Assessment of Hazard in Firefighting Job Using Triangular Neutrosophic Sets and Hybrid Multi-criteria Decision Making

Luz M. Aguirre Paz, María Pico Pico

Docente de la carrera de Software de la Universidad Regional Autónoma de los Andes (UNIANDES). Ecuador

Docente de la carrera de Software de la Universidad Regional Autónoma de los Andes (UNIANDES), Ecuador

Emails: direccionadmision@uniandes.edu.ec; ua.mariapico@uniandes.edu.ec

Abstract

Traditional approaches to recognizing hazards and evaluating their risks have several shortcomings, including data confusion and unpredictability, an inability to accurately reflect human thought processes, a failure to give weight to factors, the use of established data and tables, and the influence of the evaluator on the final risk evaluation outcomes. Thus, refining current techniques and creating new ways with more precision and sensitivity is essential. We proposed a framework for risk assessment of firefighting. Firefighting has various criteria, so the concept of multi-criteria decision-making (MCDM) deals with these criteria, such as life safety, resource allocation, incident duration, weather conditions, access, etc. We collected ten risk criteria and 25 alternatives. The proposed framework has two main stages. First, we apply the average method to ten risk criteria to show the weights and the importance of the criteria. Then, in the second stage, we used the grey rational analysis (GRA) method to assess the firefighting risks. The GRA method is an MCDM methodology used to rank the alternatives. The GRA method is integrated with the triangular neutrosophic sets (TNSs) to deal with vague and uncertain information. Then, the principal results show that life safety is the highest weight, and the incident duration is the lowest. The outcome of the GRA method shows that risk 25 is the highest and risk 17 is the lowest. We applied the sensitivity analysis to show the stability of the results. We offer the model is adequate, and the results are stable.

Keywords: Triangular Neutrosophic Sets; Multi-Criteria Decision Making (MCDM); GRA Method; Firefighting Job.

1. Background

It's no secret that firefighting is a dangerous profession. While performing jobs like putting out fires, rescuing those in need, and providing assistance, they are exposed to more complicated psychological, physical, chemical, and biological risks. There are more than 1.2 million firefighters in the United States, according to the National Fire Protection Association (NFPA). There were 70 firefighter fatalities in the line of duty in the United States in 2021, a 13% increase from the year before. According to projections, there were 64,875 accidents to firefighters in 2020, a seven % rise over the total number of injuries in 2018 and 2019. During the same year, 17,050 reported interactions with potentially harmful conditions and 20,900 contacts with infectious illnesses[1]–[4].

Doi: https://doi.org/10.54216/IJNS.230117
Received: May 21, 2023 Revised: August 11, 2023 Accepted: November 23, 2023

According to the aforementioned incidents, there is an imperative for risk evaluation and the adoption of organized, competent, and uniform measures to avoid accidents and treat occupational disorders encountered by firefighters[5], [6].

Evaluating the risks of a hazard, the efficiency of current measures, and the acceptability of those risks are all part of a comprehensive risk evaluation.

Important locations and potential sources of accidents may be identified and mitigated using risk recognition and risk evaluation techniques. Methods used in risk assessment may foresee future occurrences, determine who is at risk and how much damage they could suffer, and make working conditions safer and more enjoyable[7]–[9].

Risk assessment in a firefighting job is a multi-criteria decision-making (MCDM) due to various criteria and factors. This paper used grey relational analysis (GRA) to rank the alternatives and build the decision matrix between criteria and alternatives[10]–[12].

Traditional GRA models need precise data that is only sometimes available in practice. But in many circumstances, statistics must be more reliable, complete, and precisely quantified. In contradiction to conventional reasoning, Zadeh initially developed the concept of fuzzy sets (FSs). Many researchers have now looked into this area because of this study[13], [14].

Regarding vagueness, Zadeh's fuzzy sets can only handle the membership function. Atanassov developed intuitionistic fuzzy sets (IFSs), an extension of FSs, to address this data deficiency. Several GRA models also make use of intuitively hazy information[15], [16].

However, not all varieties of uncertainty, including conflicting and indeterminate information, can be dealt with by the theory of IFSs, even if it can manage partial information for numerous real-world concerns. For this reason, Smarandache developed the neutrosophic set (NS) as a solid, all-encompassing structure that encompasses both classical fuzzy sets (FSs) and all other types of fuzzy sets (IFSs)[17], [18].

NSs construct three different forms of membership function autonomously and can handle indeterminate, vague, and contradictory information when indeterminacy is defined[19], [20].

Various NS variants have been introduced recently, including interval NSs, bipolar NSs, single-valued NSs, and neutrosophic linguistic sets. Further, extensions to the domains of logic, measure, likelihood, and calculus have been developed in the study of neutrosophic sets[12], [21], [22].

