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# Failure Mode and Effect Analysis

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**Abstract- Quality management is a way to get better effects. Due to the great competition on world market amongst production companies there appeared a need for effective ways of improvement of the quality level of products. For many years different methods were tried to change the quality e.g. through economical instruments, however it turned out that there had been no significant relationship between the quality and the financial result. FMEA is an inductive reasoning (forward logic) single point of failure analysis and is a core task in reliability engineering, safety engineering and quality engineering. A successful FMEA activity helps identify potential failure modes based on experience with similar products and processes—or based on common physics of failure logic. It is widely used in development and manufacturing industries in various phases of the product life cycle. Effects analysis refers to studying the consequences of those failures on different system levels.**

**Keywords- FEMA, quality, productivity, failure.**

## I. INTRODUCTION

A noticeable increase in the significance of the quality management systems and of products quality is a phenomenon of our times. The quality is regarded as the most important weapon in the market competition and the international trade [1]. Quality management is a way to get better effects. Due to the great competition on world market amongst production companies there appeared a need for effective ways of improvement of the quality level of products.

For many years different methods were tried to change the quality e.g. through economical instruments, however it turned out that there had been no significant relationship between the quality and the financial result [2].

The economic policy of the organization in the sphere of the quality depends on various outside factors and internal abilities.

Such activity decides on choice about the optimum strategy, which according to E. Kindlarski takes the following form [3]:

- Supremacy, imposing personal quality patterns and not-allowing for foreign standards,
- Of skid, it is a concentration on achieving quality standards with using foreign standards,
- Maintenances of the equal status, creating personal competing quality patterns,
- Of convergence, taking the production of products on about the big coincidence withthe own production program and the personal structure,
- Of critical factor, it is taking what decides into account on the market about the product success.

**1. According to ISO 9000:2005 standard - point [4]:**

Quality management systems and other management system focuses - The quality management system is that part of the organization's management system that focuses on the achievement of results, in relation to the quality objectives, to satisfy the needs, expectations and requirements of interested parties, as appropriate. The quality objectives complement other objectives of the organization such as those related to growth, funding, profitability, the environment and occupational health and safety. The various parts of an organization's management system might be integrated, together with the quality management system, into a single management system using common elements.

This can facilitate planning, allocation of resources, definition of complementary objectives and evaluation of the overall effectiveness of the organization. The organization's management system can be assessed against the organization's management system requirements. The management system can also be audited against the requirements of International Standards such as ISO 9001 and ISO 14001. These management system audits can be carried out separately or in combination.

Quality management is also implementing the management function in the relationship to the quality management system and the quality of processes. It is a philosophy replacing the lost time and human effort by engaging people into the process of management [5-7]. For better understanding of Modern Quality Philosophy the Enterprises have to define a ways of quality monitoring and quality control. Such approach serves the improvement in the effectiveness and the elasticy of the production and the business as the whole. Standard ISO 9000:2005 indicate aspects of modern quality: Self-assessment and Continual improvement [5].

**1.1 Self-assessment:** An organization's self-assessment is a comprehensive and systematic review of the organization's activities and results referenced against the quality management system or a model of excellence. Self-assessment can provide an overall view of the performance of the organization and the degree of maturity of the quality management system. It can also help to identify areas requiring improvement in the organization and to determine priorities‖ [5].

**1.2 Continual improvement:** The aim of continual improvement of a quality management system is to increase the probability of enhancing the satisfaction of customers and other interested parties. Actions for improvement include the following:

- Analysing and evaluating the existing situation to identify areas for improvement;
- Establishing the objectives for improvement;
- Searching for possible solutions to achieve the objectives;
- Evaluating these solutions and making a selection; implementing the selected solution;
- Measuring, verifying, analysing and evaluating results of the implementation to determine that the objectives have been met;
- Formalizing changes.

Results are reviewed, as necessary, to determine further opportunities for improvement. In this way, improvement is a continual activity. Feedback from customers and other interested parties, audits and review of the quality management system can also be used to identify opportunities for improvement‖ [5].

