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IDENTIFICATION AND ASSESSMENT OF MAN-MADE THREATS TO CITIES USING INTEGRATED GREY BWM-GREY MARCOS METHOD

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Abstract: *Identifying and evaluating any threat against the critical infrastructures, including history, methods, abilities, and motivations, is essential for crisis management and cities' passive defense. Threats, including natural and unnatural (man-made), are directed at cities' critical assets and infrastructures. Essential assets are considered valuable components, so the slightest malfunction or damage to the body causes damage to the system. This study uses Tehran, the capital of Iran, as a case study to identify and assess man-made dangers to cities and their vital resources. This work creates an innovative integrated MCDM approach that can handle information ambiguity in crisis management. Therefore, at this stage of identifying man-made threats, library methods and interviews with experts were used, and multi-criteria decision-making techniques were implemented. Moreover, this research benefits from the grey Best-Worst method (BWM) to evaluate the research criteria and grey Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS) to rank the threats. The research findings indicated that the three main threats to Tehran city are cyber, military, and terrorist attacks. Finally, a sensitivity analysis based on two practical experiments is done, and research results are verified.*

Keywords: Man-made threats, Cities, Grey theory, Infrastructures, Multiple-criteria decision-making, BWM, MARCOS.

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1. Introduction

Since the beginning of creation, man has always faced insecurity and threat. It is impossible to ignore the possibility of such events occurring in cities, given the history of man-made threats such as air and missile attacks, terrorist threats, deliberate sabotage, bombings, and cyber-attacks on various infrastructures such as water, electricity, gas, oil, telecommunications, and transportation. Regarding the dynamic nature of man-made threats, continuously updating this type of menace is necessary. The primary task of this research is to evaluate the man-made threats to cities based on a case study, Tehran. Tehran is the largest city in Iran and the pole of economy, population, culture, and the origin of the most prominent social, religious, political, and national activities. This city, with an area of about 730 square kilometers, had a fixed population of about 8.8 million and a floating population of 9 to 11 million in 2011. The allocation of resources is given in Tehran, most of the communication networks end in Tehran, and the presence of ministries, embassies, higher education institutions, medical centers, exceptional hospitals, large economic companies, etc., indicate the increased importance of Tehran city from the urban and country point of view. As a result, Tehran's ability to withstand man-made dangers greatly influences how resilient the nation is. Identifying the risks themselves is the first step in strengthening Tehran's resistance to man-made threats. For this purpose, among the most important research carried out in this regard, the following papers can be mentioned:

The study "Evaluation of seismic vulnerability of urban spaces using Catastrophe theory (case: Varzeghan city),"(Mesri Alamdari & Khairizade Arogh, 2020) offered a systematic framework for speedy and effective evaluation of the vulnerability of urban regions. The results of the study indicate that high residential and construction density, low quality of buildings, old and undesirable materials of buildings, confinement, lack of urban open spaces, infrastructure weaknesses, lack of optimal access to hospital and fire services, etc., lead to an increase in the consequences of earthquake threat in the studied sample. The natural hazards, such as earthquakes, to reduce the damage caused by them were considered by many researchers in many studies.

Pal et al. (2023), a book titled "Science and Technology for Multi-hazard Vulnerability, Climate Change, and Resilience Building" states that complex urban issues are multifaceted matters, and overcoming those perils can lead to risk reduction and stable development. They claimed that various structures might be made resilient in any city with the aid of crisis management policies and community involvement. This book presents evidence-based problem-solving techniques from social, natural, engineering, and other perspectives, linking data, research, and conceptual work with practical cases on disaster risk management to address multisectoral aspects of resilience and adaptation strategy against disasters. Shaw el al. (2016) book "Urban Disasters and Resilience in Asia" provides the latest information on the severity and frequency of disasters in Asia. They argued that with the help of crisis management strategies and community engagement, a wide range of buildings could be made robust in any city. They claimed that various structures might be made resilient in any city with the aid of crisis management policies and community involvement.

Cui et al. (2021) worked on scientific research challenges on natural hazards and disaster risk and finally identified the challenges of natural threats for China between 2025 and 2035 (Jalali Farahani, 2013a) reviewed and improved research on new approaches to deal with threats and present categories in this field. Modiri et al.

(2015) utilized SWOT to assess suitable strategies for the urban management of Rasht Metropolis, which were defined by identifying the weaknesses, strengths, opportunities, and threats concerning the vulnerability of crisis management. Salehi et al. (2020) used ENTROPY-TOPSIS integrated technique to evaluate crisis management systems in petrochemical industries. They evaluated five petrochemical facility crisis management systems' organizational, human, and technological components. A survey was created to cover all three factors. There were 34 questions on the survey. DEMATEL-ANP was used by (Jamali et al. 2023) to evaluate urban resilience levels. They used GIS overlay to provide visual outputs. As a result of the study, disasters and natural hazards in the environmental dimensions, urban infrastructure in physical dimensions, and employment rate in socioeconomic dimensions were found to be the most influential criteria for urban resilience. Javari et al. (2021) used fuzzy theory, TOPSIS, and GIS software to analyze the resilience of urban settlements in Malayer City.

Lyu & Yin (2023) used AHP-FAHP-ANP-GIS to assess the risk of multi-hazards in Hongkong. Abdullahi et al. (2015) developed an integrated technique that combines MCDM, Bayes theorem, and RADAR technology to evaluate the compactness and sustainability of Kajang City, Malaysia. Balali et al. (2021) used ANP-COPRAS to assess the risk of human resources threats in natural gas supply projects. Brodny & Tutak (2023) evaluated European Union member states' energy and climate sustainability using CODAS, EDAS, TOPSIS, VIKOR, and WASPAS. da Silva Borges Barbosa et al. (2022) assessed the risk of 148 abandoned urban mines in Ouro Preto city using the AHP method.

