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FROM THE EDITOR

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Dear people of the scientific world,

CSS JOURNAL started publishing in 2023. CSS Journal is a social science platform where everyone who is engaged in academic studies in the field of social sciences can have their say.

I would like to express my gratitude to our valuable professors on the board of directors of the journal, who have contributed to the activities of CSS Journal since its establishment, as well as to our valuable professors, both at home and abroad, who have been on the advisory, publishing and referee boards and contributed to us with their areas of expertise.

In this journey that we have embarked on to contribute to academic life to some extent, we would like to have you, the valuable people of the scientific world, with us as the editorial board, advisory board, referee board and author. Additionally, your guidance and suggestions to help us achieve perfection will give us even more strength.

I would like to thank you for all your support for CSS Journal and offer my best regards.

Assist.Prof.Dr. Burçin ATASEVEN DOĞRU

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CONTENTS

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Contents

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Research Article
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Eliminating the Communication Problem That May Occur After an Earthquake by Positioning Flying Base Stations

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ABSTRACT

Earthquakes cause severe disruptions to communication networks, delaying critical rescue operations. This study investigates the use of Unmanned Aerial Vehicles (UAVs) and Flying Base Stations (FBS) to establish temporary GSM coverage in disaster-stricken areas, inspired by the February 2023 Kahramanmaraş earthquake. Using a Location Covering Model implemented in GAMS, we optimized FBS deployment to minimize costs while ensuring effective coverage. The model identifies strategic charging station locations and drone assignments to maximize efficiency. Our findings demonstrate that UAV-based communication systems can significantly enhance rescue efforts by reconnecting survivors and first responders. This innovative approach provides a scalable, cost-effective solution to one of the most pressing challenges in disaster management.

Keywords: disaster communication, earthquake response, location covering model

INTRODUCTION

In the face of natural disasters, humanity faces the most difficult challenges. Among these, seismic events such as earthquakes not only cause widespread destruction but also disrupt communications networks, increasing the complexity of rescue and relief efforts. Aware of the necessity of innovative solutions, this research focuses on the field of Unmanned Aerial Vehicles (UAVs) and Flying Base Stations (FBS) and investigating their potential for use in post-earthquake communication infrastructure.

Continuously developing technology enables the emergence of different usage areas for UAVs today. As agile and adaptable vehicles, drones offer a unique opportunity to overcome the limitations of traditional ground-based communication systems. This research deals with a scenario that puts individuals in a difficult situation immediately after the earthquake, where communication is broken and the need for fast and effective help comes to the fore.

While deepening this review, we are inspired by past earthquake experiences, especially the Kahramanmaraş earthquake of February 6, 2023, and we always keep in mind the fact that our country is an earthquake country. These incidents highlighted the important role individuals with access to their phones play in their own rescues. In response to such critical scenarios, we direct our focus to GSM connectivity via UAVs or FBS; The goal is not only to close the communication gap, but also to enable people in distress to report their location and speed up their rescue.

In the crucible of disaster response, our research brings a model with Location Covering Model. This model, executed through the GAMS, finds which charging stations to send drones to which debris points by minimizing costs.

LITERATURE REVIEW

In disaster-stricken areas, particularly during seismic events like earthquakes, the breakdown of communication infrastructure poses a critical challenge. The disruption in cellular networks and communication towers severely impedes the ability to reach and assist individuals trapped under debris. This leads to a dire situation where those in need of immediate assistance remain inaccessible due to the loss of connectivity. Conventional infrastructure's vulnerability to natural disasters necessitates the development of a robust, resilient communication solution that can immediately connect rescuers to survivors even amidst the chaos caused by earthquakes.

With the developing technology, drones and unmanned aerial vehicles can be used in many areas. They are especially actively used in rescue work in disaster areas.

The possibility of installing LTE (Long Term Evolution) base stations were examined on drones as a backup plan in cases where the current infrastructure is overloaded (Wyckmans, Joseph, & Martens, 2018). In addition to calculating the number of drones needed to maximize user coverage, the tool they design will identify the best placements for these drones based on base station characteristics and drone power consumption. For their algorithm, they employed the ratio approach and the hotspot technique. They discovered that the ratio strategy works better when there is greater user coverage. Still, there is very little variation—between 0.01% and 0.22%. The study's first findings indicate that researching drone use in emergency situations is a potential option.

In another research of these authors, their research investigates the viability and effectiveness of an unmanned aerial vehicle (UAV) emergency network in the event of a major catastrophe (Deruyck, Wyckmans, Martens, & Joseph, 2016). To do this, they suggest a deployment tool for an emergency network assisted by UAVs that would offer user coverage in the event of a major disaster. They created an algorithm for UAV-assisted network deployment by utilizing Java. A four-part algorithm. In the first, they produce the actual user traffic that the network will be built to handle. The second step is to compile a list of potential base station locations. In the third stage, we design the actual network by determining the best locations for the base stations based on this list.

Daniel Câmara's study introduces an autonomous drone fleet for effective disaster search and rescue operations. The specialized drones are equipped to perform tasks such as mapping affected regions, establishing communication, and identifying hot spots with potential victims. The focus is on autonomy and self-organization to streamline data collection during critical hours. The study demonstrates that an autonomous drone fleet can significantly enhance search and rescue efforts in disasters. The fleet's ability to immediately gather critical information autonomously allows human resources to concentrate on life-saving activities. The emphasis on opportunistic communication and coordination among drones improves overall operational efficiency in disaster scenarios.

Another study addresses challenges in using Unmanned Aerial Vehicles (UAVs) for disaster response, focusing on limited range, high sensor costs, and skilled operator requirements (Alex & Vijaaychandra, 2016). The proposed solution involves a networked system of drones, each assigned specific tasks and sensors. Pathfinder drones create 3D maps sent to the cloud, enabling infrared-equipped drones to locate stranded individuals. This information guides heavy lift cargo drones for efficient aerial supply drops. Simulations validate the cost-effective system, demonstrating its potential for quick and efficient disaster response. The networked drones, sharing data through the cloud, offer a low-cost solution without compromising effectiveness in mapping and locating survivors.

Rising internet traffic during mass gatherings demands improved wireless network performance (Seda, Pokorny, Seda, & Hosek, 2021). This paper proposes leveraging Unmanned Aerial Vehicles (UAVs) as Flying Base Stations (FBS) to optimize connectivity. A mathematical model based on the location set covering problem is presented to minimize FBS deployment while meeting user throughput requirements. Cuckoo search and differential evolution algorithms are implemented and evaluated in a real music festival scenario. The results highlight computational efficiency differences, offering insights for cost-effective FBS placement in commercial applications. The paper introduces a novel mathematical model for optimal FBS distribution, addressing key aspects like user capacities and computational complexity. Cuckoo search and differential evolution algorithms showcase efficiency differences, guiding network infrastructure design and providing insights for cost assessment in large-scale scenarios. Future research should consider real-life measurements for enhanced accuracy.

As a result of literature research, many studies have been conducted to find the optimal number and placement points of UAVs. The fact that most of the studies were based on a case study of all natural disasters with huge destructive effects caused many factors to be ignored. The biggest shortcoming of studies created within the framework of natural disasters is that flying base stations or unmanned aerial vehicles are designed to assist officers during Search and Rescue operations. These vehicles have the functions of assisting search dogs, providing communication between teams, or notifying teams of signals they detect by measuring body temperature. On the other hand, studies have been carried out on placing flying base stations in the right places with the right numbers in places where internet traffic is intense.

Our study is about people who were trapped under the rubble after the earthquake, were able to access their phones, and were waiting to be pulled out from under the rubble. The national experience gained from the February 6, 2023 Kahramanmaraş earthquakes has shown that there were people who could survive for very long hours under the rubble. In the same incident, it was observed that people who were able to access their phones were rescued after they were able to indicate their location to their relatives or on social media. The focus of this study is to provide GSM via unmanned aerial vehicles or flying base stations to people who are trapped under rubble in a region and can reach their phones and enable them to reach aid teams. Although all points within the region have equal priority, mathematical modeling in the methodology to be used will be made according to this criterion.

To indicate the scope of our study, we focused on the predicted Istanbul earthquake. Location preference is based on the characteristics of the UAV and the region or district where the number of people to be reached will be highest to increase applicability and maximize the efficiency of the study. This will be done by taking into consideration the land areas of the neighborhoods within a district. The findings obtained because of the literature review are mentioned below.

METHODOLOGY

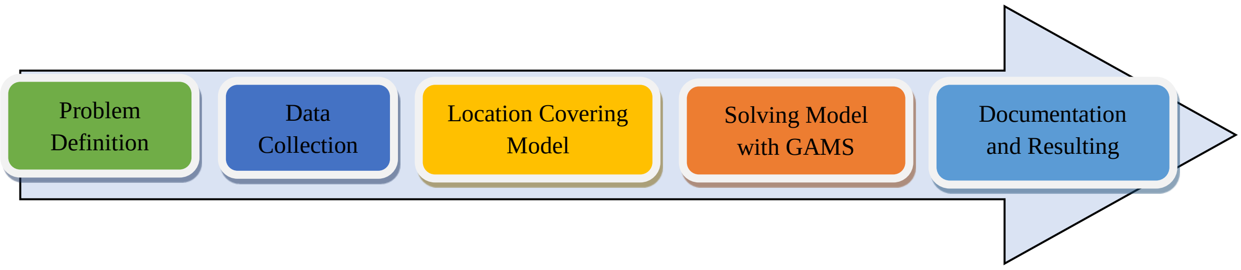

Figure 1: Visual Diagram of The Methodology

Problem Definition

The objective is to design a Location Covering Model for optimizing the cost for deployment of flying base stations (FBS) and coverage the whole determined area which is in earthquake-affected region. In the Location Covering Model, we have main distribution centers and flying base stations. The goal is to optimize the cost and cover the entire earthquake-affected area effectively.

Data Collection

- Identification of Risky Areas: Review seismic data and reports from the Istanbul Metropolitan Municipality to pinpoint areas most susceptible to earthquake impact.
- Analysis of Flying Base Station Studies: Analyze reports from previous studies involving flying base stations to understand their successes, challenges, and potential applications.
- Assessment of Technological Capabilities: Evaluate the technological capacities of airborne communication systems and their reliability during seismic events.
- Community Feedback: Conduct surveys in high-risk zones to gather insights into past communication challenges during disasters and expectations for emergency communication.
- Surface Area Data: Using a website to get detailed surface data for a determined area. In further of this study, this data is going to be used to calculate the required number of drones to cover surface.

Table 1: Distances between charge station to debris point

	Charge Station					
Debris Points	Maltepe	Merkezefendi	Seyitnizam	Beştelsiz	Yenidoğan	Kazlıçeşme
Beştelsiz	2810	1240	789	520	1370	2310
Çırpıcı	2810	1580	1210	1000	1580	2370
Gökalp	3510	2000	1490	322	600	1530
Kazlıçeşme	3880	2980	1860	830	500	2040
Maltepe	1000	1300	2060	3360	4280	4910
Merkezefendi	1630	426	533	2140	3500	3500

Nuripaşa	4180	3200	2150	1030	225	813
Seyitnizam	2060	783	301	1420	2330	3000
Sümer	4330	3350	2360	1350	748	1000
Telsiz	2720	1200	699	660	1500	2460
Veliefendi	3250	2300	1450	809	1200	1940
Yenidoğan	4000	3000	2000	825	90	1000
Yeşiltepe	3560	2560	1630	630	760	1540

Mathematical Model

The Location Covering Model seeks to optimize the distribution strategy for a single product across two tiers: from central warehouses to primary distribution centers and further to secondary distribution points, ensuring efficient delivery to end-users. Widely applied in supply chain and logistics management, this model aims to enhance distribution network efficiency and minimize costs.

