Evaluation of product quality nonconformity risk found at production

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Abstract: This article deals with the possibilities of risk evaluation of product quality nonconformity found at production. In first parts of article main steps needed for risk analyses are defined, including created by the author’s mathematic models for risk evaluation and scoring system for characteristics, weighted based on expert consultation. In the following part developed methodic is approbated at production of household appliances on example of washing machines production. Risk of increase of technical call rate and warranty costs are evaluated. General risk level based on probability of risk occurrence, severity of risk consequences is also calculated. In the last part, using the knowledge from the previous parts document for evaluation of risks of quality nonconformity found during production process is created.

1. Introduction
Modern time influences almost all areas of disciplines and risk management is not an exception. Risk is an inherent part of doing business in any industry or niche, starting from financial risks to cyber-attacks. Variety of international organizations for standardization created documents that provide requirements, specifications, guidelines or characteristics that can be used to minimize risks at organization, such as: «ERM. Enterprise Risk Management — Integrating with Strategy and Performance» (COSO) [1]; « Risk Management Standard » (FERMA) [2]; ISO 31000 «Risk management. Principles and Guidelines on Implementation» [3]; ISO 9001 «Quality management system – Requirements» [4]. There are several methods and instrument to assess different kinds of risks such as: FMEA, SWOT analyses, PEST analyses, FMECA, Fault Tree Analyses (FTA), Hazard Analysis Critical Control Point (HACCP), Hazard and Operability Study (HAZOP), Process Hazard Analysis (PHA). The preferable method for risk management by most organizations is FMEA analyses. This tool is used and adapted by different industries. FMEA analysis are used to increase reliability, quality, safety and its contribution towards cost saving and reduction of waste and non-value added operations [5]. FMEA method could be combined with fuzzy evidential approach and grey theory. This combination is complicated in usage in comparison to traditional FMEA approach, but could be used in more accurate results calculations and prioritization of risks. [6]. The level of risk could be assessed with elements of FMEA analyses by using of extended point method, where the probability and consequence of events are evaluated. The level of the risk is calculated as the multiplication of these parameters and is classified into categories [7]. SWOT analyses are mainly used for strategical planning. This method enables analysis of estimates and combining of internal factors with information from external sources on the market and in business environment [8]. Method
of risk analyses depends on task, complexity and specific of product or service. With respect to the amount of standards, methods and investigations there is description of methodology how to deal with risk analyses of quality nonconformity found during production process. Therefore, this article is focused on developing of simple and practical method of risk management of parts and components, as well finished goods which are produced out of specification in significant amount taking into consideration not only assessment of severity and probability of occurrence, but also risk of damaging of reputation (increase of warranty cases in market) and economic consequences, such as production losses and warranty costs.

2. **Methodology**

In order to take into consideration all possible consequences by decision making, regarding materials, parts, components or finished goods produced in a big amount out of specification or standards that methodology was created.

2.1. **Problem identification**

The first step in risk assessment process is analyzing of complete situation. All significant factors should be taken into account: material number and title, defect description, photo, name of supplier, process description, where material is used, suspected sampled population of parts out of specification, quantity of parts with quality nonconformity found during sorting process.

2.2. **Root cause analysis**

In order to obtain an objective assessment of process it is necessary to have a system, which supports the working team by finding a root cause of quality nonconformity taking. In this case semantic analysis techniques could be a right method [9]. These are the factors, which greatly influences on the failure behavior: manufacturing process, constructive aspects, operating conditions. The results of the developed event tree of risk – contributing factors at production with elements of semantic analysis techniques are shown in figure 1.

Assessment of the causes of accidents in the practice of production processes formed the basis for the creation of method for assessing and reacting on the risks. During analyze phase scope and nature of defect, severity of the problem and possible effect on the customer to be assumed.

To evaluate the identified risks effectively it is recommended to involve experts from different responsibility areas (production, quality, development, customer service, marketing). For assessment of probability of risk occurrence (OB) (table 1) and severity of risk consequences (OT) (table 2) score system is created.

