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# Manufacturing Process Improvement through FMEA Analysis and Fuzzy Logic

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*Abstract* – **The paper presents a method for improvement a robotized manufacturing process of electronic devices. It includes statistical Failure Mode and Effects Analysis (FMEA), fuzzy logic and visual technique for results interpretation. Collected data from experts are processed according to FMEA and used for development of intelligent fuzzy inference system, which result is visualized through heatmap. Such approach can support engineers for fast and correct decision making at manufacturing process with dynamic changes.**

*Keywords* – **dynamic manufacturing process; FMEA; fuzzy logic; industrial robot, statistics.**

## I. INTRODUCTION

Nowadays, adoption of innovative methods for management and optimization of manufacturing process in the area of electronics lead to producs quality improvement, to time decreasing for conducting any single task, to limitation the influence of negative environmental factors. Despite the manufacturing robotized lines are in continuous development, becoming more complex and sometimes fully automated, different tasks performance need further examination and evaluation.

The evaluation of a manufacturing process with goal it to be improved is considered for a certain period of time, dealing with the available current information. Therefore, the optimization is possible under certain conditions and in a monitored period of time. Some changes in the future will make this optimized solution inefficient or at least there will be another option, which will be optimal under the new conditions.

The dynamics in the manufacturing factors makes it necessary to prepare models that allow the continuously occurring changes to be considered. This means that when developing a specific model, it is necessary to take into account the time factor, as well as the sequence of operations performed. In this way, it is possible a more complete presentation of the studied real process to be created, without need for its complete simplification.

The dynamics and complexity of a manufacturing processes require its better understanding through using some modeling techniques and creation adequate models reflecting on the real settings. Such models could assist the managing authorities in faster decision making and appropriate reactions in a given situation. The choice regarding implementation of a specific model in practice is determined by the characteristics of the production and the goals pursued. The static models of manufacturing process do not have ability to take into account the time factor and they prove to be unsuitable in a changing manufacturing environment. Therefore, attention is focused on dynamic models, characterized by complexity in their preparation and application.

Performing an analysis of a manufacturing process gives the engineers an opportunity to see and predict the risk of the failure and the cessation of the work process. Risk analysis is important in clarification the main factors that should be taken into account at the optimization of different stages from a manufacturing process and at the manufacturing process at whole.

The aim of the paper is to present an exploration regarding risk analysis and improvement of an automated manufacturing process of electronic devices that integrates the advantages of the Failure Mode and Effects Analysis (FMEA) and fuzzy logic. The examined manufacturing process includes a robotized line with the following operations: robot preparation, starting/stopping, programming, testing, soldering, components integrating, and external bonds placing. Its improvement leads to set of measures for prevention against unexpected situations like operators' mistake, wrong machine programming, technical defect, imprecise operation, etc. The proposed method is verified through gathered data from experts.

## II. RESEARCH METHOD

The research method consists of the following procedures: (1) Exploration regarding the currently applied techniques for improvement a manufacturing process according to published scientific papers. The accent is placed on FMEA and fuzzy logic utilization. (2) Creation of a FMEA model with possible reasons for failures of robotized line and recommendations for improvement. (3) Development a model based on fuzzy logic in support of decision making when some risks are observed. (4) Classification the results from intelligent fuzzy inference system and results visualization.

## III. THE STATE OF THE ART

FMEA is a methodology applied before some failure to occur, exploring when it is possible to emerge, what could be the consequences, and what kind of preventive measures could be taken [1]. It is used in different industries for identification and evaluation of potential risk problems through strongly defined metrics at products design and products manufacturing. Nowadays, FMEA continues to be used as proved in practice method for finding the bottlenecks

