Influence of Contingency Factors on the Application of Quality Tools

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The subject of this paper is constitution of a model of critical contingency factors for the application of quality tools and its experimental confirmation on the products in-group of engine and tractor manufacturers. The expected relations between contingency factors and the application of quality tools are confirmed and statistical models, describing the influence of technical and organizational factors on quality tools implementation and choice indicators, are given. Results of the survey showed that factors identified in the proposed model have an influence on the choice of quality tools, and laws of their influence are given as regression equations. Practical benefits from this paper are: a) it is possible to determine the necessity of application of a certain quality tool prior to it's implementation; b) it is possible to determine the need for a wider range of application of a certain quality tool during the process of its implementation; c) it is possible to determine a set and range of application of required quality tools before the production of new products starts and d) in case of failure of application of a certain quality too, it is possible to discover its possible causes.

Keywords: *quality tools, contingency factors, technical and organizational factors, regression analysis, quality tool application indices.*

1. INTRODUCTION

The basic motive in selecting this topic for a paper is not only the present interest in the ISO 9000 series of standards, where the choice of quality tools and the application problem is not discussed in detail. It is also the fact that according to the well-established contingency theory the contemporary theory and practice seek description of the character of the effect critical factors have on organization performance, in order to successfully put them under control.

The subject of this paper is constitution of a model of critical contingency factors for the application of quality tools and its experimental confirmation on the products in-group of engine and tractor manufacturers, which are the leaders in the field. We expect that the factors identified in the proposed model have an influence on the application of quality tools and plan to describe these relations by regression equations.

In previous research, the following was noted:

- Only some available research results are concerned with the impact of certain factors on the choice and application of quality tools, but no attempts were made to develop any mathematical model;
- An integral model of factors which has an impact on the application and choice of quality tools has not been developed in previous investigations;
- There is still no answer to the question of the number and choice of quality tools that should be investigated;
- The need for determination and qualification of principles on which one or more factors have an impact on the choice of quality tools was noticed, but not realized in previous research work.

The following surveys should be emphasized:

- Lockyer et al. [1] investigated application of 3 quality tools in practice, showing as the result the portion of enterprises using quality tools;
- Oakland and Sohal [2] showed in their paper the value of indices for application of 7 quality tools;
- Lascelles and Dale [3], together with Barad [4], investigated the impact of enterprise size on the number of quality tools applied. Lascelles and Dale included 28 quality tools in their investigation, while Barad considered only 5 of them;
- Sohal et al. [5] broadened the scope of Lascelles and Dale's investigation by taking into account the industrial sector, but reduced the number of analyzed quality tools to 3;
- Jayaram et al. [6] identified in his research available quality tools (26 quality tools) and investigated partial impact of quality attributes and quality strategy on the choice and application of quality tools;
- Lagrosen and Lagrosen [7] discussed 12 quality tools and their usage in different organizational configurations.

2. INTEGRAL MODEL OF CHOICE FACTORS FOR QUALITY TOOLS AIN HEADING

The number of choice factors for quality tools is, theoretically, unlimited, but it has to be restricted in practice [8]. It is also certain that in this paper, no matter how thorough it is, it won't be possible to discuss all relevant factors. For this reason only the factors that

Received: May 2009, Accepted: July 2009

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are, in the authors' opinion, critical, and fit in with the chosen problem approach and are suitable for experimental research will be studied in detail.

The basic assumption for developing a model of quality tool choice factors is that contingency factors, which have an impact on quality improvement activities also have an influence on the choice of quality tools. This assumption is regarded as valid because quality tools are utilized in order to achieve continuous quality improvements.

It is a well established and confirmed fact, in literature, that technical factors have an impact on quality improvement activities, application of quality tools being one of them, in 2 ways: indirectly, through organizational factors significant on higher hierarchy levels, and directly on operational levels.

Organizational factors exert their influence through organizational changes induced by a quality improvement process. The contingency approach has been used for their determination, where the environment, strategy, technology and enterprise size are dominant factors, in terms of their impact on the continual quality improvement process.