Creating the Location Covering Model:

Indexes:

k = 1..., 6 (Charging station)

j = 1…, 13 (Debris)

Parameters:

F_{kj} = fixed cost of sending 1 unit of flying base station from charging station k to debris j

a_{jk} = binary constant equal to 1 if charging station k can serve debris j

Decision variables:

y_k = 1 if charging station k is used, $k \in V_1$

x_{jk} = 1 if charging station k send 1 unit of flying base station to debris j

Objective function:

$$min\, z = \sum_{k \in V_1} \sum_{j \in V_2} F_{jk} . x_{jk} \qquad (1)$$

$$\sum_{k \in V_1} a_{jk} x_{jk} = 2, \qquad j \in V_2 \qquad (2)$$

$$\sum_{j \in V_2} x_{jk} \leq |V_2| y_j, \qquad k \in V_1 \qquad (3)$$

$$y_k \in \{0,1\}, \qquad k \in V_1 \qquad (4)$$

$$x_{jk} \in \{0,1\}, \qquad k \in V_1,\ j \in V_2 \qquad (5)$$

The objective function (1) aims to minimize the cost of sending flying base stations from charging stations to debris points. The first constraint (2) ensures that all debris points are served, planned in a way that two drones are dispatched to each debris point. This is because, from the perspective of rescuing individuals under debris, we want to ensure that everyone can be reached for assistance. The second constraint (3) ensures each charging station can serve all debris points by limiting the sum of drone assignments to no more than the total number of debris points multiplied by the charging station indicator. In our final equations, one (4) check whether the charging station is being used, while the other (5) assesses whether a flying base station (FBS) is being sent from the charging station to the debris point.

Solutions with Gams

The mathematical model will be implemented and solved using the General Algebraic Modeling System (GAMS) with the Mixed Integer Programming (MIP) solver. GAMS provides an efficient platform for formulating and solving complex optimization models. Since our model does not include any nonlinear terms and only includes integer variables, we solved the model with MIP.

Determining Optimal Deployment of Drones

Evaluate the results obtained from the mathematical model to determine which charging stations to send drones to which debris point. Consider factors such as cost effectiveness and coverage efficiency when making these deployment decisions.

IMPLEMENTATION

We tried to set a replenishment number so as not to leave any area without a drone in the first 24 hours. While determining this, we considered the need for 1 hour for the drones to be fully charged and the restrictions on flying time, and we realized that if we made the charging stations every 1 km, we could fix the number of replenishments. That's why we determined a total of 6 charging stations by going 1 kilometer from the width and height of the Zeytinburnu map. These are in "Maltepe, Merkezefendi, Seyitnizam, Beştelsiz, Yenidoğan and Kazlıçeşme Neighborhoods."

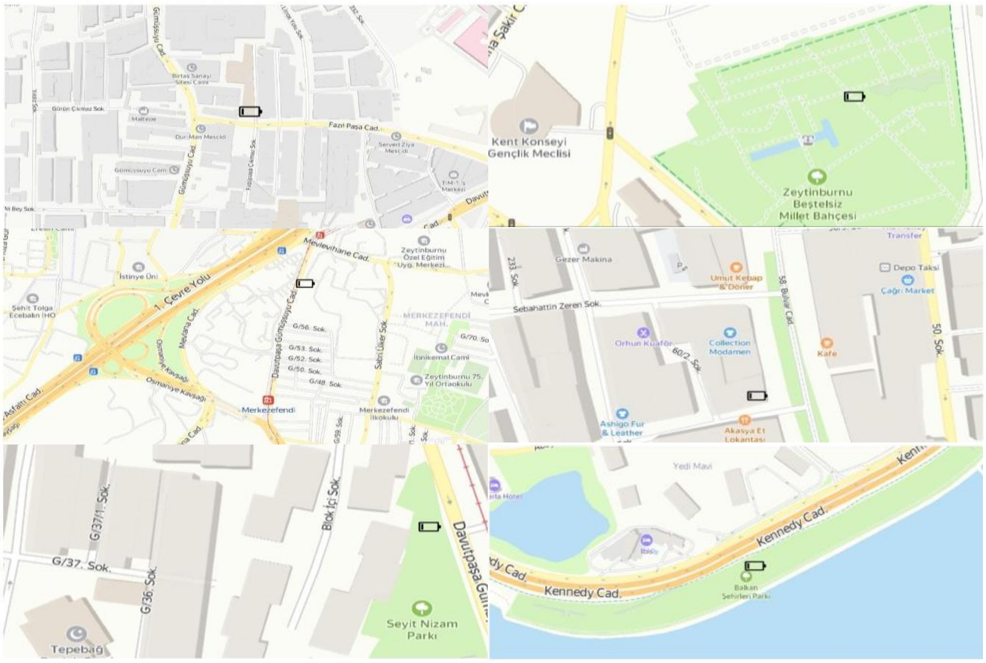

Figure 2: Map of Charge Stations

RESULTS

In this section, GAMS results are presented. Then, the results of the study that is prepared according to GAMS results are explained.

```
----      72 VARIABLE y.L  if charge station k used

1 1.000,    2 1.000,    3 1.000,    4 1.000,    5 1.000,    6 1.000
```

Figure 3: Result of decision variable y(k)

Figure 3: Result of decision variable y(k)shows that each of the six stations are used. This means that all stations will serve to some demand points.

---- 72 VARIABLE x.L if charge station k sent to debris point j

	1	2	3	4	5	6
1		1.000			1.000	
2		1.000	1.000			
3		1.000	1.000			
4			1.000	1.000		
5	1.000	1.000				
6	1.000	1.000				
7				1.000	1.000	
8		1.000		1.000		
9				1.000	1.000	
10		1.000			1.000	
11			1.000			1.000
12			1.000	1.000		
13			1.000			1.000

Figure 4: Result of decision variable x(j,k)

Figure 4: Result of decision variable x(j,k)shows the result indicating which charge station should serve to which demand point. In the model, demand of debris points is not specified, and no capacity is assigned to charge stations. What is expected from the mathematical model and GAMS software is to find which charge station should serve which demand point at minimum cost. The costs are determined by considering time and distances between charge stations.

```
----     72 VARIABLE obj.L                 =  2850000.000
```

Figure 5: Result of objective function

Figure 5**:** Result of objective function shows that the minimized cost is 2.850.000,00 Tl.

In the final phase of the study, we have determined which charge station should send how many drones to demand points to satisfy demands. Firstly, the assignments are tried to be done with balance to the stations. Secondly, all demands are multiplied with 3 due to considering replenishment of the drones. After the 1st, 2nd and 3rd drones respectively served the point, we calculated that the 1st drone, which went to charge, was able to catch up with the 3rd drone. This means: an area with a diameter of 700 meters can be serviced by a total of 3 drones throughout the study period (24 hours) Table 2**:** Demand Table shows demand of each debris point. The second column shows how many drones ranges the area can be covered. The third column shows how many drones are needed to serve the area for 24 hours. Lastly, Table 3**:** Required drones for each station below shows how many drones should be in stations to satisfy demands of debris points. Also, it shows which stations are going to be serving to which demand point by indicating the number of drones.

Table 2: Demand Table

Demand Point	Demand	With Replenishment (Demand*3)
BESTELSIZ	2	6
ÇIRPICI	3	9
GÖKALP	2	6
KAZLIÇESME	1	3
MALTEPE	2	6
MERKEZEFENDI	3	9
NURIPASA	3	9
SEYITNIZAM	4	12
SÜMER	4	12
TELSIZ	4	12
VELIEFENDI	3	9
YENIDOGAN	1	3
YESILTEPE	2	6
TOTAL	**34**	**102**

Table 3: Required drones for each station

		Charge Stations					
		1	**2**	**3**	**4**	**5**	**6**
Demand Points (Debris Points)	**1**		2			4	
	2		3	6			
	3		0	6			
	4			3	0		
	5	6	0				
	6	9	0			0	
	7				9		
	8		2		3	7	
	9				4	8	
	10		12				
	11			1			8
	12			0	3		
	13			1			5
	Total	**15**	**19**	**17**	**19**	**19**	**13**

CONCLUSION

The goal of this research study is to use flying base stations (FBS) and unmanned aerial vehicles (UAVs) to overcome communication issues that occur following earthquakes. Particularly focused on those trapped beneath debris, this study intends to strategically optimize the deployment of flying base stations from charging stations to specific regions in earthquake-affected areas to construct a comprehensive communication network. A mathematical model called the Location Covering Model was developed and put into use using GAMS with the goal of reducing the expense of allocating flying base stations to charging stations in the best possible way.

Drone assignments, fixed costs, and charging station locations are all included in the mathematical model. The GAMS application's results show how to use all six charging stations efficiently and provide a cost-effective assignment plan. Decision variables make it evident which charging station drones belong in which area. The analysis also considers factors of practical implementation, such as the assignments required for different regions and the charging station placements on the Stainburn map. One of the study's ideas is to assign 102 drones from charging stations, with a focus on each station assigning drones to a certain zone. In this manner, a 24-hour window for thorough communication is set.

In conclusion, this research study offers important insights into catastrophe management and communication infrastructure for future improvements by fusing technical and practical factors.

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Optimizing the Location for an Advanced Biological Wastewater Treatment Plant in Antalya: A Multi-Criteria Decision-Making Approach

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ABSTRACT

This article offers a comprehensive examination aimed at ascertaining the optimal site for a novel wastewater treatment facility within the heart of Antalya. The research evaluates three possible sites: Döşemealtı, Kepez, and Konyaaltı, using Multi-Criteria Decision-Making (MCDM) techniques, notably the Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Important factors are taken into account, including the impact on the environment, proximity to water bodies, existing infrastructure, flood risk, distance from residential areas, and odor control. The study tackles the urgent requirement to handle the city's expanding population and seasonal tourists, which will probably exceed the existing infrastructure's capacity by 2030. Konyaaltı is the best site for the new facility, according to the weighted criteria. The current study offers useful data for Antalya's sustainable urban development as well as a well-organized framework for making decisions in comparable situations. Subsequent investigations may examine supplementary elements or approaches designed to improve the quality of decision-making procedures.

Keywords: wastewater treatment, facility location optimization, Multi-Criteria Decision-Making, Analytic Hierarchy Process, Antalya

INTRODUCTION

Antalya is one of the most well-liked and heavily populated towns on the Mediterranean coast, with over 2.6 million residents as of 2021. Five metropolitan districts comprise Antalya's city core: Aksu, Döşemealtı, Kepez, Konyaaltı, and Muratpaşa. It is anticipated that the Hurma facility in Konyaaltı and the Lara facility in Muratpaşa, the two effective biological wastewater treatment facilities that these districts now depend on, will be able to meet the needs for wastewater treatment until 2030. Although because of increasing immigration and seasonal variations in the amount of wastewater produced by visitors, a new wastewater treatment plant in the city center is desperately needed (Demirel et al., 2023).

The research comprises evaluating the existing research on MCDM applications in wastewater treatment plant location selection, defining relevant evaluation criteria, identifying and characterizing three potential locations within the metropolitan districts, and applying the chosen MCDM method to determine the best site. The report is organized into four sections: an introduction, a literature review, a methodology part, an implementation and outcomes section, and a conclusion that offers recommendations for using the findings and points to potential directions for further research.

LITERATURE REVIEW

Sustainable engineering provides solutions that meet present needs without risking the capacity of future generations to meet their own. Multi-criteria decision-making (MCDM) has become fundamental in the field of sustainable engineering, despite the fact that it considers the perspectives of several stakeholders and tackles complex issues. Sustainable engineering provides solutions that meet present needs without jeopardizing the capacity of future generations to meet their own. It does this by taking into account the environmental, social, and economic impacts of a system's design across its complete life cycle. MCDM approaches facilitate informed decision-making and promote sustainable solutions in many industries such as building design, transportation, energy, water systems, and manufacturing processes by achieving balancing between these components. The literature on MCDM techniques in sustainable engineering covers a wide range of topics, including renewable energy, supply networks, risk assessment, fuzzy sets, sustainability principles, and decision-making frameworks. This wide variety demonstrates the breadth of application of sustainable engineering. An extensive examination of MCDM methods clarifies their applications, benefits, drawbacks, challenges, and possible directions for future research. By providing essential direction, the ensuing corpus of work improves the ability of scholars and practitioners in the field to employ sustainable engineering solutions (Štilić & Puška, 2023).

As well as In order to promote resilience and long-term sustainability Cetkovi and Kneževi (2023) ensures a sustainable engineering approach to problem-solving that takes into account the many repercussions of engineering decisions. The incorporation of MCDM approaches allows for this. Wastewater treatment is necessary to reduce pollutants to levels safe for the health of humans and animals as well as for the preservation of the ecosystem. Municipal wastewater, particularly that which contains high levels of organic matter, phosphorus, and nitrogen, has to be treated efficiently utilizing technologies such as the Moving Bed Biofilm Reactor (MBBR). The study aims to maximize wastewater treatment in Dojran, North Macedonia, by evaluating three possible methods. Numerous aspects are considered throughout the appraisal process, such as the size of the site, treatment efficiency, system analysis, and financial limits (Cetkovi & Kneževi, 2023).

