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Advanced risk assessment in reverse supply chain processes: A case study in Republic of Serbia

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A B S T R A C T

Management of a reverse supply chain (RSC) often takes place in an uncertain environment, so it is supposed to be analyzed through the proactive approach for avoidance/elimination of risks. Management initiatives based on the assessed risk level and priority of potential failure mode (PFM) should lead to the increase of business effectiveness, the competitive advantage and sustainability of the RSC. Therefore, the focus of this research is set to proposing the reliable method that would be user-friendly and suitable for the determination of risk level and priority of PFMs in RSC. Uncertainties related to the severities of Potential Effect(s) of Failure (PEF) and their frequencies', as well as detection of PFMs are described by pre-defined linguistic expressions and modelled by the interval type-2 trapezoidal fuzzy numbers (IT2TrFNs). The assessment of the relative importance of risk factors is set as a fuzzy group decision-making. The weights vector is calculated based on the procedure of fuzzy number comparison. The value of each risk factor at the level of each PFM is assessed through the predefined linguistic expressions modelled by IT2TrFNs. The rank is obtained by modified Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. The proposed model is tested on a real-life data from RSC that operates in Serbia. In the domain of practical implications, it may be noticed that the application of the proposed model could decrease the influence of potential causes of failures modes on the overall RSC business activities especially in the terms of strategic management and human resource practices. The novelty of the proposed model may be underlined as it is used for the analysis of different RSC activities and many interconnected issues may be solved by the proposed management measures after conducted analysis.

A R T I C L E I N F O

Keywords:
Reverse supply chain;
Risk;
Multi-criteria decision analysis;
Interval type-2 trapezoidal fuzzy numbers;
Fuzzy FMEA framework;
Fuzzy TOPSIS

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1. Introduction

In the last few decades, the development policies for both, developed and developing countries in the EU is mainly designed in the compliance with the objectives of national sustainable development strategies and the Draft Declaration on Guiding Principles adopted by the EU in 2005. It may be assumed that RSCs play a key role in achieving sustainable development goals. In the scope of activities undertaken as a part of the strategies for achieving sustainable development goals, many crucial issues may arise that need to be solved. Reducing or eliminating those issues that may occur in the recycling processes (RPs) are one of the most important tasks of the managers in the considered economic domain. In the research domains and practice, there are many methods for identification and elimination of potential failures.

Pervasive changes in the business environment have led to the emergence of a growing number of various types of uncertainties in the RSC's activities. It may be suggested that uncertainties with the greatest influence on the RSC's activities embrace the different aspects of the risk so they may be denoted as causes or Potential Cause(s)/Mechanism(s) of Failure (PCMF). In the literature, the PCMFs are defined at different levels, but they are mostly described in a comprehensive manner at the operational level [1-3]. Consequently, PCMFs may lead to failures. One of the most used methods at the level of industrial processes for the failure analysis is Failure Mode and Effects Analysis (FMEA) [4]. The conventional FMEA is realized through the two steps: (a) each identified failure can be evaluated by three risk factors, which are the severity (S), the occurrences of failure realization (O) and the difficulty of failure detection (D), and (b) identifying the PCMFs that lead to the occurrence of PFMs and determination of management initiatives that can be used to eliminate the influence of the identified PCMFs.

Nowadays, the RSC is rather vulnerable and exposed to high levels of risk, so the motivation of this research is to rank the identified PFMs in RSC with respect to S, O, and D simultaneously, as well as their weights.

Nevertheless, some researchers believe that the main disadvantages of conventional FMEA are: (a) that the crisp values of risk factors are implemented, and (b) that the relative importance among risk factors are neglected [5]. In order to improve the failure analysis process in many papers, the FMEA is combined with fuzzy sets theory and various fuzzy Multi-Criteria Decision Making Methods (MCDMs) [5, 6]. Utilizing the type-1 fuzzy sets may not be suitable in these cases, so different mathematical tools needed to be improved. The development of mathematical theory, in particular the interval type-2 fuzzy sets (IT2FS), made it possible for imprecisions and uncertainties to be more adequately described in a quantitative sense. The stated facts are aligned with the motivation for this research since the accuracy of the failure analysis may be increased if IT2FS is applied in the scope of modified FMEA. The intention of the obtained data is to provide solid support for the decision-making process in the scope of management, especially in the scope of human resource management [7].

In the scope of research, the modelling of linguistic variables is conducted by an application of the IT2FS [8]. The successfully solved issues within the context of risk management that favors usage of IT2FS can be found in the literature [9]. At the same time, it is worth to mention that the extension of MCDM with IT2FS has been the subject of many researchers' considerations [10].

The main objective of this research is to develop a model that integrates FMEA and fuzzy TOPSIS method with IT2TrFNs for the purpose of proactive analysis and mitigation the PCMFs. According to the obtained rank of PFMs as well as the PCMFs analysis, where PCMFs imply the failure ranked at the first place, the appropriate management initiatives for reduction or elimination of the PCMFs' influence may be defined. These activities may be propagated to the failures' elimination. Lastly, it can be said that the realization of the research goal may be useful in supporting actions regarding national sustainable development strategy.

The paper is organized in the following manner. Section 2 presents an overview of the scientific papers from the literature sources. Description of the PFMs that may occur in RP at the level of RSC, handling of possible uncertainties within the S, O, and D, as well as their relative importance, and the proposed algorithm are shown in the Section 3. In the Section 4, the proposed model is illustrated with the real-life data, which originate from one RSC that operates in Central Serbia. Conclusions are presented in the Section 5. The list of abbreviations used in this paper is given in Appendix A.

2. Literature review

Improving the RP is one of the most important tasks of each RSC operational management and it can be realized in different ways. Human resource management (HRM) practices aligned with the organizations' strategy can alleviate uncertainties in the RSC's activities, especially in the domain of employees' skills and abilities. HRM activities that are directed towards the enhancement of employees' skills and knowledge results in higher productivity and organizational performance [11]. In compliance with the stated, the considered problem is complex and it may be realized through the following steps: (a) identification of PFMs that may occur in RP of one RSC, as well as PCMFs which induce identified PFMs, (b) assessment of the relative importance of S, O, and D, (c) assessment of the values of S, O, and D at the level of each PFM, (d) ranking of the identified PFMs by using the proposed fuzzy TOPSIS, and (e) the determination of suitable measures for reducing or eliminating failures.