In that sense, the aspiration towards fulfilling quality system demands, certification according to ISO 9000 being the final goal, is regarded as an environmental factor. The time to certification, i.e. to rectification as the certificate is valid for 3 years, represents the dominant environmental factor.

Quality improvements strategies, as an integral part of enterprise seeking quality improvements overall strategies, appears in the following terms:

- Strategy of inspection;
- Strategy of process control;
- Strategy of quality improvements;
- Strategy of quality planning.

Technology, as an organizational factor, influences the way work is structured, and is represented, from the quantitative perspective, by the type of production (unit, batch or mass production) [9]. At the same time, it is a technical factor as well.

Enterprise size presents one of the basic factors of enterprise organizational situation, which also has an impact on the application of quality tools. The majority of authors take the number of employees as the enterprise size index, although it is useful to include criteria such as equipment and machine number and condition, gross profit.

Technical factors are generated in quality loop phases accomplished through a quality system structure including enterprise operative systems. Phase quality is generated in each operative system of an enterprise. However, since the number and presence of certain operative systems varies in different business systems, it is not possible to generate a model of technical factors relying on phase quality. It is much more convenient to consider basic qualities of a product. Basic qualities (quality of design, manufacturing and exploitation) are much more convenient for discussion since each of them comprises quality generated in operative systems interconnected based on a process. Thus, these three basic qualities are assumed present in all business systems. Therefore, the basic assumption of a model of technical factors is that they have an impact on creating three basic qualities resulting in product overall quality.

Product complexity presents one of the most important factors (based on product complexity, we recognize simple and complex products). The lowest level of assembly, the level of parts, is present both in simple and complex products and therefore product complexity will be represented in this paper by the number of parts, while permanent aspirations towards simplification and standardization of product components suggests that the number of different parts, standardized parts and different construction materials used should also be considered.

The following elements stand out as factors of the complexity of manufacturing processes:

- share of own production in the final product and number of suppliers (related to a purchase operative system),
- number of machines, number of tools, number of manufacturing and assembly operations and number of pages (information) of technical/technology documentation and production type (related to operative systems for planning, manufacturing and assembly technologies) and
- number of control devices and control operations (related to an operative system of quality control).

Important characteristics and features, i.e. quality attributes, are of great importance to customers. Literature offers different opinions on quality attributes, which converge in the sense that basic quality attributes are:

- function attributes,
- esthetic attributes,
- reliability,
- durability,
- maintainability and
- other attributes (supplement to basic product function).

Technical and organizational contingency factors listed are correlated and the integral model of choice factors for quality tools is posted according to the following premises:

- Quality tools are being utilized for the purpose of obtaining a desired overall product quality level;
- Overall quality is generated in a quality loop, according to which a quality system organizational structure is generated i.e. the present organizational structure of the enterprise modified due to organizational factors;
- Technical factors, which have impact on product quality, are generated in quality loop as well;
- Phase quality represents the connection between organizational factors that have an impact on structuring of operative systems in an enterprise and technical factors, which have impact on creating basic product quality.

3. EXPERIMENTAL RESEARCH OF CRITICAL FACTORS FOR THE APPLICATION OF QUALITY TOOLS

It is necessary to confirm experimentally the adequacy of the model of critical factors for the choice of quality tools, Fig. 1. Therefore, the basic assumption of this paper is that the factors defined in the model have an impact on the application of quality tools.

3.1 Area of data collection

The research includes the majority of enterprise in-group of engine and tractor manufacturers, which are leaders in their field. Time limitation and data availability prevented us from collecting data on each product, and therefore a basic product, i.e. typical representative for a family of products, was chosen as a basic unit of research in corresponding factories. A sample containing 42 basic products of engine/tractor groups was structured in that way.

3.2 Research design

The experiment was modeled to meet two goals: collect data on critical factors for the choice and application of quality tools and data on particular quality tool utilization.