Worth the attention are method applied in the process of controlling of quality: Statistical Process Control (SPC), Analysis of value, decision-making, calculation of quality costs, Seven Tools, Failure Mode and Effect Analysis (FMEA), Quality Function Deployment (QFD), Six Sigma, 5S, Kaizen, Taguchi Method, DOE, Brainstorming. W.E. Deming said that: ― Isn‘t said that the company is supposed to be for centuries in the business‖. Important aspect is skill efficient connection of Deming‘s Cycle PDCA: Plan-Do-Check- Act with use of Quality estimation method, techniques and tools [8-10].

The enterprises must take quality into account in all processes future. They are able to do it well enough, to what extent are able well to manage the present time. Creating conditions for quality development in which the organization can ensure the profitability of production and to project against the risk is necessary. Getting and keeping the confidence of the customer for the organization, in the light of requirements of the ISO 9000:2005 norm, is the most significant task.
Understanding customer’s needs has the key meaning for the definition of proper strategies. These proper strategies permit to hold or to raise the company‘s position in direct environment [11].

**(a)**

## II. FUNCTIONAL FAILURE MODE AND EFFECTS ANALYSIS

Failure mode and effects analysis (FMEA; often written with "failure modes" in plural) is the process of reviewing as many components, assemblies, and subsystems as possible to identify potential failure modes in a system and their causes and effects. For each component, the failure modes and their resulting effects on the rest of the system are recorded in a specific FMEA worksheet. There are numerous variations of such worksheets.

An FMEA can be a qualitative analysis, but may be put on a quantitative basis when mathematical failure rate models are combined with a statistical failure mode ratio database. It was one of the first highly structured, systematic techniques for failure analysis. It was developed by reliability engineers in the late 1950s to study problems that might arise from malfunctions of military systems. An FMEA is often the first step of a system reliability study.

A few different types of FMEA analyses exist, such as:

- Functional
- Design
- Process

Sometimes FMEA is extended to FMECA (failure mode, effects, and criticality analysis) to indicate that criticality analysis is performed too.

FMEA is an inductive reasoning (forward logic) single point of failure analysis and is a core task in reliability engineering, safety engineering and quality engineering.
A successful FMEA activity helps identify potential failure modes based on experience with similar products and processes—or based on common physics of failure logic. It is widely used in development and manufacturing industries in various phases of the product life cycle. Effects analysis refers to studying the consequences of those failures on different system levels.

Functional analyses are needed as an input to determine correct failure modes, at all system levels, both for functional FMEA or Piece-Part (hardware) FMEA. An FMEA is used to structure Mitigation for Risk reduction based on either failure (mode) effect severity reduction or based on lowering the probability of failure or both. The FMEA is in principle a full inductive (forward logic) analysis; however the failure probability can only be estimated or reduced by understanding the failure mechanism. Hence, FMEA may include information on causes of failure (deductive analysis) to reduce the possibility of occurrence by eliminating identified (root) causes.

The FME(C)A is a design tool used to systematically analyze postulated component failures and identify the resultant effects on system operations. The analysis is sometimes characterized as consisting of two sub-analyses, the first being the failure modes and effects analysis (FMEA), and the second, the criticality analysis (CA). Successful development of an FMEA requires that the analyst include all significant failure modes for each contributing element or part in the system. FMEAs can be performed at the system, subsystem, assembly, subassembly or part level.

The FMECA should be a living document during development of a hardware design. It should be scheduled and completed concurrently with the design. If completed in a timely manner, the FMECA can help guide design decisions. The usefulness of the FMECA as a design tool and in the decision-making process is dependent on the effectiveness and timeliness with which design problems are identified. Timeliness is probably the most important consideration. In the extreme case, the FMECA would be of little value to the design decision process if the analysis is performed after the hardware is built.