In the literature, there are many papers where failure analysis is based on FMEA combined with fuzzy sets theory and MCDM [12]. Further, a summary of the literature for both marked sub-problems is provided.

There are many approaches for determination of the PCMFs, the PFMs and their PEFs which can be found in the literature. The simplest procedure for identification of the PFMs, the PCMFs and PEFs is a checklist. The effectiveness of this procedure depends on the knowledge, skills and expertise of the decision-makers (DMs). A large number of authors have tried to define the list of PCMFs for a specific group of manufacturing plants, especially when the resources are limited [13, 14]. In addition, the PFMs and their PEFs are identified, with respects to DMs assessment.

In some papers, the risk factors values are described by crisp values [15], as it has been proposed in the conventional FMEA [4]. It should be underlined that this assumption is not sufficient in practice since DM cannot express their estimates well enough if they use precise numbers.

Some authors suggest that the imprecise numbers could be appropriate for modeling of linguistic expressions that are used to describe the risk factors' values. Development of specific mathematical theories, particularly of fuzzy sets theory [16, 17] has allowed adequate quantitative description for these uncertainties. These uncertainties could be modelled by type-1 fuzzy numbers [18, 19]. Representation of a type-1 fuzzy set is by its membership function whose parameters are of the shape and the location in the universe of discourse. For the determination of the membership function, DMs knowledge or experience is applied. The well-known fact is that the linguistic terms used to describe uncertainty, generally, have a different meaning for different people [8]. Also, determination of the membership function for a larger number of uncertainties is performed under complex an uncertain environment. The concept of a type-2 fuzzy sets demand a large number of complex calculations, consequently, they do not have a wider application in modelling of real uncertainties. The IT2FS may be seen as a special case of a type-2 fuzzy set [8]. The computational processing with the IT2FS is reduced compared to the type-2 fuzzy sets so they are widely employed to solve different decision-making problems [10]. A significant number of uncertainties that exist in various problems could be modelled by the IT2FS [20-22]. In this paper, the risk factors' values are modelled by the interval type trapezoidal fuzzy numbers (IT2TrFNs).

Defining the priority of the PFMs by using the procedure proposed in the conventional FMEA [4] has numerous shortcomings. One of the main disadvantages according to the opinion of some researchers is that it neglects the relative importance among risk factors [5]. The PFMs' ranges could be adequately determined by means of FMEA combined with MCDM. In the literature, there are many papers where FMEA is combined with different MCDM with type 1 fuzzy sets [5, 6].

By respecting the assumption that existing uncertainties in risk assessment problem are far more accurately modelled with IT2FS, many authors have expanded the proposed MCDM with IT2FS [10]. Furthermore, special attention is focused on the papers that proposed TOPSIS with IT2FS [20, 23-26]. The comparative analysis of the proposed TOPSIS with IT2TrFN with other similar models is described and presented in Table 1.

Taking in account the stated, it can be argued that when the model presented in this paper is compared with the models from the literature, the certain advantages in terms of describing the real problems may be noticed.

In the literature, there is a certain number of papers where FMEA is combined with MCDM with IT2FS [23]. In this paper, the ratings of the identified PFMs in FMEA, and their relative importance are modelled by IT2FS. The rank of the identified PFMs with respects to the values and the relative importance is obtained by applying grey relational analysis.

In this paper, integrated FMEA and fuzzy TOPSIS with IT2TrFNs have been proposed for the analysis and ranking of PFMs in RPs.

Table 1 The summarized comparative analysis

	Chen and Lee, 2010 [23]	Ghaemi Nasab and Rostamy-Malkhalifeh, 2010 [24]	Kahraman and Sarı, 2012 [20]	Temur *et al.* 2014 [25]	Zamri and Abdullah, 2014 [26]	The proposed model
The linguistic variables for the relative importance of criteria	IT2TrFN	IT2TrFN	IT2TrFN	IT2TrFN	IT2TrFN	IT2TrFN
Granularity/relative importance of criteria	7	7	7	7	7	3
Domain of linguistic variables for the relative importance of criteria description	[0-1]	[0-1]	[0-1]	[0-1]	[0-1]	[1-5]
Determination of the criteria weights	Fuzzy averaging method	Fuzzy averaging method	Ranking of IT2TrFNs	Fuzzy averaging method	Assessment	Fuzzy averaging method
The linguistic variable for the criteria values	IT2TrFN	IT2TrFN	IT2TrFN	IT2TrFN	IT2TrFN	IT2TrFN
Granularity/criteria values	7	7	7	7	7	7
Domain of linguistic variable for describing the criteria values	[0-10]	[0-10]	[0-10]	[0-1]	[0-1]	[0-1]
PIS/NIS	Ranking of IT2TRFNs [27]	Fuzzy averaging method; Ranking of IT2TRFNs [27]	The procedure from the conventional TOPSIS	Ranking of IT2TRFNs [27]	Ranking of IT2TRFNs [27]	-
distance	Normalized Euclidean distance	Normalized Euclidean distance	Normalized Euclidean distance	Normalized Euclidean distance	-	Based on conventional TOPSIS and Fuzzy algebra
Closeness coefficient	Conventional TOPSIS	Conventional TOPSIS	Conventional TOPSIS	Conventional TOPSIS	-	Based on conventional TOPSIS and Fuzzy algebra
Rank	Conventional TOPSIS	Conventional TOPSIS	Conventional TOPSIS	Conventional TOPSIS	Based on the procedure for ranking of IT2FNs [27]	Defuzzification procedure [28] and conventional TOPSIS

The priority of management initiatives could be determined by exact methods [15]. Many authors believe that optimal risk management should be based on the determined risk level [19]. It is assumed that the order of management initiatives realization could be based on the rank of PFMs and analysis of the frequency of PCMFs which lead to the realization of high priority PFMs. In other words, by applying this method, answers to two questions could be obtained: (a) Which impact of PCMFs that needs to be reduced? and (b) How much it needs to be reduced? In this way, the effectiveness of risk management increases, while at the same time costs are reduced, which is further propagated to increase the effectiveness of RSC's business and its competitiveness.

