Ranking and Analysis the Strategies of Crowd Management to Reduce the Risks of Crushes and Stampedes in Crowded Environments and Ensure the Safety of Passengers

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Abstract: Public gatherings, transit hubs, stadiums, and crowded retail malls are just a few examples of places where crowd management has become an urgent issue in recent years. Effective crowd management strategies have been required due to the increasing population, urbanization, and frequency of large-scale meetings. These strategies are used in dynamic, sometimes chaotic circumstances to protect people and facilitate their free movement. The purpose of this study is to analyze and rank various strategies for crowd management to reduce risks of crushes and stampedes, improve security, and facilitate smoother traffic flow. This study used the single-valued neutrosophic set to deal with uncertain and vague information in the evaluation process. There are various factors in ranking the various strategies. So, the concept of multi-criteria decision-making (MCDM) is used to deal with various criteria. The neutrosophic set integrated with the MCDM methodologies to rank various strategies. This study used the analytical hierarchy process (AHP) method to compute the weights of factors. Then the technique for order preference by similarity to the ideal solution (TOPSIS) method is used to rank the various strategies. An application was conducted to apply the proposed method. The outcome shows the safety and security factor is the heights important. The sensitivity analysis is applied to show the rank of strategies under various weights of factors. Finally, the comparative analysis is applied to show the robustness of the proposed method compared with other MCDM methods.

Keywords: Crowd Management; Neutrosophic Set; AHP; TOPSIS; Strategies; Risks.

1. Introduction

Public gatherings, transit hubs, stadiums, and crowded retail malls are just a few examples of places where crowd control has become an urgent issue in recent years. Effective crowd control measures have been required due to the increasing population, urbanization, and frequency of large-scale meetings. These methods are used in dynamic, sometimes chaotic circumstances to protect people and facilitate their free movement. The purpose of this study is to investigate and evaluate current approaches to crowd control to lessen hazards, improve security, and facilitate smoother traffic flow [1, 2].

Understanding crowd behavior and dynamics is crucial for effective crowd management. Researchers and practitioners can handle the issues given by various crowds by researching the nuances of crowd formation, movement, and response to stimuli. In addition, proper risk assessment and careful planning are essential for efficient crowd control. Event planners, facilities managers, and security staff may prepare thorough backup plans to enable rapid and effective reactions during crises by identifying possible hazards, weaknesses, and congested areas [3, 4].

Safety and order can't be maintained without using crowd control tactics. Crowds are managed via the use of physical barriers, staff, access control systems, and surveillance technology. To

maximize the efficiency of crowd movement and lessen the likelihood of accidents, several crowd control strategies are used [5, 6]. Staff members who are well-prepared and have had enough training are also essential for managing large crowds successfully. To effectively manage a wide variety of crowd scenarios, security professionals, event workers, and volunteers should have thorough training in crowd psychology, conflict resolution, emergency response, and first aid [7, 8].

1.1 Crowd Management Challenges

There are a number of factors to consider and solutions to use when attempting to manage large crowds in crowded settings. Comprehensive crowd control strategies are of critical importance as populations rise and metropolitan areas become more congested. Public events, transit hubs, stadiums, and retail malls are just a few examples of the many different places where crowd management presents a unique set of issues. Stakeholders can assure the safety, security, and efficient movement of people in congested environments by recognizing and comprehending the difficulties they face [3].

Unpredictability of crowds presents the first difficulty in crowd management. Due to their fluid nature and sometimes complicated behavior patterns, crowds are notoriously difficult to predict. Crowds are notoriously difficult to control, and a thorough grasp of crowd psychology is essential for doing so, due to factors such as emotions, group dynamics, and external influences.

The possibility for congestion and overcrowding is another major obstacle. Overcrowding and capacity issues are common in high-density areas due to population growth. Threats to public safety, delays in responding to emergencies, and lower productivity are all possible outcomes. The dangers associated with overcrowding may be reduced by the use of crowd management measures such as controlling crowd density, avoiding bottlenecks, and allocating sufficient space [2].

When dealing with large groups of people, communication may be a real headache. It might be difficult to get the word out to a big group of individuals in a timely and precise manner, particularly under pressure. Confusion, fear, and compromised security are all possible outcomes of inefficient communication. Strong mechanisms that allow efficient two-way communication between organizers, security officials, and the audience are necessary to overcome communication issues and ensure that clear instructions, emergency warnings, and pertinent updates are properly transmitted.

Another difficulty with crowd control is that different crowds have different demographics. Audiences at various events have varying demographics, preferences, and risk profiles. A crowd at a music festival, for instance, is likely to behave differently from one at a sports event. In order to successfully adapt crowd management tactics and execute suitable measures to handle certain crowd dynamics, it is essential to understand and accommodate these varied characteristics.

Maintaining order and keeping people safe in densely populated areas is a very difficult task. Stampedes, terrorist attacks, and criminal acts are only some of the dangers that might arise in large crowds. Essential components of crowd management techniques to meet safety and security concerns include developing thorough risk assessment and management plans, employing sufficient security personnel, adopting surveillance technology, and creating efficient emergency response procedures [1].

So this paper aims to identify and rank the set of strategies to overcome these challenges and obtain safety and security.

There are many contributions to this paper:

- The first study ranks and analyses the crowd strategies to reduce the crushing and obtain safety and security.
- The first study uses the neutrosophic set to deal with uncertain data in the evaluation process.
- This study uses the multi-criterion decision-making (MCDM) methods to analyze and rank crowd strategies.
- There are six factors and ten strategies gathered in this study.
- The analytical hierarchy process (AHP) method is used to compute the weights of factors.