While the FMECA identifies all part failure modes, its primary benefit is the early identification of all critical and catastrophic subsystem or system failure modes so they can be eliminated or minimized through design modification at the earliest point in the development effort; therefore, the FMECA should be performed at the system level as soon as preliminary design information is available and extended to the lower levels as the detail design progresses.

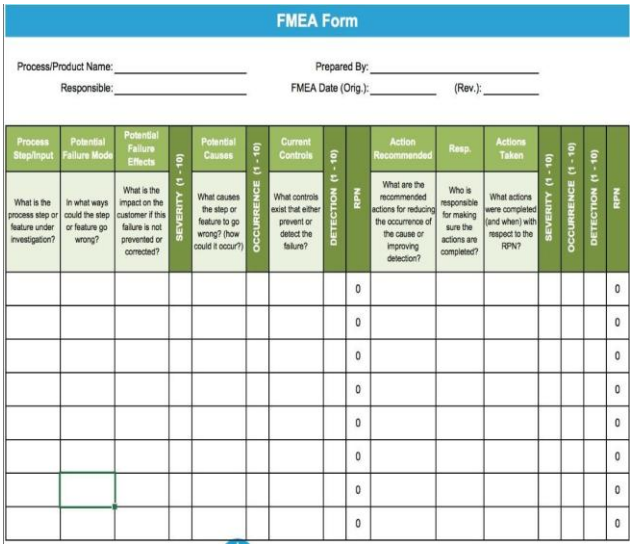
Remark: For more complete scenario modelling another type of Reliability analysis may be considered, for example fault tree analysis (FTA); a deductive (backward logic) failure analysis that may handle multiple failures within the item and/or external to the item including maintenance and logistics. It starts at higher functional / system level. An FTA may use the basic failure mode FMEA records or an effect summary as one of its inputs (the basic events). Interface hazard analysis, human error analysis and others may be added for completion in scenario modelling.

The analysis should always be started by listing the functions that the design needs to fulfil. Functions are the starting point of a well done FMEA, and using functions as baseline provides the best yield of an FMEA. After all, a design is only one possible solution to perform functions that need to be fulfilled. This way an FMEA can be done on concept designs as well as detail designs, on hardware as well as software, and no matter how complex the design.
When performing an FMECA, interfacing hardware (or software) is first considered to be operating within specification. After that it can be extended by consequently using one of the 5 possible failure modes of one function of the interfacing hardware as a cause of failure for the design element under review. This gives the opportunity to make the design robust for function failure elsewhere in the system.

## III. FMEA PROCEDURE

Assemble a cross-functional team of people with diverse knowledge about the process, product or service, and customer needs. Functions often included are: design, manufacturing, quality, testing, reliability, maintenance, purchasing (and suppliers), sales, marketing (and customers), and customer service.

Identify the scope of the FMEA. Is it for concept, system, design, process, or service? What are the boundaries? How detailed should we be? Use flowcharts to identify the scope and to make sure every team member understands it in detail. Fill in the identifying information at the top of your FMEA form. (Figure 1 shows a typical format.) The remaining steps ask for information that will go into the columns of the form.



FMEA Form

Process/Product Name: _____ Prepared By: _____

Responsible: _____ FMEA Date (Orig.): _____ (Rev.): _____

| Process Step/Input | Potential Failure Mode | Potential Failure Effects | SEVERITY (1 - 10) | Potential Causes | OCCURRENCE (1 - 10) | Current Controls | DETECTION (1 - 10) | RPN | Action Recommended | Resp. | Actions Taken | SEVERITY (1 - 10) | OCCURRENCE (1 - 10) | DETECTION (1 - 10) | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| What is the process step or feature under investigation? | In what ways could the step or feature go wrong? | What is the impact on the customer if this failure is not prevented or corrected? | | What causes the step or feature to go wrong? (how could it occur?) | | What controls exist that either prevent or detect the failure? | | | What are the recommended actions for reducing the occurrence of the cause or improving detection? | Who is responsible for making sure the actions are completed? | What actions were completed (and when) with respect to the RPN? | | | | |
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Fig 1. FMEA Example.

