A NEUTROSOPHIC MCDM FRAMEWORK FOR PRIORITIZING PREVENTIVE AND DETECTION ACTIONS IN AUTOMOTIVE MANUFACTURING

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Abstract:

The quality and reliability of the production process in the automotive industry can significantly affect the market reputation and overall business performance of the entire company. In this paper, a Multi-Criteria Decision-Making (MCDM) model is defined for determining the priority of preventive and detection actions, i.e., a guideline that can be used to follow the prioritization of these actions. To model uncertainty and imprecision in expert evaluations, the model integrates Single-Valued Neutrosophic Sets (SVNSs) with the Single-Valued Neutrosophic Weighted Averaging Operator (SVNWAO) and the ELimination Et Choix Traduisant la REalité (ELECTRE) method. SVNWAO is used for determining the weights of criteria, while ELECTRE is applied for ranking the considered actions. The proposed methodology is applied in a case study conducted in a company that is a tier-1 supplier in the automotive industry. In cooperation with company experts, a total of 12 specific management actions and 6 criteria were identified according to which these actions were evaluated. The research results showed that Poka-Yoke by design is the most reliable action, providing long-term efficiency, followed by Update of standardized work instructions, Additional operator training, and Increased inspection frequency. The proposed model, as well as the results of this research, provide practitioners with a robust and objective tool for prioritizing actions, as well as for allocating resources in a complex and dynamic industrial environment.

1 Introduction

The modern automotive industry is based on the continuous improvement of processes. In the context of meeting the requirements of international standards, as well as customer requirements, the production process is the most exposed to continuous improvement activities. Improving the quality and reliability of this process is highly important for the overall business performance of the company and its market reputation. Such improvements can be achieved in different ways and with different levels of success, while other factors such

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as investment costs, complexity, and sustainability of the solutions may also vary. Due to limited resources and capabilities, it is not possible in real industrial environments to implement all identified or recommended actions. Therefore, in modern industrial manufacturing, achieving a balance between technical performance and economic efficiency is often one of the primary objectives [1], [2], [3], [4]. In addition to the challenges related to problem identification, which are addressed through various approaches, most commonly through the application of Failure Mode and Effects Analysis (FMEA), engineers and management are faced with the question of which action should be implemented in order to maximize technical efficiency while considering all real-world constraints. The selection of the optimal action requires the analysis of multiple criteria, which are often conflicting, as is frequently the case in many other engineering decision-making problems [5], [6], [7]. It should be emphasized that there are studies [8] demonstrating that, in modern industrial environments, the production process and its organization largely depend on preventive actions and the efficiency of their implementation. In addition, research shows that different actions in the domain of process management have varying impacts on both productivity and the efficiency of process activities [9]. For this reason, determining the overall priority of actions represents an important decision-making problem in modern industrial environments.

The aim of this paper is to define a Multi-Criteria Decision-Making (MCDM) model for ranking improvement actions by using expert knowledge and experience obtained from the company operating as tier-1 suppliers in the automotive industry. Although contemporary industrial problems in the relevant literature are increasingly being addressed through the application of data-driven artificial intelligence models [3], [10], [11], [12], [13], MCDM still remains an indispensable tool in situations where decision-making depends on factors such as discrete problems, the presence of multiple conflicting criteria, historical data, and expert knowledge. The motivation for conducting this research lies in the fact that the existing literature does not provide guidelines that engineers can follow in similar situations. The problem is highly practical and realistic, and in industrial practice it always requires discussion. Therefore, the proposed model, as well as the results of this research, may serve as useful guidelines for practitioners in their future work. It is important to note that the proposed actions should be monitored and controlled as a means of verifying the effectiveness of their implementation, as also suggested by authors in the relevant literature [14]. To model the uncertainty and imprecision of expert evaluations, Single-Valued Neutrosophic Sets (SVNSs) [15], [16] were used in this study. The main motivation for selecting these sets lies in their ability to simultaneously handle incomplete, indeterminate, and inconsistent information. Therefore, these sets are suitable for application in complex decision-making systems. For determining the weights of the criteria, the Single-Valued Neutrosophic Weighted Averaging Operator (SVNWAO) [17] was used. For ranking the alternatives, namely preventive and detection actions, the ELECTRE (French: *ELimination Et Choix Traduisant la REalité*) method [18], [19] was applied in this study. This method was selected because it possesses a specific mechanism for comparing alternatives through concordance and discordance pairs, which makes it suitable for problems involving conflicting criteria. Unlike a large number of MCDM methods, ELECTRE does not provide a compromise solution, but instead identifies outranking relations, thereby ensuring a robust ranking of alternatives. One of the motivations for combining SVNSs and ELECTRE is the scientific gap that exists in this domain. In the relevant literature, there are no studies in which these methods have been applied to the problem of ranking management actions in an industrial environment. Furthermore, through the aggregation of expert evaluations using the SVNWAO and the modified ELECTRE method (SVNWAO-ELECTRE), this paper presents an innovative model that enables objective and reliable decision-making.

The proposed model makes both theoretical (methodological) and practical contributions. From a theoretical perspective, the contributions of the proposed framework are as follows: (1) the development of an integrated SVNWAO-ELECTRE framework for prioritizing preventive and detection actions; (2) the extension of the existing ELECTRE approach under a Single-Valued Neutrosophic Numbers (SVNNs) environment through a modified procedure for constructing the concordance matrix and determining the discordance matrix by combining the normalized Hamming distance with the conventional ELECTRE procedure; and (3) the modeling of uncertainties associated with the decision-makers' (DMs) weights, the relative importance of criteria, and the criterion values through the application of SVNNs. From a practical perspective, the contributions are as follows: (1) the proposed framework provides FMEA teams and practitioners with a structured and mathematically grounded decision-support tool; (2) the study offers practical guidance regarding the selection of actions with the highest expected impact on process quality and reliability; and (3) the proposed model is validated through a real industrial case study, demonstrating its applicability in practice. The rest of the paper is organized as follows: Section 2 presents a literature review. Section 3 presents the fundamentals of the concept of SVNSs and SVNNs. The proposed model is presented in Section 4. A case study is presented in Section 5, while the conclusions are given in Section 6.

2 Literature review

As already stated in the introductory section of this paper, very few studies in the relevant literature have addressed the problem of selecting methods for business process improvement, particularly in the context of manufacturing processes. Existing research has mainly focused on the limitations of the traditional FMEA approach [20], [21], [22], [23], [24], [25], which further leads to recommendations regarding the implementation of preventive and detection actions. In addition to improving the FMEA methodology itself, several authors have also focused on the development of frameworks for continuous process improvement. Thus, in study [26], the authors developed a framework for prioritizing improvement initiatives while considering process-related variables. A similar approach was applied in study [27], where the authors identified strategies for eliminating non-value-adding activities. Their research showed that Poka-Yoke solutions have the highest importance, indicating that they should be assigned the highest priority. In study [11], the authors performed the evaluation and selection of methods for manufacturing process reliability improvement. For this purpose, intuitionistic fuzzy sets (IFSs) and genetic algorithms were used. The results of this research demonstrated that the application of fuzzy logic and predefined linguistic terms enables a more effective representation of uncertainty compared to the use of precise numerical values. In this study, the problem of prioritizing preventive and detection actions is formulated as an MCDM problem extended through the application of SVNSs. The initial idea of modeling uncertainty emerged with the development of fuzzy set theory, also known as type-1 fuzzy sets [28]. These sets enabled linguistic variables to be quantitatively described in a sufficiently accurate manner. A large number of studies in the literature have extended MCDM approaches through the application of different fuzzy set theories. A particular type of fuzzy sets frequently used in MCDM problems are intuitionistic fuzzy sets (IFSs), introduced by [29]. Many authors, such as [30], argue that conventional type-1 fuzzy sets, as well as type-2 fuzzy sets [31], [32], are capable of processing incomplete information, but cannot adequately represent indeterminate and inconsistent information, which commonly exist in belief systems. It should be emphasized that interval type-1 [33], [34] and type-2 fuzzy sets [35] are still used in the relevant literature in situations where only incomplete and uncertain information is considered. However, they are not suitable in cases involving inconsistency and indeterminacy, for which other types of numbers are specifically designed. As is well known, the main characteristics of type-1 fuzzy numbers and type-2 fuzzy sets are the membership function, granularity, and domain. Granularity is most commonly determined based on the assessments of DMs, taking into account the size and complexity of the problem. Furthermore, the domains of the applied fuzzy sets are usually defined on the real line and belong to different intervals. In [29], in addition to the membership function, introduced the non-membership function in order to improve the modeling of uncertain and imprecise variables.