- The technique for order preference by similarity to the ideal solution (TOPSIS) method is used to rank several crowd strategies.

2. Related Work

This section introduces some previous work in crowd management and gives the limitations and outcomes of each work as shown in Table 1. From Table 1, there is no precious work introducing the neutrosophic set with crowd management. So, this paper integrated the neutrosophic set with the MCDM methods to rank and analyze the crowd strategies to reduce crowd crushes and give more safety and security.

Table 1. Previous work was in crowd management.

Year	Ref.	Techniques	Findings	Limitations
2019	[9]	Fuzzy Logic	The findings validate the use of fuzzy logic in emergencies. When using the directed selection criteria, people act naturally and with a clear focus on the intended outcome. Adjustments to velocity using fuzzy logic and the addition of a psychological impact component have both been shown to be effective in experiments. In addition, considering a person's proximity to exits, fuzzy Cellular Automata rules for intuitive exit selection have been included.	No validation of their models by the real data.
2021	[10]	Fuzzy System	The key contribution is the development of a fuzzy-based arousal and valence inference system. Because capturing the expressions of people in a throng is challenging. They used characteristics of a crowd (such as its enthalpy, variation in movement magnitude, confusion index, and density) to characterize its mood. The arousal fuzzy system takes as input variables the crowd's enthalpy and the variation in the magnitude of the crowd's movement. The inputs of the valence fuzzy inference system are the confusion index and the crowd density. In addition to emotion categorization, the suggested fuzzy system also provides arousal and valence ratings for the emotions of the audience as an output. The experimental findings confirm the viability of using this approach to assess the mood of a crowd. Two-feature fuzzy systems have been proven to be more flexible than single-feature systems. Crowd behavior and emotion are difficult to predict, making it challenging to find a universal solution that works in all situations.	A few crowd images, silent features, and emotion description models.

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2020	[11]	Attentive Multi-stage CNN	Attentive Multi-stage CNN for Crowd Counting (AMCNN) is a unique network architecture presented by the researchers. Both a hierarchical density estimator (HDE) and an auxiliary count classifier (AUCC) are included in the AMCNN. The HDE takes a hierarchical approach to mine semantic characteristics from coarse to fine to solve the issue of size shifts and viewpoint distortions. The final density map is made using the collected composite characteristics. In addition, a soft attention mechanism is included in the AMCNN to differentiate between foreground and origins, which improves the quality of the density map.	The small size of the dataset.
2016	[12]	Fuzzy Logic	It is suggested to use a fuzzy logic method to characterize the behavior of crowds during an evacuation, factoring in the impact of potential attackers. The micro-level pedestrian and assailant models are first constructed, with each character's goals in mind during evacuation drills. There are three subgroups of pedestrians based on whether they have been targeted by violent criminals. Adjustable weighting factors, which are updated in real-time depending on the perceptions obtained from the intricate relationship with the surrounding situations, are used to integrate the suggestions of local obstacle-avoiding behavior, regional path-searching behavior, and global goal-seeking behavior to assess an individual's behaviors.	There are a small number of features.
2023	[13]	Fuzzy logic	They detailed a novel method for evaluating crowd health that broadens the range of possible interactions between people and motor vehicles. They employed fuzzy logic sorting to make the algorithm better at spotting outliers in large groups of people. A unique deep transfer learning (DTL) method is used to collect images from unmanned aerial vehicles to enhance making choices. The suggested combined model has a 98.5% accuracy percentage, good performance, and resilience to population behavior.	Their proposed model is not validated with other models.
2017	[14]	Fuzzy Theory	To examine the effects of communication on crowd dynamics, a fuzzy-theory-based	They haven't overcome the

			approach was provided. Human states are notoriously difficult to describe precisely, which is why fuzzy functions and rules were developed. Decision-making output values, like the rates and directions of pedestrian motion, are determined using reasonable inference. Good crowd dispersal phenomena are accomplished by modeling in four-way pedestrian settings. The simulation results under various scenarios show that the effective dispersal of the crowd cannot be guaranteed by the transmission of information. This is particularly relevant when considering the cohesiveness and efficiency of decision-making techniques in response to threat information in large groups. Increases in both the drift intensity at low density and the proportion of pedestrians selecting one of the furthest empty Von Neumann neighbors from the harmful origin as the drift route at high density were shown to be beneficial in dispersing the throng.	uncertain information in their proposed model.
2022	[15]	Heuristic Technique	Procedural methods are effective at solving a wide variety of issues. Nevertheless, these techniques aren't always feasible due to their slowness; sometimes it's just impossible to achieve an outcome using primitive methods. When the optimal answer cannot be guaranteed, a heuristic technique may be used to get close enough for practical purposes. The use of heuristic-based modeling helps clarify crowd behavior and enhance simulation dependability, and heuristic approaches are utilized for many real-world challenges, especially crowd management.	No focus in the time.
2022	[16]	Machine Learning	They researched automated machine learning support systems, which are useful for crowd control. Machine learning (ML) is a subset of AI that helps developers improve software's predictive abilities in ways that weren't originally designed for that purpose. To predict future output values, machine learning methods take in historical data as input. Given the significance of data, the next step towards fully autonomous agents must be the development of better ways for effectively	No model validation with other machine learning models.

			handling the now-ubiquitous crowd-powered content-gathering platforms. Apps for mobile devices, computers, the internet, and even online security all employ similar methods. They conclude that a machine-learning-based automated support system is necessary for efficient crowd control.	
2019	[17]	Reinforcement Learning	They developed a deep-reinforcement-learning-based smart routing method to ease network congestion and equalize network load for promoting smart city amenities with striking inequalities, thereby rendering the dispersed information and communication facilities thoroughly feasible and fulfilling the latency limitations of service demands from the crowd.	No model validation.