Identify the functions of your scope. Ask, "What is the purpose of this system, design, process, or service? What do our customers expect it to do?" Name it with a verb followed by a noun. Usually one will break the scope into separate subsystems, items, parts, assemblies, or process steps and identify the function of each.

For each function, identify all the ways failure could happen. These are potential failure modes. If necessary, go back and rewrite the function with more detail to be sure the failure modes show a loss of that function.
For each failure mode, identify all the consequences on the system, related systems, process, related processes,

product, service, customer, or regulations. These are potential effects of failure. Ask, "What does the customer experience because of this failure? What happens when this failure occurs?"

Determine how serious each effect is. This is the severity rating, or S. Severity is usually rated on a scale from 1 to 10, where 1 is insignificant and 10 is catastrophic. If a failure mode has more than one effect, write on the FMEA table only the highest severity rating for that failure mode.

For each failure mode, determine all the potential root causes. Use tools classified as cause analysis tools, as well as the best knowledge and experience of the team. List all possible causes for each failure mode on the FMEA form.

For each cause, determine the occurrence rating, or O. This rating estimates the probability of failure occurring for that reason during the lifetime of your scope. Occurrence is usually rated on a scale from 1 to 10, where 1 is extremely unlikely and 10 is inevitable. On the FMEA table, list the occurrence rating for each cause.

For each cause, identify current process controls. These are tests, procedures or mechanisms that you now have in place to keep failures from reaching the customer. These controls might prevent the cause from happening, reduce the likelihood that it will happen or detect failure after the cause has already happened but before the customer is affected.

For each control, determine the detection rating, or D. This rating estimates how well the controls can detect either the cause or its failure mode after they have happened but before the customer is affected. Detection is usually rated on a scale from 1 to 10, where 1 means the control is absolutely certain to detect the problem and 10 means the control is certain not to detect the problem (or no control exists). On the FMEA table, list the detection rating for each cause.

(Optional for most industries): Ask, "Is this failure mode associated with a critical characteristic?" (Critical characteristics are measurements or indicators that reflect safety or compliance with government regulations and need special controls.)

If so, a column labeled "Classification" receives a Y or N to show whether special controls are needed. Usually, critical characteristics have a severity of 9 or 10 and occurrence and detection ratings above 3. Calculate the risk priority number, or RPN, which equals S × O × D. Also calculate Criticality by multiplying severity by occurrence, S × O. These numbers provide guidance for ranking potential failures in the order they should be addressed. Identify recommended actions. These actions may be design or process changes to lower severity or occurrence. They may be additional controls to improve detection. Also note who is responsible for the actions and target completion dates. As actions are completed, note results and the date on the FMEA form. Also, note new S, O, or D ratings and new RPNs.

## IV. USES

- Development of system requirements that minimize the likelihood of failures.
- Development of designs and test systems to ensure that the failures have been eliminated or the risk is reduced to acceptable level.
- Development and evaluation of diagnostic systems
- To help with design choices (trade-off analysis).

## V. ADVANTAGES

- Catalyst for teamwork and idea exchange between functions
- Collect information to reduce future failures, capture engineering knowledge
- Early identification and elimination of potential failure modes
- Emphasize problem prevention
- Improve company image and competitiveness
- Improve production yield
- Improve the quality, reliability, and safety of a product/process
- Increase user satisfaction
- Maximize profit
- Minimize late changes and associated cost
- Reduce impact on company profit margin
- Reduce system development time and cost
- Reduce the possibility of same kind of failure in future
- Reduce the potential for warranty concerns

## VI. PAST STUDIES

**Qin, Jindong et al. (2020)** presented a way to combine interval type-2 fuzzy sets (IT2FSs) with evidential reasoning (ER) method, which is able to overcome some disadvantages of the conventional FMEA approach and deal with uncertainties more efficiently.