Taking into account truth, falsity, and indeterminacy membership functions for each input and output of DMUs in the NS aids decision-makers in gaining a more accurate understanding of facts in GRA that may be ambiguous, indeterminate, or inconsistent in the real world. Using the NS in GRA also allows analysts to adjust their confidence levels in each piece of information more precisely. With NSs, we can view all aspects of the decision-making process, leading to a more accurate picture of reality. As a result, the NS can forcefully and quickly accept imprecise, unclear, partial, and inconsistent evidence. Different difficulties in neutrosophic settings may be addressed in several ways[23]–[25].

The key contributions of this paper are:

We conducted an MCDM methodology to assess the risks in firefighting jobs.

The GRA method ranks the alternatives with a set of criteria and alternatives.

The GRA method is integrated with the triangular neutrosophic sets to deal with vague and uncertain information. We used the triangular neutrosophic numbers to assess the criteria and alternatives.

The application is introduced to show the results of the proposed method based on a set of alternatives and select the best one.

The sensitivity analysis is applied to show the stability of the results in the application and the rank of alternatives under different cases.

Doi: https://doi.org/10.54216/IJNS.230117
Received: May 21, 2023 Revised: August 11, 2023 Accepted: November 23, 2023

2. Suggested Methodology

To get around the fact that the concept of exclusion middle doesn't work with his new logic, Smarandache blends non-standard analysis with three-valued logic, set theory, probability theory, and philosophy. As a consequence, neutrosophic implies "neutral thinking knowledge." Fuzzy sets and intuitionistic fuzzy sets distinguish between this definition and the usage of neutral, together with the components of truth (membership) and falsity (non-membership). In this context, a quick summary of the unconventional analysis is warranted[26]–[28].

The neutrosophic sets can be defined by using three membership values as (T, I, F) truth, indeterminacy, and falsity values.

Let triangular valued neutrosophic numbers (TNNs) as $B = \left((x^l, x^m, x^u), (y^l, y^m, y^u), (z^l, z^m, z^u)\right)$

$$T_B(A) = \begin{cases} \frac{(A-x^l)}{(x^m-x^l)} & x^l \le A \le x^m \\ 1 & A = x^m \\ \frac{(x^u-A)}{(x^u-x^m)} & x^m \le A \le x^u \\ 0 & otherwise \end{cases} \tag{1}$$

$$I_B(A) = \begin{cases} \frac{(A-y^m)}{(y^m-y^l)} & y^l \le A \le y^m \\ 0 & A = y^m \\ \frac{(A-y^m)}{(y^u-y^m)} & y^m \le A \le y^u \\ 1 & otherwise \end{cases} \tag{2}$$

$$F_B(A) = \begin{cases} \frac{(A-z^m)}{(z^m-z^l)} & z^l \le A \le z^m \\ 0 & A = z^m \\ \frac{(A-z^m)}{(z^u-z^m)} & z^m \le A \le z^u \\ 1 & otherwise \end{cases} \tag{3}$$

Let $B = \left((x^l, x^m, x^u), (y^l, y^m, y^u), (z^l, z^m, z^u)\right) \; and \; C = \left((e^l, e^m, e^u), (r^l, r^m, r^u), (t^l, t^m, t^u)\right) \; two \; TNNs.$ The basic operations of TNNs are:

$$B \oplus C = \begin{Bmatrix} \left((\min(x^l, e^l)), (\min(x^m, e^m)), (\min(x^u, e^u))\right); \\ \left((\min(y^l, r^l)), (\min(y^m, r^m)), (\min(y^u, r^u))\right); \\ \left((\min(z^l, t^l)), (\min(z^m, t^m)), (\min(z^u, t^u))\right) \end{Bmatrix} \tag{4}$$

$$-B = \left((-x^u, -x^m, -x^l), (-y^u, -y^m, -y^l), (-z^u, -z^m, -z^l)\right) \tag{5}$$

$$\rightthreetimes B = \begin{Bmatrix} (\rightthreetimes x^l, \rightthreetimes x^m, \rightthreetimes x^u); \\ (\rightthreetimes y^l, \rightthreetimes y^m, \rightthreetimes y^u); \\ (\rightthreetimes z^l, \rightthreetimes z^m, \rightthreetimes z^u) \end{Bmatrix} \tag{6}$$

In this part, we introduce the GRA method with the triangular neutrosophic sets (TNSs). Figure 1 shows the steps of the suggested approach. Figure 1 shows the steps of the proposed method. The following are the steps of the GRA method with the TNSs:

Doi: https://doi.org/10.54216/IJNS.230117
Received: May 21, 2023 Revised: August 11, 2023 Accepted: November 23, 2023

Figure 1: The steps of the triangular neutrosophic GRA method.

