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Synergy-based approach to quality assurance

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Abstract. Product development and design as well as the efficiency of quality management system have a key influence in product quality costing. Therefore they should be closely integrated. It is suggested that the main obstacle in attaining better quality is the so-called "bad" engineering, mostly caused by human shortcomings in design and quality management. The paper presents a novel opportunity to empower human activities in the framework of quality management system through the synergy-based approach to quality assurance. Finally, a methodology is proposed for the preparation of the company's quality management system for ISO certification.

Key words: quality management, quality assurance, product quality, product development, dependency matrix, synergy.

1. INTRODUCTION

At the beginning of the present century there has been a new wave of research into human behaviour in engineering activities. The probable reason for it is that the engineering design research community has come to the conviction that engineering design is not a purely technical problem any more, but a complex activity, involving artefacts, people, tools, processes, organizations and conditions of the real economic environment [1,2]. A new paradigm in this field is the synergy-based approach to engineering design [3]. The synergy-based approach makes it possible to collect design parameters, market conditions and human factors under one umbrella [4]. The goal of the present research is to find an effective way to fight against the "bad" engineering by extending the synergy-based approach to quality assurance activities.

Firstly it is necessary to define the concept of "synergy", used in the present context. By Oxford Dictionary the word *synergy* or *synergism* refers to integration or cooperation of two or more drugs, agents, organizations, etc. to produce a new or enchanced effect compared to their separate effects. Sometimes in the business theory it is called the $2+2=5$ effect. So there must be "something" that makes integration successful and it is called (positive) synergy. However, sometimes we are also witnesses of unfortunate integration and it is called *asynergy* (negative synergy) [5]. In order to accent the importance of the tendency of the processes, the terms positive and negative synergy have been used in the present research. The synergy-based approach has been used successfully in physics, chemistry, sociology, medicine, business and also in engineering. Probably the best example of using the synergy-based approach in engineering is ferroconcrete where the compensation of mutual weaknesses and amplifying their common useful effects (physical optimization) has real content. It is quite natural that by solving an engineering task all activities must be aimed at attaining the maximum positive synergy and pressing down the negative synergy.

Synergy results from the interaction of complex and mostly non-linear subsystems and therefore the synergy level is not directly measurable or computable. The parametrical approach to the synergy level is possible by using the principles of synergetics to determine the order or enslaving parameters that can be interpreted as the amplitudes of the macroscopic patterns at the self-organization of microscopic ones [6]. The key to order-parameters is optimization in its wider interpretation including its logical, mathematical and physical basis [3]. The evaluation of the synergy level may be provided on the conditional scale from -100% to $+100\%$ of indefinite target values. A synergy level close to $+100\%$ is attained in safety-critical products for space and nuclear technology. The -100% synergy marks a failure in product functioning due to its full worn-out.

In this context the question about synergy and quality interrelations crops up. A research, provided for this purpose [7], has shown that the goals and nature of their assurance are quite close to each other and that every effort to increase synergy brings along better quality. The main difficulties, related to the quality dimension, are associated with the problem that it is at the same time a perceptual, technical and market-driven concept. The quality paradigm is changing and the procedures to deal with "perception", "value", "feeling" and "mindset" have become a modern field of research activities [8]. The technical side of product quality continues to be a key driver of the product development process and more attention is paid to improving the upstream activities of the product development process to ensure that quality is built in the product. At the same time, quality and reliability problems of non-safety-critical products have changed into market-driven factors. In order to achieve a high level of reliability, and therefore low service dependability, the cost of the product rises and it is difficult to sell. If the dependability is too high, the level of warranty costs rises, the service network must be expanded and the reputation of the organization may suffer. As a result, the quality level is optimized in market competition.

The use of the Total Quality Management (TQM) and ISO 9000 standard series should guarantee good quality. In the 1990s there was a heated dispute in business media over the problematic impact of the TQM on the financial performance of enterprises. The analysis, provided by Singhal [9], is based on the evaluation of TQM investments benefit of 600 quality award winners in the USA. They were compared with the firms of the similar size from the same industry and it was found out that quality award winners outperformed the benchmarks on almost every performance measure.

The present research focusses on fighting against “bad” engineering using the synergy-based approach to empower quality assurance. According to the above-stated facts, the present research has two main problems to solve: to study empirically the role of human shortcomings in quality assurance and to develop a suitable framework to help to prepare a company’s quality management system for ISO cerfication audit.