3. Methodology

In this section, we integrated the single-valued neutrosophic set with the MCDM methods. We used the AHP and TOPSIS methods. The AHP method is used to compute the weights of the criteria. The TOPSIS method is used to compute the rank of strategies. Figure 1 shows the proposed method.
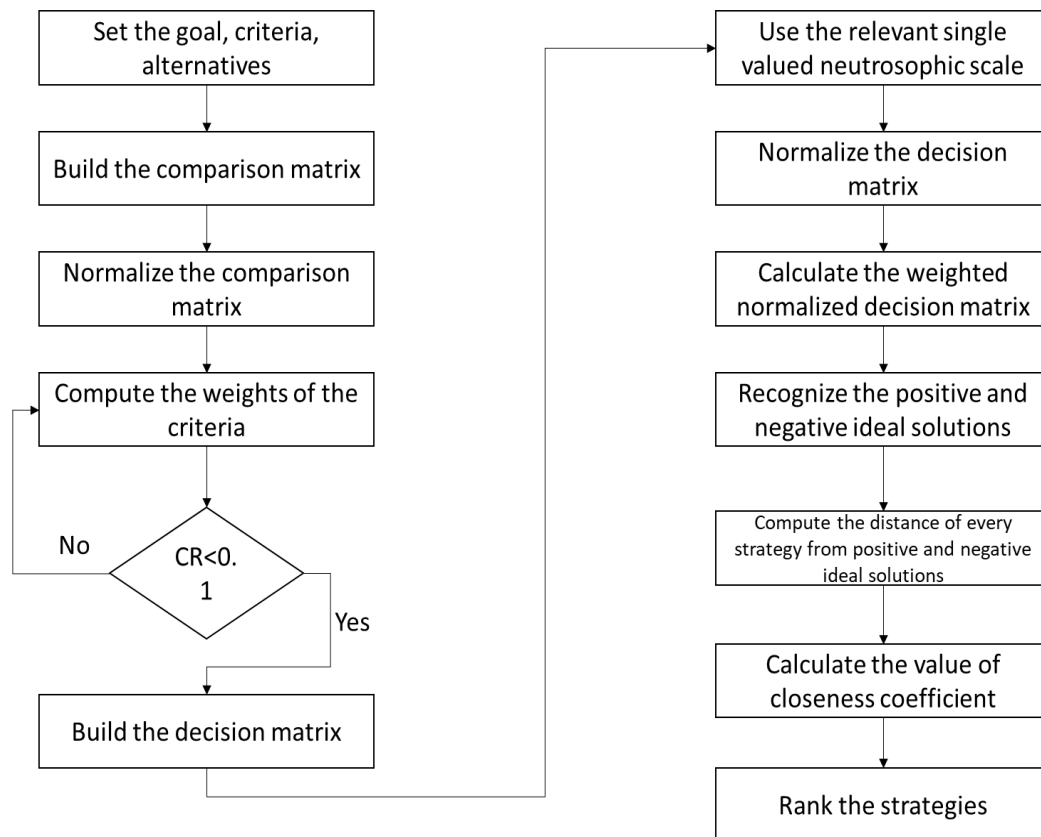

Figure 1. The framework of the proposed model.

3.1 Problem Definition

Public gatherings, transit hubs, stadiums, and crowded retail centers all provide unique crowd control difficulties. The issue at hand is how to manage large groups of people in a way that protects their health, safety, and happiness. The following critical challenges are becoming more important to handle as crowd sizes and complexity increase.

The danger of physical injury and injuries is elevated when there are huge numbers of people present. Accidents, falls, stampedes, and trampling events may occur as a result of overpopulation, inadequate infrastructure, poor crowd flow management, and insufficient safety measures. The challenge is coming up with plans and procedures to lessen these dangers and make the crowd a secure place for everyone.

Fires, terrorist attacks, and acts of violence are just a few examples of the types of events that may cause large crowds and provide a serious challenge to crowd control. Consequences from such incidents tend to multiply in high population concentrations because of the speed with which they may spread. In order to properly manage these circumstances and reduce the number of casualties among the crowd, we need to design thorough emergency response plans, perform risk assessments, and train employees.

Crowded places increase the likelihood that infectious illnesses may be spread among the crowd's participants, which poses a threat to public health. Infections may spread rapidly due to factors including close proximity, lack of sanitary facilities, poor ventilation, and restricted access to medical care. Public health concerns in large gatherings may be reduced with the help of improved sanitation and hygiene practices, as well as the installation of medical facilities and first-aid stations.

Concerns of a Social and Behavioral Nature, disorder, and illegal activity have been known to escalate in large crowds. Individuals may feel emboldened to participate in disruptive behavior in a crowded area, putting the safety and enjoyment of others at risk. The challenge is to find ways to keep the peace among the throng, resolve any conflicts that arise, and prevent any disruptive behavior from taking place.

The growing dependence on technology for crowd control raises concerns about the potential for disruptions and safety risks in the event of system failure or improper usage. Threats to crowd control activities might come from broken surveillance equipment, unstable communication lines, or malicious cyber activity. The challenge is to take precautions against cyberattacks, establish secure networks, and perform routine maintenance on all systems.

So, this paper used the set of criteria to rank crowd management strategies to reduce crowd crushes and obtain safety and security.

3.2 The AHP method

Saaty introduced AHP as a relative measuring strategy for qualitative and intangible criteria. It is a mathematical method that may also be used as a tool for decision analysis. It is an MCDM tool that puts complicated problems in a hierarchical sequence for easy analysis [18]–[23]. The following are only a few of the reasons why the AHP method was chosen for this study:

It provides support for dealing with complicated, unstructured, multi-attribute challenges.