3. Materials and methods

Economic development of each state should be should be aligned with its sustainable development. This can be achieved, inter alia, through the continuous realization of the RPs in RSCs. For the activities of the risk assessment in RPs, the decision-making team could be defined in compliance with the needs of the treated enterprise. In the presented research, it is scoped to three members: top manager, manager of the recycling process, and logistics manager.

3.1 Definition of the finite set of PCMFs

According to the results in practice, it is perceived that many possible PCMFs may impact one or several PFMs in RSC operating processes. Generally, identified PCMFs may be presented by the set of indices $i = \{1, \dots, i, \dots, I\}$, where I present the total number of PCMFs, and the index of each PCMFs is denoted as $i, i = 1, \dots, I$. In this paper, PCMFs have been analyzed according to the existing literature [13, 14], and scoped to the operational level in RSC: *Demand and supply uncer-*

tainty $(i = 1)$ – this factor is related to the situations where the unreliable and uncertain resources create supply chain interruption, thus producing risk that can be explained as uncertainty between supply and demand [29]; *Failure to select the right suppliers* $(i = 2)$ – represents the factor that could lead to downside of the RSC business strategy, its vision for future cooperation, it could increase the RSC lack of the expertise and experience, and it may lead to lower level of competitiveness, quality and reputation [30] as well as other issues in interconnected systems [31]; *Lower responsiveness performance* $(i = 3)$ – this factor is related to the operative structure of RSC, so it may be assumed that if the RSC operates as a several closed chains it could be less responsive [32]; *Inflexibility of supply source* $(i = 4)$ – if the RSC is vulnerable to this factor, then it is not able to respond quickly and efficiently to an inconsistent RSC demands and these inflexibilities may arise due to the rate of changes and uncertainties in the business environment [33]; *Poor quality or process yield at supply source* $(i = 5)$ – this factor is related to the issues that can appear in supply cost, delivery and quality changes, supply base reduction, failure to comply with long-term RSC partners, poor information exchange, poor suppliers technical capabilities, etc. [2]; *Coordination complexity/effort* $(i = 6)$ – this factor exposes RSC to the most challenging coordination issues, such as: customers' diversity and their different demands, different resources, unanticipated change and level of goal difficulty among RSC members and the customer may lead to an extra coordination burden due to information inaccuracy, different goals of RSC members, or disputes between the partners [34]; *Information technology (IT) and information sharing risks* $(i = 7)$ – this factor is related to the lack of necessary IT infrastructure and mechanism to capture and propagate information among RSC members in a timely manner [3]; *The lack of sustainable knowledge/technology* $(i = 8)$ – this factor may arise when there is discrepancy between forecast and actual demand, or lack of sound knowledge and understanding about sustainable technology, operations and methods among partners appear [29].

3.2 Definition of the finite set of PFMs

It may be comprehended that the realization of each PCMFs $i, i = 1, \ldots, I$, at the level of RSC could lead to the occurrence of one or more PFMs in RPs. These PFMs are identified by DMs with respects to the evidence data, experience and the results of benchmarking analysis. In other words, it is considered that the DMs should define a list of all PFMs that may formally be represented with a set of indices $j = \{1, \ldots, j, \ldots, J\}, j = 1, \ldots, J$. The total number of identified PFMs is indicated as J, and $j, j = 1, \ldots, J$ is an index of PFM.

For the purpose of research presented in this paper, the PFMs that can be found in operating processes of the treated RSC that is a part of one RSC are: unfair competition impact $(j = 1)$, high level of stock in volatile prices' presence $(j = 2)$, inattention or neglecting working procedures $(j = 3)$, failures of transport vehicles $(j = 4)$, error or discontinuity in information flow $(j = 5)$, failures regarding lack of human skills and knowledge $(j = 6)$, failures induced by natural disasters effects $(j = 7)$, generation of hazardous waste $(j = 8)$, ineffective resource consumption $(j = 9)$, losses induced by inflation and exchange rate differences $(j = 10)$, and failures resulting in hazardous environment work $(j = 11)$.

3.3 Definition of the finite set of risk factors

Evaluation and ranking of identified PFMs may be performed in terms of a certain number of risk factors that can be formally presented as a set of risk factors indices $= \{1, \ldots, k, \ldots, K\}, k = 1, \ldots, K$. The total number of risk factors is denoted as K, and $k, k = 1, \ldots, K$ is the index for each risk factor. In the literature, numerous authors suggest that the selection of risk factors for PFMs evaluation in any research domain should be based on FMEA. Respecting this fact, in this paper, identified PFMs of RP are evaluated according to the three risk factors S, O, and D.

3.4 Selection of appropriate linguistic expressions for the assessment of the relative importance of risk factors

It is assumed that the determination of the severity, occurrence and detection weights should be stated as the fuzzy group decision-making problem. Each DM could describe the relative importance of considered risk factors by one of the three defined linguistic expressions which are modelled by the IT2TrFNs:

low importance (L) – $\left((1,1,2,3;\,1.1),(1,1,2,2.5;\,0.7,0.7)\right)$
medium importance (M) – $\left((1.5,2.5,3.5,4.5;\,1,1),(2,2.5,3.5,4;\,0.7,0.7)\right)$
high importance (H) – $\left((2,4,5,5;\,1.1),(2.5,4,5,5;\,0.7,0.7)\right)$

The domain values of the IT2TrFNs are defined on the interval [1-5]. The value 1 denotes that risk factor $k, k = 1, \dots, K$ has an almost negligible influence in the evaluation of PFMs, and the value 5 means that risk factor $k, k = 1, \dots, K$ has a conspicuously extreme big influence in the evaluation of PFMs, respectively.