As it is clear, few types of research focused on man-made threats to cities and resilience assessment of cities using MCDM techniques.

To the best of our knowledge, no previous study has covered the following gaps:

First, no previous study has assessed man-made threats and their criteria comprehensively for capital cities.

Second, full grey techniques were rarely used in the literature to confront the uncertainty of the subject.

The proper research methodologies and the experts' group were initially chosen to accomplish this study's goals. Then, research criteria for evaluating man-made hazards to cities are established utilizing library resources and expert interviews. Moreover, the grey theory is used to confront the ambiguity of information and data. Finally, grey BWM is used to assess the criteria, and grey MARCOS is used to rank the threats.

2. Materials and Methods

The present research aims to study the present conditions, and extract the man-made threats, focusing on Tehran city as a case study. Quantitative and qualitative approaches can be used to collect and analyze data in research. A combined (quantitative-qualitative) method was chosen. To identify man-made threats to cities, the literature and the related events records were studied. An innovative integrated multi-criteria decision-making approach that can handle the ambiguity of the issue and the information is presented to prioritize the man-made dangers to cities. As a result, a brief explanation of the Grey hypothesis is given first. Then, the Grey BWM method is explained and later used to obtain the weight of the research criteria.

An elite group, including eight experts with experience and expertise in city defense knowledge, is created to create the primary decision matrix and determine criteria weights. Furthermore, the Grey MARCOS method ranks man-made threats to cities. Figure 1 illustrates the mentioned process.

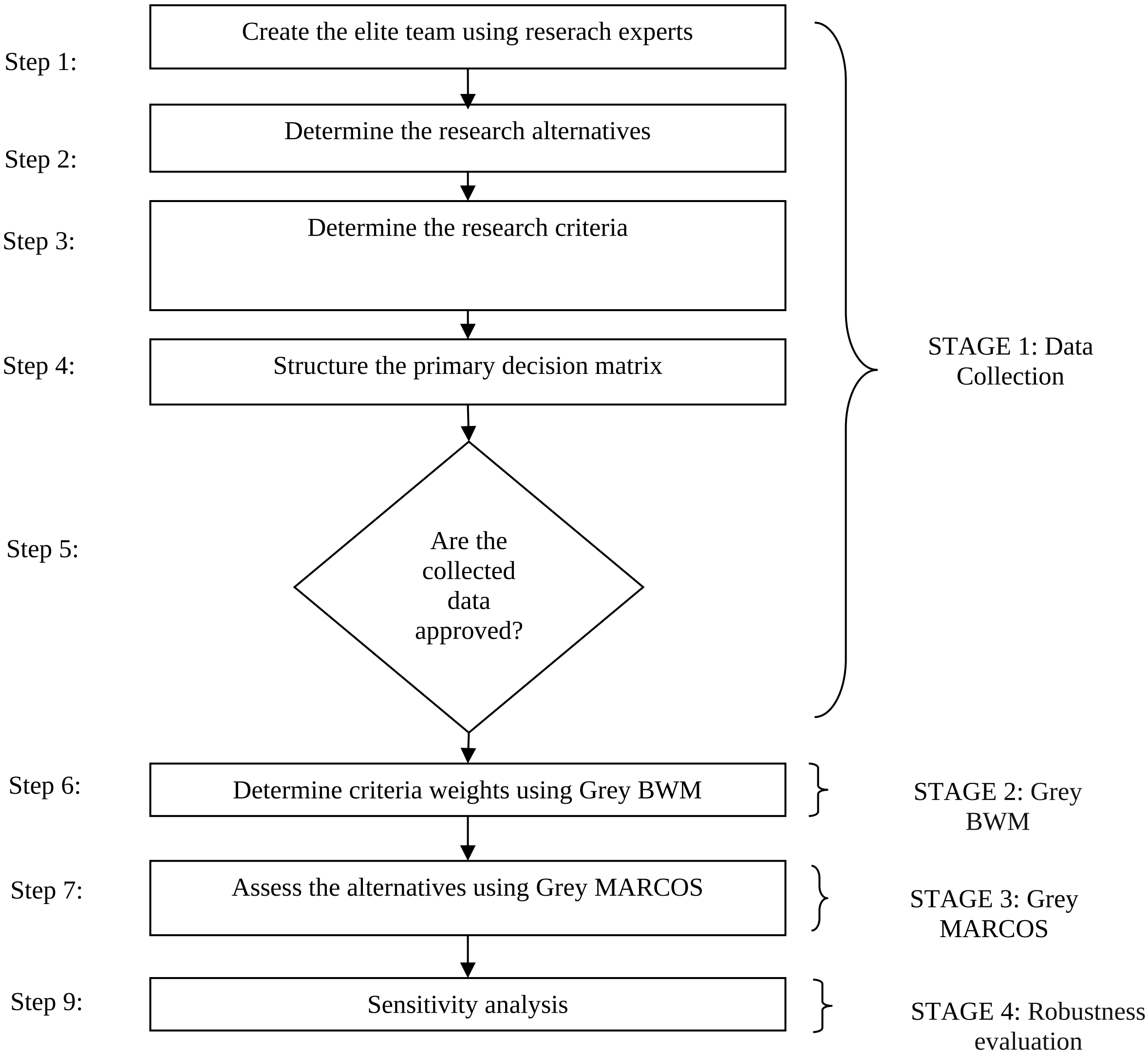

Figure 1. Research methodology diagram

Moreover, the developed methodology consists of integrating two robust and newly introduced MCDM methods (Grey BWM-Grey MARCOS) to confront the uncertainty of research for the first time.