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and for improving the manufacturing process. An extensive review of FMEA utilization in the field of smart grids environments as well as the results of performed FMEA in smart grid system are discussed [2]. This review confirms the contemporary interest to the FMEA by researchers. Another case study regarding application of FMEA for evaluation of a manufacturing process for cylinder heads is presented in [3]. The goal is the quality and efficiency of the manufacturing to be increased. The authors conclude that the usage of FMEA can decrease the defected products, can save time and decrease the overall losses. In addition of the classical version of FMEA some new advanced FMEA versions are proposed to solve the problems concerning risk analysis of complex products and manufacturing processes. Cui et al. in their work [4] present model-based FMEA (MB-FMEA) for analysis the workability of electronic products that are characterized with many parts and circuit relationships. This approach shows the reliability of the proposed method at prevention the failures of complex electronics products. Combination of FMEA and fuzzy logic is presented in [5] to solve the problem with crisp values of the explored risk factors. This methodology is verified in a spindle manufacturing process. Some other papers discuss the application of fuzzy logic in support of decision making in manufacturing process. Fuzzy logic in used for making decision about re-engineering in manufacturing process [6]. The fuzzy model includes 5 input and 1 output variables and 9 fuzzy rules. Literature review about utilization of fuzzy techniques and fuzzy programming in manufacturing is conducted in [7], where the authors discuss the wide possibilities of fuzzy logic in solving manufacturing challenges. Intelligent fuzzy logic tool is constructed for defining the level of changeability of a manufacturing system [8]. According to the result of product evaluation and necessity the organizational strategy to be changed, the intelligent fuzzy system point outs three levels of changeability. The proposed approach could be used as a guide when designers prepare plans for manufacturing systems building.

This review point outs the increased interest by researchers to the FMEA and fuzzy logic usage for solving a wide variety of problems at manufacturing different products. Such techniques are used in this work to evaluate the possible risks and failures in a robotized manufacturing line of electronic products.

## IV Proposed method

The proposed method is presented on fig. 1 and includes the following stages: (1) Data collection regarding all functions of the robot and all possible factors that influence on its correct workability; (2) FMEA conduction to the manufacturing process and the result is in the form of Risk Priority Numbers (RPNs), obtained for every factor before performance of recommended actions and after that. (3) Receiving the level of improvement for every factor after undertaken actions through developed intelligent fuzzy inference system (IFIS). (4) Classification the obtained values of the improvement in groups. (5) Visualization the improvement through a heatmap.

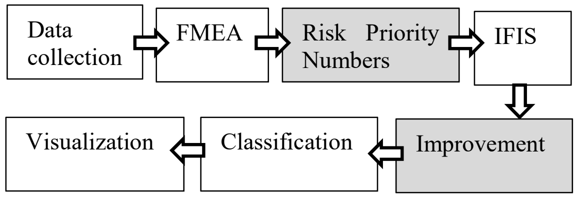


Fig. 1. The proposed method

## V Process Failure Modes and Effects Analysis

### A. Robot Functions

The explorations are based on functionality of industrial robot FANUC-M-10 and its application at production of electronic components. The following ten functions are typical for this industrial robot: robot start, robot programming, robot testing, components placement, soldering 1, placement of external bonds, soldering 2, robot functions verification, soldering 3, robot stop.

### B. Process FMEA

Process Failure Modes and Effects Analysis (PFMEA) presents a structured and qualitative framework that is utilized here for evaluation the potential risk at manufacturing of electronic components with robot FANUC-M-10. This allows the possible failures at different stages of manufacturing process to be controlled or removed in the future. After the expert opinion, the results of the PFMEA is summarized in forms that include information about: process function, potential failure mode, effects of failure and cause of failure, current control. The evaluation of this information is conducted through three criteria: Occurrence (O) – it is the probability of failures, rated in scale from 1 (very low) to 10 (very high); Severity of effect (S) – it shows how much the failure effect is important for the next operation as the rating scale is from 1 (none) to 10 (very high severity) and Detection (D) – it shows the capability of current control to detect the failure cause and it is rated from 1 (detection of almost all causes) to 10 (the control cannot detect the cause). Then, the Risk Priority Numbers (RPNs) are calculated as the product of Occurrence, Severity and Detection is obtained:

$$RPN = OxSxD. \quad (1)$$

Based on the RPNs the experts recommend some actions for every factor of all examined robot functions. After implementation of recommended or undertaken actions the failure evaluation is performed again according to the same criteria: O, S, D. The obtained RPNs present the effectiveness of the conducted actions.