3.5 Choice of appropriate linguistic expressions for the assessment of the severity and detection of PFMs in RP

In general, severities of the manifested PEFs and the detection possibility of the identified PFMs can be determined according to the decision-makers' assessment. Detection of the identified PFMs depends on: (1) the level of security control of RPs and employees in the RSC, and (2) the level of automation of the applied control procedures. There are no defined rules or recommendations on how to determine the number and type of linguistic expressions that DMs should use to describe the values of S and D. The number and type of linguistic expressions depends on the type and the size of the problem as well as on the applied concept of control in the considered RSC.

In this paper, DMs expressed their assessments of values S and D at the level of each identified PFM with seven pre-defined linguistic expressions that are modelled by the IT2TrFNs and presented in Table 2. It is worth to mention that defined expressions take into account the conventional FMEA analysis and present state in recycling centers.

Table 2 The severity of the PEFs and detection of PFMs during the implementation of the RP

Linguistic expressions	IT2TrFNs	Description of severity	Description of detection
Almost no dangers/Certain chance of detection (L1)	$\left((0,0,0.1,0.25;\,1.1),(0,0,0.1,0.2;\,0.8,0.8)\right)$	Failure has no impact on the recycling process	There are constraints that prevent failure
Low danger/ Very high chance of detection (L2)	$\left((0,0.15,0.25,0.4;\,1.1),(0.05,0.15,0.25,0.35;\,0.8,0.8)\right)$	There is little or no effect on the continuity of the recycling process	In the recycling process, the principle of zero failures is applied or the control is automated
Low to moderate danger/High chance of detection (L3)	$\left((0.1,0.25,0.35,0.5;\,1.1),(0.15,0.25,0.35,0.45;\,0.8,0.8)\right)$	Failure could result in minor recycling process problems that can be overcome with minor modifications to the recycling process	In the recycling process, the principle of zero failures is applier or the control is not automatized
Moderate danger/Moderate chance of detection (L4)	$\left((0.3,0.45,0.55,0.7;\,1.1),(0.35,0.45,0.55,0.65;\,0.8,0.8)\right)$	Failure could result in minor customer dissatisfaction and/or major recycling process problems	There is a process for inspections on the sample, but it is not automated and/or relies on vigilance of employers and workers
Moderate to high danger/Remote chance of detection (L5)	$\left((0.5,0.65,0.75,0.9;\,1.1),(0.55,0.65,0.75,0.85;\,0.8,0.8)\right)$	Failure could result in a high degree of customer dissatisfaction and/or major recycling process problems which require reworking	The error can be detected with manual inspection, but no inspection process is in place so that failure can be detected accidentally
High danger/Unreliable chance of detection (L6)	$\left((0.6,0.75,0.85,1;\,1.1),(0.65,0.75,0.85,0.95;\,0.8,0.8)\right)$	Failure could result in a serious recycling process disruption with an interruption in service, with prior warning	The failure can be detected only with a thorough inspection, and this is not feasible or cannot be readily performed
Extremely high danger/No chance of detection (L7)	$\left((0.75,0.9,1,1;\,1.1),(0.8,0.9,1,1;\,0.8,0.8)\right)$	Failure could result in a breakdown of the total recycling process, without any prior warning	There is no known approach for failure detection

The domains of these IT2TrFNs are defined by the interval from 0 to 1. The value 0 denotes that the severity of a PEF is extremely low, and the value 1 denotes that severity of a PEF is extremely high, respectively. Similarly, values are defined in the domain of IT2TrFNs when detection is considered. The value 0, i.e. the value 1 denotes that it is quite certain that the PFM would be detected, or that it is quite certain that there is no possibility of PFM detection, respectively.

The above-described procedure for the definition of IT2TrFNs domains, both for severity and for detection, allows a reduction in the complexity and volume of computing since it is not necessary to apply a normalization process nor to take into account the type of these two risk factors according to which PFMs are evaluated.

3.6 Choice of appropriate linguistic expressions for the assessment of the occurrence of PFMs in RP

If there is an automated failure detection system, or if there is an up-to-date database of all failures that occur in the considered RSC, then it is possible to calculate the probability of PFM occurrence. In the RSCs that is the subject of research, it is not possible to calculate the probability of occurrence of RPs' PFMs accurately. Hence, in these cases, DMs may assess the possibility of each identified PFM occurrence based on their experience and benchmarking with similar RPs by using pre-defined linguistic expressions. The definition of these linguistic expressions is given according to the assessment of DMs and the relevant literature [18]. The used linguistic expressions are modelled by IT2TrFNs as shown in the Table 3 and they take into account the conventional FMEA analysis and present state in recycling centers.

The domains of these IT2TrFNs should be defined into the interval from 0 to 1. The value 0 denotes that the possibility of PFM occurrence is the lowest, and the value 1 denotes that the possibility of PFM occurrence is highest, respectively. In this way, it is not necessary to perform a normalization procedure.

Table 3 The occurrence rating scale

Linguistic expressions	IT2TrFNs	Description of severity
Low possibility of occurrence (O1)	$((0,0,0.1,0.25;1.1),(0,0,0.1,0.2;0.8,0.8))$	Failure occurs rarely, or failure occurs about once per year.
Moderate possibility of occurrence (O2)	$((0.1,0.25,0.35,0.5;1.1),(0.15,0.25,0.35,0.45;0.8,0.8))$	Failure occurs occasionally, or failure occurs once every 3 months
High possibility of occurrence (O3)	$((0.3,0.45,0.55,0.7;1.1),(0.35,0.45,0.55,0.65;0.8,0.8))$	Failure occurs approximately once per month
Very high possibility of occurrence (O4)	$((0.5,0.65,0.75,0.9;1.1),(0.55,0.65,0.75,0.85;0.8,0.8))$	Failure occurs frequently, or failure occurs about once per week.
Failure is almost inevitable (O5)	$((0.75,0.9,1,1;1.1),(0.8,0.9,1,1;0.8,0.8))$	Failure occurs at least once a day, or failure occurs almost every time.

3.7 The proposed fuzzy TOPSIS with the IT2TrFNs

The proposed research Algorithm may be realized through a certain number of steps, which are further clarified.