2.3. **Risk assessment**

To ensure certainty of the statistical deduction and interpretation of the performed statistical results, minimum sample size, regardless of total number of population, to be defined [10]. By disclosure of quality nonconformity at production it should be found out the level of scrap rate of the delivered or produced materials or finished products. Expected increase of technical call rate (calls of the customer to the rework services) during warranty period to be calculated. Mathematically, this can be expressed by formula 1.

\[
\frac{N_{af}}{N_y} \cdot (\omega - |\omega|) \cdot 10^6 \leq TCR \leq \frac{N_{af}}{N_y} \cdot (\omega + |\omega|) \cdot 10^6,
\]

where TCR (technical call rate) – quantity of calls from the customers to the service, \(N_y\) – total number of sampled population, produced during the year, \(N_{af}\) – amount of appliances, produced during affected period of time, \(w\) – the resultant value from the measured quantities, \(\Delta w\) - an absolute error from the resultant value \(w\) for checked quantity of parts or finished goods.
Figure 1. Event tree of risk – contributing factors at production.

Final year results of technical call rate increase mathematically are expressed by formula 2:

$$T_{CR_y} = \frac{N_{af} \cdot (\omega - \bar{\omega})}{N_y} \cdot 10^6 \leq TCR \leq \frac{N_{af} \cdot (\omega + \bar{\omega})}{N_y} \cdot 10^6$$

$$TCR_y = \frac{T_{CR}}{TCR_y}.$$

TC$_{RC}$ - current technical call rate.

Increase of warranty costs is depending on different factors: repair costs, currency rate and amount of performed repairs by customer service within guaranty period.
As a basis for calculation of economic risk of the organization due to found quality nonconformity proposed following mathematical formula:

$$\mu_R (w - \Delta w) \leq G_i \leq (w + \Delta w) \mu_R, \quad (3)$$

where \(- G_i\) - guaranty costs, \(w\) - the resultant value from the measured quantities, \(\Delta w\) - an absolute error from the resultant value \(w\) for checked quantity of parts or finished goods, \(\mu R\) - average cost of repair.

**Table 1. Score system of probability of risk occurrence (OB).**

| Probability of risk occurrence | Criteria                                                                 | Score |
|-------------------------------|--------------------------------------------------------------------------|-------|
| Very high                     | Avoidance of risk is not possible                                         | 1     |
|                               | Very high probability of risk occurrence, more likely risk will occur     | 2     |
| High                          | High possibility of risk occurrence                                       | 3     |
|                               | Such kind of risk frequently is detected by customer                      | 4     |
|                               | Such kind of risk has a fifty – fifty chance to appear by customer        | 5     |
| Medium                        | There is a possibility that risk will appear time to time during life cycle of the appliance | 6     |
|                               | Such kind of risk has low chance to appear by customer                    | 7     |
| Low                           | Possibility of risk occurrence is unlikely but still possible             | 8     |
|                               | Possibility of risk occurrence is minimized by undertaken measures        | 9     |
| Very low                      | Such kind of risks will not appear/ will not be detected by customer     | 10    |

**Table 2. Score system for severity of risk consequences (OT).**

| Severity of risk consequences | Criteria                                                                 | Score |
|-------------------------------|--------------------------------------------------------------------------|-------|
| Very high                     | Potential failure mode affects product safety or involves noncompliance with government without warning. Life or health risks. | 1     |
|                               | Potential failure mode affects product safety or involves noncompliance with government with warning. Life or health risks. | 2     |
| High                          | Loss of primary function. Appliance is inoperable. Customer is very unsatisfied. | 3     |
|                               | Appliance is operable. Degradation of primary function. Efficiency is reduced. Customer is unsatisfied. | 4     |
| Medium                        | Appliance is operable. Loss of secondary function (comfort features are not working). Discomfort of the customer. | 5     |
|                               | Appliance is operable. Degradation of secondary function (loss of efficiency of comfort features). Irritation of customer. | 6     |
| Low                           | Appliance is operable. Visual defects, appearance of noise out of specification. Item is noticed by most of customers (> 75%) | 7     |
Appliance is operable. Visual defects, appearance of noise out of specification. Item is noticed by many customers (> 50%).