The remaining two characteristics of fuzzy sets, namely granularity and domains, are defined in the same manner as in type-1 and type-2 fuzzy set theory. The concept of neutrosophic sets (NSs) is proposed in [36]. NSs are characterized by three functions: truth-membership, indeterminacy-membership, and falsity-membership. Unlike intuitionistic fuzzy sets, NSs introduce an independent indeterminacy-membership function, meaning that DMs use truth-membership T(x), indeterminacy-membership I(x), and falsity-membership F(x) to describe their judgments regarding an object. NSs can be considered a generalization of intuitionistic fuzzy sets and provide DMs with the possibility to express their opinions in a more accurate and detailed manner. In NSs, truth-membership, indeterminacy-membership, and falsity-membership are completely independent. In [15], SVNSs were developed as a practical instance of neutrosophic sets, and various properties of SVNSs were presented. It can be stated that SVNSs represent a highly useful tool for characterizing evaluation information provided by DMs under indeterminate and inconsistent conditions. In this paper, the relative importance of DMs and the values of criteria are represented by SVNNs within the SVNS framework. The algebraic operations of fuzzy sets with SVNSs were proposed by [37]. In many studies found in the literature, the evaluation of criteria is formulated as a fuzzy group decision-making problem [30], [38], [39] using SVNS framework, as is also done in this paper. The granularity and domains of these SVNSs are defined according to the approaches presented in the literature [38]. In recent years, numerous studies have been conducted in the field of aggregation operator development [30], and it has been shown that the

Bonferroni operator is not suitable for aggregating SVNSs. One of the operators widely applied for the aggregation of SVNSs is the Single-Valued Neutrosophic Weighted Averaging Operator (SVNWAO), proposed by [17], which is also applied in this research.

The ranking of alternatives in different domains is frequently performed using MCDM approaches extended with SVNSs [38], [39], [40], [41], [42], [43], [44]. In studies by [38], [39], [42], the ranking problem was addressed through the application of the TOPSIS method under an SVNS environment. In these approaches, the Fuzzy Positive Ideal Solution (FPIS) and the Fuzzy Negative Ideal Solution (FNIS) are determined from the aggregated weighted fuzzy decision matrix. Subsequently, by applying the normalized Euclidean distance measure and the conventional TOPSIS procedure, the closeness coefficient and the ranking of alternatives are obtained. In [42], the comprehensive evaluation matrix was constructed using the linguistic neutrosophic weighted averaging operator proposed by [45]. Based on the comprehensive and power functions, the utility matrix was established. By applying regret theory, the regret and rejoicing matrices were constructed according to the proposed procedure. Considering these matrices, regret risk and rejoice risk values were determined, while the ranking of identified alternatives was obtained according to the risk criterion through an analogy with the conventional PROMETHEE method. The PROMETHEE approach with SVNNs is conceptually similar to the framework proposed by [42]. In studies [40], [43], combinations of different MCDM methods extended through the application of SVNNs were used. The ELECTRE method under an SVNN environment was proposed by [41]. In their study, concordance and discordance sets were determined based on the weighted fuzzy decision matrix. These sets were further classified into strong, moderate, and weak concordance and discordance sets. In contrast, the framework proposed in this study introduces a different procedure for constructing the concordance matrix. Furthermore, the values of the discordance matrix are obtained by combining the normalized Euclidean distance with the procedure used in the conventional ELECTRE method. Finally, the concordance dominance matrix, as well as the ranking of alternatives, are determined using the conventional ELECTRE procedure. Additionally, the ELECTRE method extended through the application of SVNNs was also used in study [44], where the authors applied this approach to extend the FMEA methodology. In this study, a two-stage approach based on subjective expert evaluations modeled through the application of SVNNs was developed. Although numerous objective methods for determining criteria weights can be found in the literature [6], [7], [46], [47], the focus of this research is placed on expert knowledge and experience, and consequently on the aggregation of evaluations using the SVNWAO operator. The ELECTRE method was selected because it is suitable for the direct comparison of alternatives with respect to each criterion, i.e., it possesses an outranking dimension. Such an approach is particularly appropriate in situations characterized by conflicting criteria and a high degree of uncertainty in expert judgments.

3 Preliminaries on SVNNs

A neutrosophic set originates from neutrosophy, a new branch of philosophy that reflects the origin, nature, and scope of neutralities, as well as their interactions with different ideational spectra [36]. In this section, some basic definitions, operations, and properties regarding SVNSs are provided [15]. An SVNS is an instance of a neutrosophic set that can be used in real scientific and engineering applications.

Definition 3.1.

Let X be the universe of discourse, with a generic element in X denoted by x. Then, NS A in X is as follows: $A = \{x | x \in X\}$, where $T(x), I(x)$ and $F(x)$ are the truth-membership function, the indeterminacy membership function and the falsity-membership function, respectively, $T(x), I(x), F(x): X \to [0,1]$ and $0 \leq T(x) + I(x) + F(x) \leq 3$ [36]. The set, $I(x)$ may represent not only indeterminacy, but also vagueness, uncertainty, imprecision, error, contradic tion, undefined, unknown, incompleteness, redundancy, etc. [48]. In order to catch up vague information, an indeterminacy-membership degree can be split into sub components, such as *contradiction*, *uncertainty*, and *unknown* [49].

Definition 3.2.

Let X be the universe of dis course. The Single Valued Neutrosophic Set A over X is an object having the form: $A = \{x | x \in X\}, T(x), I(x)$ and $F(x)$, where are the truth membership function, the intermediacymembership function and the falsity-membership function, respectively, $T(x), I(x), F(x): X \rightarrow [0,1]$ and $0 \leq T(x) + I(x) + F(x) \leq 3$ [15]. SVNS is represented as an ordered triple $\langle T(x), I(x), F(x)\rangle$.

Definition 3.3. Let A be an SVNS over a universe set U:

1) A is said to be absolute SVNS denoted by $\tilde{A}$ if $T_{\tilde{A}}(x) = 1$, $I_{\tilde{A}}(x) = 0$ and $F_{\tilde{A}}(x) = 0$ for all $x \in X$.
2) A is said to be an empty or null Φ_A if $T_{\Phi_A}(x) = 0$, $I_{\Phi_A}(x) = 0$and $F_{\Phi_A}(x) = 0 = 0$ for all $x \in X$.
In the remainder of this paper, evaluations are represented by SVNNs, which are specific realizations of SVNSs.

Definition 3.4.

Let us consider two SVNNs, $\tilde{A} = \langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\rangle$ and $\tilde{B} = \langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x)\rangle$.
The following set of operations is given in [15]:
1) $\tilde{A} \subseteq \tilde{B}$ if and only if $T_{\tilde{A}}(x) \leq T_{\tilde{B}}(x)$, $I_{\tilde{A}}(x) \geq I_{\tilde{B}}(x)$, $F_{\tilde{A}}(x) \geq F_{\tilde{B}}(x)$ for all $x \in X$.
2) $\tilde{A} = \tilde{B}$ if and only if $\tilde{A} \subseteq \tilde{B}$ and $\tilde{B} \subseteq \tilde{A}$ for all $x \in X$.
3) $\tilde{A}^c = \langle T_{\tilde{A}}(x), 1 - I_{\tilde{A}}(x), F_{\tilde{A}}(x)\rangle$ for all $x \in X$.
4) $\tilde{A} \cup \tilde{B}$=$\langle \max\left(T_{\tilde{A}}(x), T_{\tilde{B}}(x)\right), \min\left(I_{\tilde{A}}(x), I_{\tilde{B}}(x)\right), \min\left(F_{\tilde{A}}(x), F_{\tilde{B}}(x)\right)\rangle$, for all $x \in X$.
5) $\tilde{A} \cap \tilde{B}$=$\langle \min\left(T_{\tilde{A}}(x), T_{\tilde{B}}(x)\right), \max\left(I_{\tilde{A}}(x), I_{\tilde{B}}(x)\right), \max\left(F_{\tilde{A}}(x), F_{\tilde{B}}(x)\right)\rangle$, for all $x \in X$.

Definition 3.5.