All necessary data on technical factors was derived from a company’s technical documentation (technical drawings, lists of operations, bills of material), except those related to quality attributes that were obtained from quality control department documentation (procedures for market information management). The technical factor data had a wide range of values and variations, so it was logarithmically transformed, which was convenient for later linearization of the regression model.

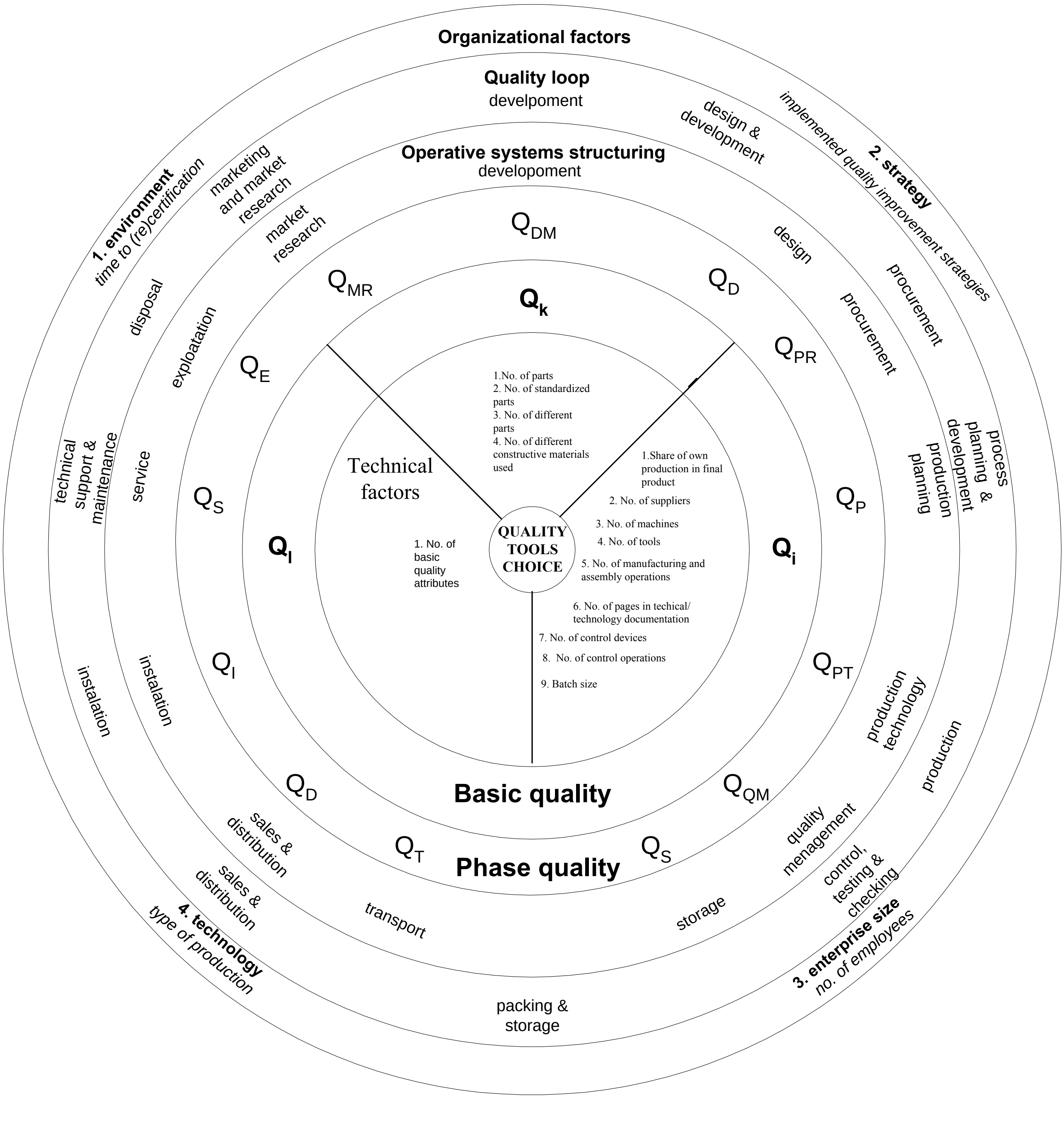

Figure 1. Model of choice factors for quality tools [10]

Application data for quality tools was collected by means of interviews and questionnaires, because no previous surveys on the application of quality tools had been conveyed in factories (therefore, there was no available documentation on the application of quality tools).