2. RESEARCH OF HUMAN SHORTCOMINGS IN QUALITY ASSURANCE

First, it is appropriate to establish what kind of human activities in quality management should be taken into account (Fig. 1).

As the quality management system is mostly based on human activities, it is appropriate to go deep into real human behaviour in the quality management context. The 10-year database of human shortcomings is compiled, where the results of more than 200 production companies’ real quality management system certification processes are analysed. That is possible since during the certification audit all the noticed shortcomings in the company’s quality management system were documented. In the framework of the present research all the noticed shortcomings were analysed, classified according to the reason and inserted into the general database. It is important to underline that during certification only the data on human shortcomings are available.

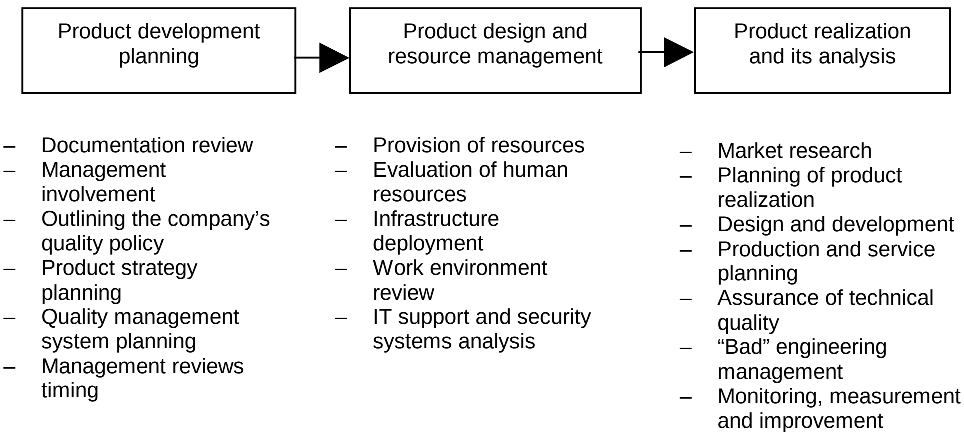

Fig. 1. Deployment of quality management activities.

First of all, the terms used in the further analysis should be specified. On a large scale (Fig. 2), all the revealed human shortcomings can be divided into faults **F** and mistakes **M**. Faults are wrong decisions that have no justification. Communication misunderstandings between the client and the design team belong to the faults' category **F1**. To the category of faults **F2** belong all shortcomings connected with negligence. Faults may be treated as a result of negative synergy in teamwork or person's inner negative synergy. Communication problems of the team members have been the research area of psychologists and the person's inner synergy (communication) in medicine. To both areas the present research team can contribute only by analysing the registered results. Well-organized teamwork is the key to better communication synergy, where capabilities of team members by cooperation are used in the best possible way by compensating their weak sides and amplifying the common useful abilities. Only in teamwork it is possible to press down most of the human shortcomings as accepted decisions are collective. The inner communication synergy of individuals determines their fitness, creativity and in summary possible contribution ability to cooperation. The increasing of the positive synergy of human organs, neural system and psychology is the key to attain the top form in sports, arts and creative engineering.

Mistakes have a far more complicated nature. To this category belong wrong decisions **M1**, caused by lack of core competence in quality management activities. Another category of mistakes **M2** is conditional and is caused by unknown matters at the moment of certification audit and they may be resolved in the course of further activities of quality assurance. The only real way to reduce human mistakes is to train and upgrade the personnel or to use the help of qualified experts.

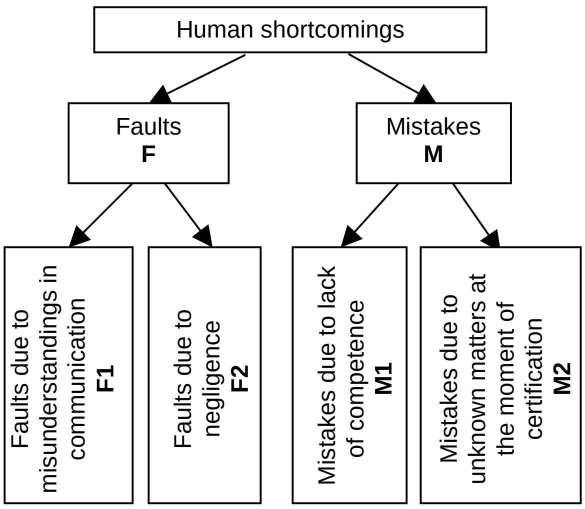

Fig. 2. Classification of shortcomings by the quality assurance.