Al Nasiri and Al Fazari. (2023) The Analytic Hierarchy Process (AHP) approach was used to aid in decision-making, and it was ultimately determined that the construction of a new treatment station employing MBBR technology for 6,000 equivalent households was the most advantageous solution. MBBR technology has several benefits over conventional methods, including high efficiency, minimal space requirements, affordability, and user-friendliness. These advantages make MBBR the ideal choice for effective wastewater treatment. In another side STPs, or sewer treatment plants, are crucial for reducing the water scarcity that urbanization has caused. A study employing a Multi-Criteria Decision-Making Analytic Hierarchy Process (MCDM-AHP) model inside a Geographic Information System (GIS) framework was conducted to identify suitable locations for STPs in Muscat, Oman. The study considered eight characteristics, including slope, elevation, and proximity to inhabited regions. It determined that the coastal districts of A'Seeb and Bowsher were the most suitable contenders for the STP location. Applying MCDM approaches is crucial to urban infrastructure design in order to meet multiple needs and be in line with the Sustainable Development Goals. Additionally, it makes decision-making more deliberate. This study highlighted the need of standardized data for compatibility and integration to enhance urban sustainability planning. What distinguishes the study is its relevance to Oman, where it offers valuable data for urban planning and policy. With the backing of Sultan Qaboos University, the research ensures that all data are publicly available, improving the area's transparency and stimulating additional study initiatives (Al Nasiri & Al Fazari, 2023).

METHODOLOGY

Figure 1 illustrates how a directed procedure guides the methodology part. Accurate evaluation of the problem description is the first step in the research process. Next, criteria that highlight the essential elements for decision-making are developed. Subsequently, the alternative evaluation procedure presents a variety of possibilities. The accurate collection of data, which yields important information to aid in decision-making, is the following stage. To make comparative evaluation easier, the criteria are weighted using the Analytic Hierarchy Process (AHP). The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is then used to thoroughly examine the options. The results analysis offers a summary of the discoveries along with enlightening suggestions for more study.

Figure 6: Flowchart Diagram

Problem Definition

An additional wastewater treatment plant in Antalya's city center is urgently needed, given the expected rise in immigration and the seasonal changes in wastewater volume induced by tourists. The Hurma facility in Konyaaltı and the Lara facility in Muratpaşa, Antalya's present wastewater treatment facilities, are expected to be able to handle the city's residential wastewater treatment demands only until 2030. In order to meet this demand, the selection criteria for the location of the new plant are weighed and their relative priority is established using the Analytic Hierarchy Process (AHP). The towns of Konyaaltı, Kepez, and Döşemealtı are possible sites for the new wastewater treatment facility. After the criteria have been weighted using AHP, the potential sites will be ranked according to how well they perform in relation to the weighted criteria using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). A comprehensive and transparent decision-making process will be ensured by employing this method to determine the ideal site for Antalya's new wastewater treatment facility.

Criteria

The project of constructing a new wastewater treatment plant in the city center of Antalya needed a thorough assessment of the relative importance of several factors. Each criterion was ranked as High, Medium, or Low based on the specific impact that determined its relative relevance. Strategic planning and decision-making were aided by this in-depth knowledge of the needs and how they relate to one another, which produced essential understanding into how each component influences the project's conclusion. By developing a comprehensive criterion matrix and taking into account the following factors, every factor was accurately weighted: Odor Control (High), Flood Risk (Medium), Proximity to Water Bodies (High), Environmental Impact (High), and Distance from Residential Areas (Medium). These specifications made sure that every possible site was assessed for its effects, which is crucial for the long-term and prosperous growth of the wastewater treatment facility.

Alternatives

Döşemealtı, Kepez, and Konyaaltı have been selected as the alternative options for the new sophisticated biological wastewater treatment plant in the heart of Antalya due to their advantageous positions and room for expansion within the metropolitan area. Döşemealtı's expanding residential and industrial zones make it a well-balanced site suitable for a large-scale treatment facility. Kepez is a heavily inhabited region that offers a vital potential to enhance wastewater treatment in a densely populated area due to its ongoing urban expansion. Konyaaltı has a number of benefits for effective integration and growth due to its built infrastructure and close proximity to already-existing facilities. Three alternate locations on Google Maps are shown in Figure 2 below.

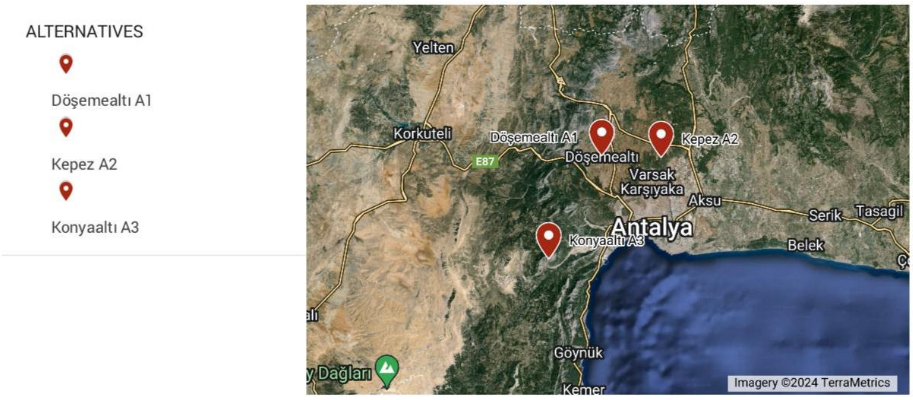

Figure 7: Alternatives Maps Location

DATA COLLECTION

We thoughtfully selected our research data, with an emphasis on significance, correctness, and comprehensiveness, to guarantee the validity of our study. We have carefully selected a wide variety of elements and characteristics from prior research to assist us accomplish our study's aims. Each criterion was weighed in accordance with its particular elements and relevance during this procedure. A thorough and in-depth evaluation approach was produced by carefully scaling each possible site on a range of 1 to 10 using these weighted parameters. With thorough validation procedures, we have made sure that the data quality meets the highest standards and closely aligns with the goals and needs of the study's conduct.

Environmental Impact

An important factor in determining the wastewater treatment plant's possible influence on the environment is its environmental impact. This entails assessing the possibility of contamination of the air, water, and soil in addition to the impacts on nearby species and ecosystems. Reducing the project's environmental effect is essential to its sustainability and compliance with regulations. Long-term ecological health and compliance with environmental laws and regulations are ensured by effective management of environmental consequences, and this is essential for securing the required licenses and public support.

Proximity to Existing Infrastructure

To ascertain how readily the new facility can be linked with present systems, its proximity to existing infrastructure is assessed. This considers factors like the proximity to current roadways, electricity grids, sewage lines, and other facilities. Being adjacent to existing infrastructure eliminates the need for substantial new installations, which can lead to significant savings on construction and operating expenses. It may also improve logistical efficiency, which makes managing operations and moving supplies simpler. There would probably be less delays and issues throughout the building process at a site with good infrastructural connections.

Proximity to Water Bodies

A useful feature for treated water discharge is the criterion's measurement of the distance to the closest bodies of water. The process of dumping treated effluent can be made simpler by being closer to water bodies, which can eliminate the need for lengthy pipelines and pumping stations. Nonetheless, cautious environmental management is also necessary to prevent pollution and save aquatic habitats. Reduced infrastructure costs and improved environmental sustainability are among the possible advantages, if discharge requirements are closely followed and closely monitored.

Flood Risk

In order to guarantee the wastewater treatment plant's operational stability and resilience, flood risk assessments are crucial. This criterion entails estimating the probability of flooding in the region, which can be impacted by variables including terrain, climatic trends, and past flood data. It is better to choose locations with less chance of flooding in order to prevent future facility damage, business disruptions, and higher maintenance expenses. A location that is less likely to flood guarantees longer-term operations that are safer and more dependable, lowering the possibility of catastrophic failures and the ensuing negative effects on the environment and the economy.

Distance from Residential Areas

In order to guarantee the wastewater treatment plant's operational stability and resilience, flood risk assessments are crucial. This criterion entails estimating the probability of flooding in the region, which can be impacted by variables including terrain, climatic trends, and past flood data. It is better to choose locations with less chance of flooding in order to prevent future facility damage, business disruptions, and higher maintenance expenses. A location that is less likely to flood guarantees longer-term operations that are safer and more dependable, lowering the possibility of catastrophic failures and the ensuing negative effects on the environment and the economy.

Odor Control

A vital requirement for preserving air quality and public opinion is odor management. This entails determining how well the location can control and lessen the smells produced throughout the wastewater treatment process. Sufficient odor management strategies are necessary to stop offensive odors from spreading to neighboring regions, which can result in complaints from the public and lower living standards for locals. To guarantee that the facility runs with minimal olfactory effect, cutting-edge odor control technology and procedures may be put into place. This will assist in maintaining a healthy connection with the local community and assure regulatory compliance.

AHP Method

Decision-makers are able to quantify their subjective assessments by using AHP, which use pairwise comparisons to assess the relative relevance of criteria and alternatives. Decision-makers first determine the appropriate criteria and choices in the AHP. After that, they assign a relative priority or preference rating by comparing each criterion to every other criterion and every alternative to every other alternative. Using these comparisons, a hierarchy is created, with the ultimate objective at the top, the criteria in the center, and the alternatives at the bottom. In general, the Analytic Hierarchy Process (AHP) offers an organized method for making decisions that aids in deciphering intricate choices, ranking criteria, and choosing the optimal option through a methodical assessment procedure. assuming that a_{ij} is the weight for each criterion, c_{ij} is the column total, and r_{ij} is used for normalization.

Calculate Normalization and Weight for each criteriona

$$c_{ij} = \sum_{i=1}^{n} a_{ij} \quad (1)$$

$$r_{ij} = \frac{a_{ij}}{c_{ij}} \quad (2)$$

$$a_{ij} = \frac{\sum_{j=1}^{n} r_{ij}}{n} \quad (3)$$

By adding up the values a_{ij} linked with each criterion, this equation determines the total value of each criterion, c_{ij}. It stands for each criterion's total preference or significance during the decision-making process. The normalization function r_{ij} compares the individual criterion values to the overall criterion value. It guarantees that every criterion is assessed uniformly in relation to the others, considering their collective significance. By averaging the normalized values for every criterion, a_{ij} determines the weight of each criterion. It establishes how important each criterion is in relation to the others in the decision hierarchy. These formulas, which offer a methodical approach to assessing and ranking criteria in decision-making procedures, are essential to the (AHP) Method. The ratings provide a trustworthy foundation for evaluating options and determining which best fits the established requirements and goals.

TOPSIS Method

A Multi-Criteria Decision-Making (MCDM) technique called Technique for Order of Preference by Similarity to Ideal answer (TOPSIS) is used to rank options according to how close they are to an ideal answer. In order to represent the weight of each criterion, a decision matrix must first be constructed, normalized, and then weighted. The process finds the negative-ideal solution, which does the opposite, and the ideal solution, which maximizes benefit criteria and minimizes cost criteria. TOPSIS estimates the relative proximity of each option to the ideal solution by computing the Euclidean distance of each alternative from these solutions. Next, the options are ordered, with the optimal choice being indicated by the one with the highest relative proximity.

Normalized Calculation or Relative Values:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (4)$$

The normalization procedure is expressed by the equation above, which divides the value of each criteria by the sum of the values in the associated column. With this adjustment, every criterion is guaranteed to be fully reflected, properly reflecting its role in the decision-making process.

Calculate Weighted Normalized Numbers:

$$a_{ij} = w_{ij} r_{ij} \quad (5)$$

Overall normalized values for every criterion are multiplied by the relevant weights in the TOPSIS technique to obtain the weighted normalized values. Because it makes it easier to create composite ratings for each choice, this step is crucial. By assigning weight to each criterion, decision-makers may effectively ascertain the relative importance of each during the decision-making process. Aggregate ratings were produced as a result of the procedure, providing decision-makers with useful data on the overall efficacy of each option. Taking into consideration the weighted relative relevance of each criterion, these ratings show the extent to which each choice satisfies the specified requirements. Eventually, these composite ratings are a significant aid in assisting decision-makers in making well-informed decisions.