The gathered experts' information is summarized in ten tables, describing the robot functions, possible risks, failure causes, controls, recommended and undertaken actions. One example about information for the function Soldering 1 is presented in Table 1 concerning two factors: *unstable soldering* and *higher soldering temperature*. It can be seen that for the function *Soldering 1* and the first factor the RPN is 45. It points out the high possibility for potential failure, because of unstable soldering. The reason for this potential risk is programming mistake or wrong component. The recommended actions is focused on corrections in programming code. The undertaken actions address improvement the programming skills of programmer through suitable training. After conductance of the recommended actions the calculated RPN is 12 for the risk unstable soldering and 18 for usage of wrong components. The calculated RPN for the second factor *higher soldering temperature* is 10 and after some actions taken it is received to be 6. It means that the applied FMEA analysis for this function leads to its improvement.

TABLE 1. ROBOT' S FUNCTION SOLDERING 1

| **Process name** | **Potential failure** | **Potential Effects of failure** | **S** | **Potential cause** | **O** | **Current control** | **D** | **RPN** | **Recommended actions** | **Responsible engineer** | **Undertaken actions** | **S** | **O** | **D** | **RPN** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soldering 1 | Unstable soldering | Unstable component | 5 | Programming mistake | 3 | Visual control | 3 | 45 | Programming corrections | Product engineer | Improvement the programming skills through training | 2 | 3 | 2 | 12 |
| | | | | Wrong components | 3 | Components testing | 3 | 45 | | | Programmer training | 3 | 3 | 2 | 18 |
| | Higher soldering temperature | Higher time for soldering | 1 | Unskilled programmer | 5 | Visual inspection | 2 | 10 | Programming corrections | Product engineer | Programming code correction | 1 | 3 | 2 | 6 |

## VI. INTELLIGENT FUZZY INFERENCE SYSTEM

The theory of fuzzy sets and fuzzy logic [9] are used for development of intelligent fuzzy inference system (IFIS), following the steps of fuzzification, preparation of knowledge base and defuzzification as well as taking into account the collected information through PFMEA. Fuzzy logic is suitable for implementation when a system is characterized with uncertainty, changeability and complexity, when some variables cannot be expressed with crisp values (they vary in an interval), but the outcome must be exactly defined.

The IFIS is constructed trough Mamdani method and its general view is presented on fig. 2. The IFIS follows the occurring changes in the manufacturing process, recognizing its dynamics in time and possible failures.

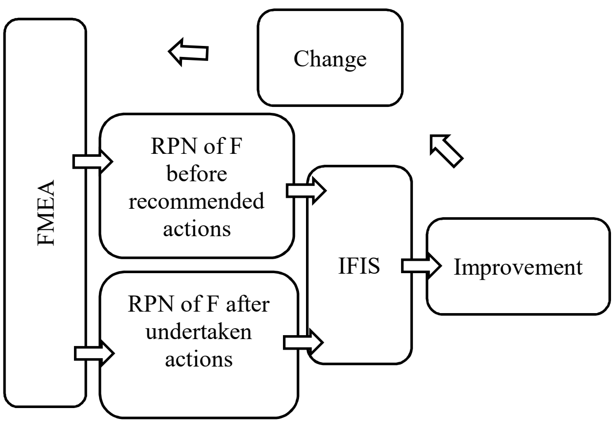


Fig. 2. Intelligent Fuzzy Inference System

The IFIS is characterized with two input variables: *RPN of a factor before conductance the FMEA recommended actions* and *RPN of a factor after undertaken actions*. They are expressed in the form of linguistic variables with 5 terms: very small (the RPN in fuzzy numbers is (0, 0, 50), small (0, 50, 100), average (50, 100, 150), big (100, 150, 200), very big (150, 200, 200). The output linguistic variable is *Improvement* and it reflects on the occurred undertaken actions in the manufacturing process. The *Improvement* is presented with the terms: none change (0, 0, 50), small (0, 50, 100), average (50, 100, 150), big (100, 150, 200) and very big change (150, 200, 200) (Table 2). The values are taken from 0 to 200, because the authors' practice shows that the obtained RPNs in the explored case, are in this interval.