Step 1. Fuzzy rating of the relative importance of each considered risk factor is given by each DM.

$$\tilde{\tilde{W}}_k^e, k = 1, \dots, K, \qquad e = 1, \dots, E$$

Step 2. The aggregated relative importance of considered risk factors are calculated by using the fuzzy averaging method:

$$\tilde{\tilde{W}}_k = \frac{1}{E} \cdot \sum_{e=1}^{E} \tilde{\tilde{W}}_k^e \tag{1}$$

Step 3. The determination of the risk factors weight is based on the ranking values procedure of IT2TrFNs [23].

The likelihood $p\left(\tilde{\tilde{W}}_k^U \geq \tilde{\tilde{W}}_{k'}^U\right), k, k' = 1, \dots, K$ is determined:

$$p\left(\tilde{\tilde{W}}_k^U \geq \tilde{\tilde{W}}_{k'}^U\right) = max\big((1 - max(\delta, 0)), 0\big) \tag{2}$$

where:

$$\delta = \frac{max\left(a_{4k'}^U - a_{4k}^U, 0\right) + max\left(a_{3k'}^U - a_{2k}^U, 0\right) + max\left(a_{2k'}^U - a_{2k}^U, 0\right) + max\left(a_1^U - a_{1k}^U, 0\right) + \left(a_{4k'}^U - a_{1k}^U\right) + max\left(\alpha_{k'}^U - \alpha_k^U, 0\right) + max\left(\beta_{k'}^U - \beta_k^U, 0\right)}{\left|a_{4k'}^U - a_{4k}^U\right| + \left|a_{3k'}^U - a_{3k}^U\right| + \left|a_{2k'}^U - a_{2k}^U\right| + \left|a_{1k'}^U - a_{1k}^U\right| + \left(a_{4k'}^U - a_{1k'}^U\right) + \left(a_{4k}^U - a_{1k}^U\right) + \left|\alpha_{k'}^U - \alpha_k^U\right| + \left|\beta_{k'}^U - \beta_k^U\right|}$$

which has the following properties:

$$0 \leq p\left(\tilde{\tilde{W}}_k^U \geq \tilde{\tilde{W}}_{k'}^U\right) \leq 1 \tag{3}$$

$$p\left(\tilde{\tilde{W}}_k^U \geq \tilde{\tilde{W}}_{k'}^U\right) + p\left(\tilde{\tilde{W}}_{k'}^U \geq \tilde{\tilde{W}}_k^U\right) = 1 \tag{4}$$

$$p\left(\tilde{\tilde{W}}_k^U \geq \tilde{\tilde{W}}_k^U\right) = 0.5 \tag{5}$$

The likelihood $p\left(\tilde{\tilde{W}}_k^L \geq \tilde{\tilde{W}}_{k'}^L\right), k, k' = 1, \ldots, K$ can be considered in a similar way.

Determination of the upper fuzzy preference matrix, and the lower fuzzy preference matrix can be presented as:

$$p^U = \left[p\left(\tilde{\tilde{W}}_k^U \geq \tilde{\tilde{W}}_{k'}^U\right)\right]_{K\times K} \text{ and } p^L = \left[p\left(\tilde{\tilde{W}}_k^L \geq \tilde{\tilde{W}}_{k'}^L\right)\right]_{K\times K} \tag{6}$$

The ranking value $Rank\left(\tilde{\tilde{W}}_k^U\right)$ and the ranking value $Rank\left(\tilde{\tilde{W}}_k^L\right)$ are calculated by the procedure developed by [27]:

$$Rank\left(\tilde{\tilde{W}}_k^U\right) = \frac{1}{K\cdot(K-1)}\cdot\left(\sum_{k=1}^{K} p\left(\tilde{\tilde{W}}_k^U \geq \tilde{\tilde{W}}_{k'}^U\right) + \frac{K}{2} - 1\right) \tag{7}$$

$$Rank\left(\tilde{\tilde{W}}_k^L\right) = \frac{1}{K\cdot(K-1)}\cdot\left(\sum_{k=1}^{K} p\left(\tilde{\tilde{W}}_k^L \geq \tilde{\tilde{W}}_{k'}^L\right) + \frac{K}{2} - 1\right) \tag{8}$$

The ranking values of IT2TrFN $\tilde{\tilde{W}}_k$, $Rank\left(\tilde{\tilde{W}}_k^L\right)$ can be calculated by using the following expression:

$$Rank\left(\tilde{\tilde{W}}_k\right) = \frac{1}{2}\cdot\left(Rank\left(\tilde{\tilde{W}}_k^U\right) + Rank\left(\tilde{\tilde{W}}_k^L\right)\right) \tag{9}$$

Step 4. Each severity, the frequency of occurrence, and the possibility of each identified error detection are assessed, $\tilde{\tilde{x}}_{jk}, k = 1, \ldots, K, j = 1, \ldots, J$.

Step 5. The fuzzy weighted decision matrix $[\tilde{\tilde{z}}_{ik}]_{I\times K}$ is constructed, where $\tilde{\tilde{z}}_{jk} = w_k \cdot \tilde{\tilde{x}}_{ik}, k = 1, \ldots, K, i = 1, \ldots, I$.

