that organizational aspects took around four months (organizing the team, generating the database with personal data, training the team), customization of the quality cost structure took three months and the first monitoring phase was completed in 6 months. This experience has shown that, besides the obvious purpose of monitoring and quantifying value-added activities in monetary units, the implementation of a QCMS generates cultural transformations, debates around formalizing business processes, as well as improvements on process maturity, transparency and traceability. So, all these, together, actually led to almost one year implementation time. Thinking about medium to long term contribution of a QCMS, one year duration of the set-up and pilot phases is justified, as long as relevant benefits occur even during the pilot phase.

6 Conclusions and Further Researches

Quality cost management systems are powerful tools both to capture at a higher extend the interest of the top management in continuous process improvement and to link quality to business performance. This paper proposes a reliable framework of QCMS that faces to the increasing dynamics and non-linearity of the business environment. In a complex world there is no optimal solution but a set of several solutions with high potential. The framework proposed in this paper should be understood in the same spirit. It provides means to increase flexibility, to enhance customizability in a cost-effective and user-oriented way, as well as to increase the level of “intelligence” for supporting the decision-making process. The framework is highly suitable for being transposed in a software application.

It is highlighted the opinion that an effective intelligent agent for supporting the decision-making process within a QCMS stands to a high extend in the quality of input data introduced by experts and operators in the system. Based on several innovations related to the way of structuring information in the system, as well as to the way of linking system’s components (processes, modules, activities, cost items) and related to the selected scale for describing relationship and correlation levels between system’s components, this paper proposes an accessible and reliable model for supporting the decision-making process within a QCMS.

The model in this paper is subject to some limitations which open further research opportunities. Thus, future researches could be conducted on enhancing the “level of intelligence” of the monitoring agent. In this respect, learning agents might be of real interest. “Learning algorithms” have the advantage of allowing agents to enrich their competence using historical data and to foresee potential multiple futures. This might bring additional information in the decision-making process. In the same register, researches could be extended to the inclusion of multiple agents and multi-agent hierarchical systems in the analysis of the results within a QCMS. This means sub-agents could perform lower level functions for better understanding the task environment (e.g. inclusion of supplementary questions about various areas of the QCMS such as to improve the level of competence in the decision making process).

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Stelian BRAD is full professor at the Technical University of Cluj-Napoca, Romania, leading the research group on Competitive Engineering in Design and Development. He is also the Director of the Department of Research, Development and Innovation Management of the same university. His research interests include competitive engineering, engineering and management of innovation, intelligent industrial robotics.