TABLE 2. MAP WITH FUZZY RULES

| RPN of a factor before / RPN of a factor after | Very small | Small | Average | Big | Very big |
|---|---|---|---|---|---|
| Very small | None | Small | Average | Big | Very big |
| Small | None | None | Small | **Average (R)** | Big |
| Average | None | None | None | Small | Average |
| Big | None | None | None | None | Small |
| Very big | None | None | None | None | None |

The membership functions are chosen to be with regular form of semi-trapezoidal at the end and triangular in the middle of the explored scale. The knowledge base is created through 25 rules (Table 2) in the conjunctive form:

**R:** IF *RPN of a factor before* IS *Big* AND *RPN of a factor after* IS *Small* THEN *Improvement* IS *Average*.

The proposed model of IFIS is verified in the environment of FISPro software as the infer result for selected rule **R** is shown on fig. 3.

The defuzzification is performed through choosing the "area" technique [10].

The obtained conclusions after defuzzification for every factor are classified in three groups:

- group A contains factors with very low risk for failure,
- group B consists of factors with average risk and
- group C includes factors with high risk for failure (Table 3).

Fig. 3. IFIS inference for rule R

TABLE 3. FACTORS GROUPING

| Function | Factor | Improvement | Group |
|---|---|---|---|
| fu1 | f1 | 134 (big) | A |
| | f2 | 76 (average) | B |
| fu2 | f1 | 42 (small) | C |
| | f2 | 41 (small) | C |
| | f3 | 20 (none) | C |
| … | | | |

Then, a heatmap is created, presenting in visual way all explored factors. Usage of visual technique for explaining the final results can facilitate engineers very fast to identify the risk factors with small improvement or without any improvement (fig. 4). Also, the factors with big improvement after performing of recommended actions can be seen. Analysis through visualization is well accepted approach for understanding the critical and well-functioning parts in a robotized line.

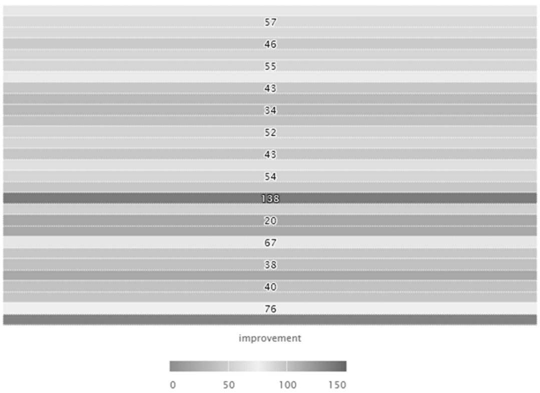


Fig. 4. Heatmap with improvement of factors

## V. CONCLUSION

In this work a method for analysis of risk operations of a robot in a manufacturing process of electronic devices is presented. Firstly, a model of FMEA analysis is created that gives information in all units of the production process, whether there is a greater risk of unforeseen situations, which would lead to the suspension of the work process. Secondly, an IFIS is developed to outline the dynamic change and improvement of each examined factor at robot functioning. It is driven by information obtained during the FMEA, which is used as knowledge base in the form of fuzzy rules. The defuzzified inference allows the factors to be classified in groups and visualized, which approach leads to clarity and better understanding regarding the risk factors and failure modes. Such preventive strategy can avoid the occurrence of unexpected situations that would lead to the cessation of the production. Through the developed models it is possible to track the entire production process and to show the units at high risk of potential damage in the process of working with the robot. The positive side of the proposed method is that it allows to optimize and improve the parameters at any time, which would lead to reasons for failures or errors in the work process.

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