Calculate $\boldsymbol{A}^*$ and $\boldsymbol{A}^{\Diamond}$:

$$a_j^* = \begin{cases} \max a_{ij} & j = 1, \dots, k \\ \min a_{ij} & j = k, \dots, n \end{cases} \quad \text{Benefit Criteria} \qquad (6)$$

$$a_j^\diamond = \begin{cases} \min a_{ij} & j = 1, \dots, k \\ \max a_{ij} & j = k, \dots, n \end{cases} \quad \text{Non-Benefit Criteria} \qquad (7)$$

Two matrices, a_j^* and $a_j^\diamond$, are essential to the TOPSIS approach. The highest attainable performance for each criterion over all options is denoted by a_j^* in this case, whereas the least achievable performance is represented by $a_j^\diamond$, These matrices are used as reference values to get the negative-ideal and ideal solutions, respectively. The greatest and least desirable outcomes may be determined by decision-makers by comparing the performance of each choice to these criteria. This comparison makes it easier to see which options don't satisfy the required standards and which ones do. These standards are essential to the decision-making process's effectiveness. They give decision-makers a precise frame of reference for weighing options, empowering them to make defensible decisions.

Calculate $\boldsymbol{d}^*$ *and* $\boldsymbol{d}^\diamond$*:*

$$\boldsymbol{d_i^*} = \sqrt{\sum_{j=1}^{n} \left(\boldsymbol{a_{ij}} - \boldsymbol{a_j^*}\right)^2} \qquad (8)$$

$$\boldsymbol{d_i^\diamond} = \sqrt{\sum_{j=1}^{n} \left(\boldsymbol{a_{ij}} - \boldsymbol{a_j^\diamond}\right)^2} \qquad (9)$$

Calculating $\boldsymbol{d_i^*}$ and $\boldsymbol{d_i^\diamond}$ is explained in full in Equ. (8) and Equ. (9). The normalized values of each option are compared to their corresponding ideal and negative-ideal values in these equations. Finding the square root of the sum of squared differences is how this comparison is made. This technique streamlines the evaluation process by quantifying each alternative's deviation from the greatest and worst potential performance across all criteria.

It gives decision-makers a straightforward and consistent method to evaluate the performance of each choice, which facilitates the process of selecting the best one.

Calculate Relative Distance $\boldsymbol{D_i^*}$*:*

$$D_i^* = \frac{d_i^\diamond}{d_i^* + d_i^\diamond} \qquad (10)$$

The formula divides each alternative's length from the $d_i^\diamond$ solution by the total of its distances from the d_i^* and $d_i^\diamond$ solutions in order to get D_i^*. This ratio gives important details about how each option stacks up against the ideal and negative-ideal options. Decision-makers may learn more about how well each option performs in comparison to the best and worst-case scenarios by examining this ratio. By showing which options are closer to and further from the ideal answer, this comparison helps decision-makers. In the end, this ratio aids in choosing the best option depending on how well it performs overall across every single parameter.

IMPLEMENTATION AND RESULTS

After carefully defining criteria and options, data collecting starts in this step. The environmental impact, proximity to existing infrastructure, proximity to water bodies, flood risk, distance from residential areas, and odor control are the most commonly cited factors for the wastewater treatment plant project in Antalya. Three options were presented: Konyaaltı, Kepez, and Döşemealtı. Benefits and non-benefits criteria were divided into two groups. Proximity to water bodies, proximity to existing infrastructure, and odor control were noted as beneficial factors. In contrast to the non-benefits criteria, which comprise Environmental Impact, Flood Risk, and Distance from Residential Areas, the systematic classification allowed for the availability of effective criteria analysis and optimal alternative selection, it facilitated the use of the Technique for Order of Preference by Similarity to to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP) methodologies.

Table 4: Criteria Data

	Environmental Impact	Proximity to Existing Infrastructure	Proximity to Water Bodies	Flood Risk	Distance from Residential Areas	Odor Control
Environmental Impact	1	3	2	2	2	2
Proximity to Existing Infrastructure	1/3	1	1/2	1/2	1/2	1/2
Proximity to Water Bodies	1/2	2	1	4	2	3
Flood Risk	1/2	2	1/4	1	1	1
Distance from Residential Areas	1/2	2	1/2	1	1	1
Odor Control	1/2	2	1/3	1	1	1

Information regarding the criteria collected for use in the Analytic Hierarchy Process (AHP) application is presented in Table 1.

Table 5: Alternatives Data

	Environmental Impact	Proximity to Existing Infrastructure (KM)	Proximity to Water Bodies (KM)	Flood Risk	Distance from Residential Areas (KM)	Odor Control
Döşemealtı	6,78	5	9	5,75	11	6,27
Kepez	7,33	7	8,6	6,39	8	7,23
Konyaaltı	7,61	10	10,1	6,58	18	6,67

Table 2 outlines the criteria and alternatives that need to be considered when utilizing the TOPSIS method.

AHP Application

Table 6: Results of the Normalization Phase

Normalization					
0,3000	0,2500	0,4364	0,2105	0,2667	0,2353
0,1000	0,0833	0,1091	0,0526	0,0667	0,0588
0,1500	0,1667	0,2182	0,4211	0,2667	0,3529
0,1500	0,1667	0,0545	0,1053	0,1333	0,1176
0,1500	0,1667	0,1091	0,1053	0,1333	0,1176
0,1500	0,1667	0,0727	0,1053	0,1333	0,1176

Table 3 presents the outcomes of the normalization matrix derived from equations 1 and 2 as discussed in section *i*.

Table 7: Weight Results

Weight
0,283
0,078
0,263
0,121
0,130
0,124

Table 4 shows the weight results after the normalization phase.

Application of TOPSIS Method

Table 8: Alternative Data with Criteria

	Environmental Impact	Proximity to Existing Infrastructure	Proximity to Water Bodies	Flood Risk	Distance from Residential Areas	Odor Control
Weight	0,283	0,078	0,263	0,121	0,130	0,124
Döşemealtı	6,78	5	9	5,75	11	6,27
Kepez	7,33	7	8,6	6,39	8	7,23
Konyaaltı	7,61	10	10,1	6,58	18	6,67

Table 5 presents the criteria and alternative data, along with their corresponding weights, for the evaluation of Döşemealtı, Kepez, and Konyaaltı. The criteria considered include proximity to residential areas, environmental impact, distance to the nearest major road, proximity to existing infrastructure, regulatory compliance, and distance to the nearest power plant. These criteria will be used in the application of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to make decisions.

Table 9: A^* and A^Δ Results

	Environmental Impact	Proximity to Existing Infrastructure	Proximity to Water Bodies	Flood Risk	Distance from Residential Areas	Odor Control
Döşemealtı	0,153	0,030	0,147	0,064	0,064	0,067
Kepez	0,165	0,042	0,141	0,072	0,046	0,077
Konyaaltı	0,172	0,059	0,165	0,074	0,104	0,071
A^*	0,153	0,059	0,165	0,064	0,046	0,077
$A^\diamond$	0,172	0,030	0,141	0,074	0,104	0,067

Table 6 above presents the results for A^* and $A^\diamond$, which were derived using equation 1 in section *ii*, equation 1 of section *iii*, and equations 1 and 2 from section *iv*.

Table 10: d^* and d^Δ Outputs

d^*	d^Δ
0,040	0,046
0,034	0,060
0,062	0,039

Table 7 presents the results for $d^*$and d^Δ, which were obtained through the application of Equations 1 and 2 from section *v*.

Table 11: Results D^*

d^*	d^Δ	D^*
0,040	0,046	0,534
0,034	0,060	0,642
0,062	0,039	0,386

Table 8 above shows the outcomes for, calculated using Equation 1 in section *vi*. Additionally, based on the results, Kepez City emerges as the optimal location for establishing a new wastewater treatment plant.

Döşemealtı, Kepez, and Konyaaltı were the three possible sites that were thoroughly and methodically examined as part of the site selection process for the construction of a new modern wastewater treatment facility in Antalya. Six essential factors: environmental impact, proximity to existing infrastructure, proximity to water bodies, flood risk, distance from residential areas, and odor control,were determined to be important for the project's success and served as the basis for the evaluation. All of these components were further divided into collections that were beneficial and those that was not. Because these factors immediately assist operational efficiency and environmental integration, they became favorable criteria, along with proximity to water bodies, existing infrastructure, and excellent odor control. To minimize the negative effects, non-beneficial characteristics including high environmental impact, increased flood danger, and excessive closeness to residential areas were reduced. In order to ensure an effective decision-making process, two innovative multi-criteria decision-making (MCDM) approaches were utilized: the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and the Analytic Hierarchy Process (AHP). By distributing weights according to methodical comparisons between pairs, the AHP approach was utilized to determine the relative significance of every criteria. These weights gave the evaluation of the options a well-organized basis. After that, TOPSIS was used to rank the three sites based on all weighted criteria by comparing their performance to the ideal and anti-ideal solutions.

The research provided in-depth information on the advantages and disadvantages of each site. Although Döşemealtı provided a reasonable level of odor control and a comparatively excellent environmental performance, its distance from residential areas was a drawback. Despite its advantageous closeness to water sources, Konyaaltı posed difficulties because of its increased environmental effect and possibility of flooding. With the best combination of closeness to already-existing infrastructure, little environmental effect, controllable flood risk, and a secure distance from residential areas, Kepez turned out to be the most well-rounded choice. In the TOPSIS study, it received the highest score, indicating that it is a suitable location for the treatment facility.

This methodical and fact-based approach made sure that the choice took sustainability and operational viability into account. In addition to improving the selection process's objectiveness, the use of AHP and TOPSIS made it possible to conduct a thorough assessment that complies with the project's technical, social, and environmental goals. In the end, Kepez was determined to be the best site since it supported the strategic objectives of the wastewater treatment plant project and offered the best compromise between conflicting considerations.

CONCLUSION

In brief, this research carried out an exhaustive examination to ascertain the most advantageous site for a novel wastewater treatment plant within Antalya's city center, with particular emphasis on the options Döşemealtı, Kepez, and Konyaaltı. The study employed Multi-Criteria Decision-Making (MCDM) techniques, namely the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and the Analytic Hierarchy Process (AHP). Important factors were carefully considered, such as the impact on the environment, proximity to water bodies, existing infrastructure, flood risk, distance from residential areas, and Odor control. The necessity to handle projected population expansion and seasonal fluctuations which by 2030 are predicted to outpace present infrastructural capacity was the driving force for the study. Kepez was found to be the most ideal site for the new facility based on the weighted criteria. This study offers a systematic method for decision-making and important insights for Antalya's sustainable urban development. Additional components or alternative MCDM approaches might be investigated in future research to improve the decision-making process even further. Involving a wider range of stakeholders, such as local communities and environmental specialists, may also lead to better infrastructure development projects and deeper insights.

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An MCDM Application for Cost Effective and Sustainable Production Recipe Selection: The Case of Ceramic Tile Production

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ABSTRACT

This study investigates the selection of cost-effective and sustainable production recipes in the ceramic tile industry. It focuses on improving environmental sustainability while maintaining economic viability. Rising raw material costs and environmental concerns require innovative solutions for ceramic production. The study uses Multi-Criteria Decision Making (MCDM) methodologies, Analytic Hierarchy Process (AHP), and Preference Ranking Technique by Similarity to Ideal Solution (TOPSIS) to evaluate and prioritize various production recipes. Initially, the problem was defined by identifying critical criteria such as water usage, natural gas usage, gas emissions and waste generation, natural resource utilization, and cost. Five alternative recipes were formulated and evaluated according to these criteria. The data were collected and evaluated in cooperation with a ceramic production company by personally taking the necessary steps. The AHP method was used to assign weights to each criterion reflecting their relative importance. These weights were then integrated into the TOPSIS analysis to rank the alternatives. The results show that the fourth alternative with broken glass and reduced amounts of feldspar emerged as the most favorable alternative, providing the best balance between sustainability and cost-effectiveness. The study concludes with a recommendation to adopt the fourth alternative due to its superior performance on environmental and economic metrics. This approach not only enhances competitive advantage but also aligns with the sustainability objectives of the industry, providing a sound framework for decision-making in ceramic tile production.