Appliance is operable. Visual defects, appearance of noise out of specification. Item is noticed by discriminating customers (< 25%).

No discernible effect

Very low

On the basis of the calculated results, risk level to be defined according to scoring system for guaranty and TCR (technical call rate) factors, presented in the table 3 and 4.

**Table 3.** Scoring system for evaluation of risks of guaranty costs increase.

| Guaranty costs, % increase from yearly KPI | Level description       | Score |
|------------------------------------------|-------------------------|-------|
| $G_y < 0,01 \%$                          | Dramatically low         | 5     |
| $0,01 \% \leq G_y < 0,1 \%$              | Very low                | 60    |
| $0,1 \% \leq G_y < 1 \%$                 | Low                     | 115   |
| $1 \% \leq G_y < 3 \%$                   | Between low and medium   | 170   |
| $3 \% \leq G_y < 5 \%$                   | Medium                  | 225   |
| $5 \% \leq G_y < 7 \%$                   | Conservative            | 280   |
| $7 \% \leq G_y < 10 \%$                  | Between high and conservative | 335 |
| $10 \% \leq G_y < 20 \%$                 | High                    | 390   |
| $20 \% \leq G_y < 50 \%$                 | Very high               | 445   |
| $G_y \geq 50\%$                         | Dramatically high       | 500   |

In case if the results are on the border of interval higher value to be chosen.

**Table 4.** Scoring system for evaluation of risks for increase of the technical call rate within guaranty period.

| Technical call rate, % increase from yearly KPI | Level description       | Score |
|------------------------------------------------|-------------------------|-------|
| $TCR_y < 0,01 \%$                             | Dramatically low         | 5     |
| $0,01 \% \leq TCR_y < 0,1 \%$                | Very low                | 60    |
| $0,1 \% \leq TCR_y < 1 \%$                   | Low                     | 115   |
| $1 \% \leq TCR_y < 3 \%$                     | Between low and medium   | 170   |
| $3 \% \leq TCR_y < 5 \%$                     | Medium                  | 225   |
| $5 \% \leq TCR_y < 7 \%$                     | Conservative            | 280   |
| $7 \% \leq TCR_y < 10 \%$                    | Between high and conservative | 335 |
| $10 \% \leq TCR_y < 20 \%$                   | High                    | 390   |
| $20 \% \leq TCR_y < 50 \%$                   | Very high               | 445   |
| $TCR_y \geq 50\%$                            | Dramatically high       | 500   |

Critical risk level weighted to be calculated based on the results of evaluation of probability of risk occurrence and severity of risk consequences. This parameter can be calculated by the formula:
where \( R_{wi} \) – critical risk level, \( O_b \) – probability of risk occurrence, \( O_t \) - severity of risk consequences, \( R_{wi,1,2,3,4,5} \) – experts' evaluation.

As a methodological basis for assessing of risk of found quality nonconformity materials, semi-finished parts or products in a mass scale following risk evaluation model is created:

\[
R_g = q \cdot R_{wi} + q \cdot G_y + q \cdot TCR_y .
\]

where \( R_g \) – general risk level, \( R_{wi} \) – critical risk level, \( TCR_y \) – result of increase of the customer calls to repair center at the end of the year, \( G_y \) - result of increase of warranty costs at the end of the year, \( q \) – weighted coefficient of the factor.

Weighting of factors is done based on expert evaluation method. Ranking matrix is presented in the table 5.