2.1. Preliminaries of Grey theory

Gray numbers are numbers with an unknown value but a known range. There are usually two ways to represent gray numbers: a closed interval or a set of numbers (Torkayesh et al. 2021)

A gray number is defined as(Liu et al. 2012):

$$\otimes G \in [G^l, G^u],\ G^l \leq G^u \tag{1}$$

We define a Whitening degree as $\frac{G^l+G^u}{2}$ which is used by Badi and Pamucar (2020). For two gray numbers $\otimes G_1$ and $\otimes G_2$, the mathematics operations can be defined (Turskis & Zavadskas, 2010) as:

$$\otimes G_1 + \otimes G_2 = [G_1^l + G_2^l , G_1^u + G_2^u] \tag{2}$$

$$\otimes G_1 - \otimes G_2 = [G_1^l - G_2^u , G_1^u - G_2^l] \tag{3}$$

$$\otimes G_1 \times \otimes G_2 = [\mathrm{Min}\{G_1^l \times G_2^l, G_1^l \times G_2^u, G_1^u \times G_2^l, G_1^u \times G_2^u\}, \mathrm{Max}\{G_1^l \times G_2^l, G_1^l \times G_2^u, G_1^u \times G_2^l, G_1^u \times G_2^u\}] \tag{4}$$

$$\otimes G_1 \div \otimes G_2 = \left[\mathrm{Min}\left\{\frac{G_1^l}{G_2^l}, \frac{G_1^l}{G_2^u}, \frac{G_1^u}{G_2^l}, \frac{G_1^u}{G_2^u}\right\}, \mathrm{Max}\left\{\frac{G_1^l}{G_2^l}, \frac{G_1^l}{G_2^u}, \frac{G_1^u}{G_2^l}, \frac{G_1^u}{G_2^u}\right\}\right] \tag{5}$$

Length of the grey number is defined as follows:

$$L(\otimes G) = |G^u - G^l| \tag{6}$$

The possibility degree of two grey number $\otimes G_1$ and $\otimes G_2$ expressed (Li et al., 2007) as:

$$P\{\otimes G_1 \leq \otimes G_2\} = \frac{\max(0, L(\otimes G_1) + L(\otimes G_2) - \max(0, G_1^u - G_2^l))}{L(\otimes G_1) + L(\otimes G_2)} \tag{7}$$

For the position relation between two grey intervals,

if $P\{\otimes G_1 \geq \otimes G_2\} < 0.5$ then $\otimes G_1 < \otimes G_2$, which means that $\otimes G_1$ is smaller than $\otimes G_2$;

if $P\{\otimes G_1 \geq \otimes G_2\} = 0.5$ then $\otimes G_1 = \otimes G_2$, which implies that $\otimes G_1$ is equal to $\otimes G_2$;

if $P\{\otimes G_1 \geq \otimes G_2\} > 0.5$ then $\otimes G_1 > \otimes G_2$, which means that $\otimes G_1$ is more significant than $\otimes G_2$.

2.2. Grey best-worst method

Rezaei (2015) introduced this method as a mathematical programming-based weighting method in the field of MCDM. BWM benefits from a pairwise comparison while identifying the best and worst research criteria. Compared to its predecessors, like AHP, BWM makes fewer pairwise comparisons and offers more accurate weights. Aslani et al. (2021) used grey BWM, WASPAS, and TOPSIS for sustainable supplier selection problems. Ulutaş et al. (2022) used grey WISP and grey BWM for the sustainable supplier selection problem. Mahmoudi et al. (2020) developed a novel version of grey linear BWM when the decision-making process includes multiple experts. Balouei Jamkhaneh et al. (2022) used group grey BWM to analyze logistics 4.0 service quality and its sustainability enabler scenarios in an emerging economy. We used the grey linear BWM model introduced by (Aslani et al. 2021)

$$\begin{aligned}
&\min \chi \\
&\text{s.t.} \\
&\left|[w_B^l, w_B^u] - [a_{Bj}^l, a_{Bj}^u][w_j^l, w_j^u]\right| \leq [\chi, \chi], \forall j \\
&\left|[w_j^l, w_j^u] - [a_{jw}^l, a_{jw}^u][w_w^l, w_w^u]\right| \leq [\chi, \chi], \forall j \\
&\quad w_i^u \geq 0,\ \forall j \\
&\quad w_i^l \geq 0,\ \forall j
\end{aligned} \tag{8}$$

$$w_i^u - w_i^l \geq 0,\ \forall j$$

$$\sum_{i=1}^{n} \frac{(w_i^l + w_i^l)}{2} = 1, \forall j$$

2.3. Grey measurment according to compromise solution

This section presents the algorithm of the Grey MARCOS method. MARCOS method specifies the relationships between options and reference values (ideal and non-ideal options). The utility functions of the possibilities are established based on these established relationships, and the compromise is ranked in regard to the ideal and anti-ideal solutions. Decision preferences are defined using utility functions. The utility function displays where a certain choice stands in relation to ideal and anti-ideal solutions. Ideally, you should select the alternative closest to the ideal while being the furthest from the anti-ideal (Stević et al. 2020)

Based on the MARCOS method, recent research as follows: (Hosseini Dehshiri & Firoozabadi, 2022) used the MARCOS method to locate a solar site to produce electricity and hydrogen. Badi et al. (2023) applied the MARCOS method for wind farm location selection. Hasheminasab et al. (2023) used the MARCOS method to assess modern energy poverty. Hosseini Dehshiri & Firoozabadi (2023) used the MARCOS method for a new multi-criteria decision-making approach based on wins in the league to prevent rank reversal. Saha et al. (2023) used the MARCOS method to choose a warehouse location for the automotive industry. Furthermore, (Torkayesh et al. 2021) developed the grey MARCOS method to select landfill locations for healthcare waste in urban areas.