**Rezaee et al. (2020**) presented a hybrid approach based on the Linguistic FMEA, Fuzzy Inference System (FIS) and Fuzzy Data Envelopment Analysis (DEA) model to calculate a novel score for covering some RPN shortcomings and the prioritization of HSE risks. First, after identifying potential risks and assigning values to the RPN determinant factors by linguistic FMEA team members due to the differentiation of these values, FIS is used to reach a consensus opinion about these factors.

**Subriadi et al. (2020)** examined the consistency of both traditional FMEA and improved FMEA in IT risk assessment. Improved FMEA is the result of a synthesis framework to minimize consistency in traditional FMEA. Two sets of action research cycles (plan, act, observe, reflect) were applied in this research.

**Lo, Huai-Wei et al. (2020)** proposed an integrated risk assessment model where several techniques are combined to produce an FMEA model for the generation of comprehensive failure mode ranking. First, the anticipated costs and environmental protection indicators are included in the FMEA model to enhance the comprehensiveness of assessment.

**Rimawan et al. (2019)** presented the failure modes that cause product defects by using the FMEA method, getting the risk of the biggest production process failure in the value of the RPN (Risk Priority Number), providing proposed improvements for subsequent production. Based on processing with the FMEA method can identify modes of failure that occur in the process making drugs. The mode of potential failure in the process of making drugs consists of 6 types of failures.

**Ostadi et al. (2019)** presentedfailure modes and effects analysis (FMEA) technique has been utilized to find errors and their causes in the production line of the Iranian Tobacco Company. With the completion of FMEA table and calculating Risk Priority Number (RPN) values, all errors were zoned and prioritized. The prioritization of the discovered errors based on FMEA technique indicated human error as the most important factor in the emergence of errors.

**Górka et al. (2019)** presented the key issues related to quality management: starting with defining the concept of quality, its essence and the method of its management. In addition, the perception of the quality of both the consumer and the manufacturer, as well as the impact of quality on the life cycle of the product.

Cupşan et al. (2019) presented the current state of risk management in the knowledge-based organisations and the importance of a preventive approach, with emphasis on the aerospace and defence industry, as well as gives detailed information on the Failure Mode and Effects Analysis (FMEA) method, in its current known state.

## VII. RESULTS AND DISCUSSION

**1. Source of Data for analysis:**
The major potential failure modes of the engine will consist of four anti-functions such as partial function, intermittent function, no-function and unintended function [9-10]. These failures will be analyzed based the power and speed deviation from the specification, cooling, fuel injection, lubrication, electrical and auxiliary system failures. The source of data for the FMEA was collected from earlier field failure report and from the expert opinions of various engineering functional teams.

**2. Step by step procedure for structured FMEA of cylinder head:**
The activities of FMEA process were linked into various subsystems and analysis was done for all parts in the sub system. The failure modes and effects of failure were collected from various functional teams by brainstorm process and by expert opinion poll. The following step by step procedure was followed in the FMEA process.

**3. System/ product specification, design and finalization:**
The aim of this activity was to describe the engine and its function. An understanding of the engine functions and performance are important to have clear idea about the product. This understanding simplifies the process of analysis and identification of sub systems/ parts that fail without performing the intended function. The block construction of the engine system gave the clear information about subsystem and the inference about the subsystem functions.

**4. Brainstorm / expert opinion about potential failure modes:**
A failure mode is defined as the manner in which a component, subsystem, system, etc. could potentially fail to meet the design intent. This information was collected from the history data from the service department. The major failure occurred on the base engine was blow by dust entry in turbocharger due to failure of pre-cleaner, valve drop failure and wear failure of valve train parts. Failure data were analyzed for the frequency of failure, hours of operation of engine in field, load utilized during the operation, operating cycle and duty cycle information. Refinement of potential failures of each part and subsystems were completed with the discussion of cross functional team.