It helps decision-makers break down complex problems into manageable chunks that are easier on the wallet.

It works effectively with both quantitative and qualitative information.

It presents complex choice issues in a hierarchical format.

A spreadsheet may be used to find the answer.

It allows us to ensure that our evaluation methods are consistent with one another.

Here is a quick rundown of what goes into an AHP analysis:

Step 1. Set the goal, criteria, and alternatives. This step identifies the goal of the study, the factors of crowd management, and the strategies to reduce the crowds.

Step 2. Build the comparison matrix. The comparison matrix is built between criteria.

Step 3. Normalize the comparison matrix. The normalization matrix is computed by computing the sum of every column, then dividing every value in pairwise comparison by the sum of each column.

Step 4. Compute the weights of the criteria. The weights of the criteria are computed by the mean value of every row in the normalization matrix.

Step 5. Compute the consistency ratio. The consistency ratio is computed by the consistency index and random index.

$$CR = \frac{(\lambda_{max} - n/\,n-1)}{RI} \qquad (1)$$

Where n refers to the number of criteria.

3.3 The TOPSIS method

Hwang and Yoon devised this method. The goal of this approach is to return the largest possible deviation from the negative ideal solution and the smallest possible deviation from the positive ideal solution. Although it is a well-known technique in MCDM, it has several significant drawbacks. However, it falls short when dealing with topics that are, at best, nebulous [24]–[29].

Instead of utilizing numerical values, evaluating ratings and weights of the criterion using language variables is preferable. The neutrosophic set allows decision-makers to account for indeterminate, uncertain, or otherwise difficult-to-assess data and information [30]–[33].

Step 1. Use the relevant single-valued neutrosophic scale.

Step 2. Build the decision matrix. The decision matrix is built between criteria and alternatives. Then aggregate the multiple decision matrices into one matrix.

Step 3. Normalize the decision matrix. The decision matrix is normalized by using the beneficial and non-beneficial criteria.

$$a_j^* = \max a_{ij} \quad \text{beneficiale criteria} \qquad (2)$$
$$a_j^- = \min a_{ij} \quad \text{non-beneficiale criteria} \qquad (3)$$

The a_{ij} refers to the value in decision matrix $i = 1,2,3,\dots m \ (alternatives); j = 1,2,3,\dots\dots n \ (criteria)$

Step 4. Calculate the weighted normalized decision matrix.

$$H = \left[h_{ij}\right]_{m \times n} \qquad (4)$$
$$h_{ij} = a_{ij} \times w_j \qquad (5)$$

Where w_j refers to the weights of the criteria.

Step 5. Recognize the positive and negative ideal solutions.

$$S^+ = \{h_1^+, h_2^+, h_3^+ \dots h_n^+\} \qquad (6)$$
$$s_j^+ = \{\max(h_{ij})\} \qquad (7)$$
$$S^- = \{h_1^-, h_2^-, h_3^- \dots h_n^-\} \qquad (8)$$
$$s_j^- = \{\max(h_{ij})\} \qquad (9)$$

Step 6. Compute the distance of every strategy from positive and negative ideal solutions.

$$t_i^+ = \left\{\sum_{j=1}^n \left(h_{ij} - h_{ij}^+\right)\right\}^{\frac{1}{2}} \qquad (10)$$

$$t_i^- = \left\{\sum_{j=1}^n \left(h_{ij} - h_{ij}^-\right)\right\}^{\frac{1}{2}} \qquad (11)$$

Step 7. Calculate the value of the closeness coefficient.

$$F_i = \frac{t_i^-}{t_i^- + t_i^+} \qquad (12)$$

Step 8. Rank the strategies.

The strategies are ranked based on the highest value of F_i.

4.   Results and Discussion

This section aims to rank and analyze several strategies of the crowd to reduce risks of the crowd and achieve safety for passengers. This study used six factors and ten strategies. The factors of crowd management are ranked by using the AHP method. The strategies are ranked by using the MCDM methods. These methods are integrated with the single-valued neutrosophic sets to overcome the uncertain information.

Crush and stampede prevention in crowded areas calls for forethought, crowd management strategies, and clear lines of communication. The following are some measures that may be taken to prevent such potentially harmful events:

Safely managing large crowds requires knowing and sticking to the venue's maximum capacity. Keep an eye on the attendance and make sure it doesn't rise beyond the set limit. To keep an eye on crowd density and take appropriate measures if it rises to dangerous levels, crowd monitoring equipment or staff should be put into place.

The smooth flow of attendance may be ensured by designating and marking certain entrance and departure locations. Make sure the gates are large enough to prevent traffic jams at the access points. In the event of an emergency, the gathering should be dispersed as rapidly as possible.

To control the flow of people entering and exiting and to avoid congestion, it is important to establish clear and orderly lines or queues. Put up stanchions or barriers to direct the flow of people and ensure orderly lineups. Keep an eye on wait times and adjust as required to keep traffic moving smoothly.

Clear pathways should be marked out so that attendees may easily navigate the venue or event location. Make use of signs, floor markings, or electronic displays to direct traffic and avoid collisions. Avoid traffic jams and potential collisions by establishing designated routes or establishing one-way circulation patterns.

Make sure everyone in the audience knows what's going on by making announcements and posting signs that are easy to see. To ensure that critical information, instructions, and safety announcements reach everyone, use a variety of communication tools, including but not limited to public address systems, digital displays, and mobile apps.