Like in other surveys of this type (Sohal [5] and Oakland [2]) the participants were asked to estimate each quality tool application according to Likert's 10 grade scale.

Besides evaluating the application of a single quality tool, it is important to have information on overall application of quality tools. For that purpose, an "artificial" variable (like in other similar surveys), labeled application range of quality tools application range, was used.

The main advantage of the "quality tool application range" over the average application mark of quality tools is that mark 1 (when the tool has not been used at all) is not taken into account. Generally, an application range is calculated by dividing the sum of marks higher than 1 (from 2 to 10) with the highest possible mark (i.e. when all quality tools discussed are used in their full range and when their results are used in major quality improvements – mark 10) and multiplying the result by 100 in order to present the value in percents. Quality tool application ranges for each quality tool (application range of a quality tool for a particular quality tool) and each product (application range of quality tools for a particular product) were calculated. In the following paragraphs the application range of quality tools for a particular quality tool will be marked with PVA_i and the application range of quality tools for a particular product with PVP_j. Both indices can take values up to 100 %.

The following quality tools were analyzed and the reason is that they are actually being used for the products discussed: Check sheet, Histogram, Control charts, Pareto analysis, Cause-effect diagram, Brainstorming, Flowchart, Network programming, Internal audit, Benchmarking, Electronic data management, FMEA, Methods of sampling and acceptance, Data analysis, Value analysis, Process capability, performance and accuracy study, Reliability analysis, Stratification, Team work, Inspection (receipt, mfg, final), Quality costing and Employee training.

Collected data forms a basis for further analysis aiming to confirm validity of the proposed model of critical factors for application and choice of quality tools, which consist of the following methodological steps:

- Analyses of indices for the application and choice of quality tools;
- Formulation of a mathematical model describing the effect of simultaneous critical contingency factors on the application and choice of quality tools.

3.3 Experimental results – discussion and analysis

Indices for the application and choice of quality tools indicate the following conclusions:

- For products discussed, 14 to 22 (the average 17.46) quality tools have been applied;
- The only technique used to its maximum extent is in all cases inspection;
- In all cases discussed, the following techniques are used to some extent: Check sheet, Internal auditing, Electronic data management, Flowchart, Network programming, Benchmarking, FMEA, Data analysis, Teamwork, Inspection and Employee training;
- To illustrate the experimental results obtained, application ranges and percentages of quality tools for a particular quality tool application are given in descending order in Table 1;
- The values given in Table 1 show that quality tools are used in 80 % of the cases discussed, and the average is around 52 %.

Regression analysis included regression testing by means of regression parameters and variance analysis, checking of variance increasing factors in order to eliminate multicolinearation, correction of determination coefficients due to sample size, check on Mallow' s and Durbin-Watson's statistics and residual check. The "Stepwise regression – backward elimination" procedure was used.

This way, regression equations of the dependence of the application of particular and cumulative quality tools on contingency factors were generated, and they are shown in Table 2.

In Table 2 some equations are given in parenthesis because Durbin-Watson statistics was under a critical level, probably caused by autocorrelation. Due to the small sample size introducing new predictions in this survey could not solve this problem.