Let us consider two SVNNs, $\tilde{A} = \langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\rangle$ and $\tilde{B} = \langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x)\rangle$.
The following set of operations are given in [30]:
1) $\tilde{A} + \tilde{B} = \langle T_{\tilde{A}}(x) + T_{\tilde{B}}(x) - T_{\tilde{A}}(x) \cdot T_{\tilde{B}}(x), I_{\tilde{A}}(x) \cdot I_{\tilde{B}}(x), F_{\tilde{A}}(x) \cdot F_{\tilde{B}}(x)\rangle$ for all $x \in X$.
2) $\tilde{A} \cdot \tilde{B} = \langle T_{\tilde{A}}(x) \cdot T_{\tilde{B}}(x), I_{\tilde{A}}(x) + I_{\tilde{B}}(x) - I_{\tilde{A}}(x) \cdot I_{\tilde{B}}(x), F_{\tilde{A}}(x) + F_{\tilde{B}}(x) - F_{\tilde{A}}(x) \cdot F_{\tilde{B}}(x)\rangle$ for all $x \in X$.
3) $\tilde{A} - \tilde{B} = \langle \frac{T_{\tilde{A}}(x) - T_{\tilde{B}}(x)}{1 - T_{\tilde{B}}(x)}, \frac{I_{\tilde{A}}(x)}{I_{\tilde{B}}(x)}, \frac{F_{\tilde{A}}(x)}{F_{\tilde{B}}(x)}\rangle$ for all $x \in X$ which is valid under considerations $\tilde{A} \geq \tilde{B}$; $T_{\tilde{B}}(x) \neq 1, I_{\tilde{B}}(x) \neq 0, F_{\tilde{B}}(x) \neq 0$.
4) $\tilde{A}/\tilde{B} = \langle \frac{T_{\tilde{A}}(x)}{T_{\tilde{B}}(x)}, \frac{I_{\tilde{A}}(x) - I_{\tilde{B}}(x)}{1 - I_{\tilde{B}}(x)}, \frac{F_{\tilde{A}}(x) - F_{\tilde{B}}(x)}{1 - F_{\tilde{B}}(x)}\rangle$ for all $x \in X$ which is valid under considerations $\tilde{B} \geq \tilde{A}$; $T_{\tilde{B}}(x) \neq 0, I_{\tilde{B}}(x) \neq 1, F_{\tilde{B}}(x) \neq 1$.
5) $\lambda \cdot \tilde{A} = \langle 1 - \left(1 - T_{\tilde{A}}(x)\right)^{\lambda}, \left(I_{\tilde{A}}(x)\right)^{\lambda}, \left(F_{\tilde{A}}(x)\right)^{\lambda}\rangle$ for all $x \in X$.
6) $\left(\tilde{A}\right)^{\lambda} = \langle \left(T_{\tilde{A}}(x)\right)^{\lambda}, 1 - \left(1 - I_{\tilde{A}}(x)\right)^{\lambda}, 1 - \left(1 - F_{\tilde{A}}(x)\right)^{\lambda}\rangle$ for all $x \in X$.

Definition 3.6.

Let us consider two SVNNs, $\tilde{A} = \langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\rangle$ and $\tilde{B} = \langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x)\rangle$ and scalar values, $\lambda, \lambda_1, \lambda_2 > 0$.
The following properties hold:
1) $\tilde{A} + \tilde{B} = \tilde{B} + \tilde{A}$
2) $\tilde{A} \cdot \tilde{B} = \tilde{B} \cdot \tilde{A}$
3) $\lambda \cdot \left(\tilde{A} + \tilde{B}\right) = \lambda \cdot \tilde{A} + \lambda \cdot \tilde{B}$
4) $\lambda_1 \cdot \tilde{A} + \lambda_2 \cdot \tilde{A} = (\lambda_1 + \lambda_2) \cdot \tilde{A}$
5) $\tilde{A}^{\lambda_1} \cdot \tilde{A}^{\lambda_2} = \tilde{A}^{(\lambda_1 + \lambda_2)}$
6) $\tilde{A}^{\lambda} \cdot \tilde{B}^{\lambda} = \left(\tilde{A} \cdot \tilde{B}\right)^{\lambda}$

Definition 3.7.

Let us consider n SVNNs, $\tilde{A}_j = \langle T_{\tilde{A}_j}(x), I_j(x), F_{\tilde{A}_j}(x)\rangle$. The Single Valued Neutrosophic Weighted Average Operator (SVNWAO) is given [17]:

$$SVNWAO = \langle 1 - \prod_{j=1,..,n} \left(1 - T_{\tilde{A}_j}(x)\right)^{\omega_j}, \prod_{j=1,..,n} \left(I_{\tilde{A}_j}(x)\right)^{\omega_j}, \prod_{j=1,..,n} \left(F_{\tilde{A}_j}(x)\right)^{\omega_j} \rangle \quad (1)$$

Where:

$$\sum_{j=1,..,n} \omega_j = 1$$

Definition 3.8.

A real function $D: \Phi(X) x \Phi(Y) \rightarrow [0,1]$ is called a distance measure, where d satisfies the following axioms for $A, B, C \subseteq \Phi(X)$:
1) $0 \leq D(A,B) \leq 1$
2) $D(A,B) = 0 \; iff \; A = B$
3) $D(A,B) = D(B,A)$
4) If $A \subseteq B \subseteq C$ than $D(A,C) \geq D(A,B) \; and \; (A,C) \geq D(B,C)$

Definition 3.9.

Let us consider two SVNNs, $\tilde{A} = \langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x) \rangle$ and $\tilde{B} = \langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x) \rangle$.
Euclidean and Hamming distances between SVNSs are defined as follwos [17]:

1) The Euclidean distances between SVNSs is:

$$d = \sqrt{\left\{\left(T_{\tilde{A}}(x) - T_{\tilde{B}}(x)\right)^2 + \left(I_{\tilde{A}}(x) - I_{\tilde{B}}(x)\right)^2 + \left(F_{\tilde{A}}(x) - F_{\tilde{B}}(x)\right)^2\right\}} \quad (2)$$

2) The normalized Euclidean distances between SVNSs is:

$$d = \sqrt{\frac{1}{3}\left\{\left(T_{\tilde{A}}(x) - T_{\tilde{B}}(x)\right)^2 + \left(I_{\tilde{A}}(x) - I_{\tilde{B}}(x)\right)^2 + \left(F_{\tilde{A}}(x) - F_{\tilde{B}}(x)\right)^2\right\}} \quad (3)$$

3) The Hamming distances between SVNSs is:

$$d = |T_{\tilde{A}}(x) - T_{\tilde{B}}(x)| + |I_{\tilde{A}}(x) - I_{\tilde{B}}(x)| + |F_{\tilde{A}}(x) - F_{\tilde{B}}(x)| \quad (4)$$

4) The normalized Hamming distances between SVNSs is:

$$d = \frac{1}{3} \cdot \{|T_{\tilde{A}}(x) - T_{\tilde{B}}(x)| + |I_{\tilde{A}}(x) - I_{\tilde{B}}(x)| + |F_{\tilde{A}}(x) - F_{\tilde{B}}(x)|\} \quad (5)$$

Definition 3.10.

The cosine similarity between $\tilde{A} = \langle T_{\tilde{A}}(x_i), I_{\tilde{A}}(x_i), F_{\tilde{A}}(x_i) \rangle$ and ideal solution $\langle 1, 0, 0 \rangle$, $S(\tilde{A})$ for comparison of SVNNs is given by [17]:

$$S(x) = \frac{T_{\tilde{A}}(x)}{\sqrt{\left(T_{\tilde{A}}(x)\right)^2 + \left(I_{\tilde{A}}(x)\right)^2 + \left(F_{\tilde{A}}(x)\right)^2}} \quad (6)$$

Definition 3.11.

Let us consider two SVNNs, $\tilde{A} = \langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x) \rangle$ and $\tilde{B} = \langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x) \rangle$. If $S(\tilde{A}) \leq S(\tilde{B})$ then $\tilde{A} \leq \tilde{B}$, and vice versa [17].

Definition 3.12.