Staff and crowd control employees with the necessary training to regulate crowd behavior and deal with emergencies should be deployed. They need to be familiar with methods of crowd management, methods of resolving conflicts, and emergency protocols. Put them to use in high-traffic or possible stampede situations.

Prepare for any kind of disaster by making sure you have a solid strategy in place and practicing it often. Create safe escape routes and meeting areas. Staff members should be prepared to handle large crowds in the event of an emergency by learning crowd control and evacuation procedures.

Always be on the lookout for any indicators of unease or danger within the crowd by keeping tabs on its size, movement, and demeanor. Make use of tools like video surveillance and crowd monitoring devices to get timely information. After the event is over, take stock and see where your crowd control might have been better.

Detect probable incidents or risky circumstances involving crowds by using early warning systems. Sensors, video analytics, and social media monitoring tools are all possible components of such infrastructures. Be ready to act quickly if you see any symptoms of discomfort or unusual crowd behavior.

Collaborate with Local Governments: Establish and execute crowd control strategies in close cooperation with local law enforcement and emergency services. Make sure that during times of crisis, everyone is on the same page in terms of communication, reaction, and backup plans.

The potential for accidents like crashes and stampedes may be mitigated in crowded settings by using these measures and keeping a proactive attitude toward crowd control.

The previous strategies can be evaluated by the following six factors of crowd management:

Overcrowding, stampedes, and other potentially disastrous events may be avoided with the use of crowd control methods. Creating cordons, barriers, and lineups helps direct traffic and regulate access to certain locations.

The safety and security of the audience must be prioritized above everything else. This includes the use of tools like luggage inspections, metal detectors, closed-circuit television, and trained security staff to spot and deal with any crises that may arise.

Maintaining open lines of communication is essential for successful crowd control. It is the responsibility of the event staff to advise the audience of any changes or announcements that may affect the enjoyment or safety of the event.

Managing a large gathering of people requires a well-trained and sufficiently staffed team. Crowd management, dispute resolution, disaster preparedness, and effective communication are all skills that event workers should have, and they should be taught to them by the event's organizers. The crew is prepared for every eventuality thanks to their extensive training and extensive expertise.

Being ready for and anticipating possible crises is an important part of managing large crowds. Making preparations for emergencies include mapping out escape routes and arranging ready access to medical care. Staff and guests should be trained and made acquainted with emergency protocols via regular exercises and rehearsals.

Understanding the dynamics and patterns of crowd behavior is essential for creating efficient crowd control plans. Crowd behavior may be affected by a wide variety of demographic, cultural, and personal factors. Crowd behavior may be better understood and anticipated with the use of data collected via analysis of prior occurrences.

4.1 The Results of the AHP Method

The AHP method is used to compute the weights of factors as:

Step 1. Set the goal, criteria, and alternatives. The goal of this study is to reduce crowd crushing and obtain the highest safety in crowd management by ranking strategies and analyzing the factors of crowd management. This study identified six factors and ten strategies.

Step 2. Build the comparison matrix. This study builds the pairwise comparison matrix between six factors from the opinions of the experts and decision-makers. This study used single-valued neutrosophic numbers to evaluate the criteria by building the pairwise comparison matrix.

Step 3. Normalize the comparison matrix. Then compute the normalized pairwise comparison matrix as shown in Table 2. Where CMF_1 refers to the first factor, and so on.

Table 2. The normalization pairwise comparison matrix by the AHP method.

	CMF_1	CMF_2	CMF_3	CMF_4	CMF_5	CMF_6
CMF_1	0.075376	0.019299	0.043127	0.074754	0.15296	0.104908
CMF_2	0.319389	0.081774	0.035045	0.030247	0.152867	0.096599
CMF_3	0.118702	0.158477	0.067917	0.042437	0.081632	0.05141
CMF_4	0.115963	0.310929	0.184056	0.115006	0.036766	0.18673
CMF_5	0.076477	0.08302	0.129119	0.485461	0.155195	0.151038
CMF_6	0.294092	0.346501	0.540737	0.252095	0.420581	0.409316

Step 4. Compute the weights of the criteria. Then compute the weights of the criteria as shown in Figure 2. The safety and security factor is the highest rank of all factors.

Step 5. Compute the consistency ratio. Then compute the consistency ratio by using Eq. (1). The consistency ratio is less than 0.1. Then the weights of factors are consistent. Then the data is ready to apply the TOPSIS method to rank the ten strategies.
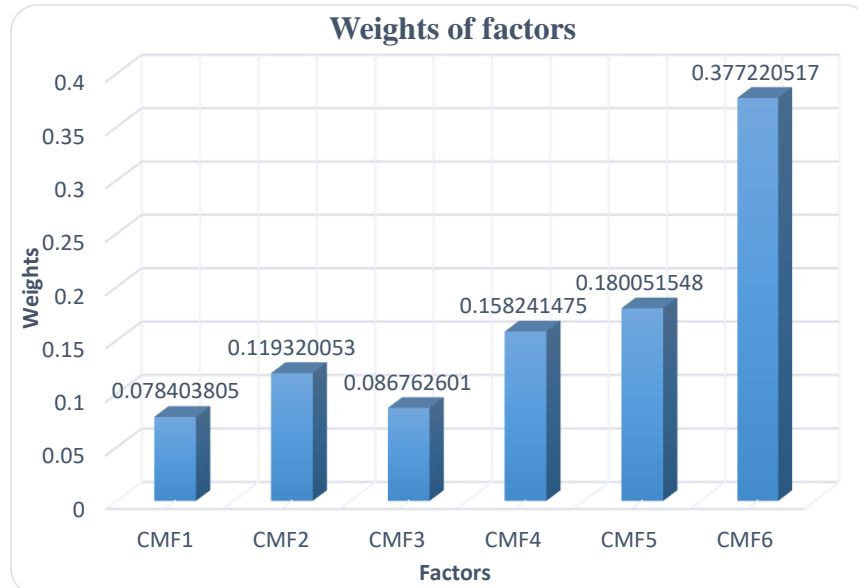
Figure 2. Weights of six factors.