Table 1. Review of application ranges for particular quality tools

Quality tool	PVA
Inspection	100
Methods of sampling and acceptance	85.83
Employee training	82.08
Check sheet	81.66
Internal audit	80.42
Team work	78.75
Data analysis	78.33
Flowchart	73.33
Control charts	70.41
Histogram	63.33
Process capability, performance and accuracy study	53.75
Cause-effect diagram	42.50
FMEA	42.08
Benchmarking	42.08
Quality costing	40.83
Pareto analysis	38.75
Brainstorming	37.92
Electronic data management	24.17
Network programming	15.42
Reliability analysis	10
Value analysis	9.58
Stratification	7.5
PVA_{sr}	52.35

Table 2. Influence of contingency factors on the choice of quality tools *

	Regression equation	$\bar{R}^2$	SE (stand. error)	DW statistics
Check Sheet	PVA_1 = - 9.82559 + 0.67952 · NO PARTS + 5.57881 · BATCH SIZE - 3.8763 · TIME TO CERT	0.8057	1.0172	1.40
Hystogram	PVA_2 = - 18.9206 + 0.625939 · NO OP TOOLS + 13.5204 · NO STR + 0.795346 · BATCH SIZE + 4.10937 · ENT SIZE + 3.69523 · TIME TO CERT	0.9164	0.681	2.42
Control Charts	(PVA_3 = 11.0696 - 13.2841 · NO STR - 11.1303 · TIME TO CERT + 11.9583 · NO ATRB)	0.8994	0.9983	0.75
Pareto analysis	PVA_4 = - 13.3992 + 33.3287 · NO STR + 1.2517 · NO PARTS + 9.3457 · TIME TO CERT - 9.97345 · NO ATRB	0.7157	0.954	1.41
Cause Effect diagram	PVA_5 = - 9.6102 + 0.505 · NO OP TOOLS + 23.2883 · NO STR + 3.1409 · ENT SIZE - 14.4571 · TIME TO CERT - 9.0903 · NO ATRB	0.9902	0.3977	1.94
Brainstorming	PVA_6 = - 15.5308 - 3.31697 · NO CD CO + 0.9721 · NO OP TOOLS + 9.02903 · ENT SIZE - 11.9523 · TIME TO CERT - 2.4964 · NO ATRB	0.9164	0.6712	2.20
Flowchart	(PVA_7 = - 7.018 - 7.7285 · NO STR + 0.81204 · NO PARTS + 0.61251 · BATCH SIZE + 5.6303 · ENT SIZE - 11.1042 · TIME TO CERT)	0.8935	0.9215	0.71
Network Programming	PVA_8 = 4.7273 + 23.7337 · NO STR + 2.431 · NO PARTS - 6.31827 · ENT SIZE	0.7940	1.3823	1.51
Internal audit	(PVA_9 = 12.9791 - 21.5215 · NO STR - 7.3391 · TIME TO CERT + 15.9419 · NO ATRB)	0.6876	1.6106	0.57
Benchmarking	PVA_{10} = - 33.9994 + 0.97998 · NO OP TOOLS + 34.2939 · NO STR + 7.72429 · ENT SIZE - 12.806 · NO ATRB	0.8119	1.4717	0.87
Electronic Data Management	PVA_{11} = - 5.55188 + 4.88104 · ENT SIZE - 11.7357 · TIME TO CERT - 4.8747 · NO ATRB	0.8596	0.9498	0.88
FMEA	PVA_{12} = - 14.0033 + 0.6301 · NO OP TOOLS + 14.3932 · NO STR + 4.6667 · ENT SIZE - 7.2968 · TIME TO CERT - 7.2893 · NO ATRB	0.9605	0.5132	2.28
Methods of sampling and acceptance	(PVA_{13} = 1.80154 - 0.52032 · NO OP TOOLS - 21.7772 · NO STR + 3.38432 · ENT SIZE + 17.7886 · NO ATRB)	0.9406	0.6736	1.05
Check Sheet	PVA_{14} = 4.24144 + 1.39603 · NO PARTS + 1.27523 · BATCH SIZE - 11.6562 · TIME TO CERT	0.8578	1.0131	1.47
Value analysis	(PVA_{15} = - 2.78962 + 0.464249 · NO OP TOOLS + 5.50323 · NO STR)	0.5092	0.7101	1.02
Process capability, performance and accuracy study	PVA_{16} = - 14.8022 + 0.38083 · NO OP TOOLS + 11.2233 · NO STR + 6.593 · ENT SIZE - 12.9921 · TIME TO CERT - 7.72921 · NO ATRB	0.9722	0.5978	1.72
Reliability Analysis	(PVA_{17} = - 4.5222 + 0.14203 · NO OP TOOLS + 5.8248 · NO STR + 1.1969 · ENT SIZE - 2.3194 · NO ATRB)	0.8405	0.2039	0.77
Stratification	(PVA_{18} = - 12.611 + 1.224 · NO OP TOOLS + 15.8431 · NO STR + 6.45324 · TIME TO CERT)	0.7648	0.8315	1.12
Team work	PVA_{19} = - 28.219 + 13.7454 · NO STR + 0.691 · BATCH SIZE + 7.8249 · ENT SIZE + 8.61849 · TIME TO CERT	0.8507	1.1319	1.80
Value analysis	PVA_{20} = 19.3741 + 25.1909 · NO STR + 2.78752 · NO PARTS - 10.8389 · ENT SIZE	0.6994	1.9633	1.44
Employee training	PVA_{21} = 7.93718 - 15.419 · NO STR + 0.537 · BATCH SIZE - 4.02482 · TIME TO CERT + 15.2371 · NO ATRB	0.9384	0.6584	1.57