Step 6. The fuzzy Positive Ideal Solution (FPIS), $\tilde{\tilde{z}}_k^+$ and Fuzzy Negative Ideal Solution (FNIS) $\tilde{\tilde{z}}_k^-$ are defined according to the vertex concept, so that:

$$\tilde{\tilde{z}}_k^+ = \left((0,0,0,0;1.1),(0,0,0,0;1,1)\right) \text{ and } \tilde{\tilde{z}}_k^- = \left((1,1,1,1;1.1),(1,1,1,1;1,1)\right)$$

Step 7. The distance from FPIS, $\tilde{\tilde{d}}_j^+$ and FNIS, $\tilde{\tilde{d}}_j^-$ is calculated according to the procedure which is developed in the conventional TOPSIS, so that:

$$\tilde{\tilde{d}}_j^+ = \sum_{k=1}^{K}\left|\tilde{\tilde{z}}_k^+ - \tilde{\tilde{z}}_{jk}\right| \text{ and } \tilde{\tilde{d}}_j^- = \sum_{k=1}^{K}\left|\tilde{\tilde{z}}_{jk} - \tilde{\tilde{z}}_k^-\right| \tag{10}$$

Step 8. The determination of closeness coefficient for each PFM $j = 1, \ldots, J$:

$$\tilde{\tilde{\xi}}_j = \frac{\tilde{\tilde{d}}_j^-}{\tilde{\tilde{d}}_j^- + \tilde{\tilde{d}}_j^+} \tag{11}$$

Step 9. The determination of the representative scalar, $\tilde{\tilde{\xi}}_j$ of the IT2TrFNs, $\tilde{\tilde{\xi}}_j, j = 1, \ldots, J$ by using the following procedure [28]:

$$DTraT = \frac{1}{2}\cdot\left\{\frac{(a_4^U - a_1^U) + (\alpha^U \cdot a_2^U - a_1^U) + (\beta^U \cdot a_3^U - a_1^U)}{4} + a_1^U + \left[\frac{(a_4^L - a_1^L) + (\alpha^L \cdot a_2^L - a_1^L) + (\beta^L \cdot a_3^L - a_1^L)}{4} + a_1^L\right]\right\} \quad (12)$$

Step 10. The crisp values, $\tilde{\tilde{\varsigma}}_j, j = 1, \dots, J$ are sorted in decreasing order. The rank of PFMs in RP is determined according to the obtained rank. At the first place in the rank, there is the PFM that has the greatest impact on the realization of RP.

Step 11. The measures for eliminating or decreasing the PCMFs that may lead to PFMs are determined according to the obtained rank and of PFMs and frequency of PCMFs' occurrence.

4. Results and discussion: A case study in Republic of Serbia

The testing of the proposed model is realized by using the real-life data from the RSC operating in the region of Central Serbia. In this research, the process of recycling does not take into account the activities out of the recycling center related to processes of purchasing and sale. The input data for the model testing is obtained through the interview with the predefined decision-making team of the recycling center. The team is consisted of three members: top manager, manager of the recycling process, and logistics manager. The risk factor values for each identified PFM $j = 1, \dots, J$ are assessed and presented in the Table 4 (Step 3 of the proposed Algorithm).

The relative importance of risk factors is assessed by DMs (Step 1 of the proposed Algorithm):

$(k = 1)$: H, H, H
$(k = 2)$: H, M, M
$(k = 3)$: M, L, L

The aggregated values of risk factors are:

$$\tilde{\tilde{W}}_1 = \big((2,4,5,5;1,1),(2.5,4.5,5,5;0.7,0.7)\big)$$
$$\tilde{\tilde{W}}_2 = \big((2.3,3,4,4.7;1,1),(2.2,3,4,4.3;0.7,0.7)\big)$$
$$\tilde{\tilde{W}}_3 = \big((1.2,1.5,2.5,3.5;1,1),(1.4,1.5,2.5,3;0.7,0.7)\big)$$

According to the procedure (Step 4 of the proposed Algorithm), the weighted fuzzy decision matrix is presented in the Table 5.

Step 3. The determination of the risk factors' weight is based on the procedure of the ranking values of IT2TrFNs [23].

Determine the likelihood $p\left(\tilde{\tilde{W}}_1^U \geq \tilde{\tilde{W}}_2^U\right)$ so that:

$$\delta = \frac{max(4.7-5,0) + max(4-5,0) + max(3-4,0) + max(2.3-2,0) + (4.7-2) + max(1-1,0) + max(0.7-0.7,0)}{|4.7-5| + |4-5| + |3-4| + |2.3-1| + (4.7-2.3) + (5-2) + |1-1| + |0.7-0.7|}$$

$$p\left(\tilde{\tilde{W}}_1^U \geq \tilde{\tilde{W}}_2^U\right) = max\left(\left(1 - max\left(\frac{27}{80},0\right)\right),0\right) = \max(0.6625,0) = 0.6625$$

In a similar way is calculated the rest of the elements of the upper fuzzy preference matrix, p^U, and the lower fuzzy preference matrix p^L, so that:

$$p^U = \begin{bmatrix} 0.5 & 0.6625 & 0.8707 \\ 0.3375 & 0.5 & 0.8800 \\ 0.1293 & 0.1200 & 0.5 \end{bmatrix} \text{ and } p^U = \begin{bmatrix} 0.5 & 0.7631 & 0.9635 \\ 0.2368 & 0.5 & 0.9024 \\ 0.0360 & 0.0976 & 0.5 \end{bmatrix}$$

Table 4 The assessed risk factor values for the recycling process

PFM (Potential failure mode)	PEF (Potential effect(s) of failure)	S	PCMF (Potential cause(s)/ Mechanism(s) of failure)	O	Current process controls	D
Unfair competition impact ($j = 1$)	Termination of contracts with customers	*L5*	$i = 1, i = 2,$ $i = 3, i = 4$	*O3*	*Regular check by the top manager*	*L2*
High level of stock in volatile prices' presence ($j = 2$)	Financial crisis of the RSC	*L7*	$i = 1, i = 2, i = 3,$ $i = 4, i = 5$	*O1*	*Regular check by the financial manager*	*L5*
Inattention or neglecting working procedures ($j = 3$)	Creation of economic loss due to delay, bad organization and making a scratch	*L5*	$i = 5, i = 6,$ $i = 7, i = 8$	*O5*	*Monitoring by the manager of the recycling process*	*L1*
Failures of transport vehicles ($j = 4$)	Delay in delivery, the impossibility of loading and unloading	*L3*	$i = 8$	*O4*	*Monitoring by the logistic manager*	*L2*
Error or discontinuity in information flow ($j = 5$)	Disruption of production plans and manufacturing disturbances	*L2*	$i = 2, i = 3, i = 4,$ $i = 6, i = 7$	*O4*	*Monitoring by the manager of the recycling process*	*L2*
Failures regarding lack of human skills and knowledge ($j = 6$)	Injury at work	*L5*	$i = 6, i = 7, i = 8$	*O3*	*Monitoring by the manager of the recycling process*	*L3*
Failures induced by natural disasters effects ($j = 7$)	The destruction of products that are water sensitive	*L5*	$i = 8$	*O1*	*Monitoring by the logistic manager*	*L3*
Generation of hazardous waste ($j = 8$)	Contamination of work and environment	*L7*	$i = 2, i = 3,$ $i = 5, i = 8$	*O5*	*Monitoring by the manager of the recycling process*	*L1*
Ineffective resource consumption ($j = 9$)	Economic losses	*L3*	$i = 5, i = 6, i = 7$	*O3*	*Regular check by the financial manager*	*L3*
Losses induced by inflation and exchange rate differences ($j = 10$)	Economic losses	*L3*	$i = 9$	*O2*	*Regular check by the financial manager*	*L2*
Failures resulting in hazardous environment work ($j = 11$)	Injury at work	*L4*	$i = 5, i = 8$	*O3*	*Monitoring by the manager of the recycling process*	*L1*