The grey MARCOS method is performed based on the following steps:

Step 1: Create the initial decision matrix based on n criteria and m options.

Step 2: Set up the extended initial decision matrix. This step expands the initial matrix by determining the ideal (AI) and anti-ideal (AAI) solutions.

$$X = \begin{array}{c} \\ AAI \\ A_1 \\ A_2 \\ \dots \\ A_m \\ AI \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} [a_{aa1}, b_{aa1}] & [a_{aa2}, b_{aa2}] & \dots & [a_{aan}, b_{aan}] \\ [a_{11}\ ,\ b_{11}] & [a_{12}\ ,\ b_{12}] & \dots & [a_{1n}\ ,\ b_{1n}] \\ [a_{21}\ ,\ b_{21}] & [a_{22}\ ,\ b_{22}] & \dots & [a_{21}\ ,\ b_{21}] \\ \dots & \dots & \dots & \dots \\ [a_{m1}, b_{m1}] & [a_{m2}, b_{m2}] & \dots & [a_{mn}, b_{mn}] \\ [a_{ai1}\ , b_{ai1}] & [a_{ai2}\ ,\ b_{ai2}] & \dots & [a_{ain}\ ,\ b_{ain}] \end{bmatrix} \end{array} \tag{9}$$

Where a_{ij} shows the lower bound and b_{ij} represents the upper bound, for $i = 1,2, \dots, m, j = 1,2, \dots, n$.

The anti-ideal solution (AAI) is the worst option, while the ideal solution (AI) has the best possessions. Depending on the personality of the criteria, AI and AAI are defined using equations (10) and (11).

$$AI = \max_i x_{ij} \text{ if } j \in B \text{ and } \min_i x_{ij} \text{ if } j \in C \tag{10}$$

$$AAI = \min_i x_{ij} \text{ if } j \in B \text{ and } \max_i x_{ij} \text{ if } j \in C \tag{11}$$

Where in these equations B represents a group of benefit criteria while C representing a group of cost criteria.

Step 3: Normalize the expanded initial matrix

$$n_{ij} = [c_{ij}\ ,\ d_{ij}] = \frac{[a_{ain}\ , b_{ain}]}{[a_{mn}\ ,\ b_{mn}]} \text{ if } j \in C \tag{12}$$

$$n_{ij} = [c_{ij}\ ,\ d_{ij}] = \frac{[a_{mn}\ ,\ b_{mn}]}{[a_{ain}\ , b_{ain}]} \text{ if } j \in B \tag{13}$$

Step 4: Determine the weighted normalized

$$v_{ij} = [v_{1ij}\ ,\ v_{2ij}] = w_j[c_{ij}\ \ ,\ d_{ij}] \tag{14}$$

Step 5: Calculate the utility degrees.

$$K_i^+ = [k_{1ij+}\ , k_{2ij+}\ ] = \frac{S_i}{S_{ai}} \tag{15}$$

$$K_i^- = [k_{1ij-}\ , k_{2ij-}] = \frac{S_i}{S_{aai}} \tag{16}$$

In these equations, S_i $(i = 1,2,..,m)$ represents the sum of the elements of the weighted matrix for lower and upper bounds.

Step 6: Determine the utility function of $f(k_i)$ options.

$$f(K_i) = [f(k_{1ij}), f(k_{2ij})] = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} \tag{17}$$

Where $f(K_i^-)$ expresses the utility function in relation to the anti-ideal solution, while $f(K_i^+)$ indicates the utility function for the ideal solution.

The utility functions related to ideal and non-ideal solutions are determined using equations (17) and (18).

$$f(K_i^-) = [f(k_{1ij-}), f(k_{2ij}-)] = \frac{K_i^+}{K_i^+ + K_i^-} \tag{18}$$

$$f(K_i^+) = [f(k_{1ij+}), f(k_{2ij}+)] = \frac{K_i^-}{K_i^+ + K_i^-} \tag{19}$$

Step 7: Rank the alternatives based on their whitened utility function $f(k_i)$ values.

2.4. Data collection

In the first step, senior managers with crisis management experience and a group of civil engineering and urban planning experts evaluated the critical criteria for man-made threats to cities in three conference meetings. The experts' information is shown in Table 1.

Table 1. History of information related to experts

Variable	Items	Number	Variable	Items	Number
(1) Civil engineering	Bachelor's degree	0	(3) Urban planning	Bachelor's degree	0
	Master's degree	1		Master's degree	1
	Ph.D	1		Ph.D	1
(2) Crisis management	Bachelor's degree	0	(4) Senior managers	Bachelor's degree	0
	Master's degree	0		Master's degree	1
	Ph.D	2		Ph.D	1

3. The process of identifying man-made threats

Threatology is one of the main components of risk assessment and analysis (Jalali Farahani, 2013b). All the dangers that impact the desired assets (or at least the most significant ones) must be identified and studied from multiple angles in order to determine the risk of a particular asset (valued component) or a collection of assets (such as urban areas) (such as severity, conditions of occurrence and mechanism of the threat). Then, with appropriate methods, such as using experts' opinions or accurate scientific estimates, the probability of any threat against assets should be determined (Jalali Farahani, 2013b).