Keywords: sustainable production, multi-criteria decision making, Analytic Hierarchy Process, TOPSIS method

INTRODUCTION

The ceramic tile industry faces significant challenges related to rising raw material costs and increasing environmental concerns. As manufacturers strive to remain competitive, the need for sustainable and cost-effective production methods becomes paramount. The combination of economic viability and environmental responsibility requires innovative approaches to manufacturing processes. This study addresses these challenges by investigating advanced decision-making methodologies to identify optimal production recipes that balance cost and sustainability.

Ceramic production involves the use of various raw materials, each of which contributes to the overall cost and environmental impact. Traditional methods often overlook the potential benefits of using alternative materials and optimizing resource use. This research aims to provide a systematic approach for the evaluation and selection of the best production recipes, focusing on MCDM methodologies.

The main objective of this research is to develop a decision-making framework that enables the selection of the most cost-effective and sustainable production recipes in the ceramic tile industry. To achieve this aim, the following research objectives need to be fulfilled:

- Identify and define the critical criteria affecting cost and sustainability in ceramic tile production.
- Formulate and evaluate alternative production recipes based on the identified criteria.
- Applying the methodologies of the AHP, and TOPSIS, to prioritize and select the most appropriate production recipe.

The current research focuses on the application of AHP and TOPSIS methodologies to evaluate and select production recipes in the ceramic tile industry. The study was applied to a ceramic manufacturing company, ensuring the relevance and applicability of the data.

To achieve the main objective of the research, fulfill the subsequent objectives, and answer the research questions, the report is divided into five main sections. Starting with the Introduction section provides an overview of the topic addressed in the research, the main aims, and objectives of the study, and outlines the significance and scope of the study. Following that, the Methodology section details the research design, including the definition of criteria, data collection methods, and the application of AHP and TOPSIS methodologies. Subsequently, the Implementation section elaborates on how the methodologies were applied to the collected data, presents the obtained results, and provides analyses. Finally, the Conclusion section summarizes the research findings, offers recommendations for implementation, and provides guidance for future research.

METHODOLOGY

Figure 1 illustrates how a directed procedure guides the methodology part. Accurate evaluation of the problem description is the first step in the research process. Next, criteria that highlight the essential elements for decision-making are developed. Subsequently, the alternative evaluation procedure presents a variety of possibilities. The accurate collection of data, which yields important information to aid in decision-making, is the following stage. To make comparative evaluation easier, the criteria are weighted using the Analytic Hierarchy Process (AHP). The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is then used to thoroughly examine the options. The results analysis offers a summary of the discoveries along with enlightening suggestions for more study.

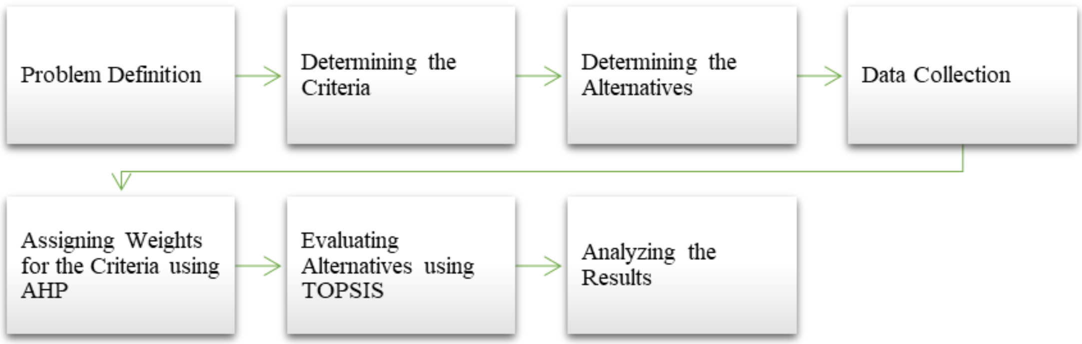

Figure 8: Visual Diagram of the Methodology

This section will go into detail about the flow diagram in **Hata! Başvuru kaynağı bulunamadı.**which visualizes the steps of the approach.

Problem Definition

Improving environmental sustainability and cost-effectiveness in the ceramic production process is the main goal of this study. Innovative solutions must be explored considering the ceramic industry's rising raw material costs and mounting environmental concerns. For businesses to remain competitive, finding a production recipe that strikes a balance between environmental impact and cost-effectiveness is essential.

Multi-criteria decision-making (MCDM) methodologies will be used throughout this research. Making decisions will be aided by methods like the Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). While TOPSIS will be used to choose the best option among options, AHP will help determine how important each criterion should be prioritized. By considering a variety of factors, this MCDM strategy will help firms make complex decisions and uncover the best tactics.

Determining the Criteria

Setting explicit standards for the evaluation process is essential to ensuring that the production recipes are evaluated fairly and that decisions are well-informed. These standards form the foundation for evaluating and choosing the best option. The study's goals and stakeholders' priorities should be taken into consideration when choosing the criteria. This stage will involve defining and identifying the primary standards that will be applied in assessing the cost-effectiveness and sustainability of various manufacturing methods.

- Water Usage (C1): This criterion deals with the volume of water used throughout the manufacturing process. Water use is crucial for cost-effectiveness as well as for the preservation of natural resources. Reducing water use is an important step toward sustainable manufacturing, and it calls for effective water resource management on the part of the company.
- Natural Gas Usage (C2): This criterion shows how much natural gas was consumed in the production process. One important energy source is natural gas, whose use can affect a company's carbon footprint and energy efficiency. Utilizing less natural gas can save expenses and lessen its negative effects on the environment.
- Gas Emissions and Waste Generation (C3): This criterion details the amount of waste and gas emissions produced during the manufacturing process. When evaluating the effects on the environment, the quantity of waste and emissions is critical. Decreased waste and emissions can help the company meet its targets for environmental sustainability.
- Natural Resource Utilization (C4): This metric indicates the number of natural resources that are used throughout the production process. Reducing environmental effects and ensuring the long-term sustainability of manufacturing processes can be achieved through the efficient and sustainable use of natural resources.
- Cost (C5): This criterion shows all the costs related to the production process. Expenses are critical to a company's competitiveness and have a direct impact on its profitability. Reduced expenses can boost a company's profit margins and provide it with a competitive edge in pricing.

Determining the Alternatives

During the process of identifying the options, we worked with a business to obtain the information and authorization needed to run tests using several recipes at their facilities. We were able to create five different recipes for assessment since the company gave us information on the different recipes they currently use. One of these recipes is the same as their standard recipe, which can be used as a reference point to evaluate the newly created substitutes. We concentrated mainly on five essential elements, which are the building ingredients of our product. By varying the contents of the other two elements, we created five different recipes to evaluate.

As stated in Table 12: Alternative recipes, the basic constituents for our product are clay, kaolin, and dolomite, and their quantities are predetermined. The table lists our possibilities based on feldspar and blunger content adjustments.

Table 12: Alternative recipes

	clay	kaolin	feldspar	blunger	dolomite
Alternative 1	27%	10%	9%	18%	3%
Alternative 2	27%	10%	broken glass %2 + feldspar 7%	18%	3%
Alternative 3	27%	10%	broken glass %4 + feldspar 5%	18%	3%
Alternative 4	27%	10%	broken glass %6 + feldspar 3%	18%	3%
Alternative 5	27%	10%	9%	wastewater 23%	3%

Data Collection

We contacted the company throughout the data-gathering phase to request data sharing on the several recipes they currently use in their production processes. We appreciate the company's cooperation in providing us with the data that was required for our analysis. Our joint endeavor yielded significant insights and data that aided in the development of substitute recipes for assessment. We ensured that our analysis was based on real-world production processes and considerations by using the company's disclosed data as a basis for our assessment and decision-making process.

We also got to talk about how important the chosen criteria are to the business and examine how the developed recipes would affect the alternatives considering these criteria. We learned about the company's priorities and factors about cost-effectiveness and sustainability through our conversations with them. This made it possible for us to modify our analysis to meet their unique requirements and goals. Furthermore, we carried out an extensive investigation based on these talks using the AHP and TOPSIS approaches. We were able to systematically assess the alternatives and criteria by considering how well each performed concerning each criterion and how important each was to the others.

All things considered, this cooperative approach, together with thorough research done with AHP and TOPSIS, gave us important insights into choosing the company's most economical and sustainable production recipe.

Assigning Weights of the Criteria using AHP

The AHP will be used in this section to establish the weights of the criteria, which are crucial for directing our decision-making. AHP offers an organized method for methodically prioritizing criteria according to their significance.

After that, these weights will be incorporated into the TOPSIS technique, which is used to assess and prioritize different recipes. Our goal is to find the best recipe that strikes an effective balance between sustainability and cost-effectiveness by combining AHP and TOPSIS.

Explanation of AHP

AHP is a fundamental approach used in decision-making processes. This method aims to select the best alternative by considering both rational and intuitive elements when evaluating alternatives against a set of criteria. AHP enables the development of overall priorities by using simple pairwise comparisons made by the decision-maker to rank alternatives. This process allows for inconsistency in decision-making judgments while also providing a means to address and improve consistency. With the use of AHP, it is possible to hierarchically structure complex systems. This structuring helps decision-makers determine the importance of factors while ensuring the consistency of decisions. (Saaty & Vargas, 2012)

$$A_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (1)$$

$$w_i = \frac{\sum_{i=1}^{n} A_{ij}}{n} \quad (2)$$

$$CI = \frac{n_{max} - n}{n - 1} \quad (3)$$

$$CR = \frac{CI}{RI} \quad (4)$$

In the AHP method, the relative importance of criteria is determined by creating a pairwise comparison matrix. This matrix includes the relative importance of each criterion compared to the others. The normalization of the pairwise comparison matrix is done by dividing each element by the sum of its column, as shown in Equation 1. This process ensures that each criterion is compared on the same scale. The weights of the criteria are then determined by taking the row averages of the normalized matrix, as indicated in Equation 2. The Consistency Index (CI) is calculated by dividing the difference between the largest eigenvalue and the matrix size by the matrix size minus one, as expressed in Equation 3. Finally, the Consistency Ratio (CR) is obtained by dividing the CI by the Random Index (RI), as stated in Equation 4. The RI is a constant number based on the size of the matrix, used as a reference in consistency evaluation. If the CR value is less than 0.1, the consistency of the matrix is considered acceptable, and the weights are deemed reliable.

Evaluating Alternatives Using TOPSIS

Our goal in this section is to choose the best choice from the five that we have already identified. These options will be assessed using our predetermined criteria and the weights that the AHP procedure allocated to them. This evaluation will make use of TOPSIS, which compares each alternative to the ideal solution while considering both the positive and negative of their performance. Through the application of TOPSIS, we hope to determine which option best achieves our goals while successfully striking a balance between sustainability and cost-effectiveness.

Explanation of TOPSIS

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is a decision-making method used to identify the best alternative from a set of options evaluated against multiple criteria. In TOPSIS, each alternative is compared to an ideal solution, representing the highest possible performance for each criterion, and an anti-ideal solution, representing the lowest possible performance.

First, the decision matrix is normalized to eliminate scale differences among the criteria. Then, weighted normalized scores are calculated for each alternative. These scores determine the proximity of each alternative to the ideal and anti-ideal solutions.

After determining the ideal and anti-ideal solutions and calculating the distances between each alternative and these solutions, TOPSIS ranks the alternatives. The alternative with the shortest distance to the ideal solution and the longest distance to the anti-ideal solution is considered the best choice. (Pavić & Novoselac, 2013)

TOPSIS provides a structured approach for decision-making, allowing decision-makers to consider multiple criteria and select the most suitable alternative that best aligns with their objectives.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{ij}^2}} \quad (5)$$

$$v_{ij} = w_j . r_{ij} \quad (6)$$

$$A^+ = \{v_1^+, v_2^+, \dots, v_n^+\}, \quad v_j^+ = \max(v_{ij}) \quad (7)$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\}, \quad v_j^- = \min(v_{ij}) \quad (8)$$

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad (9)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (10)$$

$$D^* = \frac{d_i^-}{d_i^+ + d_i^-} \quad (11)$$

The TOPSIS method involves several steps to evaluate and rank the alternatives. First, the decision matrix is normalized using the formula shown in Equation 5, where each element is divided by the square root of the sum of squares of all elements in its column. This normalization ensures comparability across different criteria. Next, the normalized matrix is multiplied by the weights of the criteria, resulting in the weighted normalized decision matrix as depicted in Equation 6. The ideal (best) and anti-ideal (worst) solutions are then determined, with the ideal solution containing the maximum values for each criterion (Equation 7) and the anti-ideal solution containing the minimum values (Equation 8). The distances of each alternative from the ideal and anti-ideal solutions are calculated using Equations 9 and 10, respectively. Finally, the relative closeness of each alternative to the ideal solution is computed using Equation 11. The alternative with the highest value of D* is considered the best option, as it is closest to the ideal solution and furthest from the anti-ideal solution.