**Table 5. Ranking matrix.**

| Factors / Experts          | 1  | 2  | 3  | 4  | 5  | Rank sum | D  | d2 |
|----------------------------|----|----|----|----|----|----------|----|----|
| TCR (technical call rate)  | 1  | 1  | 1  | 1  | 2  | 6        | -4 | 16 |
| Gi (guaranty costs)        | 2  | 3  | 2  | 2  | 1  | 10       | 0  | 0  |
| Rg – evaluation of critical risk level | 3  | 2  | 3  | 3  | 3  | 14       | 4  | 16 |
| \( \sum \)                 | 6  | 6  | 6  | 6  | 6  | 30       | 32 |    |

Difference between expert rankings is defined by the formula:

\[
d = \sum x_{ij} - \frac{n \cdot \sum x_{ij}}{n} = \sum x_{ij} - 10 .
\]

Kendall's coefficient of concordance to be calculated according to formula 7:

\[
W = \frac{12S}{m^2(n^3-n)} = \frac{12 \cdot 32}{5^2(3^3-3)} = 0.64 .
\]

The following information was obtained through evaluation of Kendall's coefficient: \( W = 0.64 \), means that responses of the experts have in overage medium level of agreement. Level of agreement between experts based on Pearson correlation coefficient theory, presented in the formula 8:

\[
\chi^2 = \frac{12S}{mn(m+1)} = n(m-1)W = 6.4 .
\]

As can be seen from the task \( 6.4 (\chi^2) \geq \) table values (5.99146), that means data can be used for further investigation. To receive weighted coefficients of ranking sum we have to calculate for each parameter reciprocal value. Calculation results are presented in table 6.
Table 6. Matrix for reciprocal values of ranking sum for evaluation of general risk level.

| Criteria               | Ranking sum ratio |
|------------------------|-------------------|
| Rg (critical risk level) | x3 = 1/14 = 0.071 |
| Gi (guaranty costs)     | x2 = 1/10 = 0.1   |
| TCR (technical call rate)| x1 = 1/6 = 0.166  |

Results of assessment of risk factors based on expert method and Pearson correlation coefficient theory are presented in table 7.

Table 7. Matrix of weighted coefficient for evaluation of quality risks at production.

| Criteria               | Ranking value | Weighted coefficient |
|------------------------|---------------|----------------------|
| Rg (critical risk level) | 0.071         | 0.5                  |
| Gi (guaranty costs)     | 0.1           | 0.3                  |
| TCR (technical call rate)| 0.166        | 0.2                  |

The results could be interpreted in following way: critical risk level calculated based on evaluation of probability of risk occurrence and severity of risk consequences has high coefficient, as it influences directly on customer satisfaction and trust level between consumer and producer. Warranty costs and technical call rate are mostly related to the factory KPIs and losses at the producer side. It is obviously that Rg (critical risk level) is the most valuable parameter for the evaluation of quality risks at production.

2.4. Risk treatment
Risk management process includes following steps: identify, assesses and then treat risks. A risk treatment is an action that is taken to manage a risk. In general, there are four types of risk treatment: avoidance (costs for reduction of treats of found quality nonconformity are too high or risk will not be minimized till accepted level by conducted measures), risk reduction (reduction of likelihood of occurrence of a risk or reduction of its consequences or both by undertaken measures), transfer of risk (transferring of risk from one place to another) and risk acceptance (potential loss from a risk is not great enough to warrant spending money to avoid it). Despite of different ways of reaction during treatment phase of risk management in condition of serial production, it is necessary to have understandable system with clear criteria’s how to deal with different situation. Establishing of scoring system should reduce reaction time and support management team in decision making. Intervals for such scoring system are presented in the table 8.