To evaluate the man-made threats to cities, three steps are taken as follows:

1. Examining internal and external literature resources
2. Studying the records of man-made threats in urban infrastructures
3. Extracting the opinions of experts and specialists

By combining these three steps, all steps of our comprehensive research will be done. First, the literature will be reviewed based on internal and external sources, and then the opinions of experts will be used for criteria and alternative evaluation.

3.1. Military threats (A_1)

A severe threat occurs whenever a country's independence and territorial integrity is in danger of being invaded by military forces of another country or an alliance of foreign governments, or internal armed opposition groups. In this threat, the ultimate goal is mainly to occupy the land. These threats rely on physical movements which are accompanied by violent behavior, open subversion, use of force and coercion, and loss of life and money(Jalali Farahani, 2013b; Rastegar et al. 2022)

3.2. Terrorist threats (A_2)

Terrorist threats are one sort of danger to metropolitan infrastructures. Today's subversive and terrorist actions have turned these risks, particularly in cities, into their primary focus (Haghir et al. 2021; Hosseini Dehshiri & Firoozabadi, 2022; Rastegar et al. 2021)

3.3. The threat of disturbance and chaos (A_3)

An action accompanied by violence by a group of people, which occurs against any group's ruling system, always brings disorder and insecurity to it.

3.4. Cyber threats (A_4)

It refers to a type of war in which the involved parties use computers and computer networks (especially the Internet) to attack and turn the battle into cyberspace. This level of threat usually has specific characteristics, which include the origin of the threat, a country instead of a group, its attack tool is a cyber weapon instead of a regular virus, the level of risk production is at the level of national security and the threatened area is focused on the centers of gravity.

3.5. Chemical threats (A_5)

Refers to intentional incidents caused by security and war measures of the enemy or industrial and unintentional sabotage caused by errors and negligence in the safety of the industrial process that occurs in infrastructures, industries, service centers, such as water treatment plants, and storage centers, storage and sale of chemical substances or in the process of production, exploitation, transportation and storage of dangerous chemical substances, and goods that cause damage to human capital, pollution, disturbance, change of state or destruction of the environment, wealth and assets.

3.6. Biological threat (A_6)

Any sign, event, or natural or unnatural incident using biological factors that cause weakening and destruction of human capital or economic damage is considered a biological threat (Jalali Farahani, 2013b).

4. Determining the research criteria

4.1. Severity of damage in infrastructure (C_1)

The severity of damage means the number of injuries, casualties, and damage caused by the threat agent to human resources, equipment, facilities, and time (Jalali Farahani, 2013a)

4.2. Threat History (C_2)

Obtaining information about enemy's previous use or non-use of a threat represents the enemy's will and interest to use the threat again (Jalali Farahani, 2013a)

4.3. Attacker capability (C_3)

The ability of the enemy to attack is the first thing considered to determine the nature of enemy's threat (Jalali Farahani, 2013a)

4.4. Having the least negative consequences for the enemy (C_4)

The opponent will attempt to utilize threats with the fewest negative repercussions because it wants to maintain public opinion in the target nation, its society, and the international community (Jalali Farahani, 2013a).

4.5. Risk level (C_5)

This criterion shows the probability of imminent danger based on enemy's capabilities and the defender's weakness (Vasileiou et al. 2022).

4.6. Civil-Military cooperation (C_6)

This criterion shows the level of cooperation between the people and the government forces in facing and dealing with the risks and national security issues initiated.

4.7. Local awareness (C_7)

This principle shows people's awareness of their duties and procedures for dealing with any threat nationally (Haque & Fatema, 2022; Park, 2011)

5. Results

5.1. Grey BWM results

As it was mentioned before, to identify and weigh the criteria, a detailed questionnaire was created and scored by the elite group to evaluate the man-made threats in Tehran. Then, the Grey Best-Worst method was implemented. First, the Severity of damage in infrastructure (C_1) and Threat history (C_2) are identified as the best and the worst criteria. The Severity of Damage in Infrastructure (C_1), with a weight of 0.353, has thus been rated first based on these findings since it reveals the casualties and devastation caused by the threat, which is one of the most crucial factors impacting the severity of the crisis produced by the threat. The risk level of threats (C_5) is ranked second with a weight of 0.202. This criterion is essential because it shows the attraction of threats against the target.

Negative consequences for the enemy (C_4) with a weight of 0.139 is in the third place, so every threat has results for the enemy, which can be divided into several parts, including the threatened response to the enemy's attack, the reaction of world public opinion, and the response of, institutions, various global organizations are against the invading country.

Enemy's capability (C_3) is ranked fourth, and its weight is equal to 0.109. The higher the Enemy's capability is, the more damage it can cause and the more critical conditions it can cause.

Local awareness (C_7) is ranked fifth place with a weight of 0.088. This criterion represents the importance of knowledge of people about the possible threats in Table 2.

Table 2. Criteria weights

Criteria	Grey lower and upper bounds	Crisp weights
C_1	0.312	0.353
	0.394	
C_2	0.033	0.033
	0.033	
C_3	0.109	0.109
	0.109	
C_4	0.139	0.139
	0.139	
C_5	0.202	0.202
	0.202	
C_6	0.077	0.0775
	0.078	
C_7	0.088	0.088
	0.088	

5.2. Grey MARCOS results

In the first step, a decision-making matrix is formed based on grey intervals, which include seven decision-making criteria and six main man-made threats (options) in Tehran. This matrix, which is shown in Table 3, is the result obtained from the opinions of the elite research community about the impact of the criteria on options. Moreover, the ideal (AI) and anti-ideal (AAI) solutions are defined.