4.2 The TOPSIS Method Results

The TOPSIS method is used to compute the rank of strategies as:

Step 1. Use the relevant single-valued neutrosophic scale. We used one single valued neutrosophic scale for the factors and strategies.

Step 2. Build the decision matrix. The decision matrix is built between the criteria and strategies by the experts and decision matrices. Then these matrices are combined into one matrix.

Step 3. Normalize the decision matrix. The normalization of the decision matrix is computed by using Eqs. (2 and 3) as shown in Table 3. by identifying the beneficial and non-beneficial criteria. All factors are beneficial factors. Where the CMS_1 refers to the first strategy and CMF_1 refers to the first factor.

Table 3. The normalization of decision matrix by the TOPSIS method.

	CMF_1	CMF_2	CMF_3	CMF_4	CMF_5	CMF_6
CMS_1	0.148622	0.44692	0.178969	0.150158	0.242999	0.415177
CMS_2	0.148622	0.221599	0.306528	0.235228	0.116009	0.345052
CMS_3	0.398004	0.604637	0.366766	0.134742	0.221506	0.237469
CMS_4	0.33125	0.221599	0.380734	0.292893	0.118262	0.270465
CMS_5	0.148622	0.313355	0.366766	0.300315	0.230516	0.45821
CMS_6	0.392336	0.221859	0.345474	0.360835	0.593185	0.299263
CMS_7	0.553553	0.221599	0.306528	0.300486	0.493695	0.408683
CMS_8	0.353921	0.204287	0.124309	0.486442	0.342583	0.167934
CMS_9	0.232379	0.221599	0.114463	0.450587	0.221975	0.237469
CMS_{10}	0.161217	0.221599	0.467067	0.260463	0.221506	0.167015

Step 4. Calculate the weighted normalized decision matrix. The weighted normalized decision matrix is computed by using Eqs. (4 and 5) as shown in Table 4. The weights of criteria are computed by the AHP method is multiplied by the value in the normalization decision matrix.

Table 4. The weighted normalization of the decision matrix by the TOPSIS method.

	CMF_1	CMF_2	CMF_3	CMF_4	CMF_5	CMF_6
CMS_1	0.011653	0.053327	0.015528	0.023761	0.043752	0.156613
CMS_2	0.011653	0.026441	0.026595	0.037223	0.020888	0.130161
CMS_3	0.031205	0.072145	0.031822	0.021322	0.039882	0.089578
CMS_4	0.025971	0.026441	0.033034	0.046348	0.021293	0.102025
CMS_5	0.011653	0.03739	0.031822	0.047522	0.041505	0.172846
CMS_6	0.030761	0.026472	0.029974	0.057099	0.106804	0.112888
CMS_7	0.043401	0.026441	0.026595	0.047549	0.088891	0.154164
CMS_8	0.027749	0.024375	0.010785	0.076975	0.061683	0.063348
CMS_9	0.018219	0.026441	0.009931	0.071302	0.039967	0.089578
CMS_{10}	0.01264	0.026441	0.040524	0.041216	0.039882	0.063002

Step 5. Recognize the positive and negative ideal solutions. The positive and negative ideal solutions are identified by using Eqs. (6-9). All factors are positive, so the positive ideal solution is computed.

Step 6. Compute the distance of every strategy from positive and negative ideal solutions. The distance from each strategy is computed by using Eqs. (10 and 11).

Step 7. Calculate the value of the closeness coefficient. The closeness coefficient is computed by using Eq. (12) as shown in Figure 3.

Step 8. Rank the strategies. The strategies are ranked based on the highest value of F_i.
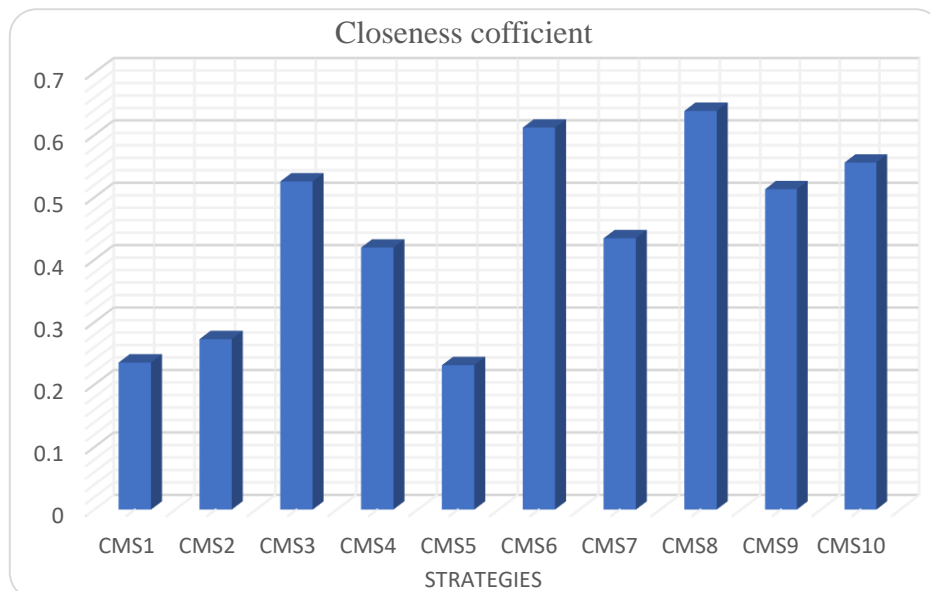
Figure 3. The closeness coefficient value.