2.1 Build the decision matrix

We built the decision matrix between criteria and alternatives. The criteria and alternatives are gathered from related work based on a set of experts. Then the decision matrix is built using terms of TNSs. Then we use the triangular neutrosophic numbers to replace these terms. Then we apply the score function to obtain the crisp values between criteria and alternatives.

2.2 Compute the normalized decision matrix

The normalized decision matrix is built based on the decision matrix with the criteria and alternatives and by using the crisp values of triangular neutrosophic numbers. The normalized decision matrix is built based on positive and negative criteria:

$$u_{ij} = \frac{q_{ij}}{\max(q_{ij})} \tag{7}$$

$$u_{ij} = \frac{\min(q_{ij})}{q_{ij}} \tag{8}$$

Where $i = 1,2,3, \ldots m\ (alternatives)\ and\ j = 1,2,3 \ldots .\, n\ (criteria)$

2.3 Compute the references series

The references series are computed through the normalized decision matrix as:

$$S_0 = \{s_{01}, s_{02}, s_{03} \ldots \ldots .. s_{0n}\} \tag{9}$$

$$s_{0j} = \max_i s_{ij} \tag{10}$$

2.4 Construct the distance matrix

The distance matric is built among the normalization decision matrix values and values of reference series as:

$$d_{ij} = s_{0j} - u_{ij} \tag{11}$$

The distance is constructed as:

Doi: https://doi.org/10.54216/IJNS.230117
Received: May 21, 2023 Revised: August 11, 2023 Accepted: November 23, 2023

$$D = \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix} \quad (12)$$

2.5 Compute the grey relational coefficient

The grey relational coefficient is computed as:

$$g_i = \sum_{j=1}^{n} w_j d_{ij} \quad (13)$$

Where w_j refers to the weights of the criteria. The weights of criteria are computed using the average method based on the evaluation of experts.

2.6 Order the alternatives

The alternatives are ranked based on the largest value in the grey relational coefficient.

3. Analysis

In this part, we introduce the results of the proposed method by application used and then we analyze these results to show the stability of the results. We collect the ten criteria of firefighting to be analyzed in this study. The firefighting criteria are used to assess the risks concerned with the firefighting operations. The description of the risk criteria is organized as:

I. Incident Duration: Because longer firefighting efforts might lead to increased tiredness and resource depletion, incident length is taken into account as a risk criterion.
II. Life Safety: This criterion refers to the preservation of the life, and safety of firefighters, occupants, and bystanders. So, life safety is an important criterion that should be evaluated in criteria risks.
III. Fire Behavior: Important risk factors include aspects of fire behavior including size, pace of spread, severity, and the potential for fast escalation.
IV. Risks Materials: Additional dangers are posed to firefighting efforts by the presence of dangerous items like combustibles and poisons. In order to contain, mitigate, and decontaminate hazardous chemicals, firefighters must first determine what kinds of materials are there, how much of them, and what could be released.
V. Incident Complexity: Important risk criteria include event complexity, which includes elements like fire area size, number of impacted buildings, and presence of various dangers.
VI. Firefighter Safety: Firefighter protection should always be first. The safety of firefighters is taken into account by thinking about things like the accessibility and efficacy of PPE, communication systems, and emergency escape routes.
VII. Access: Important risk concerns are the presence and reliability of access and escape routes for firefighters and inhabitants.
VIII. Weather Conditions: Fire behavior and firefighter safety may be greatly affected by the wind speed, direction, temperature, and humidity. In order to foresee potential shifts in a fire's behavior, firefighters evaluate the current weather.
IX. Resource Allocation: When deciding where to send firefighters and what tools to use, risk factors are taken into account.
X. Structure Stability: Safety zones for firefighting operations are determined when firefighters assess the structural stability of a building.

3.1 We built the decision matrix between ten criteria and 25 alternatives to assess the risks in firefighting. The experts evaluated the decision matrix based on their opinions. Then we used the triangular neutrosophic numbers to evaluate the criteria and alternatives. Then we used the score function to obtain crisp values.

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3.2 Then we compute the normalized decision matrix by using Eqs. (7 and 8) for positive and cost criteria. In this study the ten criteria are positive. The normalized decision matrix is shown in Table 1.

Table 1: The normalized decision matrix.