Analyzing the Results

After evaluating the TOPSIS data, A4 is the most advantageous alternative. The finding is based on its greater performance when compared to the other options. When examining the results for various criteria, A4 consistently shows the greatest scores while also displaying the lowest numbers in comparable columns.

Based on these findings, we strongly support the use of A4 as the optimal production recipe. Its distinguishing characteristics, as indicated by its near-to-optimal solution across numerous parameters, demonstrate its appropriateness for attaining our cost-effectiveness and sustainability goals. Alternatives such as A1, on the other hand, rank lower since they are further away from the ideal answer and are therefore judged less attractive.

Considering these findings, we recommend that decision-makers emphasize the use of A4 in their manufacturing processes. Its enhanced performance promises to increase competitiveness and profitability while also contributing to the industry's greener future.

IMPLEMENTATION AND RESULTS

For this section, we will use data collected from the company, with a particular focus on the criteria provided by the company and the scores assigned to each alternative based on those criteria. These scores represent each alternative's performance against the defined criteria. We will apply weights to these criteria based on their relative importance as assessed by the AHP. Following that, we will perform a TOPSIS analysis using the

AHP weights and alternative scores depending on these criteria. Using this comprehensive approach, we want to uncover the best production recipe that balances cost-effectiveness and sustainability.

Application of AHP

Table 13: Relative importance of criteria, developed in partnership with the company, illustrates the relative importance of criteria. This matrix contains pairwise comparisons for each criterion and is a useful tool for establishing the priorities of criteria.

Table 13: Relative importance of criteria

	C1	C2	C3	C4	C5
C1	1.00	3.00	2.00	4.00	6.00
C2	0.33	1.00	0.50	1.50	3.00
C3	0.50	2.00	1.00	2.00	4.00
C4	0.25	0.67	0.50	1.00	2.00
C5	0.17	0.33	0.25	0.50	1.00

Table 14: Normalization of criteria priorities illustrates the normalized results from table 2, with each criterion's importance expressed on the same scale. Although full consistency is preferable, it is not obtained in this case, resulting in the use of row averages to calculate the weights.

Table 14: Normalization of criteria priorities

	C1	C2	C3	C4	C5
C1	0.444	0.429	0.471	0.444	0.375
C2	0.148	0.143	0.118	0.167	0.188
C3	0.222	0.286	0.235	0.222	0.250
C4	0.111	0.095	0.118	0.111	0.125
C5	0.074	0.048	0.059	0.056	0.063

Table 15: Weights of the criteria contains the weights produced from the normalized matrix, which indicate the average values. These weights reflect the relative relevance of the criteria and represent the end of the AHP process, including any adjustments made for consistency.

Table 15: Weights of the criteria

C1	C2	C3	C4	C5
0.43	0.15	0.24	0.11	0.06

The computed weights in Table 4 raise concerns about their reliability and applicability. In this regard, a consistency check is performed to see whether the derived weights are acceptable and appropriate for decision-making. This phase assures that the AHP analysis results are resilient and true. The consistency check resulted in a value of 0.08, which is below the threshold of 0.1, indicating that the weights are acceptable and can be reliably used in further analysis.

Application of TOPSIS

Table 16: TOPSIS implementation table shows the data, including the weights produced by AHP and the criteria-based values for each alternative. These data allow us to compare the performance of alternatives based on a variety of criteria. We will now apply TOPSIS to this data.

Table 16: TOPSIS implementation table

	C1	C2	C3	C4	C5
weights	**0.43**	**0.15**	**0.24**	**0.11**	**0.06**
A1	5	5	5	5	1
A2	5	3	3	4	3
A3	5	2	2	3	4
A4	5	1	1	2	5
A5	3	5	5	1	2

Table 17: Results of TOPSIS shows the results of completing the necessary TOPSIS solution steps. The bottom section of the table shows the ideal and non-ideal solutions for each alternative, while the right side shows the calculated distances to these ideal and non-ideal solutions.

Table 17: Results of TOPSIS

						d+	d-	D*
A1	0.207	0.095	0.152	0.076	0.008	0.179	0.000	0.000
A2	0.207	0.057	0.091	0.060	0.024	0.120	0.075	0.385
A3	0.207	0.038	0.061	0.045	0.032	0.096	0.114	0.545
A4	0.207	0.019	0.030	0.030	0.040	0.084	0.154	0.646
A5	0.124	0.095	0.152	0.015	0.016	0.146	0.103	0.414
A+	0.124	0.019	0.030	0.015	0.040			
A-	0.207	0.095	0.152	0.076	0.008			

Result

After implementing the TOPSIS approach and computing the distances, we examine the results to select the best alternative. In this research, we see that A4 has the highest value among the options, indicating that it is close to the optimal solution. A1 has the lowest value in this context, indicating its relative distance from the optimal answer. Based on these facts, we conclude that A4 is the best alternative, followed by A3, A2, A5, and finally, A1, as illustrated in Figure 9: Final Decision.

Figure 9: Final Decision

CONCLUSION

In conclusion, this study investigated the selection of cost-effective and sustainable production recipes in the ceramic tile sector, with the goal of striking a balance between economic viability and environmental responsibility. We developed a systematic strategy for analyzing and ranking numerous manufacturing alternatives using the AHP and TOPSIS.

The complete analysis demonstrated the critical relevance of considering several criteria, such as cost, natural resource utilization, and environmental impact, when making production-related decisions. We successfully evaluated the relative relevance of these factors using AHP, opening the path for further TOPSIS study.

Furthermore, our findings demonstrated the possibility for optimization through informed decision-making, underlining the importance of sustainability and cost-effectiveness in the selection of production recipes. The study also demonstrated the effectiveness of AHP and TOPSIS in dealing with complicated choice situations, particularly those with many conflicting objectives.

Future research could increase the scope by looking into new alternative materials and expanding the criteria to include broader environmental impacts like carbon footprint and biodiversity. Furthermore, evaluating the long-term benefits and potential problems of implementing the proposed manufacturing recipes in various contexts would help to achieve a more thorough understanding and continual improvement of sustainable practices in the ceramic tile business.

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MCDM Approaches in Construction Safety Management

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ABSTRACT

Construction safety management is a critical concern in the construction industry due to the high incidence of accidents and fatalities. Considering this fact, this research explores the application of Multi-Criteria Decision-Making (MCDM) techniques in enhancing safety management practices. The study reviews various MCDM approaches, such as Fuzzy Best Worst Method (FBWM) and Interval-Valued Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IVFTOPSIS), for evaluating safety risks in construction projects. The research examines how these techniques, combined with emerging technologies like big data and IoT, can provide more accurate risk assessments and prioritize safety measures. Additionally, the paper discusses the challenges faced in implementing effective safety management systems and the need for better awareness among workers and management. The findings highlight the potential of hybrid MCDM models in improving decision-making processes and mitigating safety risks in construction projects. The research also suggests integrating advanced technologies and continuous safety training to enhance the effectiveness of safety management practices in the construction industry.

Keywords: construction safety, Multi-Criteria Decision-Making (MCDM), risk management, safety awareness, construction risk assessment

INTRODUCTION

Construction safety management is a critical area of focus in the construction industry due to the high incidence of accidents and fatalities. The complexity and dynamic nature of construction projects necessitate robust risk management and safety strategies to protect workers and ensure project success. Over the years, various Multi-Criteria Decision-Making (MCDM) approaches have been developed and implemented to enhance construction safety management, addressing the limitations of traditional methods by integrating advanced technologies and sophisticated decision-making models. One of the prominent approaches to improving construction safety is the use of MCDM techniques. These techniques facilitate the evaluation and prioritization of safety risks by considering multiple criteria and stakeholder preferences. The integration of fuzzy logic, big data technology, and hybrid MCDM models has shown promising results in providing accurate risk assessments and effective mitigation strategies. For example, the Fuzzy Best Worst Method (FBWM) combined with the Interval-Valued Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IVFTOPSIS) has been utilized to evaluate safety risks in construction projects. demonstrating significant improvements in risk prioritization and decision-making. Despite these advancements, construction safety management faces several challenges, including the effective implementation of safety measures, the integration of emerging technologies, and the need for enhanced awareness among workers and management. Addressing these challenges requires a comprehensive approach that incorporates innovative MCDM models, robust safety management systems, and continuous improvement of safety practices.

This study aims to explore and analyze various MCDM approaches in construction safety management, highlighting their effectiveness in mitigating risks and enhancing safety performance. The research focuses on a literature review on:

- Examining existing risk management models and safety management systems in construction projects, with a particular emphasis on MCDM techniques.
- Technology Integration: Examining how advanced technologies like big data, IoT, and BIM can enhance construction safety.
- Challenges and Awareness: Recognizing the obstacles to effective safety management and emphasizing the importance of safety awareness among construction stakeholders.

- Case Studies: Analyzing real-life applications of MCDM approaches in construction safety, evaluating their outcomes and benefits.

The scope of this study covers the development and application of MCDM models in construction safety management, the integration of advanced technologies to enhance safety practices, and the identification of critical factors influencing safety performance. Through comprehensive literature review and case studies, this research will provide valuable insights into the effectiveness of MCDM approaches in construction safety and offer recommendations for improving safety management practices in the industry.

LITERATURE REVIEW

Safety Management in Construction Projects

Koh et al. (2014) propose a relational framework for enhancing safety in construction projects by integrating high reliability organizing (HRO) principles with social capital. They highlight limitations in current safety management approaches in Hong Kong, which focus on compliance and error prevention, neglecting the dynamic nature of construction work. Their framework links social capital's structural, cognitive, and relational dimensions with HRO practices to improve safety through adaptive human interactions and continuous operational sensitivity. They recommend a mixed-methods research design to validate the framework, combining qualitative case studies and quantitative surveys to explore and confirm the impact of relational dynamics and HRO on construction safety. This approach underscores the importance of human factors and relational assets in effective safety management (Koh, Tuuli, & Rowlinson, 2014).

Zhao et al. (2022) developed an innovative safety management system for substation construction projects that integrates IoT and chromatographic zone management technologies. The system includes intelligent video surveillance and smart helmets for precise worker positioning and behavior prediction, aiming to prevent unsafe behaviors and enhance construction site safety and project quality. Liu et al. (2024) explore the enhancement of construction safety in megaprojects through resilient governance. They highlight the importance of engineering and technological resilience, emphasizing that improving these aspects can mitigate safety risks and enhance management efficiency by enabling timely responses and adjustments.

Patel, Raichura, and Pitroda (2021) explore the critical factors that influence the implementation of safety management in construction projects. They highlight the significant risks and financial losses due to workplace accidents in the construction industry, with a particular focus on India. The review identifies the importance of safety training, personal protective equipment (PPE), and the use of advanced technologies like drones and sensor-based systems for real- time monitoring and hazard detection. The study concludes that integrating these elements can substantially improve safety outcomes on construction sites. Hale (2003) reviews essential functions of safety management systems (SMS) in production, emphasizing the progress made and gaps that remain, particularly concerning organizational culture and nonbureaucratic management approaches. He highlights the importance of audits, self- regulation, and continuous improvement in safety management practices, especially in high- hazard industries.

Technology in Construction Safety Management

The article by Xue et al. (2022) explores the creation of a Safety Monitoring System for the South-to-North Water Diversion Project, utilizing big data technology. This large-scale initiative in China aims to address water shortages in the northern region. The project's construction sites are extensive and complex, presenting significant safety control challenges due to various accident factors. The study examines these factors from the perspectives of construction staff, equipment, management, and environment, identifying primary accident types such as collapses, falls from heights, electric shocks, object strikes, and mechanical injuries. It highlights the influence of data from personnel, equipment, management, and environmental factors on safety outcomes, underscoring the importance of thorough risk analysis and safety assessment during construction. The authors propose a big data-based safety monitoring system architecture to improve hazard identification and safety assessment capabilities. The system utilizes big data to collect and analyze various data types, facilitating dynamic risk evaluation and classification in construction projects. Technologies such as cluster analysis, association analysis, and regression analysis are employed to assess construction risks accurately and provide early warning and prevention measures. The study concludes that the application of big data technology in safety monitoring enables intelligent risk management in construction projects, promoting a shift from traditional safety management to risk intelligent management. The proposed system provides strong technical support for improving safety management levels and reducing construction accidents in large-scale projects like the South-to-North Water Diversion Project.