4.3 The Sensitivity Analysis

In this sub-section, we changed the weights of factors to show the rank of strategies under different cases in weights. We change the weights of the criteria by increasing the factor by 50% and reducing the other factors by 50% to obtain a total weight of 100%. This study introduces the seven cases of changing the weights of factors as shown in Table 5. In the first case, the weights of factors are equal. Then the other factors we put the one factor with 50% weight and five factors are 50% weight. We applied these seven cases to the TOPSIS method to show the rank of strategies as shown in Figure 4.

Table 5. The seven cases in weights of factors.

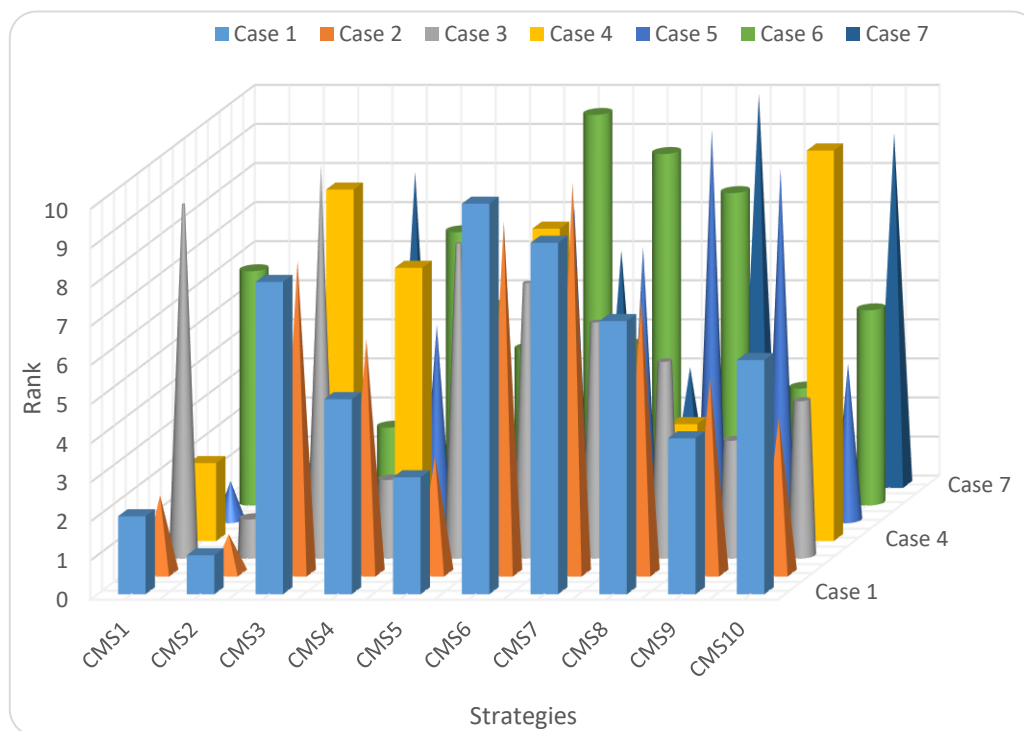|	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
CMF_1	0.17	0.5	0.1	0.1	0.1	0.1	0.1
CMF_2	0.17	0.1	0.5	0.1	0.1	0.1	0.1
CMF_3	0.17	0.1	0.1	0.5	0.1	0.1	0.1
CMF_4	0.17	0.1	0.1	0.1	0.5	0.1	0.1
CMF_5	0.17	0.1	0.1	0.1	0.1	0.5	0.1
CMF_6	0.17	0.1	0.1	0.1	0.1	0.1	0.5

Figure 4. The sensitivity analysis ranking.

4.4 The Comparative Analysis

In this sub-section, we compare the rank of strategies by other MCDM methods to show the robustness of the proposed model. This study keeps the weights of factors by the AHP the same in all the MCDM methods. This study compared the proposed model by the single-valued neutrosophic VIKOR method, single-valued neutrosophic MABAC method, fuzzy TOPSIS method, crisp TOPSIS method, fuzzy VIKOR method, and fuzzy MABAC method. Table 6 shows a comparative analysis between the proposed method and other MCDM methods.

Table 6. The comparative analysis between the proposed method and other MCDM method.

	Single-valued neutrosophic VIKOR	Single-valued neutrosophic MABAC	Fuzzy TOPSIS	Fuzzy VIKOR	Fuzzy MABAC	Proposed method
CMS_1	8	9	9	8	9	9
CMS_2	9	8	8	5	8	8
CMS_3	5	4	4	9	4	4
CMS_4	7	7	7	7	7	7
CMS_5	10	10	10	10	10	10
CMS_6	2	6	2	2	6	2
CMS_7	6	2	6	6	1	6
CMS_8	1	1	1	1	2	1
CMS_9	4	5	5	3	5	5
CMS_{10}	3	3	3	4	3	3