	FFC_1	FFC_2	FFC_3	FFC_4	FFC_5	FFC_6	FFC_7	FFC_8	FFC_9	FFC_{10}
FFR_1	0.240361	0.667614	0.756494	0.421672	0.421672	0.421672	0.421672	0.491718	0.421672	0.240361
FFR_2	0.421672	1	0.857549	0.458198	0.458198	0.458198	0.458198	0.534311	0.458198	0.421672
FFR_3	0.421672	0.421672	0.421672	0.421672	0.374391	0.421672	0.374391	0.491718	0.374391	0.756494
FFR_4	0.458198	0.458198	0.458198	0.458198	1	0.458198	1	0.280289	1	0.857549
FFR_5	0.374391	0.374391	0.374391	0.421672	0.756494	0.421672	0.756494	0.491718	0.421672	0.260045
FFR_6	0.857549	0.421672	0.857549	0.458198	0.667614	1	0.125406	0.146238	0.458198	1
FFR_7	0.421672	0.458198	0.421672	0.421672	1	0.421672	0.756494	0.882158	0.374391	0.421672
FFR_8	0.458198	0.374391	0.458198	0.857549	0.756494	0.458198	0.857549	1	0.756494	0.458198
FFR_9	0.421672	0.240361	0.374391	0.421672	0.240361	0.421672	0.421672	0.303242	0.857549	0.374391
FFR_{10}	0.458198	0.421672	0.458198	0.458198	0.421672	0.857549	0.458198	0.280289	0.421672	0.857549
FFR_{11}	0.374391	0.756494	0.374391	0.374391	0.421672	0.260045	0.421672	0.491718	0.458198	0.260045
FFR_{12}	0.756494	0.857549	0.667614	0.667614	0.458198	0.756494	0.756494	0.491718	0.374391	1
FFR_{13}	0.857549	0.260045	1	1	0.421672	0.421672	0.857549	0.534311	0.756494	0.756494
FFR_{14}	0.260045	0.240361	0.756494	0.756494	0.421672	0.458198	0.421672	0.436583	0.857549	0.857549
FFR_{15}	0.421672	0.421672	0.421672	0.667614	0.125406	0.421672	0.458198	0.491718	0.421672	0.421672
FFR_{16}	0.667614	0.667614	0.667614	1	0.667614	0.667614	0.374391	0.491718	0.458198	0.458198
FFR_{17}	1	1	1	0.756494	0.756494	1	1	0.534311	0.374391	0.374391
FFR_{18}	0.756494	0.756494	0.756494	0.857549	0.857549	0.421672	0.421672	0.491718	0.756494	0.756494
FFR_{19}	0.667614	0.240361	0.421672	0.421672	0.260045	0.458198	0.458198	0.280289	0.857549	0.857549
FFR_{20}	0.421672	0.421672	0.125406	0.458198	0.857549	0.421672	0.374391	0.491718	0.260045	0.260045
FFR_{21}	0.458198	0.667614	0.240361	0.374391	0.260045	0.458198	1	0.146238	0.756494	1
FFR_{22}	0.374391	1	0.421672	0.421672	0.421672	0.374391	0.756494	0.882158	0.857549	0.756494
FFR_{23}	0.240361	0.756494	0.667614	0.421672	0.421672	0.421672	0.240361	0.491718	0.421672	0.240361
FFR_{24}	0.421672	0.857549	1	0.458198	0.458198	0.458198	0.421672	0.534311	0.458198	0.421672
FFR_{25}	0.125406	0.260045	0.756494	0.374391	0.374391	0.421672	0.125406	0.491718	0.421672	0.125406

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3.3 Eqs. (8 and 9) are used to compute the reference series. The reference series is a maximum value in the normalized decision matrix.

3.4 Eqs. (11 and 12) are used to construct the distance matrix as shown in Table 2.

Table 2: The distance from the reference series and normalized decision matrix.