The relative importance of DM, $e, e = 1, \dots, E$ described with SVNNs $\langle T_{\tilde{E}}(x), I_{\tilde{E}}(x), F_{\tilde{E}}(x)\rangle$. The determination of the weights of DMs can be given by applying procedure [38]:

$$\omega_e = \frac{1 - \sqrt{\frac{\left(1-\left(T_{\tilde{E}}(x)\right)^2\right) + \left(I_{\tilde{E}}(x)\right)^2 + \left(F_{\tilde{E}}(x)\right)^2}{3}}}{\sum_{e=1,..,E}(1 - \sqrt{\frac{\left(1-\left(T_{\tilde{E}}(x)\right)^2\right) + \left(I_{\tilde{E}}(x)\right)^2 + \left(F_{\tilde{E}}(x)\right)^2}{3}})} \tag{7}$$

Where:

$$\sum_{e=1,..,E} \omega_e = 1$$

Definition 3.13.

The defuzzification of SVNN $\tilde{A} = \langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\rangle$ into representative scalar A can be performed by procedure [45]:

$$A = \frac{2 + T_{\tilde{A}}(x) - I_{\tilde{A}}(x) - F_{\tilde{A}}(x)}{3} \tag{8}$$

It should be emphasized that various defuzzification functions for SVNNs have been proposed in the relevant literature. In this study, the procedure adopted [45] was selected because, in the authors' opinion, it provides an effective transformation of SVNNs into representative scalar values while simultaneously taking into account the degrees of truth, indeterminacy, and falsity.

4 Proposed methodology

In this section, the fuzzy two-stage model used to solve the considered problem is briefly explained. Firstly, the relative importance of DMs is assessed by the plant manager of the manufacturing facility using predefined linguistic terms. The weights of the DMs are determined by the procedure defined by [38]. The fuzzy weight vector is obtained using the SVNWAO operator proposed by [17]. In the second stage, the fuzzy decision matrix with SVNNs is constructed according to the assessments of the FMEA team. The construction of the weighted normalized fuzzy decision matrix is based on fuzzy algebra rules [30]. The ranking of the considered failures is obtained by applying the ELECTRE method with SVNNs, which is proposed in this research. In the remainder of this section, the proposed methodology is explained in detail and presented through its implementation steps.

4.1 Defining the set of DMs

The assessment of the relative importance of the criteria is performed by three DMs. These DMs are formally represented by the set of indices $\{1, \dots, e, \dots, E\}$. The total number of DMs is denoted by E, and the index of a decision-maker (DM) is represented by e, where $e = 1, \dots, E$. In this case, the DMs were selected based on their experience and knowledge, and they include: the production manager ($e = 1$), the quality manager ($e = 2$), and the maintenance manager ($e = 3$). As already emphasized, the evaluation of each alternative with respect to each criterion is obtained according to the assessments of the FMEA team, which were made by consensus. The DMs involved in this study were selected based on their extensive professional experience in the automotive industry. All of them are involved, from different perspectives, in activities related to the planning, implementation, and continuous improvement of manufacturing processes, and they also possess practical experience in the application of FMEA analysis. The quality manager also serves as the FMEA team facilitator within the company, while the other two DMs are members of the extended FMEA team. In addition, they have worked together as a team in the company for more than three years and are continuously engaged in activities aimed at improving the manufacturing process. Their role in this study was to define the set of criteria used to evaluate the considered preventive and detection actions. Furthermore, they were asked to assess the relative importance of the criteria based on their professional knowledge and experience. The role of the FMEA team in this study was to identify the preventive and detection actions most frequently implemented within the company and to evaluate the performance of each action with respect to the six defined criteria.

4.2 Definition of a finite set of preventive and detection actions

As is well known, the application of appropriate preventive and detection actions can improve the effectiveness of the manufacturing process, which is one of the most important business processes in an automotive company. In this case, the identification of possible management measures is carried out by the FMEA team in cooperation with the company's top management. Based on their previous experience, a total of 12 actions that are most frequently applied in their company have been defined. Formally, these actions can be represented by the set of indices $\{1, \ldots, i, \ldots, I\}$, where I denotes the total number of actions, and the index of each action is denoted by $i, i = 1, \ldots, I$. In this research, the following preventive and/or detection actions were identified: Additional operator training ($i = 1$), Ergonomic improvement of the workstation ($i = 2$), Update of standardized work instructions ($i = 3$), Poka-Yoke by design ($i = 4$), Automated detection ($i = 5$), Automated visual inspection ($i = 6$), Increased inspection frequency ($i = 7$), First-piece inspection ($i = 8$), Physical "good/bad" examples at the station ($i = 9$), Digital process monitoring ($i = 10$), Preventive maintenance improvement ($i = 11$), and Implementation of Statistical process control (SPC) ($i = 12$).

4.3 Definition of a finite set of criteria

The criteria according to which the identified actions are to be evaluated are defined by the DMs in accordance with best practices. Simply put, the criteria were selected to reflect the most important characteristics of the preventive and detection actions most frequently implemented within the company. These criteria can be formally represented by the set $\{1, \ldots, k, \ldots, K\}$. The total number of criteria is denoted by K, and $k, k = 1, \ldots, K$ represents the index of a criterion. In general, criteria can be of benefit or cost type, as is the case in this research. In this paper, the set of criteria is defined as follows: Implementation Cost ($k = 1$), Defect Reduction Potential ($k = 2$), Implementation Time ($k = 3$), Impact on Productivity ($k = 4$), Sustainability of the Solution ($k = 5$), and Implementation Complexity ($k = 6$).

4.4 Selection of appropriate linguistic variables for describing the existing uncertainties

The uncertainties in the DM weights, the relative importance, and the values of the criteria can be better expressed in natural language terms than in precise numerical values. The number and type of linguistic terms should be defined according to the size of the problem. In the literature, there is no recommendation or rule for selecting an appropriate number of linguistic expressions that can adequately describe the considered uncertainty.

In this study, it is assumed that the relative importance of DMs and criteria can be adequately described using a five-point scale:

- *very low importance (W1):* $\langle 0.05, 0.8, 0.95 \rangle$
- *low importance (W2):* $\langle 0.25, 0.65, 0.7 \rangle$
- *medium importance (W3):* $\langle 0.50, 0.40, 0.45 \rangle$
- *high importance (W4):* $\langle 0.75, 0.25, 0.2 \rangle$
- *very high importance (W5):* $\langle 0.95, 0.1, 0.05 \rangle$

The values of the alternatives with respect to each considered criterion, i.e., the elements of the fuzzy decision matrix, were evaluated based on the following linguistic expressions modeled using SVNNs:

- *extremely low (V1):* $\langle 0.05, 0.9, 0.95 \rangle$
- *very low (V2):* $\langle 0.1, 0.85, 0.9 \rangle$
- *low (V3):* $\langle 0.2, 0.75, 0.8 \rangle$
- *slightly low (V4):* $\langle 0.35, 0.65, 0.6 \rangle$
- *medium (V5):* $\langle 0.5, 0.5, 0.45 \rangle$

- *slightly high (V6):* ⟨0.65,0.35,0.3⟩
- *high (V7):* ⟨0.8,0.2,0.15⟩
- *very high (V8):* ⟨0.9,0.1,0.05⟩
- *extremely high (V9):* ⟨1,0.05,0.05⟩

4.5 The proposed ELECTRE approach with SVNNs for ranking preventive and detection actions

The proposed methodology can be presented through the following steps:
Step 1. The plant manager evaluates the relative importance of the DMs using predefined linguistic terms. His assessments are based on prior experience working with them and on his subjective judgment. Using the procedure in [38], the weight vector of the DMs is determined:

$$[\omega_e]_{1xE} \tag{9}$$

Step 2. The fuzzy decision matrix can be expressed as follows:

$$[\tilde{x}_{ik}]_{IxK} \tag{10}$$

The elements of the fuzzy decision matrix are defined as the values of criteria k, where $k = 1,\ldots,K$, for actions $i, i = 1,\ldots,I$. These values are assessed by the FMEA team, which makes decisions by consensus. During the evaluation of the criteria values, the FMEA team carefully considers the type of each criterion. In this way, greater attention is required from the FMEA team throughout the evaluation process. On the other hand, normalization is not required, making the calculation process less complex.
Step 3. The aggregated criteria weights are determined using the SVNWAO [17]:

$$[\widetilde{\omega}_k]_{1xK} \tag{11}$$

Step 4. The weighted fuzzy decision matrix is defined as follows:

$$[\tilde{z}_{ik}]_{IxK} \tag{12}$$

Where:

$$\tilde{z}_{ik} = \widetilde{\omega}_k \cdot \tilde{x}_{ik} \tag{13}$$

The values of $\tilde{z}_{ik}$ are presented by SVNNs according to the fuzzy algebra rules [30].
Step 5. Determine the concordance sets, $\mathcal{S}_{ii'}$, and the discordance sets, $\mathcal{NS}_{ii'}$, for each pair of actions:

- $\tilde{z}_{ik} \geq \tilde{z}_{i'k} \rightarrow k \in \mathcal{S}_{ii'}$
- $\tilde{z}_{ik} < \tilde{z}_{i'k} <\rightarrow k \in \mathcal{NS}_{ii'}$

The comparison of SVNNs is based on the procedure proposed by [17]. According to this comparison rule, criteria for which action i is preferred to action i' are included in the concordance set, while the remaining criteria form the discordance set.
Step 6. Determine the fuzzy concordance matrix:

$$[\tilde{c}_{ii'}]_{IxI} \tag{14}$$

Where:

$$\tilde{c}_{ii'} = 0 \qquad i = i'$$
$$\tilde{c}_{ii'} = \sum_k \widetilde{\omega}_k \quad k \in \mathcal{S}_{ii'}$$

Step 7. Transform the fuzzy concordance matrix into the concordance matrix [45]:

$$[c_{ii'}]_{IxI} \tag{15}$$

Then, the average value of the concordance matrix is calculated:

$$\bar{c} = \frac{1}{I \cdot (I-1)} \cdot \sum_{i=1,\dots,I} \sum_{i'=1,\dots,I} c_{ii'} \tag{16}$$

Step 8. Construct the discordance matrix:

$$[n_{ii'}]_{IxI} \tag{17}$$

Where:

$$n_{ii'} = 0 \quad i = i' \tag{18}$$

$$n_{ii'} = \frac{\max_{k \in \mathcal{NS}_{ii'}} d(\tilde{z}_{ik}, \tilde{z}_{i'k})}{\max_{k=1,\dots,K} d(\tilde{z}_{ik}, \tilde{z}_{i'k})} \tag{19}$$

The average value of the discordance matrix is calculated:

$$\bar{n} = \frac{1}{I \cdot (I-1)} \cdot \sum_{i=1,\dots,I} \sum_{i'=1,\dots,I} \bar{n}_{ii'} \tag{20}$$

Step 9. Determine the concordance dominance matrix:

$$[m_{ii'}]_{IxI} \tag{21}$$

Where:

$$\begin{aligned} m_{ii'} &= 1\ iff \quad c_{ii'} \geq \bar{c} \wedge n_{ii'} < \bar{n} \\ m_{ii'} &= 0\ iff \qquad otherwise \end{aligned} \tag{22}$$

Step 10. Determine the comparison coefficient, M_i:

$$M_i = \sum_{i'=1,\dots,I} m_{ii'} \tag{23}$$

Step 11. Sort the comparison coefficients M_i in descending order. The actions associated with the highest values of M_i should be given priority when considering the implementation of actions for solving a given problem.

5 Case study

The case study was conducted in an automotive industry company that is a tier-1 supplier in the supply chain. The company is headquartered in Kragujevac, Republic of Serbia. A condition set by the company for participation in this research was that both the survey process and the analysis of the collected data remain anonymous. Furthermore, all other information that could enable the identification of the company has been kept confidential. The authors of the paper agree with the company's requirements and fully respect its confidentiality, as well as the ethical principles of research. The focus of this paper is the proposal of a new MCDM approach, which is presented in the remainder of this section.

According to the proposed procedure (Step 1), the weight vector of the DMs is calculated:

$$\omega_1 = \frac{1-\sqrt{\frac{(1-(0.95)^2)+(0.1)^2+(0.05)^2}{3}}}{1-\sqrt{\frac{(1-(0.95)^2)+(0.1)^2+(0.05)^2}{3}}+1-\sqrt{1-\frac{(1-(0.75)^2)+(0.25)^2+(0.2)^2}{3}}+1-\sqrt{1-\frac{(1-(0.5)^2)+(0.4)^2+(0.45)^2}{3}}}$$

$$\omega_1 = \frac{0.8085}{0.8085+0.5757+0.3910} = 0.46$$

In the same way, the weights of the remaining DMs are calculated, so that the weight vector is:

$$[0.46, \quad 0.32, \quad 0.22]$$

The fuzzy decision matrix is assessed by the FMEA team (Step 2 of the proposed procedure) and presented in Table 1. The assessment of the relative importance of the criteria is performed by the DMs as shown in Table 2.

Table 1. The fuzzy decision matrix.

	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$
$i=1$	V8	V2	V8	V2	V3	V8
$i=2$	V2	V2	V6	V5	V5	V5
$i=3$	V5	V3	V8	V5	V5	V8
$i=4$	V5	V5	V6	V2	V7	V6
$i=5$	V2	V8	V2	V5	V8	V2
$i=6$	V1	V8	V2	V4	V7	V4
$i=7$	V5	V2	V5	V3	V4	V8
$i=8$	V5	V5	V5	V6	V4	V4
$i=9$	V7	V3	V8	V2	V2	V8
$i=10$	V1	V8	V1	V5	V7	V3
$i=11$	V5	V5	V5	V4	V6	V4
$i=12$	V2	V5	V5	V2	V6	V4

Table 2. The relative importance of criteria.

	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$
$e=1$	*W4*	*W3*	*W3*	*W3*	*W5*	*W3*
$e=2$	*W2*	*W4*	*W4*	*W1*	*W2*	*W4*
$e=3$	*W3*	*W3*	*W2*	*W2*	*W3*	*W3*

The procedure for calculating the weight of the first criterion (Step 3) is presented below:

$$\widetilde{\omega}_1 = \left\langle \begin{matrix} 1-(1-0.75)^{0.46}\cdot(1-0.25)^{0.32}\cdot(1-0.5)^{0.22}, \\ (0.25)^{0.46}\cdot(0.65)^{0.32}\cdot(0.4)^{0.22}, (0.2)^{0.46}\cdot(0.7)^{0.32}\cdot(0.45)^{0.22} \end{matrix} \right\rangle$$

$$\widetilde{\omega}_1 = \langle 0.586, 0.376, 0.357 \rangle$$

In the same way, the weights of the remaining criteria are calculated, so that:

$$\widetilde{\omega}_2 = \langle 0.599, 0.344, 0.347 \rangle \qquad \widetilde{\omega}_3 = \langle 0.562, 0.383, 0.383 \rangle \qquad \widetilde{\omega}_4 = \langle 0.328, 0.556, 0.629 \rangle$$

$$\widetilde{\omega}_5 = \langle 0.803, 0.247, 0.189 \rangle \qquad \widetilde{\omega}_6 = \langle 0.571, 0.377, 0.376 \rangle$$

The weighted fuzzy decision matrix is calculated and presented in Tables 3 and 4 (Step 4 of the proposed procedure).

Table 3. The weighted fuzzy decision matrix (part 1).

	$k = 1$	$k = 2$	$k = 3$
$i = 1$	⟨0.527,0.438,0.389⟩	⟨0.059,0.902,0.935⟩	⟨0.506,0.445,0.414⟩
$i = 2$	⟨0.059,0.906,0.936⟩	⟨0.059,0.902,0.935⟩	⟨0.365,0.599,0.568⟩
$i = 3$	⟨0.293,0.688,0.646⟩	⟨0.120,0.836,0.869⟩	⟨0.506,0.445,0.414⟩
$i = 4$	⟨0.293,0.688,0.646⟩	⟨0.299,0.672,0.641⟩	⟨0.365,0.599,0.568⟩
$i = 5$	⟨0.059,0.906,0.936⟩	⟨0.539,0.410,0.380⟩	⟨0.056,0.907,0.938⟩
$i = 6$	⟨0.029,0.938,0.968⟩	⟨0.539,0.410,0.380⟩	⟨0.056,0.907,0.938⟩
$i = 7$	⟨0.381,0.594,0.550⟩	⟨0.059,0.902,0.935⟩	⟨0.281,0.691,0.661⟩
$i = 8$	⟨0.293,0.688,0.646⟩	⟨0.299,0.672,0.641⟩	⟨0.281,0.691,0.661⟩
$i = 9$	⟨0.469,0.501,0.454⟩	⟨0.120,0.836,0.869⟩	⟨0.506,0.445,0.414⟩
$i = 10$	⟨0.029,0.938,0.968⟩	⟨0.539,0.410,0.380⟩	⟨0.028,0.938,0.969⟩
$i = 11$	⟨0.293,0.688,0.646⟩	⟨0.299,0.672,0.641⟩	⟨0.281,0.691,0.661⟩
$i = 12$	⟨0.059,0.906,0.936⟩	⟨0.299,0.672,0.641⟩	⟨0.281,0.691,0.661⟩

Table 4. The weighted fuzzy decision matrix (part 2).

	$k = 4$	$k = 5$	$k = 6$
$i = 1$	⟨0.033,0.933,0.963⟩	⟨0.161,0.812,0.838⟩	⟨0.514,0.439,0.407⟩
$i = 2$	⟨0.164,0.778,0.796⟩	⟨0.401,0.623,0.554⟩	⟨0.285,0.688,0.657⟩
$i = 3$	⟨0.164,0.778,0.796⟩	⟨0.401,0.623,0.554⟩	⟨0.514,0.439,0.407⟩
$i = 4$	⟨0.033,0.933,0.963⟩	⟨0.642,0.398,0.311⟩	⟨0.371,0.595,0.563⟩
$i = 5$	⟨0.164,0.778,0.796⟩	⟨0.723,0.322,0.230⟩	⟨0.057,0.907,0.938⟩
$i = 6$	⟨0.115,0.845,0.852⟩	⟨0.642,0.398,0.311⟩	⟨0.120,0.782,0.750⟩
$i = 7$	⟨0.066,0.889,0.926⟩	⟨0.281,0.736,0.676⟩	⟨0.514,0.439,0.407⟩
$i = 8$	⟨0.213,0.711,0.740⟩	⟨0.281,0.736,0.676⟩	⟨0.120,0.782,0.750⟩
$i = 9$	⟨0.033,0.933,0.963⟩	⟨0.080,0.887,0.919⟩	⟨0.514,0.439,0.407⟩
$i = 10$	⟨0.164,0.778,0.796⟩	⟨0.642,0.398,0.311⟩	⟨0.114,0.844,0.875⟩
$i = 11$	⟨0.115,0.845,0.852⟩	⟨0.522,0.511,0.432⟩	⟨0.120,0.782,0.750⟩
$i = 12$	⟨0.033,0.933,0.963⟩	⟨0.522,0.511,0.432⟩	⟨0.120,0.782,0.750⟩

The determination of the concordance and discordance sets is performed according to the procedure (Step 5 of the proposed procedure) proposed by [17]. These sets are further presented in the tables below (Table 5 to Table 10).

Table 5. Concordance sets and discordance sets (part 1).

$\mathcal{S}_{12} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{12} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{21} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{21} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{13} = \{k_1, k_2, k_3, k_6\}$	$\mathcal{NS}_{13} = \{k_4, k_5\}$	$\mathcal{S}_{23} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{23} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{14} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{14} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{24} = \{k_3, k_4\}$	$\mathcal{NS}_{24} = \{k_1, k_2, k_5, k_6\}$
$\mathcal{S}_{15} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{15} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{25} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{25} = \{k_2, k_5\}$
$\mathcal{S}_{16} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{16} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{26} = \{k_1, k_3, k_4\}$	$\mathcal{NS}_{26} = \{k_2, k_5, k_6\}$
$\mathcal{S}_{17} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{17} = \{k_2, k_5\}$	$\mathcal{S}_{27} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{27} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{18} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{18} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{28} = \{k_3\}$	$\mathcal{NS}_{28} = \{k_1, k_2, k_4, k_5, k_6\}$
$\mathcal{S}_{19} = \{k_1, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{19} = \{k_2\}$	$\mathcal{S}_{29} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{29} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{110} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{110} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{210} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{210} = \{k_2, k_5\}$
$\mathcal{S}_{111} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{111} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{211} = \{k_3, k_4, k_6\}$	$\mathcal{NS}_{211} = \{k_1, k_2, k_5\}$
$\mathcal{S}_{112} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{112} = \{k_2, k_5\}$	$\mathcal{S}_{212} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{212} = \{k_2, k_5\}$

Table 6. Concordance sets and discordance sets (part 2).

$\mathcal{S}_{31} = \{k_2, k_3, k_4, k_5\}$	$\mathcal{NS}_{31} = \{k_1, k_6\}$	$\mathcal{S}_{41} = \{k_2, k_4, k_5, k_6\}$	$\mathcal{NS}_{41} = \{k_1, k_6\}$
$\mathcal{S}_{32} = \{k_1, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{32} = \{k_2\}$	$\mathcal{S}_{42} = \{k_1, k_2, k_3, k_5, k_6\}$	$\mathcal{NS}_{42} = \{k_4\}$
$\mathcal{S}_{34} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{34} = \{k_2, k_5\}$	$\mathcal{S}_{43} = \{k_1, k_2, k_5\}$	$\mathcal{NS}_{43} = \{k_3, k_4, k_6\}$
$\mathcal{S}_{35} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{35} = \{k_2, k_5\}$	$\mathcal{S}_{45} = \{k_1, k_3, k_5, k_6\}$	$\mathcal{NS}_{45} = \{k_2, k_4\}$
$\mathcal{S}_{36} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{36} = \{k_2, k_5\}$	$\mathcal{S}_{46} = \{k_1, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{46} = \{k_2\}$
$\mathcal{S}_{37} = \{k_1, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{37} = \{k_2\}$	$\mathcal{S}_{47} = \{k_1, k_2, k_4, k_5\}$	$\mathcal{NS}_{47} = \{k_3, k_6\}$
$\mathcal{S}_{38} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{38} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{48} = \{k_1, k_2, k_3, k_5, k_6\}$	$\mathcal{NS}_{48} = \{k_4\}$
$\mathcal{S}_{39} = \{k_1, k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{39} = \{\varnothing\}$	$\mathcal{S}_{49} = \{k_1, k_2, k_4, k_5\}$	$\mathcal{NS}_{49} = \{k_3, k_6\}$
$\mathcal{S}_{310} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{310} = \{k_2, k_5\}$	$\mathcal{S}_{410} = \{k_1, k_3, k_5, k_6\}$	$\mathcal{NS}_{410} = \{k_2, k_4\}$
$\mathcal{S}_{311} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{311} = \{k_2, k_5\}$	$\mathcal{S}_{411} = \{k_1, k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{411} = \{\varnothing\}$
$\mathcal{S}_{312} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{312} = \{k_2, k_5\}$	$\mathcal{S}_{412} = \{k_1, k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{412} = \{\varnothing\}$

Table 7. Concordance sets and discordance sets (part 3).

$\mathcal{S}_{51} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{51} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{61} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{61} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{52} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{52} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{62} = \{k_2, k_5, k_6\}$	$\mathcal{NS}_{62} = \{k_1, k_3, k_4\}$
$\mathcal{S}_{53} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{53} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{63} = \{k_2, k_5\}$	$\mathcal{NS}_{63} = \{k_1, k_3, k_4, k_6\}$
$\mathcal{S}_{54} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{54} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{64} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{64} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{56} = \{k_1, k_2, k_3, k_4, k_5\}$	$\mathcal{NS}_{56} = \{k_6\}$	$\mathcal{S}_{65} = \{k_2, k_3, k_5, k_6\}$	$\mathcal{NS}_{65} = \{k_1, k_4\}$
$\mathcal{S}_{57} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{57} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{67} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{67} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{58} = \{k_2, k_5\}$	$\mathcal{NS}_{58} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{S}_{68} = \{k_2, k_5, k_6\}$	$\mathcal{NS}_{68} = \{k_1, k_3, k_4\}$
$\mathcal{S}_{59} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{59} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{69} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{69} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{510} = \{k_1, k_2, k_3, k_4, k_5\}$	$\mathcal{NS}_{510} = \{k_6\}$	$\mathcal{S}_{610} = \{k_1, k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{610} = \{k_4\}$
$\mathcal{S}_{511} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{511} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{611} = \{k_2, k_4, k_5, k_6\}$	$\mathcal{NS}_{611} = \{k_1, k_3\}$
$\mathcal{S}_{512} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{512} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{612} = \{k_2, k_4, k_5, k_6\}$	$\mathcal{NS}_{612} = \{k_1, k_3\}$

Table 8. Concordance sets and discordance sets (part 4).