**5. Listing potential effects of failure:**
For each failure mode identified the effects were listed. A failure effects are defined as the result of a failure mode on the function of the engine. This is failure to do the indented functions.

**6. Assigning severity rankings:**
A common industry standard scale uses 1 to represent no effect and 10 to indicate very severe with failure affecting system operation and safety without warning. The intent of the ranking is to determine whether a failure would be a minor nuisance or a major damage to the customer. This enables to prioritize the failures and address the real big issues first. The severity rankings are given in Table 2.1.

Table 1. Severity rankings.

| PROBABILITY of Failure | Failure Probability | Ranking |
|---|---|---|
| Very High: Failure is almost inevitable | >1 in 2 | 10 |
| | 1 in 3 | 9 |
| High: Repeated failures | 1 in 8 | 8 |
| | 1 in 20 | 7 |
| Moderate: Occasional failures | 1 in 80 | 6 |
| | 1 in 400 | 5 |
| | 1 in 2,000 | 4 |
| Low: Relatively few failures | 1 in 15,000 | 3 |
| | 1 in 150,000 | 2 |
| Remote: Failure is unlikely | <1 in 1,500,000 | 1 |

**7. Assigning occurrence rankings:**
A numerical weight was assigned to each cause that indicates how likely that cause was. A common industry standard scale uses 1 to represent not likely and 10 to indicate inevitable. Occurrence of failures for engines parts were collected from the field failure data. In most of the higher power engines, failures were occurred due to deviation in operating profile and failure in cooling in intake system. In some cases, it was observed that the failure was happened due to poor maintenance of air intake system. Hence, the ranking of occurrence was done by formulating guidelines based on the frequency of failures happened for the same family of parts.

**8. Assigning detection ratings:**
Detection is an assessment of the likelihood that the Current Controls (design and process) will detect the Cause of the Failure Mode or the Failure Mode itself, thus preventing it from reaching the Customer. The existing test protocol associated with each part and subsystems were considered for assigning the detection rating.

**9. Calculation of RPNs:**
The Risk Priority Number is a mathematical product of the numerical Severity, Probability, and Detection ratings:

**RPN = (Severity) x (Probability) x (Detection)**

The RPN was used to prioritize items that require additional quality planning or action.

**10. Developing the action plan:**
This activity was the determination Recommended Action(s) to address the potential failures that had a high RPN. These actions could include specific inspection, testing or quality procedures, selection of different components or materials, de-rating, limiting environmental stresses or operating range, redesign of the item to avoid the failure mode, etc.

**11. Implementing the system/sub system/ components design**:
Analysis of the failure, its modes and effects were suitably ranked by expert opinions and reviews and was implemented into design.

**12. Review for the improvements:**
After the above actions, re-assessment of the severity, probability and detection was done and the revised RPN's were calculated, and system was refined.

## VIII. CONCLUSION

At the present time the enterprises should integrate quality management and quality control with customer‘s requirements, production process‘s requirements and also quality methods. Such kind of strategy will enable to achieve success for these companies. If the organization wants to be able to compete, the customer must supply the products in the required quantity and quality.

To ensure product quality it is essential to remove errors respect. The current study is based on enhancing the productivity of a manufacturing firm by exploring the process FMEA. Reducing the failure occurs during manufacturing process and increasing the productivity in the firm. The basic steps are to identify the root of the cause and potential problems that could occur, and then derive RPN which can direct improvement effort to the area of greatest concern.