	FFC_1	FFC_2	FFC_3	FFC_4	FFC_5	FFC_6	FFC_7	FFC_8	FFC_9	FFC_{10}
FFR_1	0.759639	0.332386	0.243506	0.578328	0.578328	0.578328	0.578328	0.508282	0.578328	0.759639
FFR_2	0.578328	0	0.142451	0.541802	0.541802	0.541802	0.541802	0.465689	0.541802	0.578328
FFR_3	0.578328	0.578328	0.578328	0.578328	0.625609	0.578328	0.625609	0.508282	0.625609	0.243506
FFR_4	0.541802	0.541802	0.541802	0.541802	0	0.541802	0	0.719711	0	0.142451
FFR_5	0.625609	0.625609	0.625609	0.578328	0.243506	0.578328	0.243506	0.508282	0.578328	0.739955
FFR_6	0.142451	0.578328	0.142451	0.541802	0.332386	0	0.874594	0.853762	0.541802	0
FFR_7	0.578328	0.541802	0.578328	0.578328	0	0.578328	0.243506	0.117842	0.625609	0.578328
FFR_8	0.541802	0.625609	0.541802	0.142451	0.243506	0.541802	0.142451	0	0.243506	0.541802
FFR_9	0.578328	0.759639	0.625609	0.578328	0.759639	0.578328	0.578328	0.696758	0.142451	0.625609
FFR_{10}	0.541802	0.578328	0.541802	0.541802	0.578328	0.142451	0.541802	0.719711	0.578328	0.142451
FFR_{11}	0.625609	0.243506	0.625609	0.625609	0.578328	0.739955	0.578328	0.508282	0.541802	0.739955
FFR_{12}	0.243506	0.142451	0.332386	0.332386	0.541802	0.243506	0.243506	0.508282	0.625609	0
FFR_{13}	0.142451	0.739955	0	0	0.578328	0.578328	0.142451	0.465689	0.243506	0.243506
FFR_{14}	0.739955	0.759639	0.243506	0.243506	0.578328	0.541802	0.578328	0.563417	0.142451	0.142451
FFR_{15}	0.578328	0.578328	0.578328	0.332386	0.874594	0.578328	0.541802	0.508282	0.578328	0.578328
FFR_{16}	0.332386	0.332386	0.332386	0	0.332386	0.332386	0.625609	0.508282	0.541802	0.541802
FFR_{17}	0	0	0	0.243506	0.243506	0	0	0.465689	0.625609	0.625609
FFR_{18}	0.243506	0.243506	0.243506	0.142451	0.142451	0.578328	0.578328	0.508282	0.243506	0.243506
FFR_{19}	0.332386	0.759639	0.578328	0.578328	0.739955	0.541802	0.541802	0.719711	0.142451	0.142451
FFR_{20}	0.578328	0.578328	0.874594	0.541802	0.142451	0.578328	0.625609	0.508282	0.739955	0.739955
FFR_{21}	0.541802	0.332386	0.759639	0.625609	0.739955	0.541802	0	0.853762	0.243506	0
FFR_{22}	0.625609	0	0.578328	0.578328	0.578328	0.625609	0.243506	0.117842	0.142451	0.243506
FFR_{23}	0.759639	0.243506	0.332386	0.578328	0.578328	0.578328	0.759639	0.508282	0.578328	0.759639

Doi: https://doi.org/10.54216/IJNS.230117
Received: May 21, 2023 Revised: August 11, 2023 Accepted: November 23, 2023

FFR_{24}	0.578328	0.142451	0	0.541802	0.541802	0.541802	0.578328	0.465689	0.541802	0.578328
FFR_{25}	0.874594	0.739955	0.243506	0.625609	0.625609	0.578328	0.874594	0.508282	0.578328	0.874594

3.5 Eqs. (13) is used to compute the grey relational coefficient. The weights of criteria are computed by using the average method as shown in Figure 2. We show that life safety is the highest important criterion and the incident duration is the lowest weight in all criteria. Life safety is an important criterion due to concern with the safety and security of a person. Then we compute the grey relational coefficient by multiplying the weights of criteria by the distance values as shown in Figure 3. We show that alternative 25 is the highest risk and alternative 17 is the fewest risk in all 25 risks.