Table 3. Decision-making matrix for ranking man-made threats in Tehran

	C_1		C_2		C_3		C_4		C_5		C_6		C_7	
A_1	75	90	65	75	60	70	55	65	65	75	35	50	45	60
A_2	65	80	55	65	50	60	45	55	55	65	45	60	55	70
A_3	50	60	45	55	40	50	35	45	45	55	55	70	65	80
A_4	75	85	75	90	70	85	65	85	75	90	25	40	20	35
A_5	40	50	35	45	30	40	25	35	20	30	20	25	20	25
A_6	25	35	35	45	20	30	25	35	35	45	20	25	15	30
AI	90	90	90	90	85	85	85	85	90	90	20	20	15	15
AAI	25	25	35	35	20	20	25	25	20	20	70	70	80	80

The normalized matrix is formed in the next step, which is shown in Table 4.

Table 4. Normalized decision matrix

	C_1		C_2		C_3		C_4		C_5		C_6		C_7	
A_1	0.83	1	0.72	0.83	0.71	0.82	0.65	0.76	0.72	0.83	0.57	0.4	0.33	0.25
A_2	0.72	0.89	0.61	0.72	0.59	0.71	0.53	0.65	0.61	0.72	0.44	0.33	0.27	0.21
A_3	0.56	0.67	0.5	0.61	0.47	0.59	0.41	0.53	0.5	0.61	0.36	0.29	0.23	0.19
A_4	0.83	0.94	0.83	1	0.82	1	0.76	1	0.83	1	0.8	0.5	0.75	0.43
A_5	0.44	0.56	0.39	0.5	0.35	0.47	0.29	0.41	0.22	0.33	1	0.8	0.75	0.6
A_6	0.28	0.39	0.39	0.5	0.24	0.35	0.29	0.41	0.39	0.5	1	0.8	1	0.5
AI	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AAI	0.28	0.28	0.39	0.39	0.24	0.24	0.29	0.29	0.22	0.22	0.29	0.29	0.19	0.19

In this step, The weighted normalized decision matrix is obtained by multiplying the normalized matrix with the weight coefficients of the criteria. This step is illustrated in Table 5.

Table 5. Weighted normalized decision matrix

	C_1		C_2		C_3		C_4		C_5		C_6		C_7	
A_1	0.29	0.35	0.02	0.03	0.08	0.09	0.09	0.11	0.15	0.17	0.04	0.03	0.03	0.02
A_2	0.25	0.31	0.02	0.02	0.06	0.08	0.07	0.09	0.12	0.15	0.03	0.03	0.02	0.02
A_3	0.2	0.24	0.02	0.02	0.05	0.06	0.06	0.07	0.1	0.12	0.03	0.02	0.02	0.02
A_4	0.29	0.33	0.03	0.03	0.09	0.11	0.11	0.14	0.17	0.2	0.06	0.04	0.07	0.04
A_5	0.16	0.2	0.01	0.02	0.04	0.05	0.04	0.06	0.04	0.07	0.08	0.06	0.07	0.05
A_6	0.1	0.14	0.01	0.02	0.03	0.04	0.04	0.06	0.08	0.1	0.08	0.06	0.09	0.04
AI	0.35	0.35	0.03	0.03	0.11	0.11	0.14	0.14	0.2	0.2	0.08	0.08	0.09	0.09
AAI	0.1	0.1	0.01	0.01	0.03	0.03	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02

Finally, the utility functions of alternatives are computed, and based on the calculations, Cyber threats, Military threats, and Terrorist threats are the top three most dangerous man-made threats to Tehran. Table 6 shows this process.

Table 6. Utility functions and final ranking

	S_i		K_i^-		K_i^+		$f(K_i^-)$		$f(K_i^-)$		$f(k)$		Crisp	Rank
A_1	0.7	0.8	2.69	3.08	0.7	0.8	0.21	0.21	0.79	0.79	0.67	0.77	0.72	2
A_2	0.57	0.7	2.19	2.69	0.57	0.7	0.21	0.21	0.79	0.79	0.55	0.67	0.61	3
A_3	0.48	0.55	1.85	2.12	0.48	0.55	0.21	0.21	0.79	0.79	0.46	0.53	0.495	4
A_4	0.82	0.89	3.15	3.42	0.82	0.89	0.21	0.21	0.79	0.79	0.79	0.86	0.825	1
A_5	0.44	0.51	1.69	1.96	0.44	0.51	0.21	0.21	0.79	0.79	0.42	0.49	0.455	5
A_6	0.43	0.46	1.65	1.77	0.43	0.46	0.21	0.21	0.79	0.79	0.41	0.44	0.425	6

6. Sensitivity analysis

Two extensive experiments are planned and carried out to gauge the reliability of our study technique. First, eight cases have resulted in considerable alterations to the criterion weights. Then, two other MCDM methods are implemented to verify the obtained ranking by grey MARCOS.

6.1. Experiment 1

In this experiment, eight scenarios are designed to observe the differences in rankings by changing the criteria weights. Since the research topic is sensitive, which can heavily affect the future policy-making of Tehran city, criteria weights have undergone influential changes. Table 7 shows the scenarios and their results.