Table 8. Scoring system for general risk level evaluation.

| General risk level evaluation | Interpretation of results                                                                 |
|-------------------------------|-------------------------------------------------------------------------------------------|
| Rg <100                       | Very low risk level. Risk to be accepted. Preventive measures are optional.               |
| 100 ≤ Rg < 200                | Low risk level. Risk to be accepted. Monitoring of process is necessary.                  |
|                               | Preventive measures are optional.                                                        |
| 200 ≤ Rg < 300                | Medium risk level. Risk to be accepted. Monitoring of process is necessary.              |
|                               | Preventive measures are obligatory.                                                       |
| 300 ≤ Rg < 400                | High risk level. Risk reduction or risk transferring. Corrective and                      |
|                               | preventive measures to be developed cost center for covering of losses to be defined.     |
2.5. Results and discussions

Created methodic and developed model for calculation of general risk level are approbated at the factory of household appliances on example of washing machines production. Based on defined steps document for risk evaluation of product quality nonconformity found during production process in a mass scale was developed. Results of risk analyses are presented in the table 9.

Table 9. Risk evaluation of product quality nonconformity at washing machine factory

| 1) Problem description | 2) Analyze phase | 3) Risk evaluation | 4) Conclusion |
|------------------------|------------------|--------------------|---------------|
| Name and number of material | 9001 housing | Verification method | Specification | Sample size | 152 pc | Decision | Very low risk level. Risk to be accepted. Preventive measures are optional. |
| Defect description | Visual defect | Root cause | Equipment Breakdown | Scrap level | 5,7% - 20,7% | Corrective and preventive actions | Short terms actions: |
| Photo | | | | Expert rating OB and OT | 5,5 | |
| | | | | Experts | OB | OT |
| E1 | 1 | 1 | Current TCR, ppm | 25000 |
| E2 | 1 | 2 | Current guaranty level, (euro) | 20000 |
| E3 | 2 | 2 | |
| Supplier | Preproduction | E4 | 1 | 2 | Expected TCR increase, ppm (weight: 0,2) | 95 - 345 |
| Where used? | Assembly line | E5 | 1 | 2 | Expected guaranty increase (euro) (weight: 0,3) | 5700 - 20700 |
| Sampled population | 1000 pcs | 1,2 | 1,8 | |
| Checked: | 20 pcs | \( \delta \) | 0,4 | 0,4 | Overage repair cost (euro) | 100 |
| Within NOK parts: | 6 pcs | Vo | 33% | 22% | General risk level: | 90,5 |

5) Monitoring: 

Actions completed, status checked by QM 
Name of quality controller date, signature

During production of washing machines material (housings) was blocked in amount of 1000 pc (planned overall yearly production volume 2018 - 600000 pc). Expected level of produced material with such deviation is between 5,7 – 20,7%. It can lead to TCR increase maximum in amount of 344 ppm, guarantee costs increase could be expected between 5700 – 20700 euro. Calculated general risk
level is 90, 5 points (failure will not be detected by customer (visual defect hidden for consumer) with low severity level (failure has no influence on safety or functionality of the appliance)). As a result of risk evaluation was taken a decision to accept the risk with taking preventive measures.

The outcomes of the introduction of risk evaluation process on washing machine factory according to developed methodology can be summarized as follows: due to clear and simple procedure of risk evaluation process reaction time for problem identification, risk analyze and treatment connected to quality nonconformity found in a mass scale at the production was reduced from 39 hours to 8. As a result, duration of unavailable of the production line was reduced for 5%. Amount of scrap level by production of semi-finished goods was reduced for 13%. KPI for delivery fulfillment (availability of the finished goods for market) was improved from 93% till 97%.

3. Conclusion
Risk evaluation at production is concerned with assessing probability and impact of risk on customer and organization itself. During risk evaluation of quality nonconformity found during production process following factors should be taken into consideration: probability of risk occurrence, severity of risk, economical and moral consequences. Risk management is a decision making process to be conducted in a systematic approach, which should help to identify, evaluate, and reduce or eliminate the possibility of an unfavorable event from the expected outcome of found nonconformity, should prevent the injury of customers, the loss of financial assets and loss of reputation. Correct analyses and risk evaluation process is the bases for systematichal efficiency improvement of functioning of production systems [11]. Developed methodic could be a part of the process of risks implementation in investments projects [12], a part of dynamic model of optimal production control [13] or used by analysis of the efficiency of specialization centers formation in high-tech industry [14].

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