# A New Two-Stage Fuzzy Inference System-Based Approach to Prioritize Failures in Failure Mode and Effect Analysis

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***Abstract*—This paper presents a new Fuzzy Inference System (FIS)-based Risk Priority Number (RPN) model for the prioritization of failures in Failure Mode and Effect Analysis (FMEA). In FMEA, the monotonicity property of the RPN scores is important. To maintain the monotonicity property of an FIS-based RPN model, a *complete* and *monotonically-ordered* fuzzy rule base is necessary. However, it is impractical to gather all (potentially a large number of) fuzzy rules from FMEA users. In this paper, we introduce a new two-stage approach to reduce the number of fuzzy rules that needs to be gathered, and to satisfy the monotonicity property. In *stage-1*, a Genetic Algorithm (GA) is used to search for a small set of fuzzy rules to be gathered from FMEA users. In *stage-2*, the remaining fuzzy rules are deduced approximately by a monotonicity-preserving similarity reasoning scheme. The monotonicity property is exploited as additional qualitative information for constructing the FIS-based RPN model. To assess the effectiveness of the proposed approach, a real case study with information collected from a semiconductor manufacturing plant is conducted. The outcomes indicate that the proposed approach is effective in developing an FIS-based RPN model with only a small set of fuzzy rules, which is able to satisfy the monotonicity property for prioritization of failures in FMEA.**

***Index Terms*—Failure mode and effect analysis, fuzzy inference system, similarity reasoning, monotonicity property, fuzzy rule reduction.**

## ABBREVIATIONS & ACRONYMS

| | |
|---|---|
| AARS | Approximate Analogical Reasoning Schema |
| $D$ | *Detection* |
| FCBGA | Flip Chip Ball Grid Array |
| FIS | Fuzzy Inference System |
| FMEA | Failure Mode and Effect Analysis |
| FRI | Fuzzy Rule Interpolation |
| FRPN | fuzzy RPN |
| GA | Genetic Algorithm |
| $O$ | *Occurrence* |
| MF | membership function |
| NLP | Non-Linear Programming |
| RPN | Risk Priority Number |
| $S$ | *Severity* |
| $S$-1 *FRs* | Stage 1 Fuzzy Rules |
| $S$-2 *FRs* | Stage 2 Fuzzy Rules |
| SQP | Sequential Quadratic Programming |
| SR | Similarity Reasoning |

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## NOTATIONS

| | |
|---|---|
| $\mu_x^{n_x}(x)$ | A membership function for $x \in [S, O, D]$, where $n_x = 1, 2, 3, \ldots, m_x$ |
| $A_x^{n_x}$ | A linguistic term for $x \in [S, O, D]$, where $n_x = 1, 2, 3, \ldots, m_x$ |
| $m_x$ | Number of membership function for $x \in [S, O, D]$ |
| $p_x$ | $p_x \in [1, 2, 3, \ldots, m_x - 1]$ |
| $x$ | An input for RPN model, $x \in [S, O, D]$ |

## I. INTRODUCTION

FAILURE mode and effect analysis (FMEA) is a popular reliability analysis tool that is used to evaluate the risks associated with potential failure modes of a complex system or process [1]–[3]. In FMEA, the risk of a failure mode is determined by a Risk Priority Number (RPN) [1], i.e., $RPN = f(S, O, D)$ whereby three risk factors, i.e., *Severity* $(S)$, *Occurrence* $(O)$, and *Detection* $(D)$, act as the inputs, and an RPN score is produced as the output. In this aspect, the fuzzy RPN model has been successfully applied to a variety of domains, which include maritime [3], fishing vessel [4], manufacturing [5], power generation [6], product development [7], and agriculture [8]. The focus of this paper is on the use of the Fuzzy Inference System (FIS) in FMEA, i.e., the FIS-based RPN model [9]. The advantages of using the FIS-based RPN model, as compared with the conventional RPN model, are well-established, *viz.*, (i) the FIS-based model allows modeling of nonlinear relationships between RPN and risk factors [9]; (ii) FIS is a solution for the attribute scales, which can be qualitative, instead of quantitative [9]; (iii) FIS is able to incorporate human knowledge, whereby information can be described with vague and imprecise linguistic statements [10]; and (iv) FIS avoids the scenario whereby two or more sets of $S, O$ and $D$ settings with