Table 7. Scenarios implementation

Scenario	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Grey MARCOS
S_1	0.143	0.143	0.143	0.143	0.143	0.143	0.143	$A_4 > A_1 > A_2 > A_5 > A_6 > A_3$
S_2	0.25	0.033	0.109	0.189	0.252	0.0775	0.088	$A_4 > A_1 > A_2 > A_3 > A_5 > A_6$
S_3	0.05	0.158	0.158	0.1583	0.158	0.158	0.158	$A_4 > A_1 > A_2 > A_6 > A_5 > A_3$
S_4	0.05	0.18	0.18	0.18	0.05	0.18	0.18	$A_4 > A_1 > A_5 > A_6 > A_2 > A_3$
S_5	0.15	0.15	0.15	0.15	0.133	0.13	0.13	$A_4 > A_1 > A_2 > A_5 > A_6 > A_3$
S_6	0.13	0.13	0.13	0.15	0.15	0.15	0.15	$A_4 > A_1 > A_2 > A_5 > A_6 > A_3$
S_7	0.8	0.033	0.033	0.033	0.033	0.033	0.033	$A_4 > A_1 > A_2 > A_3 > A_5 > A_6$
S_8	0.03	0.033	0.033	0.033	0.8	0.033	0.033	$A_4 > A_1 > A_2 > A_3 > A_6 > A_5$

Moreover, Figure 2 show the comparative results of implementing the scenarios.

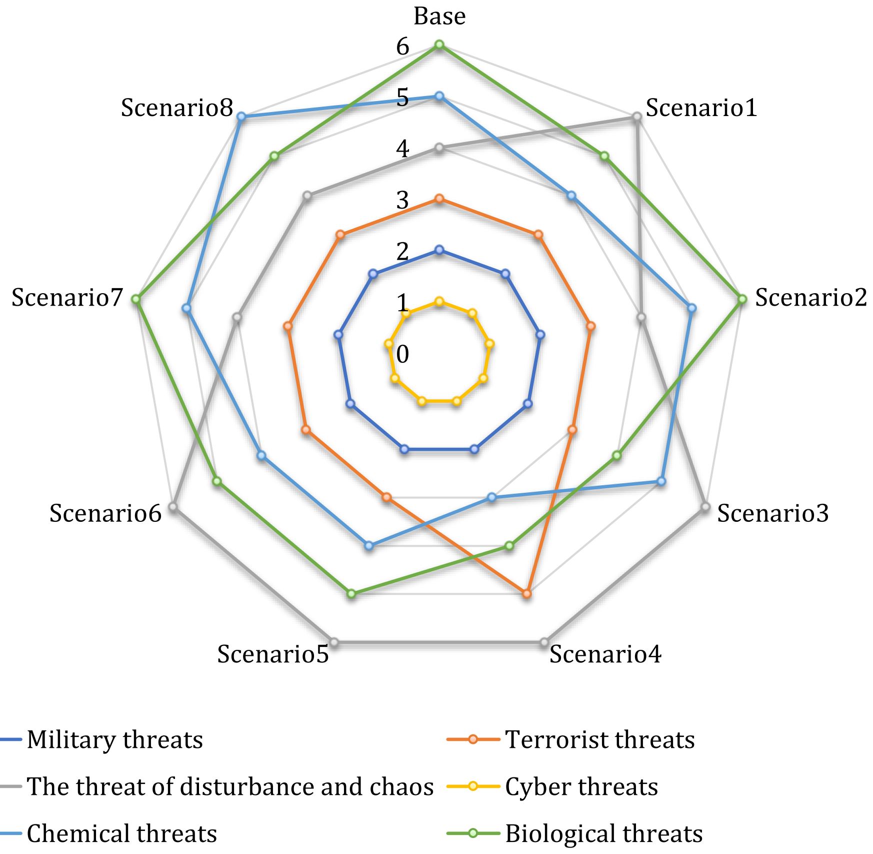

Figure 2. Scenarios comparative analysis

According to all scenarios, cyber and military threats are Tehran's top two most serious dangers. Additionally, terrorist threats rate as Tehran's third worst danger in scenarios 1-3 and 5-7. As evident from the scenarios, the changes in criteria weights are substantial, but the fluctuations in the ranking are negligible.

6.2. Experiment 2

To verify the ranking obtained by Grey MARCOS, Grey EDAS, and Grey COPRAS are implemented. Figure 3 shows the results.

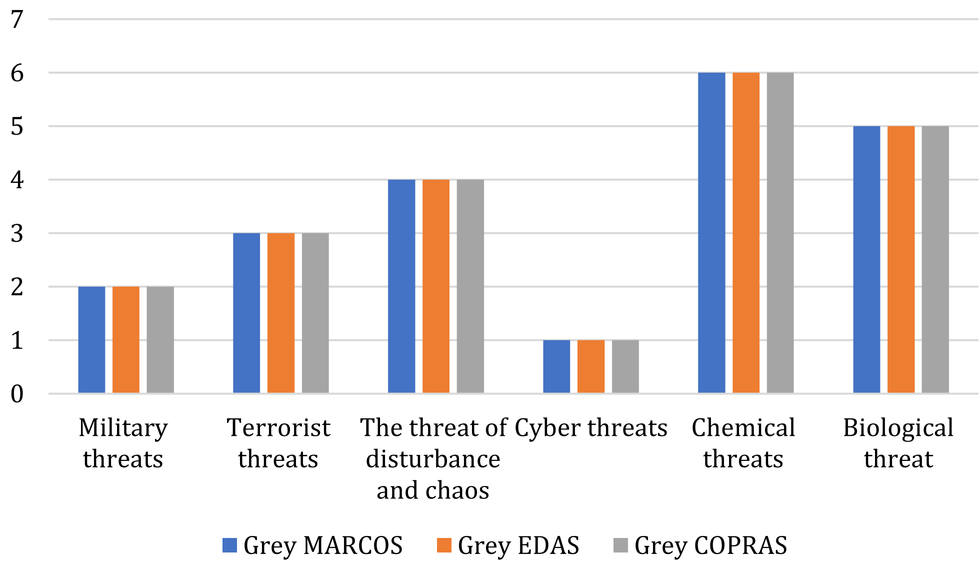

Figure 3. Three MCDM techniques results

Based on Figure 3, Grey EDAS and Grey COPRAS obtained the same prioritization as Grey MARCOS. Therefore, the results are robust enough to be trusted for future planning.