## REFERENCES

[1] Qin, Jindong, Yan Xi, and Witold Pedrycz. "Failure mode and effects analysis (FMEA) for risk assessment based on interval type-2 fuzzy evidential reasoning method." Applied Soft Computing 89 (2020): 106134.
[2] Rezaee, Mustafa Jahangoshai, Samuel Yousefi, Milad Eshkevari, Mahsa Valipour, and Morteza Saberi. "Risk analysis of health, safety and environment in chemical industry integrating linguistic FMEA, fuzzy inference system and fuzzy DEA."Stochastic Environmental Research and Risk Assessment 34, no. 1 (2020): 201-218.
[3] Subriadi, Apol Pribadi, and Nina Fadilah Najwa. "The consistency analysis of failure mode and effect analysis (FMEA) in information technology risk assessment." Heliyon 6, no. 1 (2020): e03161.
[4] Lo, Huai-Wei, William Shiue, James JH Liou, and Gwo-Hshiung Tzeng. "A hybrid MCDM-based FMEA model for identification of critical failure modes in manufacturing." Soft Computing 24, no. 20 (2020): 15733-15745.Rimawan, Erry, Apriliana Cendraleka, Johan Permana, and Dydi Purwanto. "Application of FMEA For Identifying Risk Failure of The Medicine Failure Process."(2019).
[5] Ostadi, Bakhtiar, and Mehrdad Saboory Masouleh. "Application of FEMA and RPN techniques for man-machine analysis in Tobacco Company." Cogent Engineering 6, no. 1 (2019): 1640101.
[6] Górka, M., B. Ślusarczyk, A. Woźniak, J. Baran, and E. Brągiel. "Selected issues concerning quality management in the company." (2019).

[7] Cupşan, Vlad Ciprian, Mihail Aurel Ţîţu, and Gheorghe Ioan Pop. "Enhancements to Failure Mode and Effects Analysis (FMEA) Method, Aiming to Improve Risk Management in the Knowledge-Based Organizations." In International conference KNOWLEDGE-BASED ORGANIZATION, vol. 25, no. 1, pp. 206-212. Sciendo, 2019.
[8] Oliveira, Marcelo, Samuel Batista, Dércio Reis, Gabriela Veroneze, and Raíssa Maciel. "Application Of Fmea For Improvement In The Manufacturing Process Of Mobile Phones In A Factory Of The Industrial Pole Of Manaus." International Journal for Quality Research 13, no. 4 (2019).
[9] Tao, Diana. "Using Failure Mode and Effects Analysis (FMEA) to Analyze the Manufacturing Process of Rapid Lateral Flow Immunoassays." (2019).
[10] Cagnin, Fernanda, Maria Celia de Oliveira, and Paulo Augusto Cauchick Miguel. "Assessment of ISO 9001: 2015 implementation: focus on risk management approach requirements compliance in an automotive company." Total Quality Management & Business Excellence (2019): 1-19.
[11] Fajrah, Nofriani, Nilda Tri Putri, and Elita Amrina. "Analysis of the application of quality management systems in the rubber industry based on ISO 9001: 2015." In IOP Conference Series: Materials Science and Engineering, vol. 602, no. 1, p. 012039. IOP Publishing, 2019.
[12] Altuntas, Serkan, and Semih Kansu. "An innovative and integrated approach based on SERVQUAL, QFD and FMEA for service quality improvement." Kybernetes (2019).
[13] Rimawan, Erry, and Angga Pratama. "Improvement of Quality Control of Herbicide Products using the DMAIC Method Case Study in Chemical Companies in Merak- Banten." International Journal of Innovative Science and Research Technology 3, no. 12 (2018): 84-98.
[14] Doshi, Jigar, and Darshak Desai. "Application Of Failure Mode & Effect Analysis (Fmea) For Continuous Quality Improvement- Multiple Case Studies in Automobile SMES." International Journal for Quality Research 11, no. 2 (2017).
[15] Borković, Jakov, Diana Milčić, and Davor Donevski. "Implementation of differentiated quality management system and FMEA method in the newspaper production." Tehnički Vjesnik–Technical Gazette 24, no. 4 (2017): 1203-1211.
[16] Barosz, Piotr, Marta Dudek-Burlikowska, and Marek Roszak. "Production Engineering Archives."
[17] Hąbek, Patrycja, and Michał Molenda. "Using the FMEA method as a support for improving the social responsibility of a company." In 6th International Conference on Operations Research and Enterprise Systems. ICORES, p. 39. 2017.