* Inspection is used for all products that are analyzed. Predictors are transformed by means of a logarithmic transformation in all regression equations.

From Table 2 it can be seen that a mathematical model of the regression dependence of the application range of quality tools on contingency factors shows the following:

- It was determined that the overall application range of quality tools depends on contingency factors in a linear manner, and according to the regression model:

$$\text{PVP} = -63.4207 + 70.5051 \cdot \text{NO STR} + 7.72536 \cdot \text{NO PARTS} + 20.7953 \cdot \text{ENT SIZE} + 2.40503 \cdot \text{BATCH SIZE} - 32.4902 \cdot \text{TIME TO CERT}; \quad (1)$$

- Therefore, the number of implemented strategies, number of product components, enterprise size, product batch size and time to next certification has an impact on overall application of quality tools;

- The regression equation explains 98.41 % of data variations;
- Implementation of advanced quality improvement strategies (represented in a number of strategies) increases the overall application range of quality tools;
- Increasing construction complexity leads to a higher overall application range of quality tools;
- Larger batch size implies growth of overall application of quality tools;
- Other technical factors (number of basic quality attributes, number of operations and tools and number of control operations) have a smaller influence on overall application of quality tools;
- It is possible to compute values of overall application ranges of quality tools for other products of enterprises in the engine/tractor manufacturers group (within limits of confidence) from the regression equation.

A mathematical model for regression of FMEA analysis on technical factors also shows the following:

- It was determined that the quality tool application range depends on technical factors in a linear manner, and according to the regression model:

$$PVA_{FMEA} = - 4.8022 + 0.38083 \cdot \text{NO OP TOOLS} + 11.2233 \cdot \text{NO STR} + 6.593 \cdot \text{ENT SIZE} - 12.9921 \cdot \text{TIME TO CERT} - 7.72921 \cdot \text{NO ATRB}; \quad (2)$$

- FMEA analysis is linearly dependant on the number of implemented quality strategies, enterprise size, number of basic quality attributes, and certification (in the sense that the enterprise has the ISO 9000 quality certificate); greater complexity of manufacturing and assembly processes, larger number of implemented quality strategies, larger enterprise size, smaller number of basic quality attributes and longer period from certification implies a larger range of cause-effect diagram application.

Another example is a mathematical model of regression for process capability, performance and accuracy study on technical factors showing the following:

- It was determined that the quality tool application range depends on technical factors in a linear manner, and according to the regression model:

$$PVA_{PCPA} = - 14.8022 + 0.38083 \cdot \text{NO OP TOOLS} + 11.2233 \cdot \text{NO STR} + 6.593 \cdot \text{ENT SIZE} - 12.9921 \cdot \text{TIME TO CERT} - 7.72921 \cdot \text{NO ATRB}; \quad (3)$$

- The application range of process capability, performance and accuracy study is linearly dependant on the complexity of manufacturing and assembly processes, number of implemented quality strategies, enterprise size, number of basic quality attributes, and certification (in the sense that the enterprise has the ISO 9000 quality certificate; greater manufacturing and assembly process complexity, larger number of implemented quality strategies, larger enterprise size, smaller number of basic quality attributes and longer period from certification implies a larger range of application process capability, performance and accuracy study, similar to other quality tools.