7. Discussuion and Conclusion

Due to their appeal and potential for enemy targeting, critical infrastructures, one of the locations in the nation's metropolises, need to be constructed in the framework of passive defense to reduce the chance of threats against them. This research aims to determine the human-made threat to cities based on the case study of Tehran as the first step in passive defense studies.

Therefore, MCDM techniques adapted to the ambiguous nature of the research problem are implemented. Then, the results obtained from mentioned methods are analyzed.

Based on the implementation of grey BWM, the severity of damage in infrastructures (C_1), risk level (C_5), and incorporating the least consequences of threats is our research's top three critical criteria.

In the damage severity criterion, which shows the number of casualties and physical damage to the city, cyber threats have a grey score of [75,85]. Since cities are moving towards more intelligence and urban management has become highly dependent on cyberspace, a cyber attack can threaten many infrastructures and disrupt the city's essential services.

Military threats, terrorist threats, and disturbance and chaos with a grey score of [75,90], [65,80], and [50,60] are the subsequent dangerous threats to the infrastructure of Tehran. Based on new theories in the physical and infrastructure field, the infrastructure is heavily damaged during a severe attack, and the continuity of essential services, such as electricity, water, gas, and fuel supply, is disrupted. In many ways, this problem paralyzes the city. Depending on the type of disturbance and chaos, the outcome includes a negative effect on public opinion, vandalism of important infrastructure, the closing of streets and disruption of transportation, conflict between anti-riot forces and disruption of urban security, closure of economic and educational centers, which results in material and moral harm and lowers the stability of the city. Besides, terrorist attacks are divided into three general categories; first, terrorist attacks on infrastructures are carried out to disrupt the functioning of infrastructures that have less damage than military attacks. The second type targets government officials, disrupting the systems' leadership and management. The third is blind terror, which targets ordinary people to create terror in society.

The next threat is chemical threats, with a grey score of [40,50], divided into the three categories of enemy chemical attacks, transportation of chemicals in the city and centers, and chemical industries located inside or in the city's suburbs.

The least serious danger, with a grey score of [25,35], is biological, which causes environmental contamination and human casualties but less affects infrastructures and is mostly employed for political and commercial goals. Based on experts, cyber threats have obtained the highest grey score [70,85] in the context of the enemy's capability. Military threats are ranked second with a grey score of [60,70], followed by terrorist attacks with a grey score of [50,60]. Disturbance, and chaos are ranked fourth with a grey score of [40,50]. Chemical and biological threats are ranked next with [30,40] and [20,30] scores, respectively.

One of the other criteria in evaluating man-made threats to cities, as mentioned, is incorporating the negative consequences for attackers. Based on obtained results, considering the importance of preserving the world's, and international organizations' public opinion, cyber, military, and terrorist threats are the top three most influential under the mentioned criterion.

The last index examined in this section is the occurrence history of threats, which based on the opinion of research experts, has received the lowest weight. The dynamic character of the dangers and their recurrence may be the cause. According to this criterion, cyber threats have received the highest scores, which makes sense given recent years and an increase in this type of threat in Tehran. Severe and military threats come in second, followed by threats from terrorist attacks, unrest, chaos, and chemical and biological agents. By implementing grey MARCOS, six identified man-made threats to cities are prioritized: cyber threats, military threats, terrorist attacks, disturbance and chaos, and chemical, and biological threats, respectively.

Moreover, a sensitivity analysis based on two noteworthy experiments was done to assess the research's robustness. First, eight harsh scenarios were implemented to observe ranking fluctuations under changing criteria weights. The results of this experiment showed that research outcomes are robust, and cyber threats, military threats, and terrorist attacks are the top three man-made threats to Tehran city. In experiment 2, grey EDAS and grey COPRAS were implemented, and the same results were obtained as grey MARCOS. Therefore, our research outcomes are robust enough to be considered for future policy-making and confronting man-made threats to cities, specially Tehrn as a case study. This research methodology is applicable to other countries and cities. The findings show that cyber assaults have the greatest likelihood of occurring and danger of being destructive. Of course, similar problems have occurred in the past; for instance, serious cyberattacks have targeted nuclear power plants and fuel stations. So as to prevent the nation from being immobilized in the case of assaults and catastrophes, it is advised that government institutions make investments in the cyber security sector. Military attacks are ranked second because there were many conflicts and wars in the sensitive region of the Middle East, which is under the supervision of major world powers. Iran has also been a victim of imposed wars in previous years. Strengthening the military infrastructure to prevent potential conflicts and increase regional influence and diplomacy is the key to removing threats to Iran, which can be done with a lot of investment. By the spread of Takfiri thinking and terrorist attacks in the Middle East, Iran, and especially Tehran, has not been spared from these attacks. Among these attacks, we can mention the terrorist attack on the Iran parliament on 7 June 2017.

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