In Fig. 3 the results of the statistical analysis of human shortcomings in quality management are presented. During the phase of product development planning (line PDP) the typical faults **F1** are as follows: the responsibilities inside the organization are not fully defined, the path and procedure of documentation confirmation are not clearly legitimated, absence of the overviews of clients' requirements, etc. Faults **F2** – valid instructions are not used, the introduced procedures are not followed, disorder in the drawings system, etc. Mistakes **M1** – inadequate knowledge of legal acts, as a result of which the requirements are insufficient and, therefore, cannot be followed. Mistakes **M2** are related to the lack of future perspectives when the current procedures are outdated but better solutions are not yet available.

The PDRM line in Fig. 3 shows the data of human shortcomings for the product design and resource management phase. The dominating deviations are: **F1** – professional instructions do not include qualification requirements, working environment does not correspond to standards, professional training plans are not followed, etc. **F2** – personal development talks are not provided, professional knowledge cards are not filled in, safety regulations are not followed, warning signs are absent, etc. **M1** – misleading warning signs, incompetence in store-keeping, etc. **M2** – the existing attestation systems are not used but at the same time new ones are introduced.

The PRA line in Fig. 3 presents an overview of human shortcomings for the product realization and analysis phase. Typical deviations are: **F1** – the timing of measuring equipment verification is not established and the real situation is out of control, the client's requirements are not followed, etc. **F2** – safety regulations are not followed, internal audits are missed, suppliers' evaluations are not provided, etc. **M1** – in the procedures there are references to non-existent requirements, conformity documentation is absent, etc. **M2** – absence of market investigations, superficiality in the planning of future strategies, absence of risk analysis, etc.

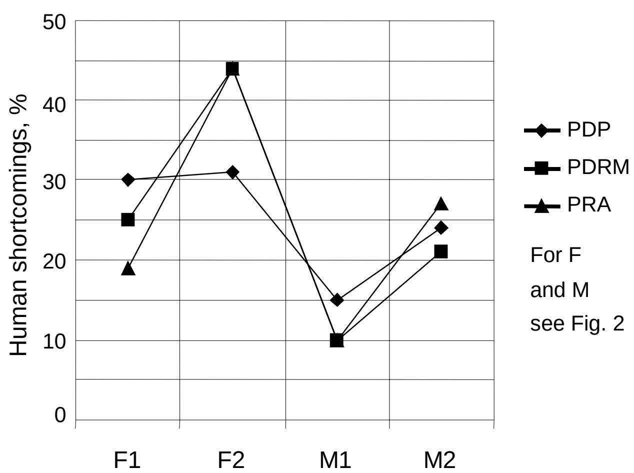

Fig. 3. Human shortcomings in quality management.

At first sight, the provided analysis of human shortcomings in quality management seems to be too bureaucratic, but it opens the full spectre of every-day human faults and mistakes that may lead to very serious problems in case of coinciding events. While having a closer look at the trends extending over the whole quality assurance process, it is seen that communication faults are reducing with time. However, at the same time the faults due to negligence are dramatically growing, reaching half of all the shortcomings in the last phase. The main reason for that seems to be a trend to ignore the procedures and standards. The competence level seems to be stable but the mistakes addressed into the future seem to form too big a share of all the shortcomings.

It is quite instructive to provide a comparative analysis of the reasons of human shortcomings in different areas of engineering activities in the quality context. In Fig. 4, data on human shortcomings for different levels of engineering design activities, collected by the research team during the last dozen years, are shown [10]. The question may arise if these data are really comparable as the previous research was focussed on product quality. To be more exact, the aim of the previous research was to specify the border between human shortcomings and technical (reliability) failures of designed products and systems. Experience has shown that the two first classification levels of human shortcomings are so universal that they are fully applicable in engineering design and in quality management. However, on the third level of classification the nature of short-comings in different researches is really very different. For better comparison of the results, in Fig. 4 the failures due to the technical reasons are excluded.

