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Optimizing construction supplier selection in conflict-affected regions: a hybrid multi-criteria framework

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Abstract
Conflicts and wars profoundly impact infrastructure, exacerbating the adversity already caused by natural disasters. Therefore, it is imperative that the reconstruction process be both effective and efficient to expedite a return to normalcy. This study aims to enhance the efficacy of reconstruction efforts through improved construction supplier evaluation and selection. It introduces an innovative hybrid multi-objective decision-making model that integrates a broad spectrum of economic, technical, and humanitarian criteria. The model is designed to optimally select and assign construction suppliers in regions affected by human and natural conflicts and crises. Fifteen criteria have been incorporated into the evaluation process to validate its effectiveness and maximize its contribution to local communities. This methodology streamlines decision-making and enhances transparency in conflict zones, aligning with the interests of all stakeholders. The study incorporates advanced methodologies, including Fuzzy Goal Programming (F-GP), Geographic Information System (GIS)-based Risk Assessment, and Fuzzy Analytic Hierarchy Process (F-AHP), leveraging real-world data and a case study. Additionally, a sensitivity analysis examines the impact of varying inputs on the model's output. The findings attest to the model's utility in conflict-affected regions and its potential applicability in stable settings.

Keywords Crisis · F-AHP · F-GP · GIS · Risk · Supplier selection

1 Introduction

In the wake of conflicts and crises, the efficient and effective reconstruction of infrastructure is crucial. The supplier evaluation and allocation process play a critical role in this context, yet traditional procurement methods often fail to meet the dynamic and complex needs of post-conflict environments (Khaled et al. 2011; Pal et al. 2013). Various multi-criteria decision making (MCDM) methods have been used in different industries such as food, automotive, healthcare, and petrochemical; however, research on the construction industry in conflict areas is rare (Tushar et al. 2022). To address this gap, the research is structured around the following central research questions (CRQs):

CRQ1: What supplier selection criteria are considered important for the construction industry in conflict areas?
CRQ2: How can we best incorporate the identified supplier selection criteria into a supplier selection process in conflict areas?
CRQ3: How can we best conduct a risk analysis in conflict areas based on GIS?
CRQ4: How does the integration of multiple evaluation criteria and GIS-based risk analysis into the supplier evaluation and allocation process utilizing fuzzy multi-criteria decision-making affect the efficiency and outcomes of construction projects in conflict zones?

We hypothesize that incorporating various humanitarian, economic, and technical criteria into the evaluation process will make it more comprehensive. Utilizing GIS-based risk analysis will lead to a more realistic assessment of risks in conflict areas. Employing fuzzy multi-criteria decision-making (incorporating humanitarian, economic, technical, and risk criteria) will result in more effective and transparent supplier evaluations and allocations, thereby enhancing project success in these environments.

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To address these CRQs, this study develops a structured hybrid fuzzy MCDM framework based on GIS-based risk assessment, F-AHP, and F-GP to tackle the supplier evaluation and allocation problem in the construction industry of northern Syria, a conflict area.

Motivated by the significant impact that procurement efficiency has on rehabilitation efforts, this research seeks to refine the procurement process in conflict-affected regions. Current methods often fall short due to the unpredictable nature of supply chains and the pressing needs of these areas (Sarkis and Talluri 2002; Christopher 2016). By developing a robust supplier evaluation and allocation model that accounts for a broad spectrum of criteria, this study aims to significantly improve transparency and effectiveness, impacting the success of reconstruction projects and the effective utilization of funds.

This study is significant as it addresses a notable gap in the literature concerning the application of fuzzy multi-objective decision-making models in post-conflict supplier selection (Ghodsypour and O'Brien 2001). The study aims to achieve the following main research objectives (MROs):

MRO1: Identify the supplier selection criteria relevant for the construction industry in conflict areas.
MRO2: Calculate weights of identified construction supplier selection criteria using the F-AHP method.
MRO3: Conduct GIS-based risk analysis in conflict areas.
MRO4: Evaluate and allocate construction suppliers using mathematical fuzzy goal programming.
MRO5: Discuss the implications of the proposed research.

This research contributes to the theoretical and practical understanding of procurement challenges and evaluation processes in conflict zones. It boosts transparency in the multi-criteria selection process, leading to a comprehensive framework, sustainability, and effective resource utilization, accelerating the return to normal life for affected populations, and contributing to the wider goal of effective reconstruction after crises. The findings are particularly relevant for non-governmental organizations, donors, local authorities, and other stakeholders engaged in reconstruction, offering them a novel approach that can lead to more informed and strategic decisions in construction supplier evaluation and allocation.

The paper is organized as follows: The literature review section outlines current methodologies and identifies their limitations. The methodology section introduces our innovative approach to supplier evaluation and allocation, while the application of this model is demonstrated through a detailed case study in section four. The final section discusses the implications of our findings and suggests potential avenues for future research.

2 Literature review

2.1 MCDM in supplier evaluation

MCDM represents a methodical process aimed at identifying the most favorable option among various feasible alternatives based on a set of defined criteria or attributes (Garg 2016a, b, 2017; Hallak et al. 2019, 2021; Hallak and Polat 2021). Selecting the correct supplier can significantly lower purchase costs and enhance an enterprise's competitiveness, illustrating why many researchers believe that selecting a supplier is one of the most important activities of the purchasing department (Ghodsypour and O'Brien 2001).

In recent years, several supplier selection and evaluation methods have been developed. A number of MCDM methods have been employed in this research area: the analytical hierarchy process (AHP) (Etlanda and Sutawidjaya 2022); the fuzzy technique for order of preference by similarity to ideal solution (FTOPSIS) (Cakar and Çavuş 2021); the best–worst method (BWM) (Amiri et al. 2020); the fuzzy decision-making trial and evaluation laboratory (FDEMATEL) (Giri et al. 2022); and the multi-criteria optimization and compromise solution (VIKOR) (Gupta and Kumar 2022). To maximize the advantages and minimize the weaknesses of specific MCDM methods, researchers often integrate two or more MCDM methods into a hybrid method (Govindan et al. 2020). The literature related to supplier selection is dominated by these hybrid MCDM approaches. Further, researchers have begun employing combinations of more than two MCDM methods, such as F-AHP, F-TOPSIS and Fuzzy inference systems (FIS) (Mina et al. 2021), and integrating F-AHP with PROMETHEE II for selecting suppliers based on circular economy principles (Tushar et al. 2022).

This research follows a novel approach by surveying the affected population to define criteria, using F-AHP to calculate weights, and implementing GIS-based risk assessments to evaluate risks associated with each supplier. Finally, all parameters are integrated into fuzzy goal programming to optimally evaluate and allocate construction suppliers for projects in the area.

2.2 Criteria used in the supplier evaluation

Although supplier selection criteria often differ from industry to industry, surveys of the literature show that criteria related to delivery, quality, and price are commonly considered across various sectors. The quality of materials and services has been a focal point in several studies (Dickson 1966; WEBER et al. 1991; Tam 2001; Chan and Kumar 2007; Gencer and Guerpinar 2007; Guo et al. 2009; Wang 2010; Balezentis and Balezentis

2011; Zeydan et al. 2011; Kilic 2013; Cristea and Cristea 2017; Tamosaitiene et al. 2017; Wang et al. 2017; Fallahpour et al. 2017), while aspects such as total price and delivery time have been emphasized by others (Dickson 1966; Weber et al. 1991; Tam 2001; Chan and Kumar 2007; Gencer and Guerpinar 2007; Lee 2009; Guo et al. 2009; Lam et al. 2010; Wang 2010; Balezentis and Balezentis 2011; Kilic 2013; Hruska et al. 2014; Cristea and Cristea 2017; Wang et al. 2017; Buyukozkan and Gocer 2017; Fallahpour et al. 2017). Certifications of products and materials (Ting and Cho 2008; Hudymacova et al. 2010; Cristea and Cristea 2017), supplier reputation (Lin and Chang 2008; Rezaei et al. 2014), and warranty periods post-delivery have also been considered key factors in supplier evaluations (Cristea and Cristea 2017; Wang 2010). Consistent performance and reliability are crucial, as emphasized in the literature (Wang et al. 2004; Chan and Kumar 2007; Gencer and Guerpinar 2007; Lee 2009; Cristea and Cristea 2017). Despite the evolving landscape and increasing emphasis on qualitative criteria, financial parameters, delivery, and quality consistently emerge as core criteria in nearly all research on supplier selection. This trend is affirmed by the aforementioned studies, which significantly influence decision-making in the supplier evaluation process.

In this study, related literature served as the primary source for identifying supplier selection criteria, supplemented by feedback from surveying 32 NGOs implementing construction projects in Syria. These surveys focused more on risk and humanitarian factors in supplier evaluation in conflict areas, whereas previous studies often concentrated on stable communities and regions. Most earlier research predominantly relied on criteria weights determined through AHP, MCDM, and/or TOPSIS under normal and stable conditions. However, there has been a notable lack of research focused on developing optimal strategies for evaluating and allocating construction suppliers in crisis areas, especially considering humanitarian and risk factors assessed through GIS. This study extends existing methodologies by identifying and weighting criteria using F-AHP, performing GIS-based risk assessments, and deriving a risk value for each supplier. These values are integrated into a mathematical model that employs fuzzy goal programming to optimally allocate construction suppliers to projects. This approach aims to provide a robust framework for supplier selection in challenging environments, ensuring that projects are equipped with the best possible resources under demanding conditions.

3 Methodology

A novel hybrid approach has been introduced to address the complexities of this multi-criteria problem. To begin, a GIS-based risk assessment methodology was employed. This entailed determining the risk values associated with each potential construction supplier within the conflict-affected region through the integration of spatial analysis. Subsequently, a multi-criteria technique was applied utilizing F-GP to effectively solve the model and identify the optimal solution. Within this framework, particular emphasis was placed on the assignment of construction suppliers to the required projects that best align with a spectrum of goals encompassing financial, technical, spatial, humanitarian, environmental, and risk considerations. The ensuing sections provide a meticulous delineation of the steps and procedures undertaken in this approach, as shown in Fig. 1:

1. Dual-Pronged Data Collection: This involves two methods, surveys and Focus Group Discussions (FGDs).

    ➢Surveys: We collected responses from 32 NGOs to obtain a broad perspective on different practices and standards in the field. These surveys provided quantifiable and comparable data about the NGOs' methods for evaluating suppliers and criteria utilized. We employed a purposive sampling approach to select NGOs for our survey. Around 40 active local NGOs that conduct construction projects were invited to participate in the surveys, but 32 NGOs responded. This approach ensured that all participants were actively engaged in construction projects within Syria, allowing for a focused examination of construction supplier evaluation practices in this specific context. This method facilitated access to targeted insights into the challenges and practices peculiar to NGOs operating in conflict-affected regions.
    Survey Validation: To ensure the reliability and relevance of our questionnaire for surveying NGOs, we implemented a validation process with input from both academic researchers and donors experienced in construction projects in Syria. The validation process included:
    • Expert Selection: Two academics specializing in construction supplier evaluation, two experts from local NGOs, and two donors involved in construction project funding were selected for their extensive knowledge and field experience, as detailed in Table 1.
    • Review Process: Experts reviewed the draft questionnaire, assessing clarity, relevance to our objec-

Fig. 1 The proposed methodology to solve the supplier problem

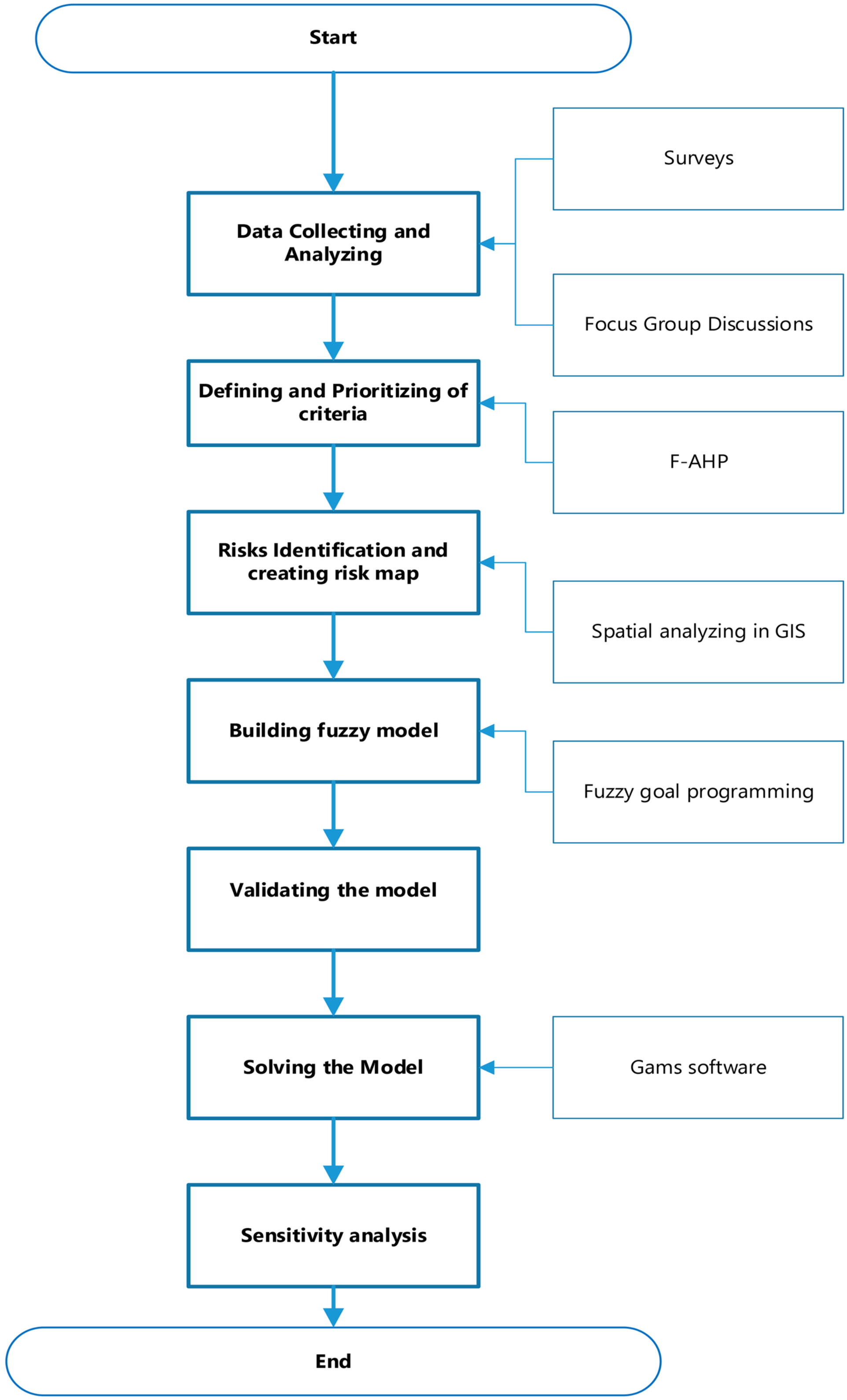

Table 1 The participating experts

Expert no	Organization Age (In Years)	Type of organization	Expertise	Experience (In Years)	Education level
1	16	Academic	Construction	8	PhD
2	12	Academic	Supply Chain	6	PhD
3	15	Local NGO	Purchase And Procurement	12	PhD
4	25	Local NGO	Construction	9	Master
5	33	Donor	Supply Chain	7	Postgraduate
6	28	Donor	Purchase And Procurement	10	Bachelor

tives, and comprehensiveness in covering the NGO supplier evaluation process in conflict zones.

• Criteria for Validation:

(I) Clarity: Questions were designed to be clear and unambiguous.

(II) Relevance: All questions directly related to construction supplier selection and evaluation practices.

(III) Comprehensiveness: The questionnaire comprehensively covered all aspects critical to NGO decision-making in supplier evaluation and selection.

• Feedback and Revisions: Experts provided structured feedback suggesting necessary revisions to improve question focus. These changes were incorporated to enhance the supplier evaluation process.

• Final Validation: The revised questionnaire underwent a final review to confirm all modifications were effectively integrated. Approval from all experts confirmed the questionnaire was validated and ready for deployment. The whole survey is provided in Appendix 1.

➢ FGDs: FGDs serve as a pivotal tool for delving deeper into issues initially highlighted through surveys. These discussions enable a nuanced exploration of the perspectives and practices of non-governmental organizations (NGOs), facilitating the identification of both common themes and divergent viewpoints. This process is crucial for developing a robust evaluation framework. For instance, when surveys reveal a lack of consensus on specific points, FGDs are instrumental in fostering collective agreement. Through FGDs, it was determined that the maximum acceptable distance for allocating a supplier to a construction project is 100 km. This limit is based on experiences showing that greater distances complicate project execution and increase logistical challenges. Similarly, it was established that suppliers within this region could be allocated to a maximum of three construction projects. This restriction reflects the administrative capacities of local suppliers who often lack the robust administrative structures necessary to manage multiple projects effectively. These conclusions are drawn from the practical insights and experiences of humanitarian actors and donors who have implemented construction projects in the region.

2. Prioritizing the criteria: Utilizing the F-AHP, a decision-making framework that allows for the incorporation of human judgment and uncertainty. It is used to determine the relative importance of a set of criteria that NGOs consider when evaluating suppliers. The "fuzzy" aspect allows it to handle imprecision, which is often the case in a crisis environment.
3. GIS Spatial Analysis: Geographic Information System (GIS) is a tool used to capture, store, manipulate, analyze, manage, and present spatial or geographic data. In this context, it helps in identifying and visualizing risks associated with different geographical locations where suppliers might operate, contributing to a comprehensive risk map. Two risks are defined: the first is the frontline risk, and the second is the hard access areas risk.
4. Building the Fuzzy Model: This involves creating a model based on fuzzy goal programming. This model can handle the complexity and ambiguity of real-world desired targets in each objective, making it suitable for evaluating suppliers where information may be incomplete or uncertain.
5. Model Validation: Before using the model for decision-making, it is critical to ensure that it accurately reflects the real-world scenario it's intended to represent. This involves testing the model against numerical examples to confirm its reliability.
6. Solving the model: The model is solved using GAMS, a high-level modeling system for mathematical programming problems. It is used to find the best solution or the most optimal supplier according to the criteria and data fed into the fuzzy model.
7. Sensitivity Analysis: After determining the optimal supplier, a sensitivity analysis is performed. This process involves changing one or more parameters in the model to see how these changes affect the outcome.

3.1 Building the model

3.1.1 Model parameters

I Set of tenders; $i \epsilon I$

J Set of candidate construction suppliers; $j \epsilon J$

N Set of targeted objectives; n ϵ N

d_{ij} Distance between candidate construction supplier j and another (acquired from building road network dataset by GIS)

SM_{ij} Submission matrix for tender i by each construction supplier j (not all supplier is submitting their offers to all tenders)

FO_{ij} Financial offer submitted by supplier j for each tender i

TVC_j Total value of previous contracts for each candidate supplier j.

RFL_j Risk at each candidate location of Candidate supplier j in terms of proximity to frontlines.

RHA_j Risk at each candidate location of Candidate supplier j in terms of hard access areas.

QM_{ij} Quality of materials submitted by candidate supplier j for each tender.

SE_j Staff experience for Candidate supplier j.

DT_{ij} Delivery time submitted by candidate supplier j for each tender.

PR_j Promptness response of quality and delivery issues for Candidate supplier j.

CE_j Capacity of each Candidate supplier j.

MC_j managemental capacity of each Candidate supplier j.

FC_j Financial capacity of each Candidate supplier j.

RL_j Recommendation letter submitted by third party for each Candidate supplier j.

CL_j Child labor involvement for each Candidate supplier j.

HP_j Commitment to humanitarian principles for each Candidate supplier j.

EV_j Commitment to environmental regulation and compliance for each Candidate supplier j.

k_n Weights of each fuzzy goal n.

AL_n Aspiration level for each fuzzy goal n.

ΔMA_n Maximum allowable deviation for each fuzzy goal n

3.1.2 Model decision variables

O_n Amount of an overachieved for each fuzzy goal n

U_n Amount of an underachieved for each fuzzy goal n

μ_n Degree of membership for each fuzzy goal n

3.1.3 Objective functions

$$Maximize \sum_{i \in I} \sum_{j \in J} t_{ij} QM_{ij} \tag{1}$$

$$Manimize \sum_{i \in I} \sum_{j \in J} t_{ij} Fo_{ij} \tag{2}$$

$$Maximize \sum_{i \in I} \sum_{j \in J} t_{ij} TV_j \tag{3}$$

$$Maximize \sum_{i \in I} \sum_{j \in J} t_{ij} SE_j \tag{4}$$

$$Minimize \sum_{i \in I} \sum_{j \in J} t_{ij} DT_{ij} \tag{5}$$

$$Maximize \sum_{i \in I} \sum_{j \in J} t_{ij} PR_j \tag{6}$$

$$Maximize \sum_{i \in I} \sum_{j \in J} t_{ij} CE_j \tag{7}$$

$$Maximize \sum_{i\in I}\sum_{j\in J} t_{ij}MC_j \tag{8}$$

$$Maximize \sum_{i\in I}\sum_{j\in J} t_{ij}FC_j \tag{9}$$

$$Maximize \sum_{i\in I}\sum_{j\in J} t_{ij}RL_j \tag{10}$$

$$Minimize \sum_{i\in I}\sum_{j\in J} t_{ij}CL_j \tag{11}$$

$$Maximize \sum_{i\in I}\sum_{j\in J} t_{ij}HP_j \tag{12}$$

$$Minimize \sum_{i\in I}\sum_{j\in J} t_{ij}RFL_j \tag{13}$$

$$Minimize \sum_{i\in I}\sum_{j\in J} t_{ij}RHA_j \tag{14}$$

$$Maximize \sum_{i\in I}\sum_{j\in J} t_{ij}EV_j \tag{15}$$

Equations (1) to (2) delineate the objectives of the proposed model. Equation (1) is designed to maximize the overall quality of materials submitted by candidate suppliers. In contrast, Eq. (2) focuses on minimizing the financial bids tendered by the construction suppliers to conduct the construction works in the area. Equation (3) seeks to maximize the aggregate value of previous contracts held by the chosen suppliers, while Eq. (4) aims to enhance the cumulative experience of their staff. Equation (5) is intended to minimize the total delivery time for completing the construction projects as proposed by the suppliers.

Subsequent equations, namely Eqs. (6) through (7), are directed towards maximizing various operational capacities of the selected suppliers. These include promptness in response (Eq. 6), equipment capacity (Eq. 7), managerial capacity (Eq. 8), financial stability (Eq. 9), and the quantity of recommendation letters (Eq. 10). Equation (11) is oriented towards minimizing the incidence of child labor among the selected suppliers.

Equation (12) addresses the commitment of suppliers to humanitarian principles, aiming for its maximization. Equations (13) and (14) target risk minimization related to the proximity of suppliers to frontlines and hard-to-access areas. Lastly, Eq. (15) is dedicated to maximizing adherence to environmental regulations by the selected construction suppliers.

Subject to:

$$\sum_{i\in J} t_{ij} = 1 \ \forall i \in I \tag{16}$$

$$t_{ij} \le SM_{ij} \quad \forall\, i \in I,\ \forall\, j \in J \tag{17}$$

$$\sum_{i\in I} t_{ij} \le 3 \quad \forall j \in J \tag{18}$$

$$\sum_{i\in I} t_{ij}d_{ij} \le 100 \quad \forall j \in J \tag{19}$$

$$t_{ij} \in [0,1] \tag{20}$$

The hard constraints of this model are encapsulated in Eqs. (16) to (20). Equation (16) mandates that each construction sub-project is to be allocated to only one supplier. Equation (17) specifies that a project can only be assigned to candidate suppliers who have submitted an offer for that particular project, as indicated by the submission matrix. Equation (18) limits the assignment of each construction supplier to a maximum of three projects. Equation (19) imposes a geographical constraint, ensuring that the projects assigned to a supplier are within a maximum distance of 100 km. Finally, Eq. (20) defines the binary variables associated with the selection of suppliers.

In existing literature, a variety of methods have been proposed to address multi-objective problems (Ulungu et al. 1994; Aiello et al. 2006; Ye and Zhou 2007; Singh and Singh 2011; Xu and Li 2012; Hathhorn et al. 2013; Emami and Nookabadi 2013; Xu et al. 2016; Li et al. 2017) In this particular study, the problem was addressed using fuzzy goal programming, F-AHP, GIS-based risk assessment, humanitarian and environmental context of the Syrian crisis.

3.2 Fuzzy goal programming

Goal programming is an approach used for solving multi-objective optimization problems that balances trade-offs in conflicting objectives. It allows for balancing all desired objectives (from Eq. 1) to Eq. 15 through direct trade-offs between all unwanted deviational variables by placing them in a normalized single-achievement function that includes all the objective deviations in just one equation (Jones and Tamiz 2010). In this study, a fuzzy goal programming model has been utilized because it provides a more realistic approximation to real case studies. This model was presented by Yaghoobi et al. (2008). The model consolidates all the objective functions into a single objective function, as formulated in Eq. 21, where efforts are made to minimize the deviations from the desired goal values in each goal, taking into account the weight of each objective function.

Consecutively, we have converted each objective function into soft constraints by adding the deviations O_n for those objective functions that we are striving to minimize, and U_n ffor those objective functions that we are striving to maximize. The soft constraints are formulated in Eqs. 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, and 50, while Eqs. 23, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, 47, 49, and 51 are constraints that ensure the sum of the normalized negative deviations, normalized positive deviations, and the membership variable μ_n equals one. The fuzzy model is presented and validated by the Yaghoobi model (Yaghoobi et al. 2008).

$$Minimize\ Z = \sum_n w_n \left(\frac{Ov_n + Un_n}{\Delta MA_n} \right) \tag{21}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij}\ QM_{ij} + Un_1 \geq AL_1 \tag{22}$$

$$\mu_1 + \frac{Un_1}{\Delta MA_1} = 1 \tag{23}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij}\ Fo_{ij} - On_2 \leq AL_2 \tag{24}$$

$$\mu_2 + \frac{On_2}{\Delta MA_2} = 1 \tag{25}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} TV_j + Un_3 \geq AL_3 \tag{26}$$

$$\mu_3 + \frac{Un_3}{\Delta MA_3} = 1 \tag{27}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} SE_j + Un_4 \geq AL_4 \tag{28}$$

$$\mu_4 + \frac{Un_4}{\Delta MA_4} = 1 \tag{29}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} DT_{ij} - On_5 \leq AL_5 \tag{30}$$

$$\mu_5 + \frac{On_5}{\Delta MA_5} = 1 \tag{31}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} PR_j + Un_6 \geq AL_6 \tag{32}$$

$$\mu_6 + \frac{Un_6}{\Delta MA_6} = 1 \tag{33}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} CE_j + Un_7 \geq AL_7 \tag{34}$$

$$\mu_7 + \frac{Un_7}{\Delta MA_7} = 1 \tag{35}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} MC_j + Un_8 \geq AL_8 \tag{36}$$

$$\mu_8 + \frac{Un_8}{\Delta MA_8} = 1 \tag{37}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} FC_j + Un_9 \geq AL_9 \tag{38}$$

$$\mu_9 + \frac{Un_9}{\Delta MA_9} = 1 \tag{39}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} RL_j + Un_{10} \geq AL_{10} \tag{40}$$

$$\mu_{10} + \frac{Un_{10}}{\Delta MA_{10}} = 1 \tag{41}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} CL_j - On_{11} \leq AL_{11} \tag{42}$$

$$\mu_{11} + \frac{On_{11}}{\Delta MA_{11}} = 1 \tag{43}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij}\ HP_j + Un_{12} \geq AL_{12} \tag{44}$$

$$\mu_{11} + \frac{Un_{11}}{\Delta MA_{11}} = 1 \tag{45}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} RFL_j - On_{13} \leq AL_{13} \tag{46}$$

$$\mu_{13} + \frac{On_{13}}{\Delta MA_{13}} = 1 \tag{47}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} RHA_j - On_{14} \le AL_{14} \tag{48}$$

$$\mu_{14} + \frac{On_{14}}{\Delta MA_{14}} = 1 \tag{49}$$

$$\sum_{i \in I} \sum_{j \in J} t_{ij} EV_j + Un_{15} \ge AL_{15} \tag{50}$$

$$\mu_{15} + \frac{Un_{15}}{\Delta MA_{15}} = 1 \tag{51}$$

3.3 Model validation

In the scholarly exposition of the case study, the validation of the proposed allocation model is meticulously articulated through a two-pronged data analysis approach. Initial validation is undertaken via synthetically constructed datasets, derived post-consultation with domain experts. This preliminary phase encompasses two distinct numerical examples: the first involving 10 construction projects and 20 potential

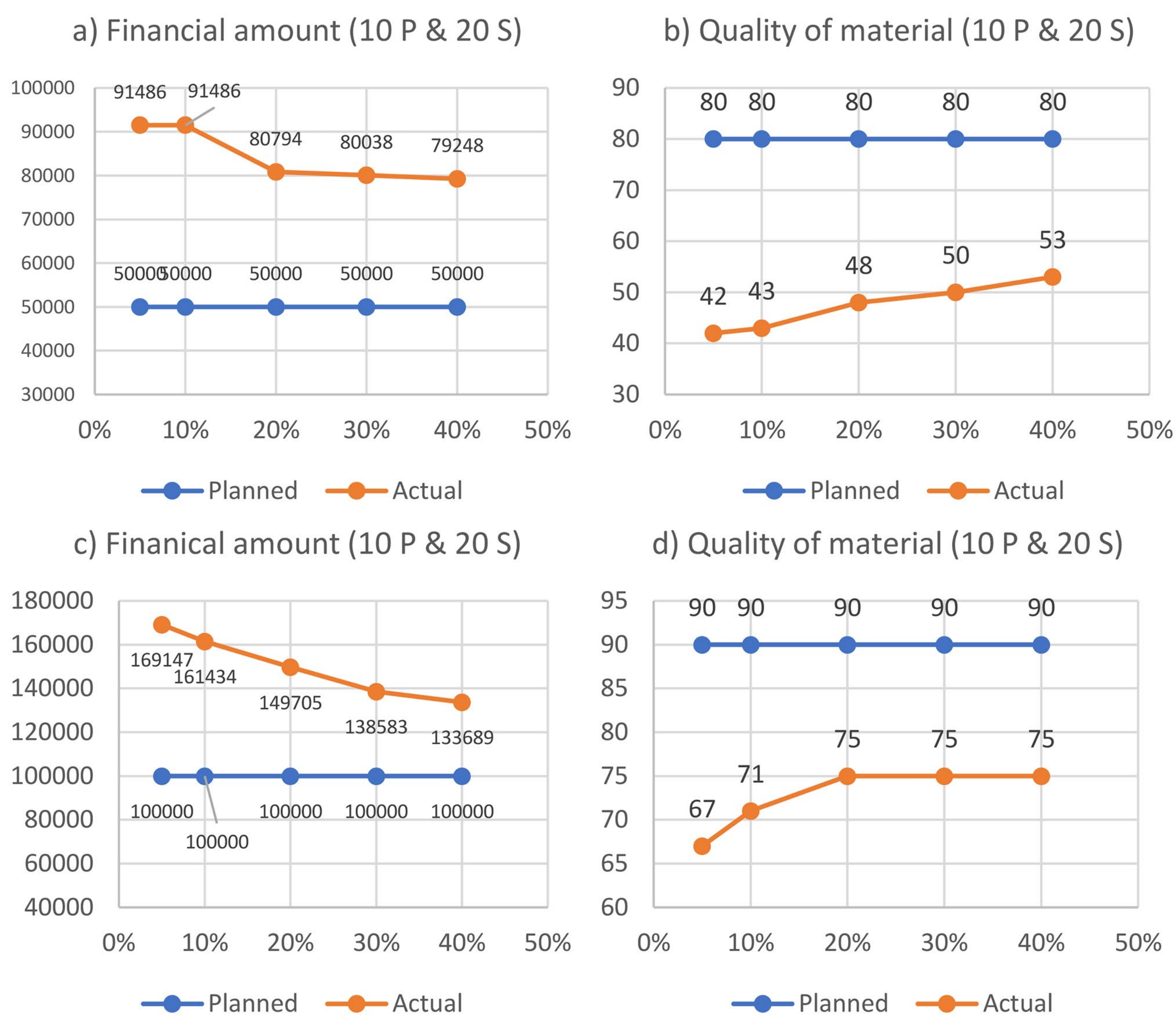

Fig. 2 Model validation results (**a**, **b**, **c**, **d**)

suppliers, and the second encompassing 20 construction projects paired with 30 candidate suppliers. These scenarios are rigorously tested against varied weight assignments, prioritizing the dual objectives of optimizing material quality and minimizing project costs. The detailed datasets and the resultant computational outcomes are systematically documented in Appendix 2.

To elucidate the model's operational efficacy, Fig. 2 is presented, delineating a comparative analysis of the synthetic datasets. This visual representation accentuates the model's capacity to negotiate between the competing objectives of material quality and cost-efficiency. Notably, the graphic illustrations within Fig. 2 delineate a positive correlation between the assigned weight to material quality and the model's propensity to enhance this particular objective. Conversely, an augmented emphasis on cost reduction is reciprocated by the model's inclination to curtail financial expenditures. Collectively, these outcomes substantiate the model's robustness and its capability to deliver balanced solutions within the complex operational landscape of Northern Syria's reconstruction endeavors.

Subsequent to the synthetic trials, the model's validity is further corroborated through empirical data amassed from field surveys and focus group discussions within the specific contexts of Al-Bab and Ar-Ra'ee, Syria. The integration of real-world data provides a pragmatic dimension to the model's applicability, with a sensitivity analysis cementing its relevance. The congruence between the model's outcomes and the practical requirements observed in the field serves as a testament to its validity and effectiveness.

4 Results and discussions

4.1 Case study

In the midst of ongoing crises in Northern Syria, the tendering process for construction projects has evolved into a multifaceted challenge. Various suppliers, eager to contribute to the rebuilding efforts, have submitted proposals to undertake one or multiple projects dispersed across the northern region of Syria in two sub-districts (AlBab and Ar-Ra'ee). An NGO, acting as the steward of these efforts, is tasked with the rigorous evaluation of these proposals against a comprehensive set of criteria. These criteria span humanitarian considerations, risk assessment considerations, environmental impact, ensuring sustainability amidst reconstruction, and technical and financial competencies, alongside the capacity to effectively deliver on project commitments.

The evaluation matrix is composed of fifteen distinct criteria, carefully designed to holistically assess each supplier's offer based on data collected from stakeholders in the area. This systematic approach aims to align the selection process with overarching objectives by proposing a novel hybrid fuzzy model. As a result, this study strives to promote equitable development and adherence to environmental and humanitarian standards, achieving a transparent framework for all stakeholders in the crisis region.

The NGO will allocate each project to the supplier that demonstrates the highest congruence with the defined criteria described in Table 2, thus ensuring the optimal alignment of project needs with supplier capabilities. It is stipulated that a single supplier may be awarded a maximum of three projects, with the stipulation that the geographical distance of these projects does not exceed 100 km for one supplier. This constraint is imposed to ensure logistical feasibility and effective project oversight, as lessons learned from previous projects as a result of FGDs.

Through this case study, the article elucidates the operational complexities and the intricate decision-making processes involved in post-conflict reconstruction. The narrative underscores the necessity of a transparent, balanced, and multi-objective approach that interweaves diverse evaluation criteria to foster comprehensive development and stability in crisis-afflicted regions.

4.1.1 Environmental regulation and compliance

Four factors were considered during the visits to each construction supplier, as shown in Fig. 3:

1. Water Conservation: Using water-efficient construction techniques, as water resources might be scarce or contaminated in crisis regions.
2. Low-Impact Materials: Choosing construction materials that have minimal environmental impact, such as locally sourced materials, to reduce transportation emissions and support the local economy.
3. Waste Reduction: Implementing strategies to minimize construction waste and ensure proper disposal, as waste management systems in crisis areas might be compromised.
4. Energy Efficiency: Incorporating energy-efficient designs in construction to reduce the long-term environmental footprint, considering the limited energy resources in such areas or utilizing photovoltaic energy to produce electricity.

4.2 Findings

In this section, we present the results from applying the proposed hybrid methodology. We extracted the risk value for each candidate supplier by creating risk maps according to each criterion and its location on the related risk map, as shown in Fig. 4.

Table 2 Criteria utilized to evaluate and select construction supplier in conflict areas

Goal/ Criterion	Type	Abbrev-iation	Description
G1	min	FO	The total financial amount to conduct the projects according to the submitted financial offers
G2	max	QM	Quality of materials submitted by suppliers to conduct the projects. To ensure a systematic and quantifiable assessment of material quality among different suppliers, committee of three dedicated engineers employs a Likert scale ranging from 1 to 5. This scale represents a gradient of quality, with '1' denoting 'low quality' and '5' signifying 'high quality'."
G3	max	TVC	The total value of previous contracts for each supplier
G4	max	SE	Staff experience for suppliers, which related to the certificates of engineers and other qualification of the staff, a Likert scale ranging from 1 to 5. This scale represents a gradient of quality, with '1' denoting 'low ' and '5' signifying 'high '
G5	min	DT	Delivery time to achieve the projects which is submitted by each supplier
G6	max	PR	Promptness response related to quality and delivery issues. Based on the previous contracts within the NGO or by asking the other NGOs about their responses, a Likert scale ranging from 1 to 5. This scale represents a gradient of response, with '1' denoting 'low ' and '5' signifying 'high'
G7	max	CE	Equipment capacity of the chosen supplier, this was conducted by a technical team consist of three dedicated engineers to evaluate the equipment of each supplier by visiting their office and their current ongoing projects. a Likert scale ranging from 1 to 5. This scale represents a gradient of quality, with '1' denoting 'low ' and '5' signifying 'high'
G8	max	MC	managemental and administrative capacity of the chosen supplier
G9	max	FC	Financial capacity of the chosen suppliers, a Likert scale based on their financial capacity by a committee as follows: (1: less than 5000$; 2: less than 10,000$; 3: less than 15,000$;4: less than 20,000$;5: less than 25,000$)
G10	max	RL	Recommendations letter of the chosen suppliers, it is related to the number of recommendation letters submitted by the supplier (1: one recommendation letter; 2: two recommendation letters; 3: three recommendation letters;4: four recommendation letters; 5: five recommendation letters)
G11	min	CL	minimizing Child labor involvement of the chosen suppliers (1: one incident report; 2: two incident report; 3: three incident reprot;4: four incident reports; 5: five incident report)
G12	max	HP	Commitment to humanitarian principles of the chosen suppliers, this is happened by visiting the place of each supplier and evaluate their commitment to those principles, the research employs a Likert scale ranging from 1 to 5. This scale represents a gradient of quality, with '1' denoting 'low quality' and '5' signifying 'high quality'
G13	min	RFL	Risk of chosen supplier in terms of proximity to frontlines. 1—low risk: Located within a region of 5 km from frontlines 5—high risk: Located in a region 10 km away from frontlines
G14	min	RHA	Risk of chosen supplier in terms of hard access areas. 1—low risk: no incident reports were involvement of armed groups occurred 5—high risk: more than 10 incident reports were involvement of armed groups occurred
G15	max	EV	Commitment to environmental regulation and compliance of chosen supplier. The research employs a Likert scale ranging from 1 to 5. This scale represents a gradient of quality, with '1' denoting 'low' and '5' signifying 'high'. Sub-Factors are considered in this factor are described in paragraph 3

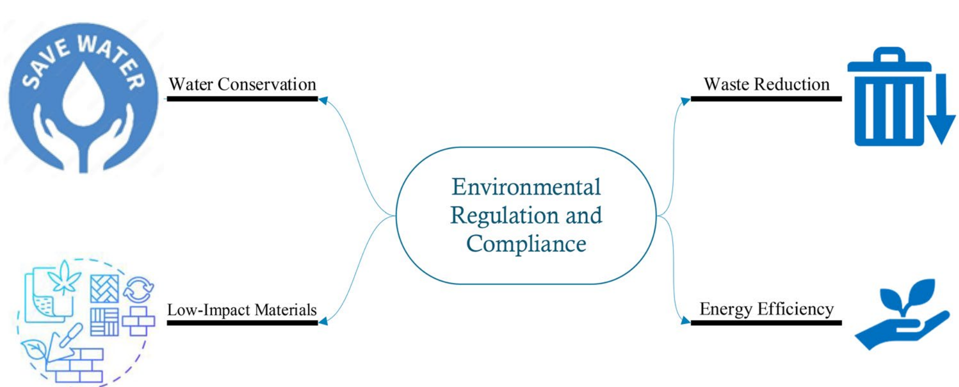

Fig. 3 Factor considered in the process of Environmental Regulation and Compliance

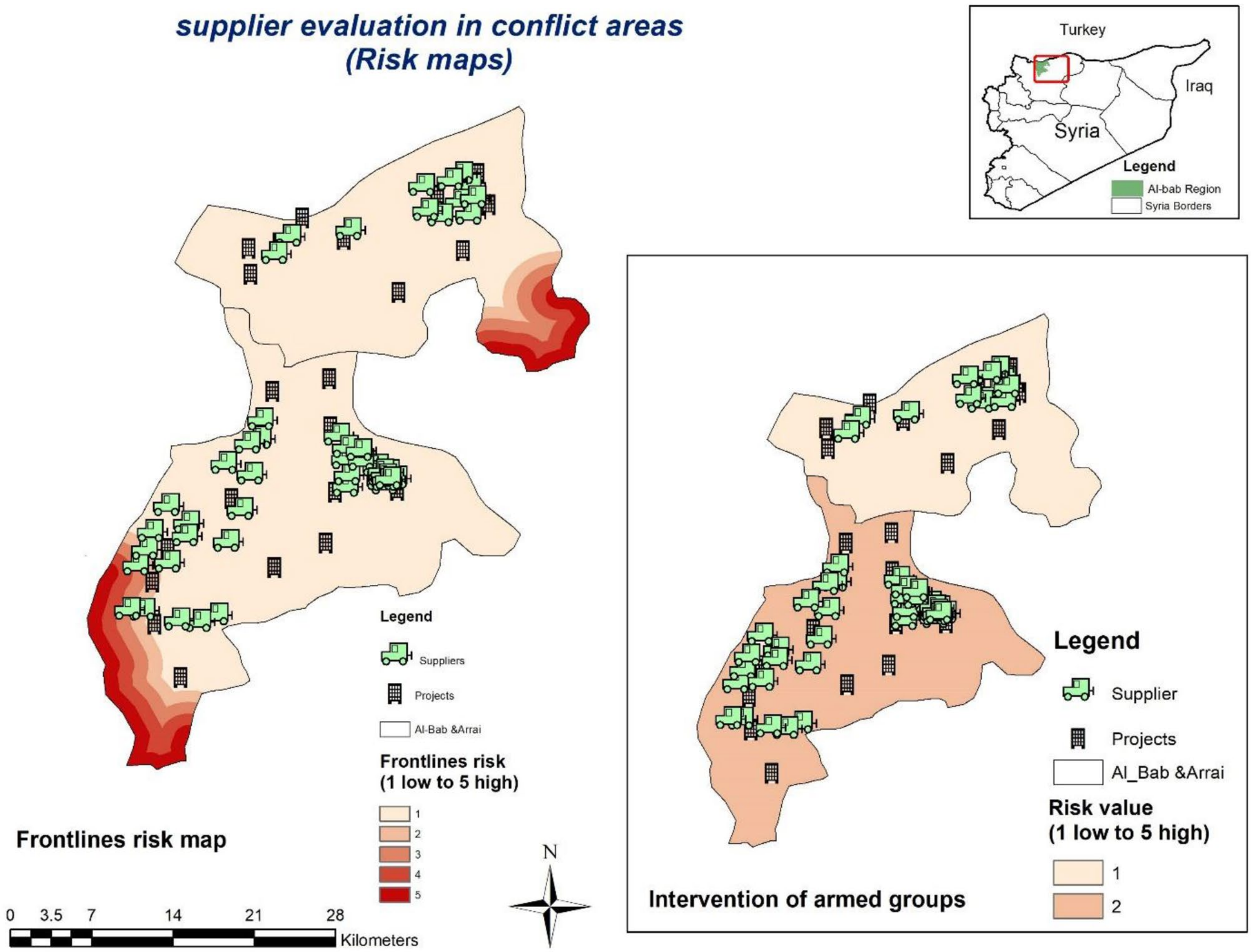

Fig. 4 Risk values in the target area

After calculating the risk value for each candidate supplier, we integrated this value into the mathematical fuzzy goal programming model as previously described. We solved the model using the software package, incorporating all fifteen goals to determine the optimal solution for the entire problem.

After calculating the risk value for each candidate supplier, we integrated this value into the mathematical fuzzy goal programming model as previously described. We solved the model using the software package, incorporating all fifteen goals to determine the optimal solution for the entire problem.

The inclusion of more criteria in the model enhances its transparency for the affected populations and suppliers within the humanitarian context and yields more varied values. This results in a marked variance between the values of candidate suppliers, which facilitates the selection process for decision-makers.

The results obtained from solving the proposed hybrid fuzzy model revealed the optimal solution achieved for each

Table 3 Planned goals vs actual as percentage

Goal/Criterion	Type	Planned	Actual	± Percentage
G1	min	300000	321526	+7.2%
G2	max	66	94	+42.4%
G3	max	1200000	1276414	+6.4%
G4	max	66	67	+1.5%
G5	min	150	260	+73.3%
G6	max	66	66	0.0%
G7	max	66	67	+1.5%
G8	max	66	66	0.0%
G9	max	66	94	+42.4%
G10	max	66	78	+18.2%
G11	min	40	44	+10.0%
G12	max	60	71	+18.3%
G13	min	30	26	-13.3%
G14	min	30	35	+16.7%
G15	max	60	61	+1.7%

goal. We have presented these in Table 3 to compare the actual values against the planned values (identified by three dedicated experts considering humanitarian aspects and similar previous projects in northern Syria). Additionally, we depict the results in Fig. 5, showcasing the actual achieved values for each objective as a percentage and obtained value.

For example, our cost target was approximately $300,000, but the actual value achieved was $321,526, reflecting an increase of 7%, which is considered relatively satisfactory as we strive to minimize this goal. While our aim was to reach a material quality scale of 66, we achieved a higher scale number of 94, which is approximately 44% higher. Our target for allocating suppliers with previous contracts was around $1,200,000, but after running the model, we achieved a very close value of $1,276,414. Throughout the model, we aimed to achieve 66 for staff experience, 150 for total delivery time to complete the projects, and scales of 66 for promptness response, equipment capacity, managerial capacity, financial capacity, recommendation letters, 40 for child labor involvement, 60 for commitment to humanitarian principles, 30 for risks related to frontlines, 30 for risks related to hard-to-access areas, and 60 for commitment to environmental regulations. In the results, we obtained 67, 260, 66, 67, 66, 94, 78, 44, 71, 26, 35, and 61, respectively.

The potential reasons for obtaining values that deviate significantly from the target values can be described as follows:

- The decision-makers in the target area consider previous projects as a baseline and attempt to predict optimistic targets for this project based on that baseline.
- Occasionally, the model may have already achieved the optimal values related to a specific criterion, indicating that there is no further possibility to improve the solution.
- The model consistently strives to balance the achievement of goals according to weights determined by the F-AHP and does not focus on any single criterion in isolation.

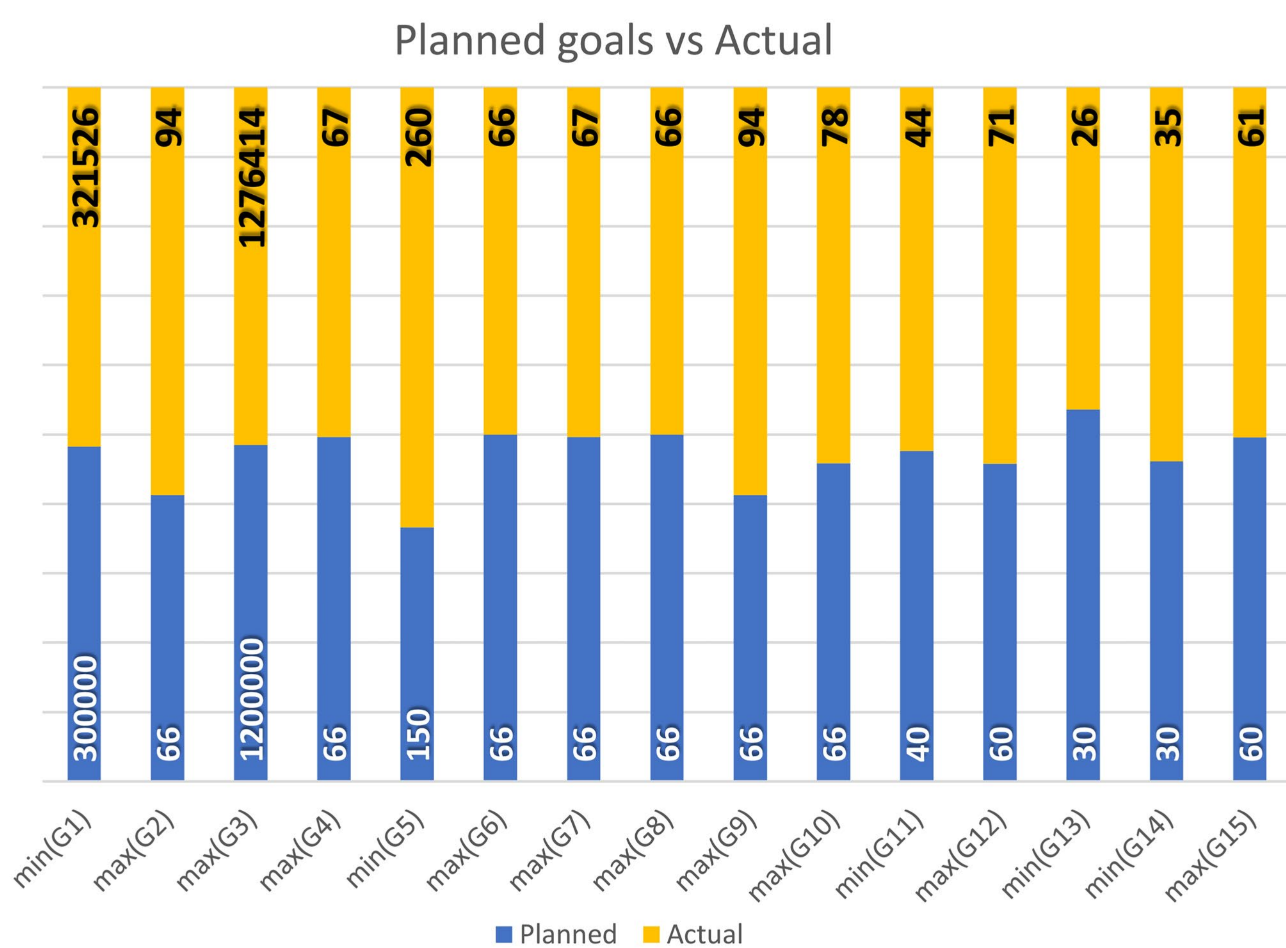

Fig. 5 Planned goals vs actual

4.3 Sensitivity analysis

4.3.1 Scenario 1: financial offers changing

In this Scenario, adjustments were made to the financial offers in response to the unstable market conditions in the area. Starting with a planned value of $300,000, the model endeavored to minimize this financial goal. A resultant value of $305,449.7 was obtained at a -5% change, as illustrated in Fig. 6. When transitioning from a 0% to a 5% change, there was an observed increase in the financial offers. However, this increase still remained less than the 5% threshold relative to the 0% change scenario. This indicates that the model consistently prioritizes minimizing financial costs while simultaneously considering the fulfillment of other objectives.

4.3.2 Scenario 2: some projects and suppliers are outside the calculation because of its location withing the frontline region

In this scenario, stakeholders acknowledge the possibility that some areas on the frontlines may become uncontrollable. This implies that construction projects and suppliers in these areas would be excluded from consideration, necessitating a resolution of the problem without their involvement. In this case, the projects and suppliers in the frontline area can be characterized as follows:

- The construction suppliers: S4, which was not selected under normal circumstances, and S5, S6, and S7, which were selected in the normal situation.
- Project P3 is also excluded from consideration.

The results obtained after solving the model under these conditions are presented in Table 4. It is observed that each project is allocated once, and the selected suppliers are assigned to a maximum of two construction projects each. In Table 5, the achieved goals are compared against the planned values. The solution in this altered scenario is less favorable compared with the normal situation, particularly concerning the first three most critical factors (G1, G2, G3). This outcome is expected due to the exclusion of three suppliers initially chosen in the normal situation from Case 2.

4.4 Implications for theory and practice

4.4.1 Theoretical implications

This research enriches the theoretical landscape by blending diverse methodologies, notably integrating Fuzzy Goal

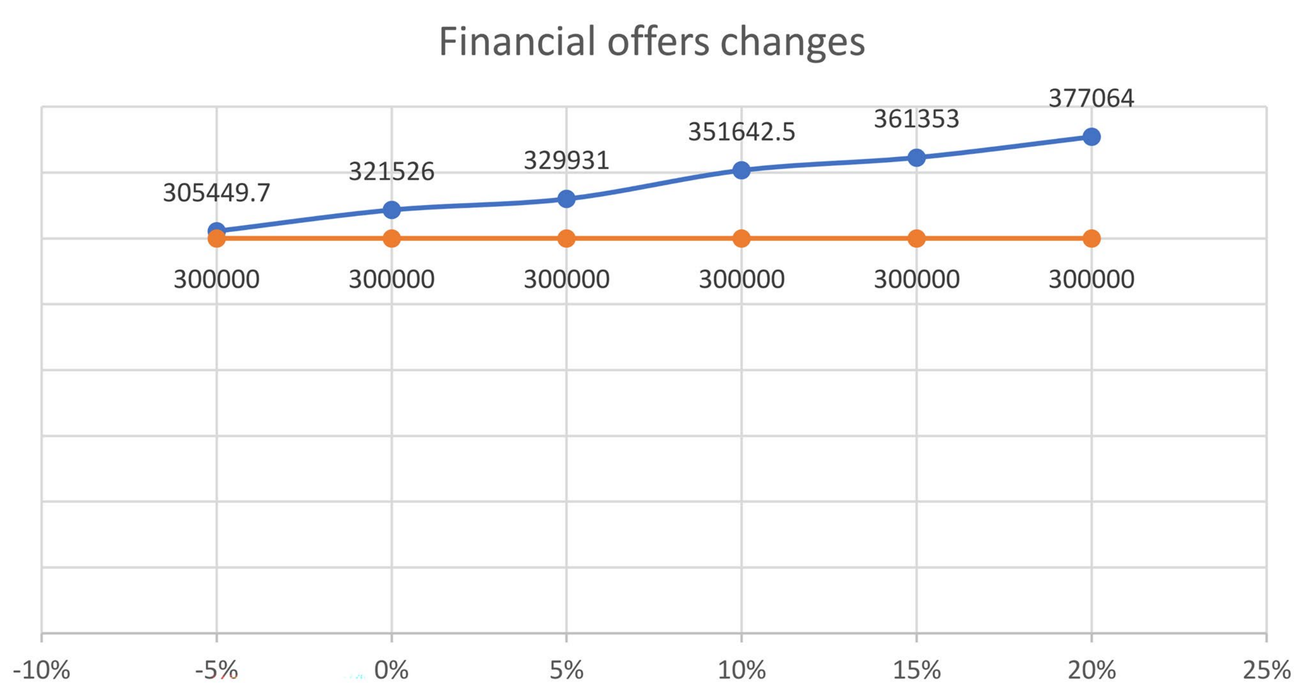

Fig. 6 Changes of financial offer

Table 4 Supplier selection and allocation in case 2

	S1	S9	S13	S23	S25	S26	S27	S28	S32	S41	S42	S43	S44	S46	S48	Total
P1											1					**1**
p2						1										**1**
P4										1						**1**
P5						1										**1**
P6					1											**1**
P7	1															**1**
P8		1														**1**
P9												1				**1**
P10							1									**1**
P11									1							**1**
P12													1			**1**
P13					1											**1**
P14				1												**1**
P15															1	**1**
P16									1							**1**
P17								1								**1**
P18		1														**1**
P19			1													**1**
P20	1															**1**
P21										1						**1**
P22														1		**1**
Total	**2**	**2**	**1**	**1**	**2**	**2**	**1**	**1**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	

Programming, GIS-based risk assessment, and the F-AHP. This multifaceted approach not only advances the understanding of MCDM but also tailors it specifically to the nuanced requirements of post-conflict reconstruction scenarios. This result is supported by Govindan et al. (2020), who emphasized the importance of using multiple methodologies to enhance decision-making processes. Such a synthesis is pivotal in offering a comprehensive framework that not only addresses but also adapts to the evolving complexities inherent in construction supplier evaluation within such zones. Additionally, the incorporation of real-world data and case studies enhances the theoretical relevance of the model, grounding abstract concepts in tangible scenarios that reflect the current challenges faced in supply chain management within conflict-impacted environments.

4.4.2 Managerial implications

From a practical standpoint, this study provides robust tools for improving decision-making in crisis situations. By systematizing the evaluation and allocation of suppliers to construction projects, the model underscores the critical importance of integrating risk and humanitarian considerations into procurement strategies. Such insights are invaluable for NGOs, donors, and local authorities engaged in reconstruction efforts, offering them a methodologically sound approach to enhance their operations. The application of this model not only promises enhanced efficiency

Table 5 Goals planned vs achieved in case 2

Goal	Type	Planned	Actual	± Percentage
G1	min	300000	371144.4	23.7%
G2	max	66	91	37.9%
G3	max	1200000	1254787	4.6%
G4	max	66	76	15.2%
G5	min	150	251	67.3%
G6	max	66	66	0.0%
G7	max	66	76	15.2%
G8	max	66	66	0.0%
G9	max	66	85	28.8%
G10	max	66	74	12.1%
G11	min	40	44	10.0%
G12	max	60	58	-3.3%
G13	min	30	21	-30.0%
G14	min	30	35	16.7%
G15	max	60	59	-1.7%

and effectiveness in project implementations but also fosters greater transparency and accountability in environments that traditionally suffer from high uncertainty and risk.

Furthermore, the strategic recommendations outlined in this study serve as a guiding framework for entities involved in reconstruction efforts. By adopting the proposed methodologies, these organizations can better navigate the complexities of supplier selection and project allocation in ways that align with both immediate project goals and long-term developmental objectives. This dual focus on operational efficiency and strategic foresight exemplifies the practical applications of the research, providing a scalable and adaptable solution that can be customized for various conflict-affected regions worldwide.

5 Conclusion

This study has developed an innovative hybrid methodology aimed at optimizing supplier selection and assignment for construction projects critical to the reconstruction efforts in Syria post-crisis and following the February 2023 earthquake. By integrating Geographic Information Systems (GIS) and the F-AHP, the approach effectively identifies the risk values associated with each potential supplier, facilitating the selection of the most suitable entities. The subsequent application of fuzzy goal programming ensures that the selection and assignment processes are guided by a robust multi-objective optimization framework, which incorporates a comprehensive set of criteria covering technical, financial, humanitarian, and risk aspects.

The findings of this research significantly contribute to both theoretical understanding and practical applications in the field of crisis management and reconstruction. Theoretically, it bridges the gap in multi-criteria decision-making models by incorporating complex and dynamic environments such as conflict zones. Practically, it offers a transparent, systematic framework that enhances decision-making in supplier selection and project assignments, which is critical for effective reconstruction efforts. The real-case application using data collected from northern Syria not only demonstrates the methodology's applicability and effectiveness but also its adaptability to other conflict-affected regions globally.

Addressing the research questions posed at the outset, the study highlights that a diverse array of supplier selection criteria, previously under-considered in conflict zones, are indeed crucial for the construction industry. The integration of GIS-based risk analysis and multi-criteria decision-making tools like F-AHP has proven effective in enhancing the efficiency and outcomes of construction projects in such challenging environments. These methodologies allow for a nuanced consideration of various risk factors and ensure that the most capable suppliers are selected and assigned to projects that they are best suited for.

Despite its innovative approach and contributions, the study acknowledges certain limitations, such as its focus on a relatively small geographic area and the omission of some potential risk factors. Future research could address these limitations by expanding the geographical scope of the study and incorporating more dynamic models that account for additional risk factors and real-time data. This would not only enhance the robustness of the model but also its applicability to a wider array of scenarios in conflict-affected regions.

In conclusion, this study not only enhances our understanding of supplier evaluation in post-conflict reconstruction but also contributes to more effective resource utilization, transparency in decision-making, and ultimately, the speedy recovery of affected communities. By continuing to refine and adapt this approach, it holds significant promise for aiding reconstruction efforts not just in Syria, but in any region emerging from crisis.

Appendix 1

Suppliers' Evaluation & Selection

Suppliers' Evaluation & Selection

We trust that you will find the survey as enjoyable to complete as we found it fulfilling to organize.
Your input is highly valued, as it will contribute to enhancing the process of evaluating and selecting suppliers in crisis areas. We kindly request you to take a few minutes (3-5 minutes) to complete this brief survey and share your insights.

Please rest assured that your responses will remain anonymous.

* Required

Which country do you implement your projects/activities?

1. Which country do you implement your projects/activities? *

- Syria
- Turkey
- Iraq
- Jorden
- Lebanon
- Other

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Suppliers' Evaluation & Selection

2. Have you been ever involved in the process of suppliers' evaluation and selection? *

- ◯ Yes
- ◯ No
- ◯ Maybe

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Suppliers' Evaluation & Selection

3. Are you working with a local NGO or an international NGO? *

- ◯ Local NGO
- ◯ International NGO

4. For how many years have you been engaged in non-governmental organizations? *

- ◯ <= 2 years
- ◯ 2 - 4 years
- ◯ 5 - 8 years
- ◯ Over 8 years

5. How long have you been dealing with suppliers' evaluation and selection process? *

- ◯ Less than 1 one year
- ◯ 1 - 3
- ◯ 4 - 6
- ◯ 7 - 9
- ◯ Over 9 years

6. How often do you update the evaluation of suppliers? *

- ◯ Each 6 months
- ◯ Yearly
- ◯ After each contract
- ◯ Other

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Suppliers' Evaluation & Selection

7. Which criteria do you think should be taken into consideration to evaluate the suppliers in crisis areas? *

- ☐ # number of contracts
- ☐ The total value of contracts
- ☐ Their staff experience
- ☐ Recommendation letters
- ☐ The quality of service/goods
- ☐ Delivery time
- ☐ Access to areas
- ☐ Capacity of equipment/tools/vehicles
- ☐ Other

8. Can you rank these factors? (Using arrows or drag and drop) *

- # number of contracts
- The total value of contracts
- Their staff experience
- Recommendation letters
- The quality of service/goods
- Delivery time
- Capacity of equipment/tools/vehicles
- The "other" in case of selecting in the previous question.

9. Have you made specific modifications to your supplier evaluation criteria over time? If yes, please explain the changes and their rationale.
*

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Suppliers' Evaluation & Selection

10. which departments are involved in the process of feedback about the supplier on the field? *

- ☐ Program team/technical team
- ☐ Mentoring and evaluation depart.
- ☐ supply chain team
- ☐ Other

11. How to identify the weights and importance of each criterion compared to others as asked in Q7? *

- ☐ A consultant
- ☐ Group of consultants
- ☐ Classification into groups
- ☐ based on Calculation
- ☐ Given by the donor
- ☐ Other

12. After collecting all data, determining the weights of criteria, and now you will give ranking to each supplier What's the way/approach/Methodology you utilize to evaluate and rank the suppliers?
please explain? (in Arabic, English or Turkish) *

13. How do you evaluate the current used ranking method? *

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Accurate	○	○	○	○	○
Easiness	○	○	○	○	○
Effectiveness	○	○	○	○	○
Based on group of decision makers	○	○	○	○	○
Transparency	○	○	○	○	○

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Suppliers' Evaluation & Selection

14. Do you think there is a need to improve the utilized method in crisis areas? *

- ◯ Yes
- ◯ No
- ◯ Maybe

15. What factors or considerations would influence your decision to adopt a new methodology for supplier evaluation and selection in crisis areas? Please select all that apply from the following options or provide your own if not listed. *

- ☐ Improved accuracy in supplier assessment.
- ☐ Integration with our existing systems and processes.
- ☐ Availability of training and support for implementation.
- ☐ More based on Group of decision maker
- ☐ More Accountable and Transparent
- ☐ Other

16. Do you address social and ethical responsibilities in your criteria of supplier selection in crisis areas? if so how? *

17. Any other comments/feedback in this regards?

18. If you would like to get the result of this research please share with us your email address.

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Suppliers' Evaluation & Selection

Appreciated.

Thanks for your feedback. This study focuses on Syria and neighboring countries.

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Appendix 2

15 construction projects, 30 alternative suppliers

Factor: Financial Amount

Weight	Planned goal	Actual goal
5%	100000	169147
10%	100000	161434
20%	100000	149705
30%	100000	138583
40%	100000	133689

Factor: Quality of material

Weight	Planned goal	Actual goal
5%	90	67
10%	90	71
20%	90	75
30%	90	75
40%	90	75

10 construction projects, 20 alternative suppliers

Factor: Financial Amount

Weight	Planned goal	Actual goal
5%	50000	91486
10%	50000	91486
20%	50000	80794
30%	50000	80038
40%	50000	79248

Factor: Quality of material

Weight	Planned goal	Actual goal
5%	80	42
10%	80	43
20%	80	48
30%	80	50
40%	80	53

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Data Availability The data that support the findings is provided upon reasonable request to the first author.

Declarations

Ethical approval An ethics vote was not required for this work.

Conflict of interest The author declare that he has no conflict of interest and no competing interest.

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