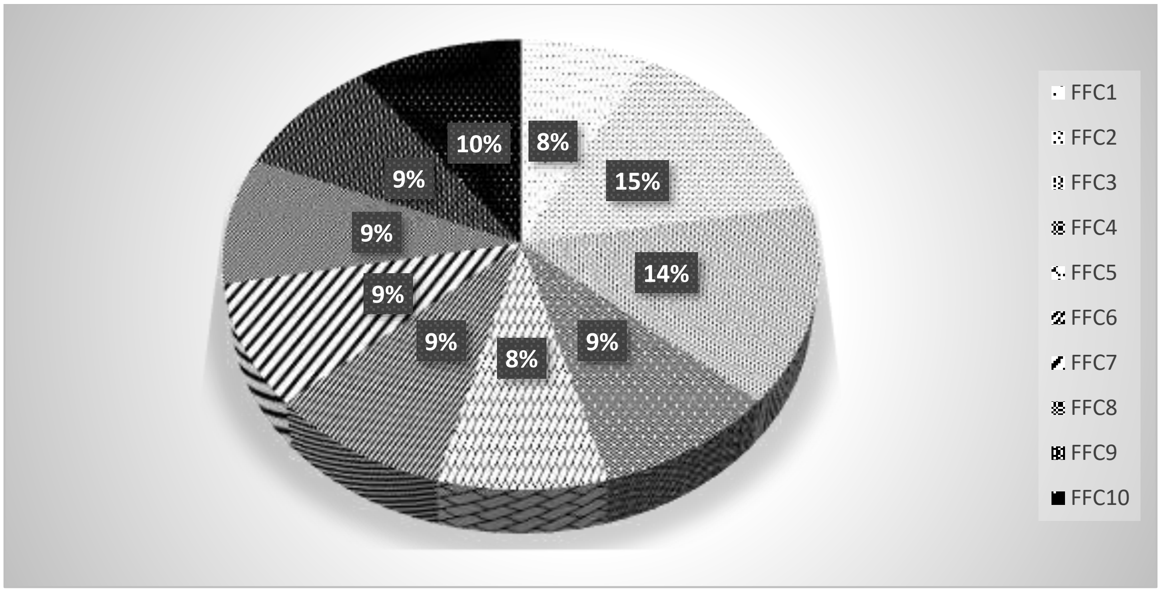

Figure 2: The weights of ten risks criteria in this study.

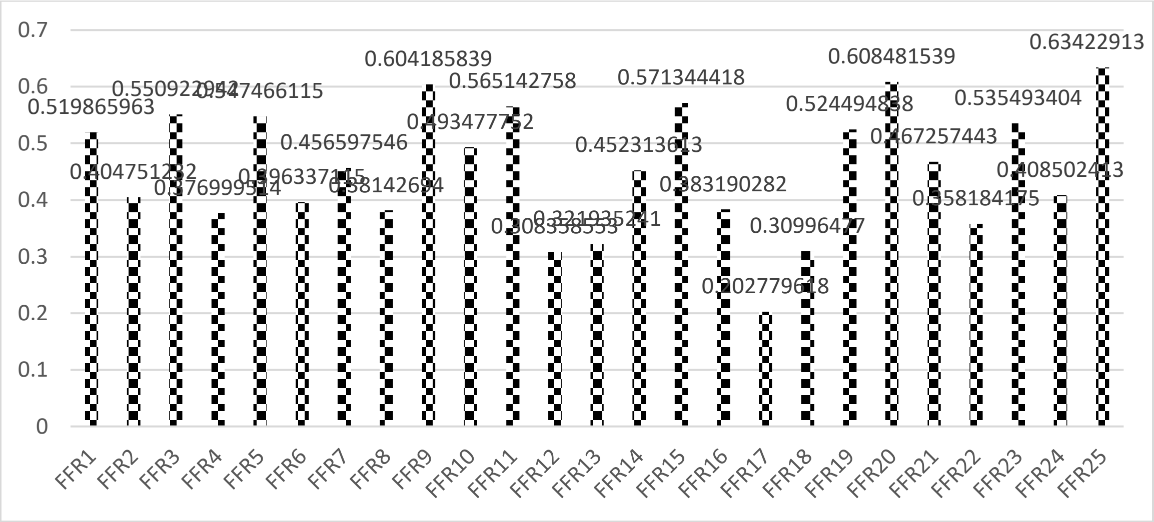

Figure 3: The coefficient of grey relational values.

Doi: https://doi.org/10.54216/IJNS.230117
Received: May 21, 2023 Revised: August 11, 2023 Accepted: November 23, 2023

3.2 Analysis

When using MCDM methods, sensitivity analysis proves to be an invaluable asset. By examining the sensitivity of outputs to changes in input values, it is possible to gauge how well decisions hold up under uncertainty. With the use of a sensitivity analysis, decision-makers may learn how shifting criteria and other options affect the final outcome.

We change the weights of the criteria by ten cases. We put one weight with 0.145 and other weights are of equal importance. Then we use these ten cases as an input of the GRA method to show the rank of alternatives under different cases. We observe that alternative 25 is the highest risk in all cases and alternative 17 is the lowest risk in all cases. We show the proposed method is effective and the results are stable.