$$Rank\left(\tilde{\tilde{W}}_1^U\right) = \frac{1}{3 \cdot (3-1)} \cdot \left(\sum_{k=1}^{3} (0.5 + 0.6625 + 0.8707) + \frac{3}{2} - 1\right) = 0.4222$$

$$Rank\left(\tilde{\tilde{W}}_1^L\right) = \frac{1}{3 \cdot (3-1)} \cdot \left(\sum_{k=1}^{3} (0.5 + 0.7631 + 0.9635) + \frac{3}{2} - 1\right) = 0.4544$$

$$Rank\left(\tilde{\tilde{W}}_1\right) = \frac{1}{2} \cdot (0.4222 + 0.4544) = 0.4383 \approx 0.44$$

The weights of the remaining two risk factors are calculated in a similar way, therefore: $Rank\left(\tilde{\tilde{W}}_2\right) = 0.3631 \approx 0.36$, and $Rank\left(\tilde{\tilde{W}}_3\right) = 0.1986 \approx 0.2$

By using the proposed Algorithm (Step 4 to Step 9) the closeness coefficient for each identified PFM is calculated. The proposed procedure is illustrated by example:

$$\tilde{\tilde{d}}_1^+ = \big((1,1,1,1;1,1),(1,1,1,1;1,1)\big) - \big((0.22,0.29,0.33,0.39;1,1),(0.24,0.29,0.33,0.37;0.7,0.7)\big) + \big((1,1,1,1;1,1),(1,1,1,1;1,1)\big) - \big((0.11,0.16,0.20,0.25;1,1),(0.13,0.16,0.20,0.23;0.7,0.7)\big) + \big((1,1,1,1;1,1),(1,1,1,1;1,1)\big) - \big((0,0.03,0.05,0.08;1,1),(0.01,0.03,0.05,0.08;0.7,0.7)\big) = \big((2.28,2.42,2.52,2.67;1,1),(2.33,2.42,2.52,2.63;0.7,0.7)\big)$$

$$\tilde{\tilde{d}}_1^- = \big((0.22,0.29,0.33,0.39;1,1),(0.24,0.29,0.33,0.37;0.7,0.7)\big) - \big((0,0,0,0;1,1),(0,0,0,0;1,1)\big) + \big((0.11,0.16,0.20,0.25;1,1),(0.13,0.16,0.20,0.23;0.7,0.7)\big) - \big((0,0,0,0;1,1),(0,0,0,0;1,1)\big) + \big((0,0.03,0.05,0.08;1,1),(0.01,0.03,0.05,0.08;0.7,0.7)\big) - \big((0,0,0,0;1,1),(0,0,0,0;1,1)\big) = \big((0.33,0.48,0.58,0.72;1,1),(0.38,0.48,0.58,0.68;0.7,0.7)\big)$$

The closeness coefficient for PFM ($j = 1$) is:

$$\tilde{\tilde{\xi}}_1 = \frac{\big((0.33,0.48,0.58,0.72;1,1),(0.38,0.48,0.58,0.68;0.7,0.7)\big)}{\big((2.61,2.903.1,3.39;1,1),(2.71,2.90,3.10,3.31;0.7,0.7)\big)} = \big((0.09,0.15,0.20,0.28;1,1),(0.11,0.15,0.20,0.25;0.7,0.7)\big)$$

The representative scalar, ς_1 of the IT2TrFNs, $\tilde{\tilde{\varsigma}}_1$ is calculated in the following way [28]:

$$\varsigma_1 = \frac{1}{2}\cdot\left\{\frac{(0.28-0.09)+(1\cdot 0.15-0.09)+(1\cdot 0.20-0.09)}{4}+0.09 + \left[\frac{(0.25-0.11)+(0.7\cdot 0.15-0.11)+(0.7\cdot 0.2-0.11)}{4}+0.11\right]\right\} = 0.17$$

The values of identified PFMs' closeness coefficients are calculated in a similar way. Their values are presented in the Table 5. The rank of the PFMs is obtained by using the proposed Algorithm (Step 10) and given in the Table 5, too.

The case study approach examines the effectiveness of the fuzzy logic approach for assessing the product and process-related PFMs within global RSC context. In this way, the management initiatives that should lead to the achievement of the zero failures' principle in the realization processes of RSCs are more precisely defined.

The obtained result indicates that the PFM that may endanger the RSC and its operating processes primarily generates the hazardous waste ($j = 8$) and lower responsiveness performance ($j = 3$). Taking into the account the input data regarding PCMFs that may originate from PFMs presented in the Table 4, the analysis points two main PCMFs. The analysis of RSC management should tackle firstly ranked PFMs: poor quality or process yield at supply source ($i = 5$) and lack of sustainable knowledge/technology ($i = 8$).