$\mathcal{S}_{71} = \{k_2, k_4, k_5, k_6\}$	$\mathcal{NS}_{71} = \{k_1, k_3\}$	$\mathcal{S}_{81} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{81} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{72} = \{k_1, k_2, k_3, k_6\}$	$\mathcal{NS}_{72} = \{k_4, k_5\}$	$\mathcal{S}_{82} = \{k_1, k_2, k_4, k_5, k_6\}$	$\mathcal{NS}_{82} = \{k_3\}$
$\mathcal{S}_{73} = \{k_2, k_6\}$	$\mathcal{NS}_{73} = \{k_1, k_3, k_4, k_5\}$	$\mathcal{S}_{83} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{83} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{74} = \{k_3, k_6\}$	$\mathcal{NS}_{74} = \{k_1, k_2, k_4, k_5\}$	$\mathcal{S}_{84} = \{k_4\}$	$\mathcal{NS}_{84} = \{k_1, k_3, k_3, k_5, k_6\}$
$\mathcal{S}_{75} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{75} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{85} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{85} = \{k_2, k_5\}$
$\mathcal{S}_{76} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{76} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{86} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{86} = \{k_2, k_5\}$
$\mathcal{S}_{78} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{78} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{87} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{87} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{79} = \{k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{79} = \{k_1\}$	$\mathcal{S}_{89} = \{k_1, k_2, k_4, k_5\}$	$\mathcal{NS}_{89} = \{k_3, k_6\}$
$\mathcal{S}_{710} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{710} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{810} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{810} = \{k_2, k_5\}$
$\mathcal{S}_{711} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{711} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{811} = \{k_1, k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{811} = \{\varnothing\}$
$\mathcal{S}_{712} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{712} = \{k_2, k_5\}$	$\mathcal{S}_{812} = \{k_1, k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{812} = \{\varnothing\}$

Table 9. Concordance sets and discordance sets (part 5).

$\mathcal{S}_{91} = \{k_2, k_4, k_5, k_6\}$	$\mathcal{NS}_{91} = \{k_1, k_3\}$	$\mathcal{S}_{101} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{101} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{92} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{92} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{102} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{102} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{93} = \{k_1, k_2, k_6\}$	$\mathcal{NS}_{93} = \{k_3, k_4, k_5\}$	$\mathcal{S}_{103} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{103} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{94} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{94} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{104} = \{k_4, k_5\}$	$\mathcal{NS}_{104} = \{k_1, k_2, k_3, k_6\}$
$\mathcal{S}_{95} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{95} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{105} = \{k_2, k_4, k_5, k_6\}$	$\mathcal{NS}_{105} = \{k_1, k_3\}$
$\mathcal{S}_{96} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{96} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{106} = \{k_1, k_2, k_4, k_5\}$	$\mathcal{NS}_{106} = \{k_3, k_6\}$
$\mathcal{S}_{97} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{97} = \{k_2, k_5\}$	$\mathcal{S}_{107} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{107} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{98} = \{k_3, k_6\}$	$\mathcal{NS}_{98} = \{k_1, k_2, k_4, k_5\}$	$\mathcal{S}_{108} = \{k_2, k_5\}$	$\mathcal{NS}_{108} = \{k_1, k_3, k_4, k_6\}$
$\mathcal{S}_{910} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{910} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{109} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{109} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{911} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{911} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{1011} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{1011} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{912} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{912} = \{k_2, k_5\}$	$\mathcal{S}_{1012} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{1012} = \{k_1, k_3, k_6\}$

Table 10. Concordance sets and discordance sets (part 6).

$\mathcal{S}_{111} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{111} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{121} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{121} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{112} = \{k_1, k_2, k_5\}$	$\mathcal{NS}_{112} = \{k_3, k_4, k_6\}$	$\mathcal{S}_{122} = \{k_1, k_2, k_5\}$	$\mathcal{NS}_{122} = \{k_3, k_4, k_5\}$
$\mathcal{S}_{113} = \{k_2, k_5\}$	$\mathcal{NS}_{113} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{S}_{123} = \{k_2, k_5\}$	$\mathcal{NS}_{123} = \{k_1, k_3, k_4, k_6\}$
$\mathcal{S}_{114} = \{k_4\}$	$\mathcal{NS}_{114} = \{k_1, k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{S}_{124} = \{\emptyset\}$	$\mathcal{NS}_{124} = \{k_1, k_2, k_3, k_4, k_5, k_6\}$
$\mathcal{S}_{115} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{115} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{125} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{125} = \{k_2, k_4, k_5\}$
$\mathcal{S}_{116} = \{k_1, k_3, k_4, k_6\}$	$\mathcal{NS}_{116} = \{k_2, k_5\}$	$\mathcal{S}_{126} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{126} = \{k_2, k_4, k_5\}$
$\mathcal{S}_{117} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{117} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{127} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{127} = \{k_1\}$
$\mathcal{S}_{118} = \{k_1, k_2, k_3, k_5, k_6\}$	$\mathcal{NS}_{118} = \{k_4\}$	$\mathcal{S}_{128} = \{k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{128} = \{k_1\}$
$\mathcal{S}_{119} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{119} = \{k_1, k_3, k_6\}$	$\mathcal{S}_{129} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{129} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{1110} = \{k_1, k_3, k_6\}$	$\mathcal{NS}_{1110} = \{k_2, k_4, k_5\}$	$\mathcal{S}_{1210} = \{k_2, k_4, k_5\}$	$\mathcal{NS}_{1210} = \{k_1, k_3, k_6\}$
$\mathcal{S}_{1112} = \{k_1, k_2, k_3, k_4, k_5, k_6\}$	$\mathcal{NS}_{1112} = \{\emptyset\}$	$\mathcal{S}_{1211} = \{k_2, k_4\}$	$\mathcal{NS}_{1211} = \{k_1, k_3, k_5, k_6\}$

By using the proposed procedure (Steps 6 to 7), the crisp values of SVNNs are determined. Accordingly, the crisp concordance matrix is:

$$C = \begin{bmatrix} - & 0.939 & 0.977 & 0.939 & 0.939 & 0.939 & 0.962 & 0.939 & 0.992 & 0.939 & 0.939 & 0.962 \\ 0.951 & - & 0.951 & 0.751 & 0.962 & 0.904 & 0.951 & 0.599 & 0.951 & 0.962 & 0.901 & 0.962 \\ 0.981 & 0.992 & - & 0.962 & 0.962 & 0.962 & 0.992 & 0.939 & 1 & 0.962 & 0.962 & 0.962 \\ 0.991 & 0.995 & 0.971 & - & 0.987 & 0.992 & 0.982 & 0.995 & 0.982 & 0.987 & 1 & 1 \\ 0.951 & 0.951 & 0.951 & 0.951 & - & 0.993 & 0.951 & 0.923 & 0.951 & 0.993 & 0.951 & 0.951 \\ 0.951 & 0.970 & 0.923 & 0.951 & 0.988 & - & 0.951 & 0.970 & 0.951 & 0.995 & 0.981 & 0.981 \\ 0.981 & 0.977 & 0.856 & 0.841 & 0.939 & 0.939 & - & 0.939 & 0.992 & 0.939 & 0.939 & 0.962 \\ 0.951 & 0.993 & 0.951 & 0.381 & 0.962 & 0.962 & 0.951 & - & 0.982 & 0.962 & 1 & 1 \\ 0.981 & 0.939 & 0.944 & 0.939 & 0.939 & 0.939 & 0.962 & 0.841 & - & 0.939 & 0.939 & 0.962 \\ 0.951 & 0.951 & 0.951 & 0.870 & 0.981 & 0.982 & 0.951 & 0.923 & 0.951 & - & 0.951 & 0.951 \\ 0.951 & 0.971 & 0.923 & 0.381 & 0.939 & 0.962 & 0.951 & 0.995 & 0.951 & 0.939 & - & 1 \\ 0.951 & 0.971 & 0.923 & 0 & 0.939 & 0.939 & 0.951 & 0.992 & 0.951 & 0.951 & 0.774 & - \end{bmatrix}$$

$$\bar{c} = \frac{1}{12 \cdot (12-1)} \cdot 123.449 = 0.935$$

Using the normalized Hamming distance, the values of the elements of the discordance matrix are calculated (Step 8 of the proposed procedure), so that:

$$N = \begin{bmatrix} - & 0.482 & 0.963 & 1 & 1 & 0.968 & 0.498 & 0.708 & 0.810 & 0.968 & 0.989 & 0.721 \\ 1 & - & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0.563 \\ 1 & 0.259 & - & 1 & 0.917 & 1 & 0.267 & 0.528 & 0 & 0.874 & 0.528 & 0.528 \\ 0.521 & 0.588 & 0.644 & - & 0.760 & 0.772 & 0.428 & 0.586 & 0.275 & 0.708 & 0 & 0 \\ 0.893 & 0.646 & 1 & 1 & - & 1 & 0.953 & 0.569 & 0.767 & 0.772 & 0.972 & 0.941 \\ 1 & 0.646 & 0.809 & 1 & 0.632 & - & 0.729 & 0.786 & 0.866 & 0.891 & 1 & 0.941 \\ 1 & 0.347 & 1 & 1 & 1 & 1 & - & 0.708 & 0.385 & 1 & 0.708 & 0.708 \\ 1 & 0.353 & 1 & 1 & 1 & 1 & 1 & - & 1 & 1 & 0 & 0 \\ 1 & 0.734 & 1 & 1 & 1 & 1 & 1 & 0.578 & - & 1 & 1 & 1 \\ 1 & 0.705 & 1 & 1 & 1 & 1 & 0.833 & 0.786 & 0.920 & - & 1 & 1 \\ 1 & 0.459 & 1 & 1 & 1 & 0.903 & 1 & 1 & 0.828 & 0.910 & - & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0.993 & 0.944 & 1 & - \end{bmatrix}$$

$$\bar{n} = \frac{1}{12 \cdot (12-1)} \cdot 108.468 = 0.822$$

By applying the proposed procedure (Step 9), the concordance dominance matrix is constructed:

$$M = \begin{bmatrix} - & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 \\ 0 & - & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & - & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & - & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 & - & 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & - & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & - & 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & - & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & - & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & - & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & - & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & - \end{bmatrix}$$

The ranking coefficient is calculated, based on which the preventive and detection actions are ranked (table 11), along with their final ranking *(Steps 10 to 11).*

Table 11. Final ranking of preventive and detection actions.

i	M_i	Rank	i	M_i	Rank
$i = 1$	5	3-4	$i = 7$	5	3-4
$i = 2$	1	9-12	$i = 8$	3	6-7
$i = 3$	7	2	$i = 9$	1	9-12
$i = 4$	11	1	$i = 10$	1	9-12
$i = 5$	4	5	$i = 11$	2	8
$i = 6$	3	6-7	$i = 12$	1	9-12

Based on the obtained ranking (Step 11 of the proposed procedure), it can be clearly seen that the top-ranked management action is Poka-Yoke by design ($k = 4$). Considering the defined criteria, which are often conflicting, it is found that this action is the most effective and can provide the best long-term results. Although it may sometimes require higher financial investment, the solutions are often not complex. The obtained result is consistent with the findings of study [27], where the authors also recognized Poka-Yoke as a reliable action, but in the domain of eliminating non-value-adding activities. The second-ranked action is Update of standardized work instructions ($i = 3$). It is often sufficient to update work instructions in order to prevent certain errors from occurring. This type of action is usually implemented quickly and is not complex. In this way, newly identified knowledge and production-related errors are incorporated into the work instructions.
The third and fourth positions in the ranking are shared by Additional operator training ($i = 1$) and Increased inspection frequency ($i = 7$). Additional operator training is often a very effective action; however, its sustainability is questionable. In particular, operator absence or job changes are factors that contribute to this limitation. On the other hand, increased inspection frequency is an action that is not complex, but it can be highly effective. The actions Ergonomic improvement of the workstation ($i = 2$), Physical "good/bad" examples at the station ($i = 9$), Digital process monitoring ($i = 10$), and Implementation of SPC ($i = 12$), which share the last position in the ranking, can be useful in certain situations; however, they often have a limited impact on productivity or are complex to implement. For this reason, they are not always the primary solution for problems that most frequently occur in the production process.

5.1 Sensitivity analysis

In order to validate the proposed model and examine the robustness of the obtained results, a sensitivity analysis was conducted. The model was tested using the same input data under three independent scenarios: (S1) when equal weights were assigned to both the DMs and the criteria; (S2) when equal weights were assigned to the DMs, while the criteria weights remained the same as those used in the case study; and (S3) when the DM weights remained the same as those used in the case study, while equal weights were assigned to all criteria. The results of the analysis are presented in Table 12.

Table 12. Final ranking of preventive and detection actions.

i	M_i	Rank	M_i (S1)	Rank (S1)	M_i (S2)	Rank (S2)	M_i (S3)	Rank (S3)
$i=1$	5	3-4	5	3-4	4	4	5	3-4
$i=2$	1	9-12	1	8-12	2	6	1	9-12
$i=3$	7	2	7	2	8	2	6	2
$i=4$	11	1	11	1	11	1	11	1
$i=5$	4	5	3	6-7	3	5	4	5
$i=6$	3	6-7	4	5	1	7-12	3	6-7
$i=7$	5	3-4	5	3-4	5	3	5	3-4
$i=8$	3	6-7	3	6-7	1	7-12	3	6-7
$i=9$	1	9-12	1	8-12	1	7-12	2	8
$i=10$	1	9-12	1	8-12	1	7-12	1	9-12
$i=11$	2	8	1	8-12	1	7-12	1	9-12
$i=12$	1	9-12	1	8-12	1	7-12	1	9-12

Based on the results presented in Table 12, it can be concluded that changes in the weights of the DMs and/or criteria have only a minor impact on the final ranking results, primarily affecting alternatives positioned lower in the ranking. The alternatives identified as the most important in the original case study remained the highest-ranked alternatives even after the weighting conditions were modified. The first and second ranked alternatives retained their positions across all three additional scenarios. The third and fourth-ranked alternatives alternated between these two positions; however, neither of them fell below fourth place in any scenario. The remaining alternatives exhibited only slight variations in their ranking positions, which can be considered negligible.
Additional confirmation of ranking stability was obtained by calculating the Spearman rank correlation coefficient. The lowest correlation coefficient between the obtained rankings was observed between the original case study and Scenario S2, with a value of 0.90. On the other hand, the correlation coefficient between the original case study and Scenario S1 was 0.98, while the correlation coefficient between the original case study and Scenario S3 reached 0.99. These results unequivocally confirm the stability and robustness of the proposed SVNWAO-ELECTRE approach.

6 Conclusion

In this paper, a new MCDM model is presented for solving the problem and engineering challenge of prioritizing management actions (preventive and detection) in the field of production processes. The model is tested on a case study in an automotive industry company, and the obtained results are most applicable to this context. The core of the model is a combined SVNWAO-ELECTRE approach, i.e., the introduction of SVNNs to reliably model existing uncertainty and indeterminacy. The research results showed that Poka-Yoke by design is, in general, the most effective action, as it offers both technical efficiency and long-term sustainability compared to the other identified actions. Nevertheless, the implementation of this action may be accompanied by various barriers and challenges. From a technological perspective, such a measure typically requires equipment modifications and/or the development of new tools. In many cases, the associated costs are not particularly high; however, they depend on the nature of the problem and the equipment to which the solution is applied. In addition, temporary process downtime may occur during the development and testing of the solution. Therefore, although this action requires careful planning and implementation, its benefits are long-term. However, it is important to emphasize that the proposed model largely depends on the knowledge and subjective judgments of experts, and therefore cannot be considered a universal rule applicable to any company. This can simultaneously be highlighted as the main limitation of the model. Therefore, it can be concluded that the results obtained in this study cannot be generalized, as they were derived from a case study conducted in only one Tier-1 company within the automotive industry. Nevertheless, it can be argued that the proposed SVNWAO-ELECTRE framework is not limited solely to the automotive industry or to this specific supplier level. With appropriate modifications regarding the DMs, criteria, and alternatives, the proposed framework can also be applied in other industrial sectors.

The main contribution of the paper lies in the introduction of a robust tool that provides management and FMEA teams with a ranking order for analyzing potential actions to be implemented. The contribution is reflected in the fact that, with the help of experts from the considered company, a broad set of actions and criteria was identified, which leaves room for further research and different application contexts. In addition, future research may focus on the application of other MCDM methods in combination with SVNNs for solving similar types of problems.

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