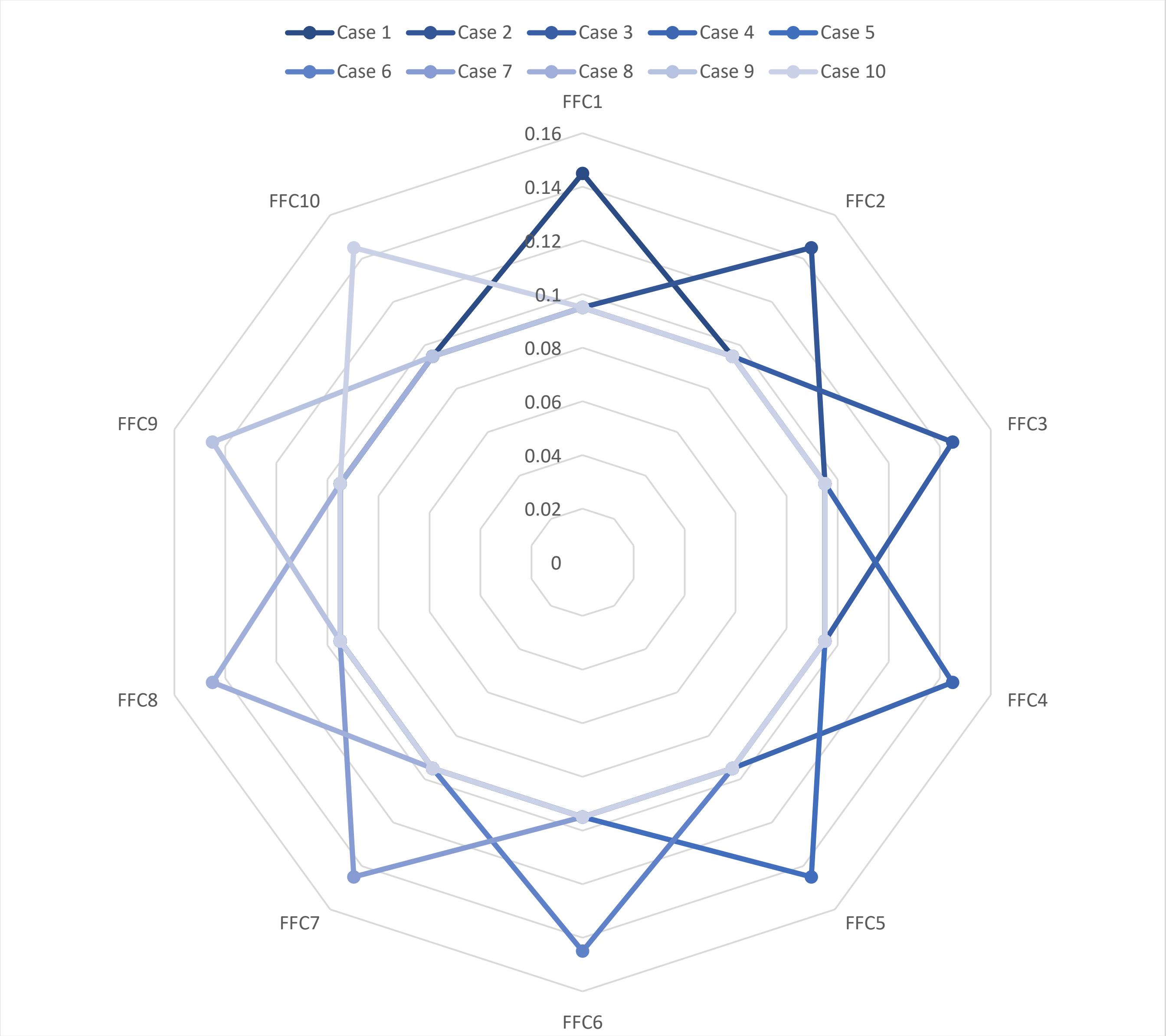

Figure 4: The ten cases in sensitivity analysis.

Doi: https://doi.org/10.54216/IJNS.230117
Received: May 21, 2023 Revised: August 11, 2023 Accepted: November 23, 2023