In the second column of Fig. 4 the results of human shortcomings in the design and production of a serial product – light fittings (LF) – are presented [11]. The scope of this database is 5 years and more than 700 descriptions of human and technical shortcomings are analysed. In the third column the data on human

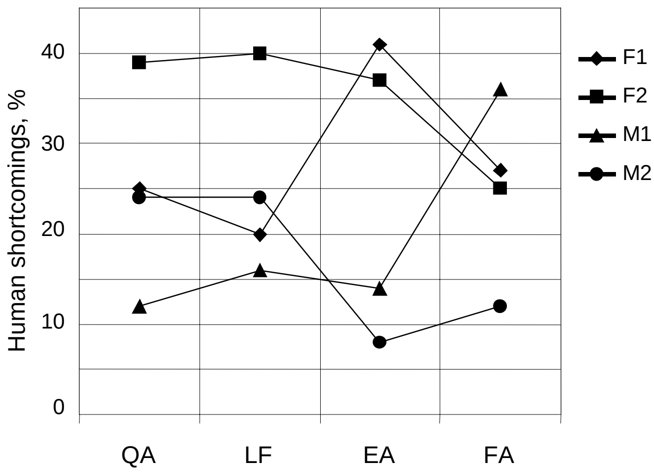

Fig. 4. Comparative analysis of human shortcomings: QA – quality assurance, LF – light fittings, EA – equipment control, FA – factory automation.

shortcomings for the design and application of equipment control systems (EA) are presented, where the experiences of 13 000 cases were analysed. In the last column the data on the design and commissioning process of factory automation systems (FA) are presented. The basis for the last column is the experience of applying 5 large factory automation systems.

As one can see, the spectrum of human shortcomings in quality management is very close to real factory data (the LF case), which leads to the conviction about the universal nature of human shortcomings in a mature company. However, in the area of equipment control the tasks always vary and work is so strenuous that the share of faults starts to dominate over the mistakes controlled by professionalism. In the more complicated area – factory automation – a lot of standard solutions are available and the share of faults is reducing but the role of mistakes **M1** is growing, as the prognosis of the process character may appear to be wrong for the real conditions.

Summarizing the points discussed above one can see that most of the problems accompanying "bad" engineering are caused by human shortcomings. In the previous research a lot of efforts have been made to find the border between human shortcomings and technical reasons (reliability) on different complexity levels of engineering design [10]. A low share of technical problems is typical in systems where mature components are used. Sometimes it is really difficult to distinguish between the failures due to reliability problems (wear, aging of the materials, etc.) and to those, which occurred because of wrong decisions by the selection of materials. Also, it can be difficult to detect the borderline between average negligence and negligence caused by physiological fatigue or stress due to wrong organization of the work.

3. DEVELOPMENT OF THE SYNERGY-BASED TQM SUPPORT FRAMEWORK AND THE METHODOLOGY FOR THE PREPARATION FOR CERTIFICATION

In any product design quality and quality management process, the main driving factor is the engineers with their experience, inherent faults-mistakes and competence. The quality management system is called forth to help them to find a way to avoid human shortcomings. At first sight it seems that in case of quality assurance we have to choose between two classical ways – either the prescriptive/administrative or the descriptive/case-based approach. In fact, there should be an interactive and adaptive environment between them. The successful separation of human and technical aspects at the design and application of systems automatization opens up new possibilities to move ahead on the way of the synergy-based approach to quality assurance in the framework of TQM. By integrating the technology of Dependency (Design) Structure Matrixes (DSM) [12,13] and the Theory of Domains [14] it is possible to include time and competence dimensions in quality assurance (Fig. 5). In other words, it is possible to develop a family of adaptive tools based on the level of competence and expert knowledge

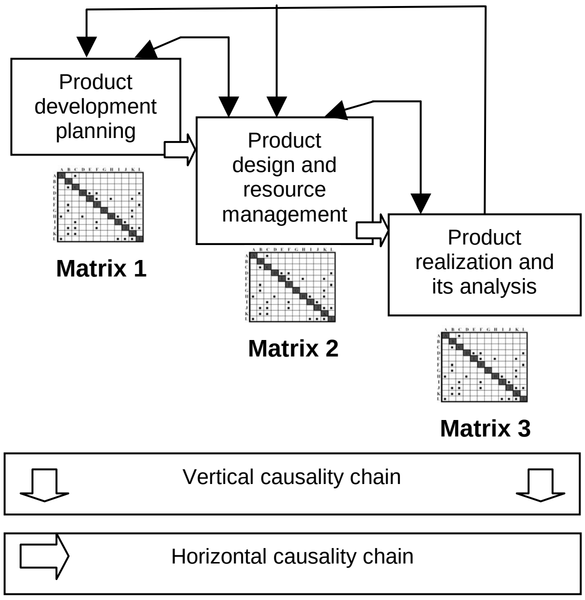

Fig. 5. The integrated model of quality assurance.

of the team and to synthesize their own roadmap algorithm to move ahead on the way of synergy-based quality assurance [3]. The proposed model makes it possible to take into account both "soft" parameters of integration – market conditions and human aspects.

In order to apply the methodology for the preparation of the company's quality management system for ISO certification it is necessary to compose 3 different matrixes (Fig. 5) for different domains of quality assurance activities (Fig. 1). Matrix 1 in Fig. 5 presents the activity type DSM that allows to take into account the marketing trends and to initiate synergy-based activities in the product strategy and its quality assurance planning so that the developed products will be competitive on the market. Matrix 2 is the activity-based DSM that gives the algorithm for the synergy-based product development process with the corresponding empowering of human resources, infrastructure and IT-support in the company. Matrix 3 is a mixed activity- and parameter-based DSM for the optimal planning of the product realization process and service in the framework of quality assurance.

In Fig. 6, an example of completing the DSM for product realization and its analysis matrix is shown. On the basis of expert knowledge of the team, a matrix for 22 inputs was compiled concerning the deployment of quality management activities. There is no need to arrange inputs in a certain order as they are all individually mathematically treated. All inputs must be preliminarily numbered and therefore the numbers of inputs must be the same on horizontal and vertical axes. The next step is to evaluate all possible interactions from the point of their strength: 0 – interaction is absent, 1 – interaction is moderate and 2 – interaction

Task Name	Level		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Market research	1	1		1		2		2			Block1														1
Planning of product realization	1	2	1		2	1	1																		2
Customer - related processes	1	3		2		1	1	2																	3
Determination of requirements related to the product	1	4	2	1	1		2	1																	4
Review of requirements related to the product	1	5		1		2		1																	5
Customer communication	1	6	2	1	2	1	1																		6
Purchasing	2	7		1	1					2	1		1		2			Block2							7
Production and service planning	2	8		1	1				2		1	2	1	1	1										8
Control of production and service provision	2	9			1				1	1		1		1											9
Validation of processes for production and service provision	2	10				1				2	1		1		1										10
Identification and traceability	2	11				1			1	1		1		1	1										11
Customer property	2	12			1	1					1		1									Block3			12
Preservation of the product	2	13				1			2	1		1	1	1											13
Control of monitoring and measuring devices	3	14					1										1	2					1		14
Customer satisfaction	3	15	1				1	1								1		1	2	1		1			15
Internal audit	3	16		1	1	1	1			1						2	1			2		1	2		16
Control of nonconforming product	3	17							1	1	1	1	1	1	1	1	2								17
Analysis of data	3	18			1		1	1		1	1	1	1	1	1	1	1	2	1		2				18
Corrective actions	3	19					1			1						1	1			2					19
Preventive actions	3	20			1		1			1			1				1						1	2	20
Assurance of technical quality	3	21	1		1		1	1		1			1	1		1		2	1	1		1		2	21
"Bad" engineering management	3	22	1		1		1	1		1				1		1	1					2	2		22
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	

Fig. 6. Quality management product realization and its analysis matrix.

is strong. After the mathematical treatment, all inputs are put into order differentiating coupled, parallel and series tasks. These large blocks represent the critical path for the duration of the whole process and point out the necessary places of reviews. The two other matrixes may be completed in the similar way.

The most important task is to determine which interactions should be allocated to the synergy-based optimization, taking into account the market-driven financial and time resources. It is a highly qualified and time-consuming job to compose a useful and suitable DSM matrix and this may be a great challenge to the team. Thus, simultaneous professional knowledge of product architecture, the product development process and quality management experience is required. Low competence of the team may result in an imperfect DSM where some important interactions may be absent or incorrectly evaluated.

Depending on the preparedness of the quality management team to handle matrix analysis there are 3 possible levels to use the proposed methodology. On the first level it is possible to fill in the DSM with synergy-interactions and to complete the tasks table by hand. Already here it is fully possible to exploit the fruits of synergy-based thinking, i.e. to use the integrated synergy-based optimization technology for the compensation of the mutual weaknesses of quality assurance activities and for the amplification of their common useful effects to increase positive synergy. On the second level the mathematical matrix analysis helps automatically to arrange the activities in the matrix. The full exploitation of the possibilities of the proposed approach requires an additional experience in probability evaluation and discrete event modelling.

An important part of the described synergy-based approach to quality assurance is the prognosis of the time for the activities. By using the appropriate mathematical tools [13] it is possible to schedule the dispersed activities by levels, grouping them into submatrixes of coupled tasks. Further it is possible to use the Latin Hypercube Sampling and parallel discrete event simulation [15] to incorporate the uncertainty of the expected duration of the tasks on three levels: optimistic, most likely or pessimistic. In Fig. 7 the result of probability analysis of the realization time for block 1 of product realization and its analysis matrix 3 (Fig. 5) is shown. Time for parallel and series tasks can be easily added on the

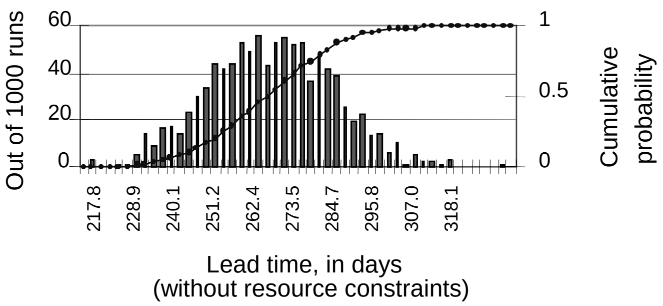

Fig. 7. Prognosis of the preparation time for certification.

basis of previous experience. Extra time should be added for the realization of the synergy-based optimization of selected interactions.

The real values of the present methodology are the following: clear decomposition of the quality management process into scheduled activities and possibility to present all information about the interactions of activities in a visible form. The statistics of human shortcomings is used for statistical probability evaluation of the time for iterations, reworking and learning. However, research into human shortcomings has given valuable information for the synergistic deployment of quality assurance activities. The synergy dimension is introduced to the DSM matrixes for the selective empowering of quality assurance activities. So far the choice of interactions in matrixes, allocated to synergy optimization, has been based on intuition and focussed on stronger interactions. Naturally, first of all interactions of negative synergy must be superseded. In summary, it can be said that this methodology serves as a good roadmap for quality thinking.

4. CONCLUSIONS

The preceding and present research into the reasons of the “bad”engineering have given sufficient evidence that most of the troubles with quality are caused by shortcomings in human activities. The results of empirical study of human shortcomings, registered by the certification of the quality management systems of more than 200 production companies, are a useful basis for arranging quality assurance activities.

The experience gained from the development of the synergy-based engineering design methodology appears to be useful for applying the same approach to quality management systems. It is shown that by this way it is possible to develop adaptive tools, based on the level of competence and expert knowledge in the company to synthesize their own roadmap algorithm to move ahead on the way of quality assurance. In such a way a suitable basis is developed to speed up the integration of still somewhat disunited quality assurance of a new product and quality management systems.

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Sünergiapõhine lähenemine kvaliteedikindlustusele

Tiit Hindreus ja Vello Reedik

Nii tootearendus ja projekteerimine kui ka kvaliteedijuhtimise süsteemi efektiivsus on võtmemõjurid toote kvaliteedi maksumuse kujunemisel. Seetõttu peavad need olema tihedalt integreeritud. Eeldatakse, et põhiliseks takistuseks parema kvaliteedi tagamisel on nn kehv inseneritegevus, mille põhjuseks on inimlikud vead ja eksimused projekteerimisel ning kvaliteedi juhtimisel. Artiklis on tutvustatud uudset võimalust inimtegevuse tõhustamiseks kvaliteedisüsteemi raamistikus, mis põhineb sünergiapõhisel lähenemisel kvaliteedikindlustusele. Lõpptulemusena on esitletud metoodikat, mis on kavandatud, abistamaks ettevõtet oma kvaliteedijuhtimise süsteemi ettevalmistamisel ISO sertifitseerimiseks.