4. CONCLUSION

The contingency factors that are considered are not equally important for the quality tools discussed, so the following should be noticed:

- Construction complexity, as an important technical factor, appears in regression models for check sheet and data analysis (positive effect);
- Type of production, represented by the batch size, is present in the regression model for check sheet, histogram, data analysis, teamwork and employee training (positive effect);
- Certification has an impact on the application range of quality tools in all cases, except in network programming and benchmarking. It is evident that the range of teamwork applications grows with the period of time required for obtaining a certificate, whilst other application ranges of quality tools grow with time from certification;
- Manufacturing and assembly process complexity is present in regression equations for the following quality tools: histogram, cause-effect diagram, brainstorming, benchmarking, FMEA and process capability, performance and accuracy study (positive effect);
- A number of control operations appear only in the regression equation for brainstorming, where they have a negative effect (if the number of control operations is larger the brainstorming range of application is smaller);
- A number of basic quality attributes are not present as an important factor in regression equations for check sheet, histogram, network programming, data analysis, teamwork and quality costing; the employee training range of applications grows with the number of quality attributes, while other quality tools ranges of application drop with a higher number of quality attributes;
- A number of implemented quality strategies, reflecting the stage of the quality concept, are present in regression equations for the following quality tools: histogram, Pareto analysis, network programming, FMEA, process capability, performance and accuracy study, teamwork, quality costing and employee training. They have a positive effect in all cases, except for employee training;
- Enterprise size is not an important factor in regression equations for check sheet, Pareto analysis, data analysis and employee training; application ranges of network programming and quality costing drop with the enterprise size, whilst a larger enterprise size implies a wider application range of other quality tools.

The results obtained in this research should be checked on a larger sample size, where analysis of a larger number of contingency factors as predictors in regression equations will be possible. In that way effects of autocorrelation that appears in some parts of the research will be solved.

Finally, practical benefits from this paper should be stressed, and these are:

- it is possible to determine the necessity of application of a certain quality tool prior to its implementation,
- it is possible to determine the need for a wider range of application of a certain quality tool during the process of its implementation,
- it is possible to determine a set and range of application of required quality tools before production of new products starts and
- in case of failure of application of a certain quality tool, it is possible to discover its possible causes.

In that way, many questions managers are facing today could be solved, and the fact that only theory that can be implemented in practice is useful for developing and improving organization in modern enterprises, has been confirmed.

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УТИЦАЈ КОНТИНГЕНТНИХ ФАКТОРА НА ПРИМЕНУ АЛАТА КВАЛИТЕТА

Весна Спасојевић Бркић, Миливој Кларин, Градимир Ивановић

Предмет овог рад је поставка модела критичних контингентних фактора за примену алата квалитета и његово експериментално потврђивање за производе моторско-тракторске групације произвођача. Очекиване везе између контингентних фактора и показатеља примене алата квалитета су потврђене и статистички модели, који описују утицај техничких и организационих контингентних фактора на примену алата квалитета су постављени. Резултати истраживања показују да фактори у предложеном моделу имају утицај на примену алата квалитета, а закони утицаја описани су регресионим једначинама. Практична корист овог рада огледа се у: а) могућности одређивања потребе за коришћењем одређеног алата квалитета пре његовог увођења у примену, б) могућности одређивања потребе за ширим обимом примене одређеног алата квалитета током његове примене, а услед дејства контингентних фактора, в) могућности одређивања потребе и опсега примене одређеног алата квалитета пре увођења производа у производњу и г) могућности одређивања узрока у случају неуспеха одређеног алата квалитета.