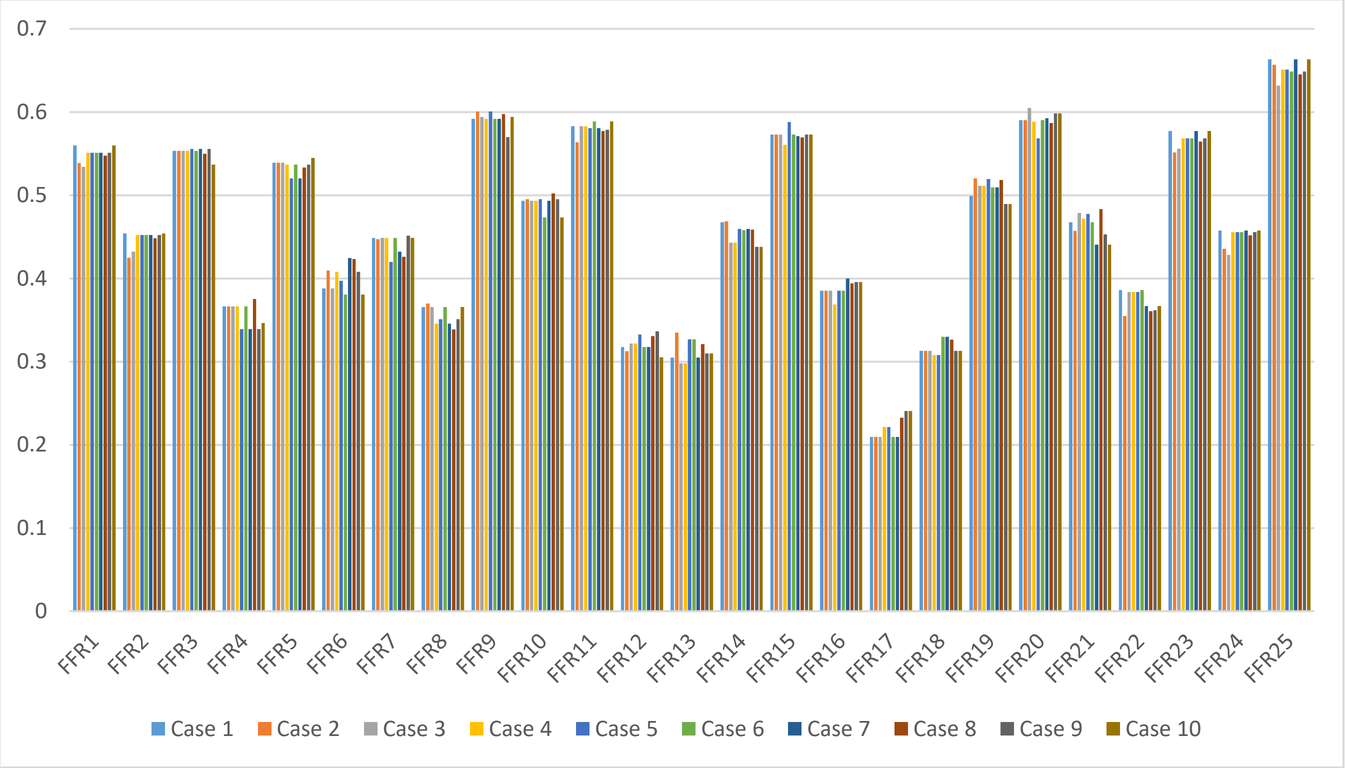

Figure 5: The coefficient of grey relational values under different cases.

4. Conclusion Remarks

Firefighters and incident commanders rely heavily on risk assessments to inform their actions and judgments. Firefighters can ensure the safety of workers and the successful reduction of fires by analyzing several risk factors to effectively identify and manage the dangers and risks of firefighting accidents.

Protecting firefighters, building occupants, and bystanders is a top priority in firefighting operations, making life safety the most critical risk criterion. Essential aspects that shape firefighting methods and tactics include fire characteristics like size, spread, and severity. Assessing the stability of a structure is critical since it reveals possible collapse threats and establishes workable areas.

Extra consideration must be given to risk assessment and mitigation when dealing with hazardous products. Personal protection equipment (PPE), reliable communication networks, and clear exit routes for firefighters in an emergency are all crucial.

The weather dramatically influences fire behavior and firefighter safety, making evaluating and adjusting tactics constantly imperative. The safety of firefighters and building residents is ensured by assessing all possible access and escape points.

Resource allocation takes risk factors into account to properly deploy persons, apparatus, and equipment in response to an event of a certain severity. Required resources and incident management systems are affected by event complexity, including factors like the fire area's size and the presence of various dangers.

It is also considered how long firefighting activities will last and precautions are taken to mitigate dangers like weariness and depletion of supplies.

Through extensive risk assessment, firefighting professionals may make educated judgments, adjust plans, and manage hazards effectively. Firefighters can improve their efficiency and effectiveness in mitigating fire incidents by prioritizing life safety, assessing weather conditions, evaluating access and egress, allocating resources appropriately, understanding the complexity and duration of the incident, and managing hazardous materials.

Doi: https://doi.org/10.54216/IJNS.230117
Received: May 21, 2023 Revised: August 11, 2023 Accepted: November 23, 2023

Firefighters can better identify risks, adapt to new situations, and protect responders and the public due to ongoing training, teamwork, and experience.

Risk assessment of firefighting is an MCDM problem due to various criteria. We used the GRA method as an MCDM method to rank the alternatives. The GRA method is integrated with the triangular neutrosophic set to deal with vague and uncertain information. We used ten risk criteria and 25 risks to evaluate. The decision-makers and experts assessed the criteria and alternatives. We compute the weights of criteria by the average method. We show that life safety is the highest weight, and the incident duration is the lowest. The GRA method shows that alternative 25 is the highest and alternative 17 is the lowest. The sensitivity analysis is applied to deliver the model's performance and the outcome's stability. We used ten cases to change the criteria weights and ranked the alternatives under ten cases. We show that alternative 25 is the highest risk in all alternatives, and alternative 17 is the lowest risk in all cases.

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