Haupt et al. (2021) explore various emerging technologies designed to enhance safety and health management on construction sites. They highlight the construction industry's inherent high-risk nature and the substantial advantages of incorporating advanced technologies like Virtual Reality (VR), Geographic Information Systems (GIS), Building Information Modelling (BIM), drones, 4D Computer-Aided Design (4D CAD), wearable robotics, and sensor-based systems. These technologies facilitate better safety training, hazard identification, and real- time monitoring, leading to improved safety outcomes. The authors also discuss the integration of traditional safety practices with these technologies to create safer and more efficient construction environments.

The article by Lin et al. (2023) introduces an innovative method for assessing the safety of excavation systems using a Multi-Criteria Decision- Making (MCDM) model based on the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) within a fuzzy environment. Excavation projects, particularly in urban areas, pose significant risks due to complex interactions among geotechnical conditions, surrounding environments, and construction methods. The study aims to accurately identify high-risk factors and implement effective countermeasures. The methodology entails building a decision hierarchy that accounts for various risk factors such as geotechnical conditions, surrounding environments, construction measurements, and management aspects. The authors incorporate an expert coefficient to assess the importance of expert judgments, blending subjective opinions and objective data using Spherical Fuzzy Sets (SFS) and Triangular Fuzzy Sets (TFS). The TOPSIS-based MCDM model identifies high-risk factors, with static load, pipeline settlement, and dynamic load ranking as the top three. A case study of an excavation project demonstrates the model's applicability and robustness. The study concludes that this methodology provides a comprehensive tool for project managers to identify and mitigate risks, improving safety and reducing accident probabilities in excavation projects.

Lin et al. (2023) developed an MCDM model based on TOPSIS within a fuzzy environment to assess the safety of excavation systems, highlighting the importance of integrating both expert judgments and measured data to identify high-risk factors in excavation projects. Singh et al. (2023) examine the obstacles to implementing Blockchain Technology (BT) in Construction Supply Chain Management (CSCM) using a fuzzy-based Multi-Criteria Decision-Making (MCDM) approach. They identify the most influential barriers as market-based risks, high sustainability costs, and its use in the underground economy. The study emphasizes significant barriers such as inadequate knowledge and employee training, contractual risk, and scalability issues. The findings suggest that addressing these barriers is crucial for the effective adoption of BT in CSCM.

Nnaji and Karakhan (2020) explore the use, benefits, limitations, and barriers of adopting technology for safety and health management in the construction industry. Their study includes a survey of 102 construction practitioners and finds that while technology can improve safety conditions and hazard awareness, there is resistance due to cost, client decisions, and required training. The study provides insights and strategies for overcoming barriers to enhance technology adoption in construction safety management.

Risk Management in Construction Projects

The article by Mohandes et al. (2020) introduces an innovative Risk Assessment Model (RAM) to evaluate construction labor safety levels. The study overcomes the limitations of traditional risk matrix methods by integrating the Fuzzy Best Worst Method (FBWM) with the Interval-Valued Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IVFTOPSIS). Through the application of RAM to a real-life case study involving maintenance activities related to lifts, the authors demonstrate the effectiveness of their approach in providing a precise ranking of risks and offering appropriate evaluation strategies for risk mitigation. The developed model contributes to construction safety risk assessment by enabling the computation of risk parameters' importance, prioritizing risks, providing wider ranges of classifications, and offering prudent evaluation strategies. The study proposes that the RAM can be utilized across different projects to enhance worker safety and health by promoting the implementation of effective mitigation strategies.

Chatterjee et al. (2017) introduce a hybrid Multi-Criteria Decision-Making (MCDM) technique for managing risks in construction projects, incorporating D numbers to address uncertainties like incompleteness and imprecision. Their approach integrates the Analytical Network Process (ANP) with the Multi-Attributive Border Approximation Area Comparison (MABAC) method and employs a consistent fuzzy preference relation (CFPR) to determine the weights of risk criteria. This methodology efficiently ranks and selects risk response strategies by handling various uncertainties. An illustrative example from the construction sector demonstrates the feasibility and robustness of this hybrid technique. Future research is suggested to optimize the computational complexity and extend the application to other domains like supplier selection and renewable energy.

The article by Zhao et al. (2021) explores the development of a Safety Risk Management System (SRMS) for electric power engineering construction in the context of big data (BD) technology. In the BD era, where vast amounts of data are generated daily, BD technology offers significant contributions to security risk management. The study focuses on the analysis and utilization of data from electric power construction sites to manage safety risks effectively. It begins by identifying the shortcomings of existing SRMS in electric power construction and highlights the advantages of BD technology. The authors then analyze the safety risks associated with BD technology. in power construction and discuss its applicability and feasibility in SRMS. Furthermore, the paper identifies and analyzes safety risk factors affecting power project construction and demonstrates the use of BD technology to preprocess and analyze on-site collected data. Through experimental research, it is found that construction personnel have the most substantial impact on safety, followed by the construction environment. Thus, the study suggests strengthening the professional skills and safety awareness of construction personnel and analyzing the construction environment to mitigate hidden safety hazards effectively. The research contributes to the enhancement of safety management in power engineering construction operations, offering guiding significance for ensuring project development and achieving expected goals. By integrating BD technology into SRMS, the study aims to provide a more comprehensive and professional approach to safety risk management in electric power engineering construction.

Rezakhani (2012) introduces a fuzzy multi-criteria decision-making (MCDM) model for risk factor selection in construction projects. The study emphasizes the importance of systematically selecting the most critical risks through an effective risk management plan. By conducting a comprehensive literature survey, the most significant risk factors in construction projects are hierarchically classified. The proposed MCDM model integrates fuzzy logic to assess uncertainty factors in group decision-making processes, such as experts' influence weights and their preferences for risk selection criteria. An intelligent checking process ensures the logical consistency of experts' preferences during decision-making. Through a case study, the applicability of the proposed model is assessed, demonstrating its efficiency in prioritizing and selecting risks based on decisions made by a group of experts in construction projects.

Challenges and Awareness in Construction Safety

The article by Gunduz and Khader (2020) emphasizes the complex and interconnected nature of construction hazards, which often lead to accidents and fatalities in the construction industry. Through their study, they employed the Analytic Network Process (ANP) along with a frequency-adjusted importance index to identify and prioritize 42 hazards across 14 categories. Their research underscores the crucial role of management involvement and the implementation of robust safety policies in mitigating these risks. By combining the frequency-adjusted importance index with the ANP tool, they provide a thorough method for evaluating and addressing safety hazards in construction projects. suggesting that focusing on root causes rather than superficial hazards can significantly enhance safety performance. This highlights the need for proactive safety management practices in the construction industry.

Additionally, the construction industry is recognized as one of the most hazardous sectors, with high rates of non-fatal injuries and fatalities (Zeng & Li, 2022). A significant factor contributing to these high accident rates is the lack of hazard awareness among workers and management (Zeng & Li, 2022). Previous research has identified various factors influencing these accidents, including personnel factors like worker age and experience, company factors such as the number of workers and budget, and immediate factors related to the timing of the accident (Cabello et al., 2021; Liaudanskiene & Bogdanovicius, 2009; Tam et al., 2004). Zeng and Li (2022) conducted a comparative analysis of construction hazard awareness between academic research and public discourse on social media. They analyzed 769 articles from the Web of Science (WoS) and 11,829 Weibo micro posts from 1991 to 2021. Their findings highlighted a disparity between the focus areas of academia and the public. Academic research tended to emphasize high-tech solutions like artificial intelligence and virtual reality for hazard identification and management. In contrast, Weibo posts predominantly focused on immediate and tangible hazards such as collapses, earthquakes, and fire safety, with less emphasis on advanced technologies (Zeng & Li, 2022). This study underscores the necessity for improved integration of advanced safety technologies in practical construction safety measures, a focus that is evident in academic research but not in public discussions on platforms like Weibo. Bridging this gap could enhance overall safety in the construction industry, as suggested by the research findings (Zeng & Li, 2022). providing valuable insights for stakeholders in the construction industry.

In their article, Sathiyaraj et al. (2023) explore construction safety management systems (SMS) using the PROMETHEE method, a decision-making tool. The study emphasizes the critical role of effective SMS in mitigating risks and ensuring worker safety in the construction industry, which is notably hazardous. The PROMETHEE method was used to rank different types of buildings—government, private, civil engineering, and industrial—based on various safety factors. The findings indicate that government buildings ranked highest in safety commitment by senior management, while industrial buildings ranked the lowest. The authors underscore the importance of systematic risk management and the implementation of safety protocols to enhance construction site safety. Additionally, the study highlights the need for standardized auditing tools to objectively measure SMS performance, aiming to improve safety practices and reduce accidents in the construction industry. In summary, these studies underscore the challenges and opportunities in construction safety, emphasizing the importance of proactive management involvement, the integration of advanced safety technologies, and systematic risk management practices to enhance safety performance and mitigate risks in construction projects.

Kang (2011) examines the state of safety production management in construction projects in Henan Province., identifying significant factors contributing to safety risks. The study finds that while safety control measures exist, they are often not implemented effectively. Many hazardous areas lack protective measures or warning signs, and workers frequently display low safety awareness and skill levels, often violating safety regulations. The insufficient inspections by government and supervisory bodies exacerbate these issues. Economic pressures, such as fierce market competition and delayed payments, lead to inadequate funding for safety measures. The study emphasizes the need for comprehensive safety legislation, adequate funding, regular safety training for workers, and increased government inspections to improve safety in construction projects.

The article "Fire safety management in public health-care buildings: issues and possible solutions" by Salim et al. (2023) explores fire safety challenges in Malaysia's public health-care facilities and suggests potential remedies. Utilizing a qualitative approach, the research examines five public hospitals through case studies and employs thematic analysis with the help of MAXQDA software. The study uncovers several problems, including insufficient enforcement of safety policies, low water pressure, poor maintenance, and inadequate communication systems. To address these issues, the authors recommend five key strategies, such as strengthening the institutional framework, enhancing emergency response teams, and the need for modern technologies and training of key personnel to increase fire safety, along with the improvement of the occupational health and safety system, has been emphasized.

Multi-Criteria Decision-Making (MCDM) Approaches

Jeon et al. (2024) introduce a novel approach using probabilistic hesitant fuzzy elements (PHFEs) for multi-criteria decision-making (MCDM) to select the best alternative for flexible packaging bags in the wake of single-use plastic bans. This study enhances the hesitant fuzzy set (HFS) framework by incorporating probabilities, thus allowing decision- makers to express preferences more flexibly and accurately. The authors propose an improved unification procedure for PHFEs to address existing deficiencies, ensuring consistency and practicality in decision-making. Their method integrates Pythagorean Fuzzy Elements (PHFEs) with the Weighted Sum Product Evaluation Method (WASPAS) and Analytic Hierarchy Process (AHP) to create a robust decision framework. This combined PHFEs-WASPAS-AHP approach was used in the selection of bioplastic bags. showing superior performance in ranking alternatives compared to traditional methods like CODAS, COPRAS, ARAS, and MOORA. The study highlights those reusable bags, particularly those with high recycled content or certified biodegradability, significantly reduce environmental impacts compared to single-use plastic bags. The findings emphasize the benefits of the proposed approach in managing uncertain information and improving decision-making processes in environmental sustainability contexts. Future research is suggested to expand this methodology to other applications and refine the computational aspects of PHFE operations.

Badalpur and Hafezalkotob (2015) introduce a methodology for managing risks in engineering, procurement, and construction (EPC) projects, focusing on liquefied petroleum gas (LPG) storage tank construction. Using multi-criteria decision-making (MCDM) techniques and earned value management (EVM), the study evaluates critical risks and determines optimal control measures (CMs) through a goal programming model. The methodology, tested in Iran's oil and gas sector, shows significant improvements in project cost, completion time, and risk mitigation. This flexible approach can be adapted to various EPC projects by adjusting risks, objectives, and organizational policies.

Rezakhani (2013) introduces a fuzzy multi-criteria decision-making model (MCDM) with the aim of selecting risk factors in construction projects. This study emphasizes on the identification and prioritization of critical risks affecting the project objectives. A thorough literature review classifies important risk factors in a hierarchical structure. This model incorporates fuzzy logic into MCDM to manage uncertainties in group decision making. An intelligent review process is used to ensure that experts' preferences are reasonably consistent when selecting risk factors. The applicability of this method is demonstrated through a case study, showing that the model effectively prioritizes risks based on expert input and considers both risk criticality and interdependence.

Vosoughifar and Araghi (2023) present a study on evaluating the modified uncertainty Markov Chain Monte Carlo (MCMC) approach to obtain a safety-quality index in precast concrete construction (PCC) projects. The authors highlight the discontinuous processes inherent in PCC projects and how they contribute to various uncertainty-related safety and quality issues. Building Information Modeling (BIM) is identified as a crucial tool for managing these discontinuous processes and improving safety and quality in PCC. The study focuses on developing a modified fuzzy Analytic Network Process (ANP) approach to determine the importance weights of input variables for managing PCC projects using BIM. The authors then utilize the modified uncertainty MCMC analysis to identify the optimal high occurrence rate of the multidimensional BIM index (IMBIM) as a management measure for safety and quality issues in PCC. The results of the study demonstrate that a high percentage of occurrence frequency for IMBIM falls within a specific range, indicating its significance in assessing the quality-safety of construction projects. The mean optimal value of IMBIM derived from the analysis serves as a management measure for addressing multidimensional problems in PCC projects.

Zhang et al. (2014) present a systematic approach to safety management for buildings adjacent to tunneling excavation projects. This approach involves a detailed, step- by-step procedure assessing safety risks at four different levels based on spatial and health parameters of nearby buildings. It employs finite element method (FEM) analyses for complex tunnel-soil-building interactions to propose appropriate protective measures. A case study in China verifies the approach`s feasibility, showing its potential application in similar urban tunneling projects to balance safety and cost effectively.

The evolution and cutting-edge technologies of construction safety management in building construction projects are covered in Zitong Jia (2022). In order to lower safety production accidents and preserve the safety of workers, equipment, and construction progress, the study highlights the significance of safety management tools and safe construction approaches. It emphasizes how important it is for businesses to have safety responsibility mechanisms in place, assign staff to oversee construction sites, and create safety management plans that are specific to the needs of the building industry. The study emphasizes how important safety construction technology is to guaranteeing both building quality and safety. To satisfy safety quality criteria, reduce safety dangers, and strengthen the main body of structures, technical measures are created. The study emphasizes how important safety construction technology is to guaranteeing both building quality and safety. To satisfy safety quality criteria, reduce safety dangers, and strengthen the main body of structures, technical measures are created. The study emphasizes the cognitive application of construction safety principles to assure safety quality and economic interests, stressing that construction safety is not only a single requirement but also a fundamental basis for analyzing the quality of building construction. In conclusion, the paper acknowledges that building construction safety is a complex issue influenced by various factors. While there is no complete solution to safety problems, the development of science and technology, improvement of industry regulations, and attention from the government contribute to finding relevant solutions. It emphasizes the importance of safety management and safety construction technology in meeting construction safety requirements, highlighting the interplay between the two as crucial for effective construction project implementation and safety quality assurance.

Enhancing Safety Awareness and Management

The article by Gunduz and Khader (2020) addresses the inherent risks in the construction industry, emphasizing the frequent occurrence of accidents and fatalities due to complex and intertwined hazards. The authors utilized the Analytic Network Process (ANP) combined with a frequency-adjusted importance index to identify and prioritize 42 hazards across 14 categories, based on input from 106 construction professionals. The study highlights the significance of management involvement and robust safety policies as key factors in mitigating these risks. The research introduces a novel approach by integrating the frequency-adjusted importance index with the ANP tool, offering a comprehensive method to assess and address safety hazards in construction projects. The findings suggest that addressing root causes rather than superficial hazards can significantly enhance safety performance, urging industry professionals to adopt proactive safety management practices.

Li et al. (2022) examine how mutual support among construction workers with different personality traits affects team safety. Using agent-based modeling (ABM) and the AnyLogic platform, the study simulates different risk environments to optimize team configurations. The study finds that personality traits significantly impact safety behaviors, with teams comprising a balanced mix of personality traits demonstrating the best improvement in safety performance. The research emphasizes the importance of understanding workers' personalities for proactive safety management in construction projects.

Table 1 provides a summary for the articles that are mentioned within the literature survey.

Table 1: Summary of the reviewed articles

Author(s) & Year	Focus Area	Methodology /Approach	Key Findings/ Contributions
Mohandes et al. (2020)	Construction labor safety risk assessment	Integration of Fuzzy Best Worst Method (FBWM) and Interval- Valued Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IVFTOPSIS)	Precise ranking of risks, precise evaluation strategies, wider classification ranges
Gunduz & Khader (2020)	Safety performance management in construction projects	Analytic Network Process (ANP) with frequency-adjusted importance index	Identification and prioritization of significant safety risks, emphasis on management role
Chatterjee et al. (2017)	Risk management in construction projects	Hybrid MCDM technique combining ANP and MABAC with CFPR	Effective risk response strategy selection, addressing uncertainties
Jeon et al. (2024)	Multi-criteria decision-making for selecting packaging bags	PHFEs with WASPAS-AHP method	Enhanced decision-making using probabilistic hesitant fuzzy elements
Koh, Tuuli, & Rowlinson (2014)	High reliability organizing for construction safety	Relational framework integrating social capital with HRO principles	Improvement in safety through adaptive human interactions
Zhang et al. (2014)	Safety management for buildings adjacent to tunneling excavation projects	Systematic approach based on FEM analyses	Feasibility of safety management in urban tunneling projects
Badalpur & Hafezalkotob (2015)	Risk management in EPC projects	MCDM techniques with EVM	Improvement in project cost, completion time, and risk mitigation
Rezakhani (2012)	Risk factor selection in construction projects	Fuzzy MCDM model	Efficient prioritization of risks considering criticality and interdependency
Vosoughifa r & Ashtiani Araghi (2023)	Safety-quality index in precast concrete construction projects	Modified uncertainty MCMC approach	Management measure for safety and quality issues in PCC projects
Jia (2022)	Development of construction safety management technologies	Advanced construction safety management techniques	Importance of safety technology in ensuring construction quality and safety
Zhao et al. (2021)	Safety Risk Management System in Electric Power Engineering Construction	BD technology for safety risk management	Improved safety through BD technology integration
Xue et al. (2022)	Safety Monitoring System for South-to-North Water Diversion Project	Big data technology for safety monitoring	Intelligent risk management through big data technology
Kang (2011)	Safety production management in construction projects	Investigation into safety management practices	Need for comprehensive safety legislation and increased inspections
Zhao et al. (2022)	Safety management system for substation construction projects	Integration of IoT and chromatographic zone management	Enhanced safety through IoT integration
Liu et al. (2024)	Construction safety management in megaprojects	Resilient governance for safety enhancement	Importance of engineering resilience in safety management

Nnaji & Karakhan (2020)	Technologies for safety and health management in construction	Survey of 102 construction practitioners	Identified technologies used, benefits and limitations of these technologies, and critical barriers to adoption; provided strategies to overcome these barriers
Patel, Raichura, & Pitroda (2021)	Critical factors influencing safety management in construction	Importance of safety training and advanced technologies	Integration of advanced technologies for improved safety outcomes
Haupt, Akinlolu, & Raliile (2021)	Emerging technologies in construction safety management	Utilization of emerging technologies for safety enhancement	Integration of emerging technologies with traditional safety practices
Zeng & Li (2022)	Construction safety and health hazard awareness	Comparative analysis of hazard awareness	Disparity between academic focus and public discourse on safety
Singh et al. (2023)	Barriers to blockchain adoption in construction supply chain management	Fuzzy-based MCDM approach	Identification of influential barriers to blockchain adoption
Sathiyaraj et al. (2023)	Construction safety management systems	PROMETHEE method for safety management	Importance of systematic risk management and standardized auditing
Lin, Zhou, & Shen. (2023)	Safety assessment of excavation systems	MCDM model based on TOPSIS in a fuzzy environment	Identification of high-risk factors and effective countermeasures
Li, K et al. (2022)	Influence of personality traits on construction team safety	Agent-based modeling (ABM) using AnyLogic platform	Teams with balanced personality traits show the best improvement in safety performance. Emphasizes proactive safety management.
Salim et al. (2023)	Issues and solutions for fire safety management in public health-care buildings	Qualitative methodology; case studies and thematic analysis using MAXQDA	Identified issues such as poor policy implementation, inadequate water pressure, and communication. Suggested solutions include enhancing institutional frameworks, emergency response, and occupational health systems.
Hale, A.R. (2003)	Safety management in production	Review of literature and safety practices	Identified key functions of SMS, highlighted gaps in knowledge, emphasized need for continuous improvement
Mohandes, S. R., et al. (2020)	Assessing construction labourers' safety levels	Fuzzy MCDM approach	Identified and assessed safety levels of construction Laboure's using a multi-criteria decision- making model.
Hallowell, M. (2008)	Assessing safety risk across different construction trades	Safety risk assessment approach	Developed an approach to assess safety risks across various construction trades, highlighting the differences in risk levels.
Aneziris, O. N., et al. (2010)	Occupational risk in tunneling construction	Quantitative risk analysis	Provided a quantitative assessment of occupational risks in tunneling construction, identifying key risk factors.
Mitropoulo s,P., & Namboodir i, M.(2010)	Measuring safety risk of construction activities	Task demand assessment method	Introduced a new method to measure safety risk based on task demand, improving accuracy in risk assessment.
Aminbakhs h, S., et al. (2013)	Safety risk assessment in construction project planning	Analytic hierarchy process (AHP)	Utilized AHP to assess safety risks during the planning and budgeting stages of construction projects.
Papazoglou, I. A., et al. (2017)	Impact of working conditions on occupational risk	Quantitative risk model	Developed a quantitative model to evaluate how different working conditions influence occupational risks.

Gunduz, M., et al. (2016)	Construction site safety performance assessment	Fuzzy structural equation model	Applied a fuzzy structural equation model to assess and improve safety performance on construction sites.
Debnath, A. K., et al. (2016)	Risks of traffic accidents at signalized intersections	Fuzzy logic-based approach	Used fuzzy logic to assess and predict the risks of traffic accidents at signalized intersections.
Mohandes, S. R., & Zhang, S. (2019)	Risk assessment in construction projects	Hybrid approach with fuzzy BWM and interval-valued fuzzy sets	Combined fuzzy best-worst method and interval-valued fuzzy sets to enhance risk assessment in construction projects.

Table 1 provides a comprehensive summary of various studies focusing on construction safety management, highlighting the methodologies employed and the key findings or contributions of each work. This detailed overview illustrates the diverse approaches and innovative solutions that have been developed to enhance safety practices within the construction industry.

CONCLUSION

In this study, the application of Multicriteria Decision-Making (MCDM) approaches in construction safety management is explored as a review of the existing studies. The review encompassed a diverse range of studies highlighting the significance of MCDM techniques in systematically evaluating and prioritizing safety risks in construction projects. The reviewed research showcased various MCDM methodologies such as Risk Assessment Models (RAMs), Analytic Network Process (ANP), and hybrid approaches integrating fuzzy logic and decision-making tools. These methodologies offer structured frameworks for considering multiple criteria, diverse perspectives, and both quantitative and qualitative data in safety decision-making processes. Furthermore, the integration of advanced technologies such as Data, Internet of Things (IoT), and Blockchain into safety management systems demonstrated the potential for innovative solutions to enhance safety practices and mitigate risks effectively. Throughout the review, it became evident that while MCDM approaches hold significant promise for improving safety outcomes in construction projects, challenges remain in effectively implementing safety management systems and overcoming barriers to adoption. Issues such as inadequate hazard awareness, insufficient training, and organizational barriers need to be addressed to realize the full potential of MCDM approaches in construction safety management. Overall, this literature review offers important insights into the current state of research. and practice in the application of MCDM approaches in construction safety management. By fostering collaboration among researchers, industry stakeholders, and policymakers, we can continue to advance safety practices, reduce accidents, and ensure the health of all individuals involved in construction projects.

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