Then compute the correlation between the proposed method and comparative MCDM methods. The correlation methods show the correlation between two variables. Figure 5 shows the correlation between the proposed method and other MCDM methods.
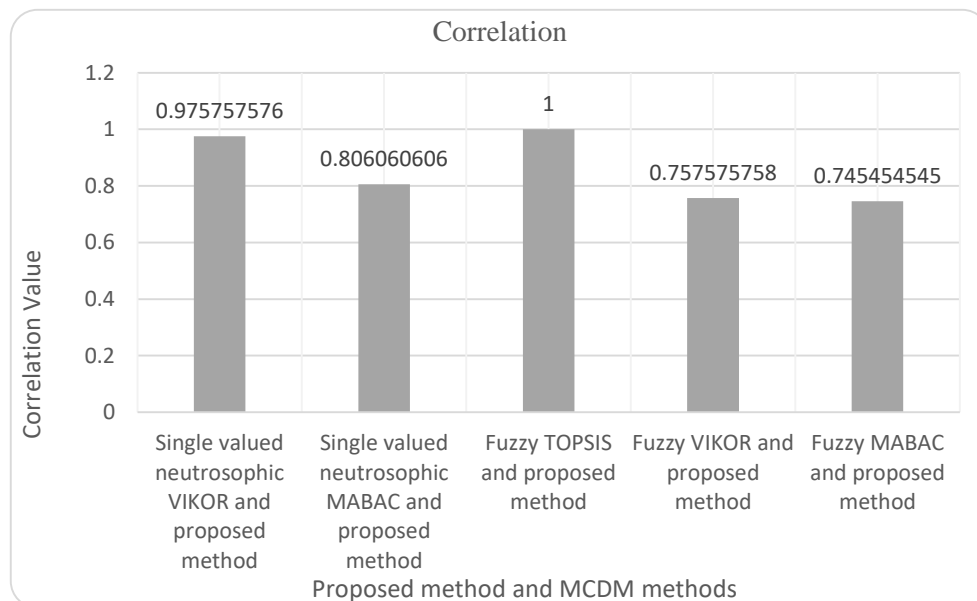
Figure 5. The correlation between the proposed method and other MCDM methods.

4.5 Managerial and Practical Implications

Discussion and management and practical implications according to the case application results are highlighted in this sub-section. The research takes into consideration a genuine situation where major difficulties with the crowd management strategies are recognized, and it then evaluates the suitable strategy selection for the effective deployment and security of the crowd management strategies ranking. Prioritization of strategies begins with an analysis of relevant criteria. To do this, we use the AHP approach, which is based on the single-valued neutrosophic set, to assign relative

importance to the various criteria associated with putting into practice and maintaining the crowd management strategies. The strategies are ranked using the TOPSIS approach based on the single-valued neutrosophic set. As a result, we offer a method that uses the single-valued neutrosophic set with the AHP-TOPSIS together to help choose the best strategy of action for crowd management. Literature, studies, official papers, and expert views provide the basis for the suggested method's evaluation of the criteria and solutions for the crowd management strategies ranking. Challenges of crowd management are studied, and a plan of action is developed to give strategies to overcome them.

Collaboration and open lines of communication among all parties involved are essential for successful crowd management. Managers should encourage communication and coordination between event planners, venue managers, security staff, first responders, and local authorities. During both normal and emergency operations, it is crucial to have established lines of communication and systems for coordination in place to guarantee a synchronized response and the exchange of important information. Consistent get-togethers, drills, and team-building activities may help.

Managers should provide training and skill development opportunities for those working with large crowds. All employees should be trained and prepared to deal with any problems that may arise as a result of large crowds. Conflict resolution, crowd psychology, emergency responses, communication, and customer service should all be part of any appropriate training. A knowledgeable and prepared staff that can manage crowds and react to crises successfully may be maintained via regular training and exercises.

There is a lack of research on the use of MCDM to prioritize strategies for the efficient rank and analysis the crowd management strategies. Consequently, the suggested technique adds a lot to the theoretical and practical knowledge base of ranking crowd management strategies. The research has the following primary theoretical and practical implications:

- For the first time in the literature, we combine the AHP based on the single-valued neutrosophic numbers with TOPSIS methodology and apply it to the prioritization of crowd management strategies the reduce the crushes risks and obtain security and safety.
- The criteria for evaluating the methods to reduce the crushing risks and obtain the security and safety of ranking crowd management strategies are developed using research literature, reports, official documents, and expert comments. This adds to the existing literature a comprehensive framework for evaluating the difficulties.
- The proposed methodology in ranking crowd management strategies to reduce the crushing risks and obtain security and safety can be applied in Africa for example Egypt.

5.   Conclusions

It is impossible to guarantee the safety, security, and efficiency of high-density settings without using appropriate crowd control strategies. Stakeholders can create safer and more organized spaces for crowds of all sizes by learning about crowd behavior, conducting thorough risk assessments, analyzing crowd flow patterns, implementing strong communication systems, deploying crowd control strategies, and providing comprehensive staff training. The purpose of this study is to investigate these strategies in depth to provide helpful information to professionals, academics, and policymakers working on crowd control. Also, ranking these strategies provides decreasing crowd crushing and increases safety and security. This study used six factors and ten strategies. Two MCDM methods are used in this paper. The AHP method is used to compute the weights of six factors. Then the TOPSIS method was used to rank the ten strategies. The single valued neutrosophic set was used to deal with uncertain information. The sensitivity analysis shows the proposal is robust. This study also compared the proposed model with various MCDM methods like VIKOR and MABAC. In future

studies, the proposed model can be used in various industries like welding selection, energy selection, and others. Also, various MCDM methods can be applied to this problem like entropy to compute the weights of factors, VIKOR, and MABAC method to rank strategies. Researchers must be more careful in their selection of experts if they want reliable results. Therefore, it is necessary to establish a set of standards by which to choose competent professionals. The reliability of the expert evaluations may also be enhanced by increasing the number of academic experts that participate. In addition, we suggest that future integrated decision-making models make use of an uncertain possibility programming framework, a precise algorithm, and a double normalized approach.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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