The poor process yield at supply source ($i = 5$) may be improved through the several activities. In the first place, the redefinition of supply strategy can be oriented to the enhancement of partnership relations with existing suppliers. Also, the ratio of raw materials or components may be redefined and proposed to existing suppliers. On the other hand, a management team may propose a new model or procedure of supplier selection and introduce new suppliers in compliance with that model. Besides the mentioned measures, the communication with suppliers and partners should be enhanced and continuously improved over time with the development or improvement of existing information systems and communication channels. Internally, company could perform analysis of logistics services' impacts on risk perception by employing suitable computation models [35].

The RSC may cope with the PCMF denoted as a lack of sustainable knowledge/technology ($i = 8$) through the enhancement of the human resources management aimed at: (a) introduction of contemporary information and communication technologies, (b) implementation of tailored recruitment and selection processes, (c) implementation of long life learning which should consequently lead to improvement of staff effectiveness, (d) enhancement of employees' motivation to learn and improve their skills constantly. These HRM practices should create human resource advantage that will positively influence not only RSC performance but overall business performance. It is worth to mention that other cases ranked at a lower place in the presented model should be also analyzed. This is further propagated to enhance RSC knowledge level, which is the most important resource for competitive advantage achievement in a long-term period.

Table 5 The closeness coefficient and rank of PFMs

PFMs	$\tilde{\tilde{\varsigma}}_j$	ς_j	Rank
$j = 1$	$((0.09,0.15,0.20,0.28;1,1),(0.11,0.15,0.20,0.25;0.7,0.7))$	0.17	5
$j = 2$	$((0.14,0.18,0.22,0.27;1,1),(0.15,0.18,0.22,0.27;0.7,0.7))$	0.19	3
$j = 3$	$((0.15,0.20,0.25,0.30;1,1),(0.16,0.20,0.25,0.28;0.7,0.7))$	0.21	2
$j = 4$	$((0.06,0.12,0.16,0.24;1,1),(0.08,0.12,0.16,0.21;0.7,0.7))$	0.14	6
$j = 5$	$((0.05,0.11,0.15,0.22;1,1),(0.07,0.11,0.15,0.20;0.7,0.7))$	0.13	7-9
$j = 6$	$((0.10,0.16,0.21,0.29;1,1),(0.12,0.16,0.21,0.25;0.7,0.7))$	0.18	4
$j = 7$	$((0.07,0.11,0.15,0.22;1,1),(0.08,0.11,0.15,0.19;0.7,0.7))$	0.13	7-9
$j = 8$	$((0.18,0.23,0.28,0.31;1,1),(0.21,0.23,0.028,0.30;0.7,0.7))$	0.24	1
$j = 9$	$((0.07,0.10,0.15,0.22;1,1),(0.07,0.10,0.15,0.19;0.7,0.7))$	0.12	10
$j = 10$	$((0.02,0.07,0.11,0.18;1,1),(0.04,0.07,0.11,0.16;0.7,0.7))$	0.09	11
$j = 11$	$((0.07,0.12,0.16,0.22;1,1),(0.08,0.12,0.16,0.20;0.7,0.7))$	0.13	7-9

5. Conclusion

The RSC has a significant influence on the development of every national economy. Effectiveness, competitiveness and long-term sustainability of RSC entities among other things could be increased and continually improved through the application of appropriate risk management activities. The determination of RSC risk management activities should be based on analytic methods, since each solution obtained in an exact way is less encumbered by the subjective decision-makers' perspectives, and therefore it may be considered as more accurate.

The main contribution of this paper is the introduction of a model for the purpose of proactive analysis and mitigation the PCMFs of operational risks in an exact manner. The main contribution may be decomposed to the several component contributions: (a) definition of the appropriate linguistic expressions to adequately describe the values of S, O, and D in the domain of RSC (these linguistic terms are defined in compliance with the brainstorming and interviews with enterprise management, quality management documentation and benchmark analysis in the treated economy field), (b) modelling of all existing uncertainties is performed by applying IT2TrFNs, (c) determination of the rank of PFMs is performed by using the proposed method that integrates FMEA, IT2FS, and fuzzy TOPSIS. The proposed method is flexible to the changes in the numbers of PCMFs and PFMs as well as in the shape of membership functions of fuzzy numbers and it can be easily incorporated into the proposed model.

The proposed model was tested on real-life data from RSC which operates as an RSC entity in Central Serbia. This paper contributes to both, practice and research. Practical contribution can be addressed to the possibility of decreasing the PCMFs' influence on the RSC business effectiveness and resource consumption. It may be noticed that the model is easy to be utilized, and as such, in the long-term it may be very useful for decision-makers dealing with human resource management initiatives.

The main advantage of the presented model presents its convenience to use the risk assessment methodology and to determine RSC management initiatives which should enable avoiding or minimizing the influence of PCMFs. Moreover, the model incorporates human resources management practices that make differentiation by developing the specific pool of human capital that leads to a competitive advantage and sustainable RSC. It can be said that the proposed model describes the considered problem significantly better in comparison to the developed models which can be found in the literature.

A wide range of evidence data sometimes cannot be easily found which presents the general limitation of the proposed model. The majority of business entities within RSC perform the data digitalization; it is realistic to assume that many data which exist in the proposed model will exist in the digital form. This will allow easier assessment of the occurrence of failures by applying the advanced statistical methods and neural networks. This would lead, consequently, to the enhancement of the proposed model and the alleviation of some drawbacks of the proposed approach. Future research should cover analysis of RSCs which exist in different industrial domains. This should bring the model validation. Moreover, the development of the software solution could provide significantly more efficient management of the operational risk in SC, which will be the subject of the future research paper.

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Appendix A

List of abbreviations:

D	Difficulty of failure detection
FMEA	Failure Mode and Effects Analysis
HRM	Human resource management
IT	Information technology
IT2FS	Interval type-2 fuzzy set
IT2TrFN	Interval type-2 trapezoidal fuzzy number
MCDM	Multi-Criteria Decision Making Method
O	Occurrences of failure realization
PCMF	Potential Cause(s)/ Mechanism(s) of Failure
PEF	Potential Effect(s) of Failure
PFM	Potential failure mode
RP	Recycling process
RSC	Reverse supply chain
S	Severity
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution