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Hybrid AHP-Fuzzy TOPSIS Approach for Selecting Deep Excavation Support System

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Abstract: This paper introduces and further applies an approach to support the decision makers in construction projects differentiating among a variety of deep excavation supporting systems (DESSs). These kinds of problems include dealing with uncertainty in data, multi-criteria affecting the decision, and multi-alternatives to select one from them. The proposed approach combines the analytic hierarchy process (AHP) with the fuzzy technique for order of preference by similarity to ideal solution (fuzzy TOPSIS) in a multicriteria decision-making (MCDM) model. The MCDM model emphasize the ability to combine expert knowledge, cost calculations, and laboratory test results for soil properties to achieve the scope. The model proved it had a superior ability to deal with the complexity and vague data that are related to construction projects. Furthermore, it was applied to a real case study for a governmental housing project in Egypt. Secant pile walls, sheet pile walls, and soldier piles and lagging are selected and studied as being the most common DESSs and as they satisfy the project requirements. The model utilized four criteria and fourteen comparing factors, including site characteristics, safety, cost, and environmental impacts. Based on the results of the model application on the investigated case study, a decision was reached that using secant piles as a supporting system in this project is mostly preferred. Furthermore, sheet pile wall, and soldier piles and lagging, come next in the ranking order. A sensitivity analysis is carried out to investigate how sensitive the results are to the criteria weights. In addition, the paper discusses in detail the reasons and factors which affect and control the decision-making process.

Keywords: construction projects; deep excavation support-system; decision-making; AHP; fuzzy TOPSIS; case study

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1. Introduction

Casanovas-Rubio et al. [1] defined deep excavation as "an excavation in soil or rock typically more than 4.5 m deep". These excavation works, especially when constructed in urban areas, require careful design and planning. Additionally, deep excavation supporting systems (DESSs) refer to an engineering solution designed to stabilize excavation sides [2]. DESSs have gained more attention recently due to the increasing demand of housing buildings and the small available spaces for constructions. Thus, in Egypt, the vertical expansion approach of buildings, instead of horizontal, has been adopted in the construction community [3]. Furthermore, underground basements have become an essential component of new urban buildings. This is because parking in large cities is mostly serviced by aged and outdated above-grade parking structures that occupy valuable above-ground space [4].

Many studies have investigated the applications of different DESSs to various constructions projects [5–8]. The performance of DESSs is related to both stability and deformation [3]. The construction of deep excavation for very tall structures can induce a deformation response in surrounding soils; therefore, there is a need for a supporting system to protect the surrounding utilities [6,7]. Dellaria and Zitny [8] combined multiple DESSs to support a height between 15 and 16.5 m for 25,500 m^2, William Eckhart Research Center at Chicago University. Furthermore, Lewis and Farr [7] studied the construction of a multi-story building in Chicago which required deep supported excavation. Not only are DESSs needed for construction projects, but tunneling projects also often require complex support of excavation systems [9]. A model concerns informal settlements based on identifying internal factors, represented by Zakaria Eraqi et al. [10].

Based on previous studies, the selection of supporting systems in deep excavation plays an important role in determining the budget, period, and performance of the project [11]. Designers and builders of excavation supports rely mainly on past experience as well as construction guidelines to perform their work [3]. However, depending on experience alone may not lead to selecting the most appropriate system [6]. Thus, this experience and the guidelines have to be documented and combined in an approach that considers the most important factors which could affect the decision. Multi-criteria decision-making (MCDM) methods are widely adopted in different disciplines for this purpose [12].

The literature contains a wide range of MCDM techniques with various applications on civil engineering projects (CEPs). Shahpari et al. [13] combined the analytic network process (ANP), Delphi method, decision-making trial and evaluation laboratory (DEMATEL), and the technique for order of preference by similarity to ideal solution (TOPSIS) method in a tool to evaluate the productivity of construction systems of residential buildings. Temiz and Calis [11] applied the analytic hierarchy process (AHP) and the preference ranking organization method for enrichment of evaluation (PROMETHEE) to select the proper excavation machine for a construction site, while Penadés-Plà et al. [14] applied the AHP for a continuous concrete box-girder pedestrian bridge deck to reach sustainable robust designs. Moreover, Singh et al. [15] integrated AHP and TOPSIS to solve a multi-criteria vendor-rating problem. The AHP and TOPSIS were combined and an approach was proposed for the selection of a best disposition alternative, based on criteria economic benefits, environmental benefits, corporate social responsibility, stakeholder needs, and reverse logistics resources [16]. Recently, MCDM techniques were also combined with programming methodologies and advanced technology. As an example, Xian and Guo [17] introduced a model based on the interval probability-hesitant fuzzy linguistic TOPSIS to help businesses find the strategic cooperation supplier, and combined TOPSIS and the nonlinear programming methodology to get the optimal attributes' weights [18].

Therefore, this paper deals with the decision-making process to support the decision makers to select the most suitable supporting system for deep excavation in various construction projects. A real case project is illustrated by comparing various DESSs to differentiate between them and clarify advantages and pitfalls of each system. This research identified four criteria in addition to 14 factors affecting the available alternatives to make a decision for selecting the most applicable DESS. Those criteria are site characteristics, safety, cost, and environmental impacts.

2. Objectives and Methodology

Most CEP project managers have difficulty examining interrelated problems at one time. Therefore, there is a need, as an alternative, to manage our challenges in a well-defined structure, which can help us to think about them thoroughly. Both simplicity and complexity are required. Thus, an innovative approach is needed to fulfill simplicity, to be easily applied, and being robust enough to handle real-world complexities and decisions.

Furthermore, the process of selecting a DESS is complex, involving many alternatives with various characteristics for each one of them. In addition, the interrelated factors affect the decision-making process; some of them are quantified criteria, and others are not. Furthermore, dealing with all of these issues in conditions of high uncertainty with vague data will lead to missed chances to make the most appropriate decision based on the characteristics of the case under study.

Additionally, each alternative has advantages and drawbacks, so comparing them is not an easy process to be completed without an appropriate MCDM approach. Furthermore, we are taking into consideration more than one source of judgement, decision makers, so adopting such an approach is a must in such situations. Finally, each criterion may have different weights depending on the project characteristics and asset owners' preferences, which needs more attention when dealing with similar problems. Additionally, relaying on just experience may not lead to selecting the most appropriate system [6]. Thus, this experience and the guidelines have to be documented and combined in an approach that considers the most important factors which could affect the decision.

Therefore, the main research objectives include (1) selecting and studying the most appropriate MCDM techniques to be combined on the proposed model; (2) exploring the common DESSs to investigate their advantages and/or pitfalls to help the asset owners increase the potential of success with reduced risks and no extra costs; (3) identifying affecting criteria including site characteristics, safety, cost, and all features affecting and controlling the decision-making process; (4) introducing a new model, applying the AHP and fuzzy TOPSIS, to support the decision makers in construction projects differentiating among a variety of DESSs and selecting the most appropriate one based on various, changing, and challenging circumstances; (5) applying the proposed approach to a real case study to verify its applicability and feasibility to similar projects.

The case study is the construction of a governmental social housing project in Egypt, Minia governorate. To achieve the research objectives, two brainstorming sessions for the decision-making group were held. The first session was about defining the available alternatives of DESSs to compare among them and pick the process' driving factors coming later. The second brainstorming session focused on prioritizing the available DESSs to select the most appropriate one to be used in the investigated project, as described later in Section 7. Furthermore, the rating sensitiveness results against the relative importance of the proposed criteria was explored through conducting a sensitivity analysis.

3. Selecting MCDM Techniques

To date, there are several MCDM methods proposed in the literature, but here, the research focuses on studying the most appropriate techniques based on the under-study problem features, particularly in CEPs, and the available data types. AHP, ANP, TOPSIS, and ELECTRE are among the most common MCDM techniques to be applied in the field of CEPs over the last two decades [19]. Both the AHP and ANP use pairwise comparison matrices to calculate the relative importance of criteria and prioritize the available alternatives. The ANP is a generalization of the AHP which is applied when decision problems cannot be structured hierarchically [20], while the number of matrices considerably increase, making the inconsistency issue become a more serious concern [21]. ELECTRE requires an accurate measurement of performance levels and standard weights that cannot be accurately measured in many real-world problems [22], while TOPSIS has the facility to be integrated with fuzzy theory to deal with bias caused by vagueness and ambiguity in the decision-making process [23].

Consequently, the research adopted two decision-making techniques through combining the AHP with fuzzy TOPSIS. The two techniques formed a group that included utmost accessible data in the CEPs and were picked carefully [24]. The AHP used the identified criteria relative weights due to their impact on the studied issue, whereas fuzzy TOPSIS can be implemented in order to arrange the obtainable alternatives based on the decision makers' preferences. The practical application of the provided decision-making methodology can assess whether the decision makers' managing judgments regarding the investigated problem are correct.

The AHP, introduced by Saaty [20], illustrated the method to calculate the relative priority of many proposed solutions in MCDM problems. This technique introduces the possibility of combining judgments on tangible quantitative criteria alongside intangible qualitative criteria [25]. Instead, fuzzy TOPSIS uses the advantage of the linguistic variables instead of precise values to recover the undocumented data and ill-defined problems [23,26]. On CEPs, triangular fuzzy numbers (TFNs) are generally adopted because of their componential simplicity and ability to promote the representation and information processing in fuzzy environments [24]. Furthermore, TFNs have proven to be an effective tool for modeling decision-making problems where the available information is subjective and vague [27]. Finally, the selected techniques show high flexibility to be unified and grouped in a model to help the decision makers in CEPs [23,24].

4. Deep Excavation Supporting Systems

Supporting systems in deep excavation are acting as lateral bracing for the retaining walls. Based on the mechanism of load transfer, this can be divided into two categories: external and internal supporting systems [28]. Firstly, external supports, or tiebacks, refer to where the lateral earth pressure is transferred beyond the active zone of the soil. In contrast, internal supports, including rakers, struts, or floor slabs, transfer the lateral loads to other internal structures or across the opposing walls.

Excavation support systems have been changed in recent decades and modern technology has been used to develop new systems or make the old systems more effective and easier [9]. Firstly, all of the common DESS alternatives were documented and discussed among the decision-making group. Inappropriate alternatives were eliminated due to their characteristics and/or the site limitations. The eliminated alternatives included soil mixing with nailing and anchorage (SMNA) and cofferdams with steel struts and walers, etc. As an example, SMNA was dismissed due to a possible disturbance to the buildings adjacent to the site. As a result, three excavation-supporting systems were selected, and a further literature review study was conducted as follows.

4.1. Secant Piles Walls

A secant pile wall is constructed by forming intersecting reinforced concrete piles, as shown in Figure 1. It can be reinforced with steel bars or steel beams, and is fabricated by drilling or augering based on the soil characteristics [29]. Primary piles are constructed first, and then secondary piles are placed in between them once the primary piles gain sufficient strength. Piles overlap, with a range between 7.5 to 12.5 cm [30].

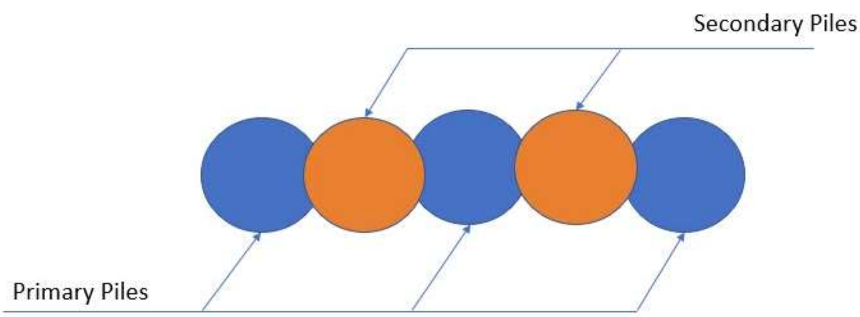


Figure 1. Construction of a secant pile wall system.

The main advantages of secant pile walls can be summarized as follows [7,30]:

1. Increase the alignment flexibility of construction;
2. Providing better wall stiffness compared to other systems;
3. Enhancement of the installation ability in difficult soil (boulders or cobble);
4. Reduction in the accompanied construction noise.

However, there are some main disadvantages, including [30]:

1. It is hard to achieve an accepted vertical tolerance for deep piles;
2. It is difficult to obtain total waterproofing in joints;
3. It is more costly compared to sheet pile walls.

4.2. Sheet Pile Walls

Sheet pile walls have mostly been used for shore excavations below the water table in coarse soil, especially when there is a relatively impermeable layer to be towed into. They are constructed by pre-fabricated sections, driven into the ground [31]. Soil conditions define whether those sections are hammer-driven or vibrated into the ground. The full wall is formed by joining adjacent sheet pile sections in a sequential installation, as shown in Figure 2. Sheet piling (especially steel sheets) is the most common because it has several advantages [31]:

1. High ability to resist driving stresses;
2. Light weight;
3. Long service life above or below water;
4. Easy adjustment of the pile length by bolting or welding;
5. Ability to be used on several projects.

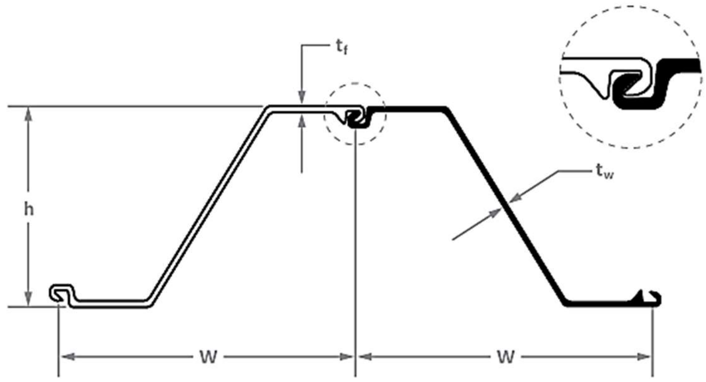


Figure 2. Sheet pile wall pre-fabricated sections (Z-type).

In contrast, sheet pile walls' disadvantages are [31]:

1. Rare use of these sections as part of the permanent structure;
2. Difficult installation in coarse soil;
3. Neighbor disturbance may be produced due to sheet piles' driving process;
4. Installation vibrations may cause settlement for the adjacent properties.

4.3. Soldier Piles and Lagging (H-System)

Soldier piles and lagging walls are also commonly known as the "Berlin Wall or H-system" when steel piles and timber lagging are used [2]. The installation of the H-system first requires driving universal steel column sections, H-piles, into the ground to a suitable depth, and then horizontal timbers are positioned between the flanges of the H-piles, as shown in Figure 3.

Soldier piles and lagging walls can act as a back form for the permanent concrete wall, but they are not easily joined into the long-lasting structure. They are constructed, approximately, 1.5 m outside of the construction basement line to keep a space for the double-sided concrete wall forms. Consequently, planners must consider the impact of construction outside of the property line. They are also very easy and fast to construct in addition to some other major advantages, including [11]:

1. A cheaper retaining system compared to other systems;
2. No requirements for advanced construction techniques;
3. Very quick system as lagging construction does not take much time;
4. Field adjustment can be easily made to accommodate changes.

The major disadvantages of H-system are [11]:

1. Cannot serve as a part of the permanent structure;
2. Extensive de-watering is needed in high water table conditions;
3. Significant surface settlements can be caused due to poor backfill or associated ground losses;
4. Low structure stiffness compared to other retaining systems.

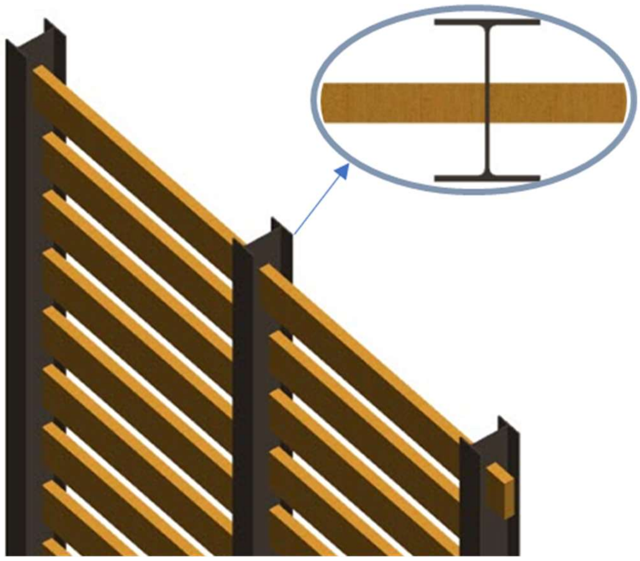


Figure 3. Soldier piles and lagging (H-system).

5. Factors Affecting the Selection of Supporting System

The selection of an appropriate excavation supporting system from all of the available alternatives, at the planning stage, is regarded as essential to increase the success probability of any project. In such a decision-making problem, the decision makers need to determine decision criteria and calculate the relative importance of the selected criteria to discover the best candidate, taking into consideration that a deep excavation in soft clay often causes additional deformations to surrounding areas [32].

Brainstorming is regarded as one of the most shared techniques for data gathering in the construction community [33,34]. To achieve the research goals, two brainstorming sessions were held at Minia University, Egypt. The first session was pursued to identify the available DESSs and the criteria affecting them. The session was carried out with research team members, two urban planners, and the consultancy team of the case study project. All participants have extensive experience in DESSs and urban planning. As a result, from this session, four criteria and fourteen factors affecting the discussed problem were identified, as shown in Table 1.

Table 1. Identified criteria and factors affecting them.

No	Criteria	Sub-Criteria
1.	Site characteristics (C1)	Soil conditions (SC11)
		Underground water table (SC12)
		Excavation depth (SC13)
		Excavation area (SC14)
		Shape of excavation area (SC15)
		Working space (SC16)

Table 1. *Cont.*

No	Criteria	Sub-Criteria
2.	Safety (C2)	Adjacent buildings (SC21)
		Underground obstructions (SC22)
		Overhead obstructions (SC23)
3.	Cost (C3)	Construction cost (SC31)
		Damage cost (SC32)
4.	Environmental impact (C4)	Air pollution (SC41)
		Noise (SC42)
		Vibrations (SC52)

6. AHP and Fuzzy TOPSIS Model

The proposed framework for the DESSs selection problem, applying the AHP and fuzzy TOPSIS, consists of three basic steps: (1) identify the criteria affecting the decision-making process; (2) complete AHP calculations; (3) evaluate the alternatives with fuzzy TOPSIS to determine the final rank. In the first stage, supporting system alternatives and the affecting criteria are determined and the decision hierarchy is created. By the end of this stage, the decision hierarchy is approved by the decision-making team. One of the main contributions of the proposed approach is the ability to deal with uncertainty related to CEPs generally and DESSs specifically. The approach mitigates or addresses the uncertainty, applying one or more of the following features:

1. Checking the consistency of all defined values in each step of the model to check the expert ability to deal with the discussed problem.
2. Adopting two fuzzy membership functions to replace precise numbers with linguistic variables on the judgments of the discussed problems.
3. Improving the uncertainty of the gathered data by taking into consideration more than one weighted source related to the discussed problem.
4. Dealing with various data types, whether precise intangible qualitative in addition to tangible quantitative data or vague data from field surveys through its two modules.

Then, identified criteria are assigned weights using the AHP. In this phase, pairwise comparison matrices are formed to determine the criteria relative weights. The comparisons are completed by employing the introduced preference scale by Saaty [20]. The pairwise can be compared based on a standardized nine-point level. This scale can be defined as follows: nine symbolizes “extremely more important”, seven symbolizes “highly more important”, five symbolizes “much more important”, three symbolizes “slightly more important”, and one symbolizes “equally important” [35]. Then, for each comparison matrix, the consistency ratio (CR) is checked to ensure that is does not exceed 0.10.

At the third stage, DESSs ranks are determined by using the fuzzy TOPSIS technique. Linguistic variables are used for evaluation of alternatives. The membership functions of these linguistic values and the TFNs related with these variables are shown in Figure 4. The support system that has the maximum closeness coefficient (CC_j) value is determined as the optimal alternative, according to the calculations by fuzzy TOPSIS. The ranking of other systems is determined according to CC_j values in descending order. The following are the steps used to calculate the CC_j value for prioritizing the alternatives [23]:

1. Decision makers establish the fuzzy decision matrix using linguistic variables that range from very good to very poor, as shown in Figure 4.
2. Both the criteria and the sub-criteria can be identified to be observed as PISs (${\nu_i}^+$) or NISs (${\nu_i}^-$). The triangular fuzzy values that concern them are determined in Equations (1) and (2).

$$ {\nu_i}^+ = (1.0, 1.0, 1.0) \tag{1} $$

$$\nu_i{}^- = (0.0, 0.0, 0.0) \tag{2}$$

where $\nu_i{}^+$—is the +ve ideal solution; $\nu_i{}^-$—is the −ve ideal solution.

3. The distance of each alternative from $\nu_i{}^+$ and $\nu_i{}^-$ are calculated using Equations (3) and (4):

$$D_j^+ = \sum_{j=1}^{n} d(\nu_{ij},\ \nu_i{}^+) \tag{3}$$

$$D_j^- = \sum_{j=1}^{n} d(\nu_{ij},\ \nu_i{}^-) \tag{4}$$

where D_j^+—is the distance to the PISs; D_j^- —is the distance to the NISs.

4. Alternatives are ordered due to CC_j using Equation (5).

$$CC_j = \frac{D_j^-}{D_j^+ + D_j^-} \tag{5}$$

where CC_j—is the closeness coefficient value.

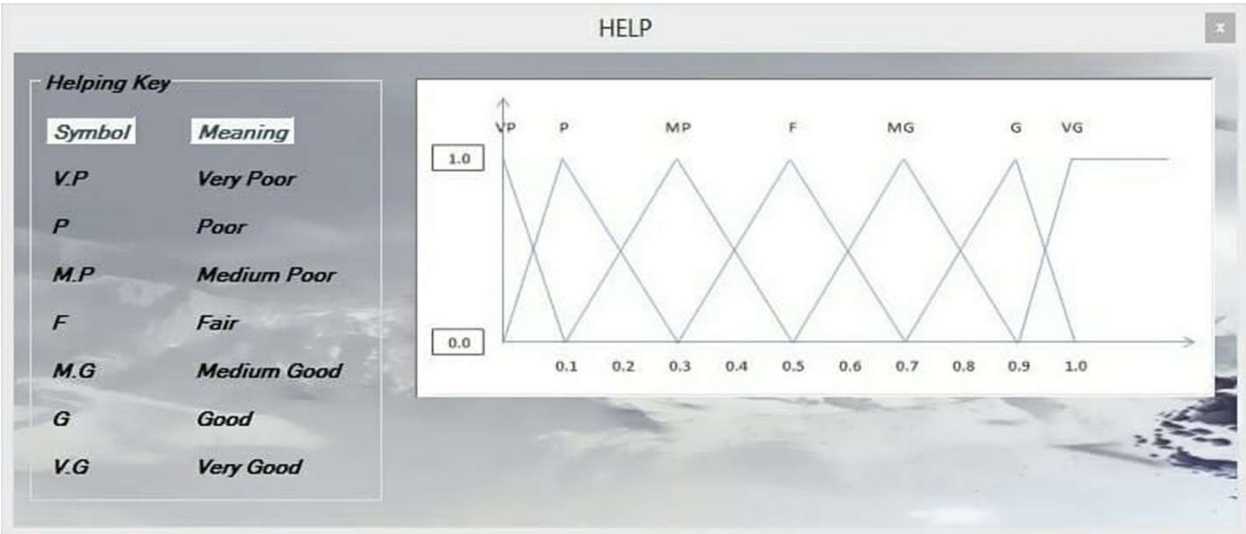


Figure 4. TFNs membership functions.

7. Case Study Description and Model Application

The case study in this research is a governmental housing project at Minia governorate, Egypt. The location of the investigated project is shown in Figure 5. The project consisted of seven buildings with 14 floors over an approximate area of 10,000 m^2. At the project planning stage, it was required to determine the most appropriate deep excavation construction alternative among three candidates for the construction of two underground floors. Secant pile wall, sheet pile wall, and soldier piles and lagging were identified as satisfying the basic project requirements. The on-site soil type was found to be clay and silt, and the excavation depth was 8.5 m. The groundwater table was observed at the level of (−4.50).

The second brainstorming session was conducted with the consultancy team members of the project who have extensive experience in planning, designing, and constructing excavations to get the data fed into the model. The decision-making group included a project manager, a construction manager, and an engineering consultant; each one was a representative for his team, with a minimum of five members for each team, and they provided their judgments. To ensure that all participants fully understood each response, this stage was started by a question-and-answer session. All participants were notified that the focus of the session was to increase effectiveness. The goal of the analysis was to prioritize one of the available DESSs to be used in the investigated project. All four identified criteria, in addition to the affecting fourteen factors, were explained for the participants and their team members.

Figure 5. Location of the investigated project.

As a first step, the AHP was conducted to compute the relative weights for all of the outlined four criteria and 14 sub-criteria. The experts' preferences were introduced in the form of several comparison matrices. The results from this step are shown in Figures 6 and 7.

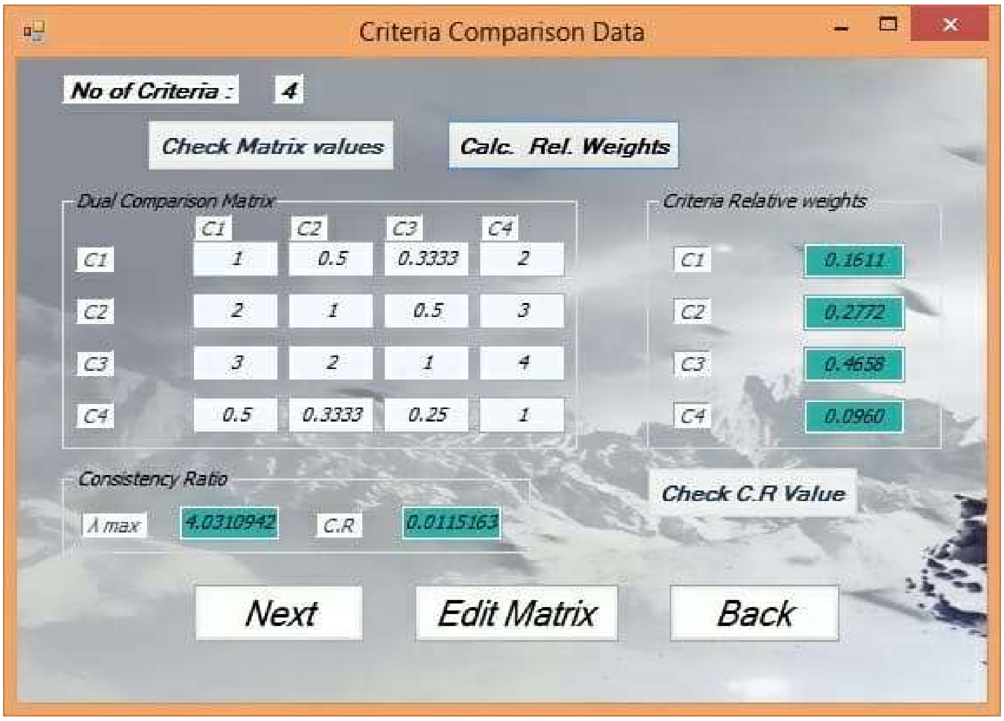
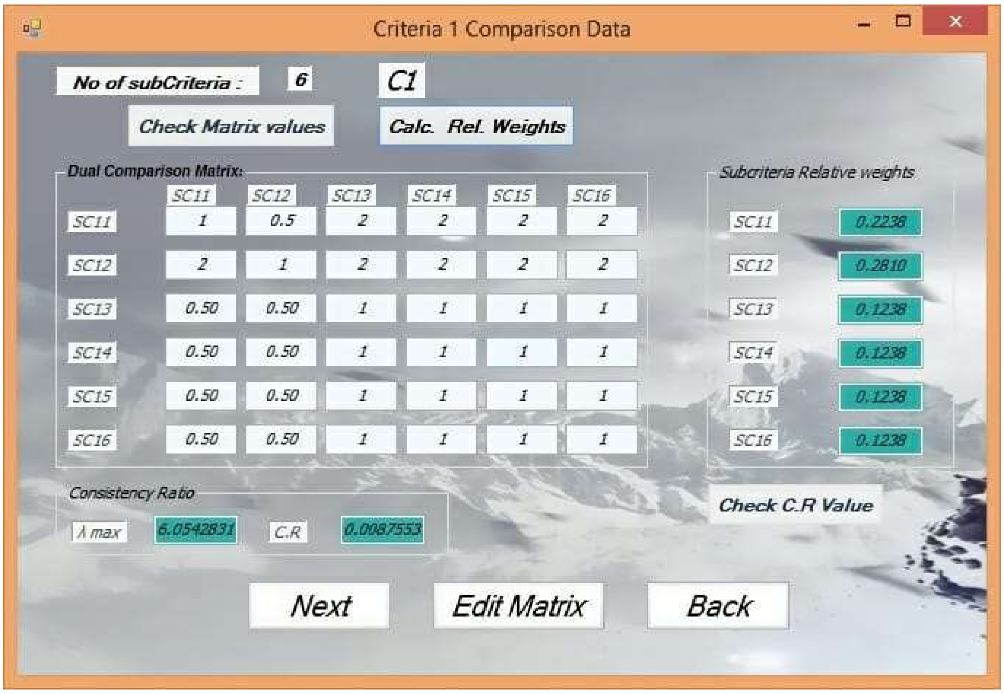
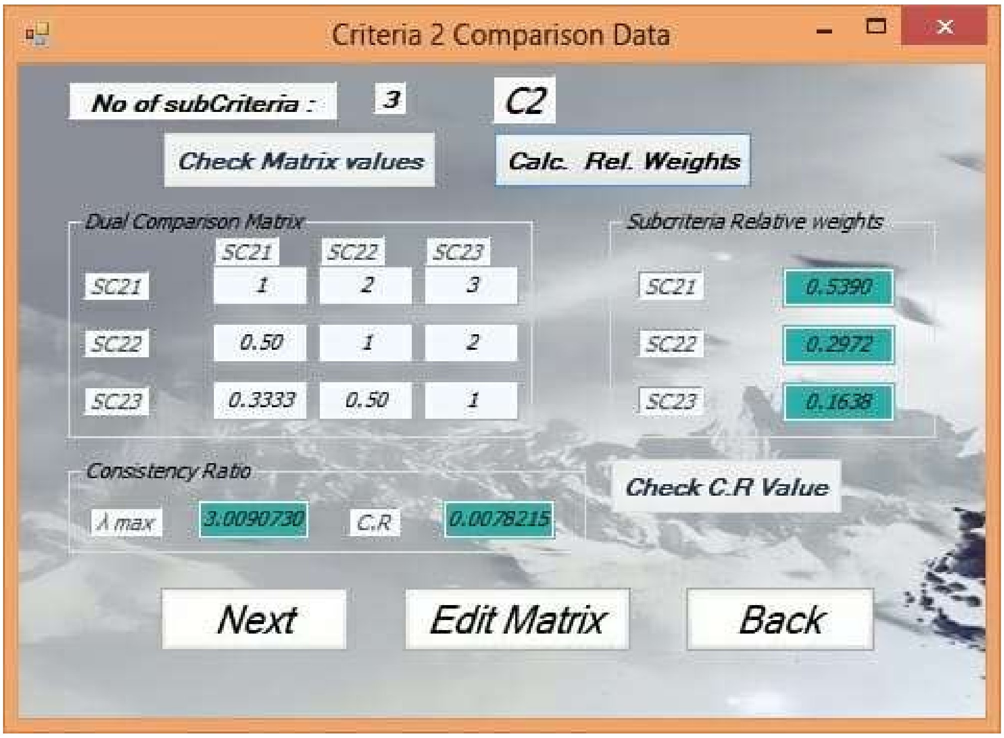


Figure 6. *Cont.*





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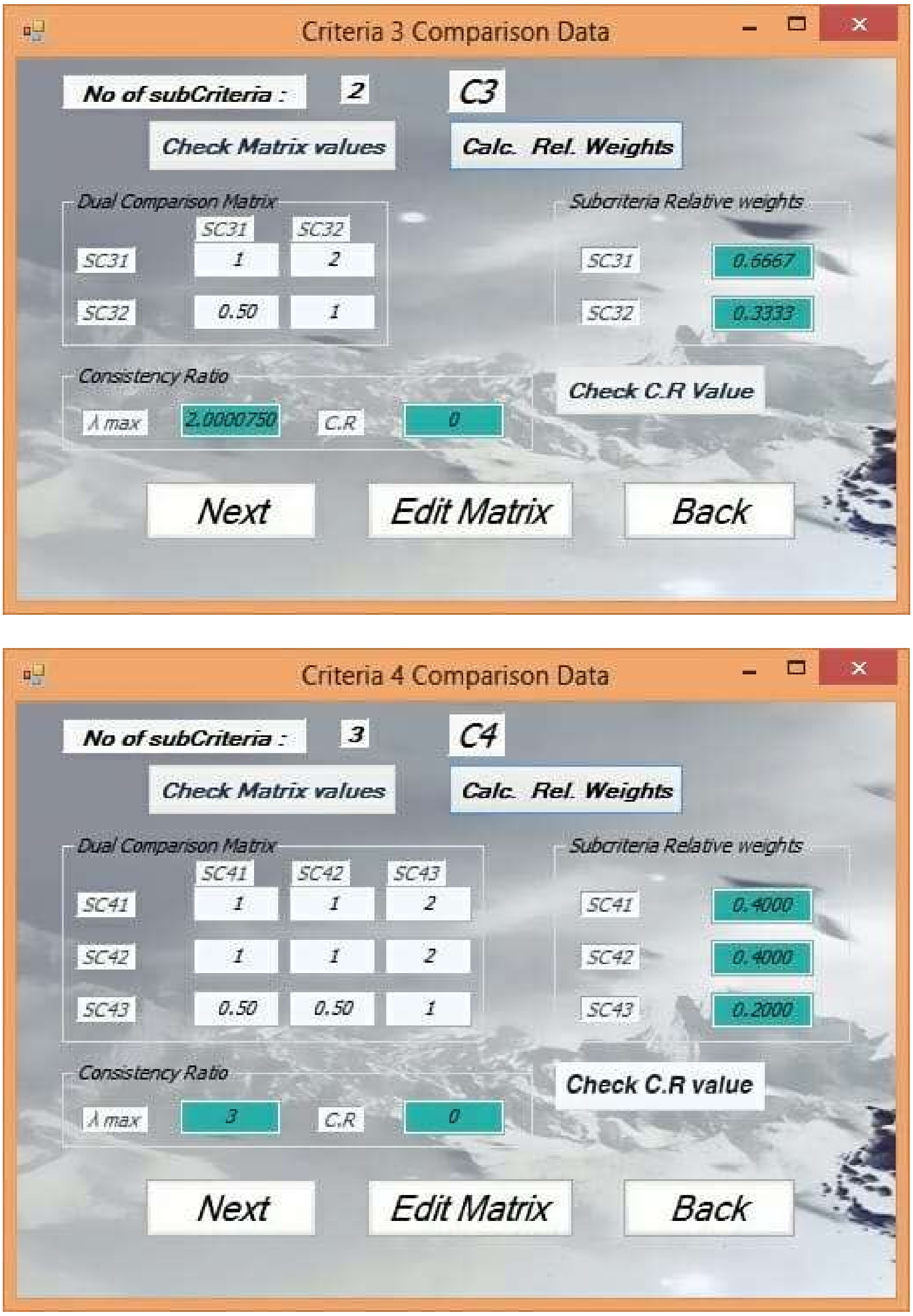

Figure 6. Relative weights of criteria and sub-criteria, and C.R values.

The decision-making group adopted TFNs "7" levels to get the benefit of applying linguistic variables in the decision-making process. Then, all alternatives were compared with the criteria affecting the decision. The experts' preferences, which are defined throughout this stage, are shown in Figure 8. The decision-making members provided their individual judgments to a designed software where an aggregation technique was employed to synthesize their preferences. They also worked in close cooperation to make consensual judgements for each pairwise comparison matrix for the AHP procedures.

Figure 7. Rel. weights of criteria and sub-criteria.

Finally, all criteria were assigned as being cost or benefit criteria. The cost criterion can be identified as the one that maximizes harm while minimizing benefits, whereas the benefit criterion is the criterion which maximizes the profits while minimizing the disadvantages. Then, CC_j was determined for each alternative to be ranked based on their CC_j values. The secant pile walls were chosen, mostly, with 0.441. Afterwards, the residual alternatives rank occupied the following positions with convergent preferences of 0.418 and 0.406, respectively, as shown in Figure 9.

Figure 8. Decision makers' preferences.

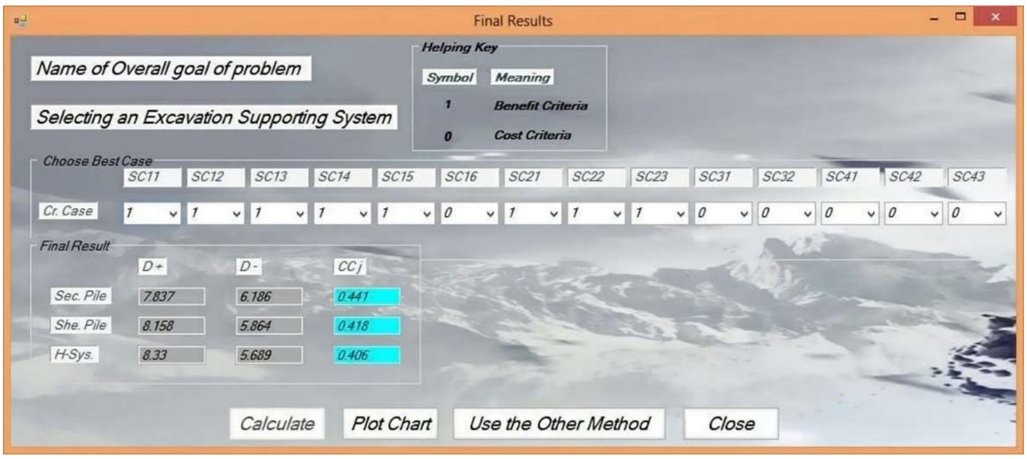

Figure 9. Identification of cost and benefit criteria, and final results.

8. Sensitivity Analysis

In this section, a sensitivity analysis was carried out to investigate the effects of various weights of criteria on the outcome ranking results. To date, there are many methods for performing sensitivity analysis in various disciplines based on the characteristics of the decision-making processes. A common method is called one-at-time (OAT) approach [36]. In this approach, the weight of a criterion is increased to its maximum and considers small values for other criteria. Moradi et al. [37] applied OAT to a wind farm site selection problem. Furthermore, Gitinavard et al. [38] investigated the sensitivity analysis of energy decision-making problems through adopting the OAT approach.

As shown in Table 2, the ranking of DESS alternatives is not affected by the increasing weights of site characteristics (C1), safety (C2), cost (C3), and environmental impact (C4), which leads to the same ranking results as below:

Table 2. Sensitivity analysis for effects of various weights of the identified criteria.

Criteria		**Criteria Weights**				
		Case Study	**State 1**	**State 2**	**State 3**	**State 4**
C1		0.1611	0.97	0.01	0.01	0.01
C2		0.2772	0.01	0.97	0.01	0.01
C3		0.4658	0.01	0.01	0.97	0.01
C4		0.0960	0.01	0.01	0.01	0.97
Ranking Alternatives	1st	Sec. Pile	Sec. Pile	Sec. Pile	Sec. Pile	Sec. Pile
	2nd	She. Pile	She. Pile	She. Pile	She. Pile	She. Pile
	3rd	H- Sys.	H- Sys.	H- Sys.	H- Sys.	H- Sys.
CC_j Values	Sec. Pile	0.441	0.406	0.491	0.406	0.410
	She. Pile	0.418	0.391	0.455	0.390	0.382
	H- Sys.	0.406	0.382	0.452	0.368	0.380

Sec. Pile > She. Pile > H- Sys.

9. Discussion and Analysis

Three DESSs were picked up to compare the efficacy of their uses when supporting the excavation sides of the investigated case of study. The identified alternatives were secant pile walls, sheet pile walls, and soldier piles and lagging. Furthermore, the four criteria and fourteen factors controlling them were recognized and form the theoretical foundation for the study.

The first criterion, site characteristics, was concerned with the soil conditions with various effects on the behavior of the used system. Each system had different performance according to the shape, depth, and area to be excavated. Lastly, an underground water table, observed in the site and availability of workspace, can also be used to recommend one system over another.

The safety criterion introduced an answer to the question of how much safer the implementation of one system is compared to the others. Three main explorations were introduced as results of the comparison matrix of this criterion. The first aspect was the effect of each alternative on the safety of adjacent buildings. The other questions illustrated the ability of different support systems to be used safely for both underground and overhead obstructions.

The third criterion, cost, was regarded as the main factor in this issue, according to the definite budget of the project. The cost was calculated based on surveying the construction community. It was the approximate cost according to the application of one support system instead of another. The cost criterion was comprised of construction costs and damage costs. Many economic problems result in the incorrect usage of a supporting system based on soil type and groundwater conditions. Therefore, the cost of a support system was a considerable factor when selecting the appropriate system. Damage cost accounted for loss due to construction failures or accidents, including the cost of repair.

Conversely, the fourth criterion, environmental impact, had the least priority compared with other criteria. This factor is concerned with the noise, vibrations, and air pollution produced from each support system that can limit the support method and equipment.

For the investigated case study, a decision was delivered to the project participants. Secant pile walls were found to be mostly preferred as it is a cheap system, compared to other alternatives, ensuring high safety rates to adjacent constructions. In addition, secant pile walls have great performance with regard to underground water when assisted by a de-watering system.

10. Conclusions

Selecting an appropriate excavation support system has a great impact on the duration, quality, safety, and profitability of construction projects with deep excavations requirements. Therefore, the research proposed an MCDM model to support the decision makers who deal with DESSs in construction projects. Additionally, this paper introduced the building of a knowledge database which can be used directly to help the asset owner or consultants choosing the appropriate excavation system. This is completed to prioritize among secant pile walls, sheet pile walls (steel sheet piles), and soldier piles and lagging (H-system) as DESS alternatives in a construction project. The proposed model illustrated the effects of safety, cost, and environmental features for construction projects in urban areas. The model combined the AHP and fuzzy TOPSIS for comparison among three suggested alternatives. Based on the results of this study, specific conclusions can be summarized, as follows:

1. The management of elements such as criteria for comparisons, including cost, safety, project duration, adjacent facility characteristics, site characteristics, etc., is the core of a planning process for excavation constructions.
2. The model results proved that using secant piles walls (0.441) as a DESS in a case study project is the best solution amongst the selected alternatives.
3. The study clarified that sheet pile walls and H-system are convergent in preference to the decision makers; however, the sheet pile (0.418) slightly surpasses the H-system (0.406).
4. The AHP and fuzzy TOPSIS demonstrated the ability to be combined in a decision-making model to support a variety of important decisions in construction projects.
5. Based on the sensitivity analysis results, it has specified that safety (C2) and environmental impact (C4) criteria versus other selected criteria make more of an impression on the decision-making process.
6. Finally, based on the feedback from the decision-making group, the developed model showed enough flexibility to be applied to other case studies.

For future work, the applied approach can be extended by combining other fuzzy techniques, such as interval-valued hesitant fuzzy sets (IVHFS). Additionally, other modules can easily be included to extend the range of model implementation, including ANP and ELECTRE.

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