Avrupa Bilim ve Teknoloji Dergisi
Sayı 50, S. 154-161, Nisan 2023
© Telif hakkı EJOSAT'a aittir
Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
No. 50, pp. 154-161, April 2023
Copyright © 2023 EJOSAT
Research Article

Determination of Protection Measures Against Fall Risks in Working at Heights by Multi-Criteria Decision Making Methods

Tolga Barışık[1*]

[1*] İstanbul Yeni Yüzyıl Üniversitesi, Sağlık Bilimleri Fakültesi, İş Sağlığı ve Güvenliği Bölümü, İstanbul, Türkiye, (ORCID: 0000-0003-0946-8534), tolga.barisik@yeniyuzyil.edu.tr

(İlk Geliş Tarihi 1 Şubat 2023 ve Kabul Tarihi 25 Mart 2023)

(**DOI:** 10.31590/ejosat.1245888)

ATIF/REFERENCE: Barışık, T. (2023). Determination of Protection Measures Against Fall Risks in Working at Heights by Multi-Criteria Decision Making Methods. *Avrupa Bilim ve Teknoloji Dergisi*, (50), 154-161.

Abstract

Work at heights is common, especially in very dangerous sectors such as construction. The most fatal occupational accidents in the construction sector are seen as the work at height. There is a need for measures to be taken against the dangers and risks that may occur during work at height. In this way, fatal work accidents will be prevented. There are measures to be taken against these risks. However, in some cases there may be confusion about which measures are prioritized, more important and beneficial. Measures should be evaluated in terms of Occupational Health and Safety. To ensure a proactive approach, the measures need to be clear. In this study, the most appropriate measure was selected with multi-criteria decision making methods. Criteria and alternatives were determined and the most appropriate measure was chosen. SWARA method was integrated while evaluating the criteria and SAW method was integrated while evaluating the alternatives.

Keywords: Working at Height, Occupational Health and Safety, SWARA, SAW, Multi-Criteria Decision Making, Risk Assessment.

Yüksekte Çalışmalarda Düşme Risklerine Karşı Korunma Tedbirlerinin Çok Kriterli Karar Verme Yöntemleri ile Belirlenmesi

Öz

Yüksekte yapılan çalışmalar özellikle inşaat gibi çok tehlikeli sektörlerde sıkça görülmektedir. İnşaat sektöründe en çok ölümlü iş kazası yüksekte yapılan çalışmalar olarak görülmektedir. Yüksekte yapılan çalışmalarda meydana gelebilecek tehlike ve risklere karşı alınacak tedbirlere ihtiyaç vardır. Bu sayede ölümlü iş kazalarının önüne geçilmiş olunacaktır. Bu risklere karşı alınacak tedbirler mevcuttur. Ancak hangi tedbirlerin daha öncelikli olduğu, daha önemli ve yararlı olduğu konusunda bazı durumlarda karışıklık olabilmektedir. İş Sağlığı ve Güvenliği açısından önlemler değerlendirilmelidir. Proaktif yaklaşım sağlanması için önlemlerin net olması gerekmektedir. Bu çalışma içerisinde çok kriterli karar verme yöntemleri ile en uygun önlemin seçimi yapılmıştır. Kriterler ve alternatifler belirlenerek en uygun önlem seçimi gerçekleşmiştir. Kriterler değerlendirilirken SWARA ve alternatifler değerlendirilirken SAW yöntemi entegre edilmiştir.

Anahtar Kelimeler: Yüksekte Çalışma, İş Sağlığı ve Güvenliği, SWARA, SAW, Çok Kriterli Karar Verme, Risk Değerlendirmesi.

[*] Sorumlu Yazar: tolga.barisik@yeniyuzyil.edu.tr

1. Introduction

Construction is one of the world's most hazardous sectors despite ongoing attempts to increase workplace safety (Choi and Lee, 2022). Work at heights is typical, particularly in industries like construction that are extremely risky (Choi and Lee, 2017). Work at height is thought to be the cause of the majority of fatal work accidents in the construction industry. The risks and dangers that could arise while performing work at height must be addressed. Fatal workplace accidents can be avoided in this way. There are steps that can be performed to reduce these hazards. There may, however, occasionally be a misunderstanding as to which actions are more necessary, useful, and prioritized. The steps must be defined in order to guarantee a proactive approach.

Many nations have also suffered significant economic, productive, and human losses as a result of falls from great heights (Umar et al., 2018, Yang et al., 2017). According to beliefs on what causes accidents, unsafe workplace conditions and worker behavior can interact to cause safety problems (Hunsang et al., 2023). According to some accident models indicate that unsafe environments, risky behaviors, and other failures interact to cause accidents. Organizational factors, dangerous supervision, the environment that leads to unsafe activities, and unsafe acts themselves are a few examples (Abdelhamid and Everett, 2000). Working at height is a dangerous activity that can result in falls from height on construction sites; risky behavior is represented by employees at heights failing to correctly secure their safety hook to an anchor point (Khosravi et al., 2014). Therefore, risky conditions (such as working at heights) and unsafe conduct (such as when the safety hook is not correctly attached to or detached from an anchor point) must be regularly monitored in order to prevent falls from height at construction sites (Shin et al., 2014.

When a worker is working over a specific height, the US's the Occupational Safety and Health Administration (OSHA) enforces obligatory safeguards to avoid falls from height (Reason, 1990). At construction sites, a number of measures are used to prevent falls from height, including safety education and training, safety (capture) nets or guardrail (exterior railings e.t.c.) systems and personal protection equipment (PPE) (Khan et al., 2022).

Studies on wearable inertial measurement unit-based semi-supervised near miss detection for ironworkers have been conducted (Yang et al., 2016). However, the final step should be to offer the necessary actions. Employees should receive fundamental training in occupational health and safety, as well as help developing a pro-safety mindset (Loosemore and Malouf, 2019). There should be training for working at heights. There are basic elements for the utilization or non-utilization of individual defensive hardware among development laborers (Wong et al., 2020). It is for the most part expressed by laborers that PPE is an exercise in futility in taking care of works.

In other words, precautions must be made to avoid the dangers and risks associated with work at height. Fatal occupational accidents can be avoided in this way. There are steps that can be performed to reduce these risks. There may, however, occasionally be a misunderstanding as to which actions are more necessary, useful, and prioritized. The steps must be defined in order to guarantee a proactive approach. In this study, multi-criteria decision making techniques were used to choose the best measure. The most appropriate measure has been selected after criteria and alternatives were established. When assessing the criteria and the alternatives, the SWARA and SAW methods, respectively, have been combined. The SWARA approach was used to calculate the weights of the criteria. The alternatives generated by applying these weights using the SAW method were ranked in order to select the best one. Alternatives outline the necessary actions. The criteria present crucial factors that must be considered when taking action.

2. Material and Method

In this study, it was decided to choose the most appropriate measure by using multi-criteria decision making methods. It is very important for the execution of the business to make the most accurate and timely decisions for important or critical problems. All managers have to make strategic and operational decisions in the short, medium and long term. Being able to make correct and timely decisions provides important advantages to decision makers (Gavcar et al., 2011). In this study, three decision makers were studied. These decision makers are occupational safety experts with construction industry experience. Decision making is choosing the most suitable one among these alternatives when decision makers are faced with different alternatives (Tekin, 2008). The options that may have been considered, the information at hand, and the criteria utilized to make the decision all have a role in how good or poor a choice is (Timor, 2010). Figure 1 shows the decision making process (Erdem, 2013).

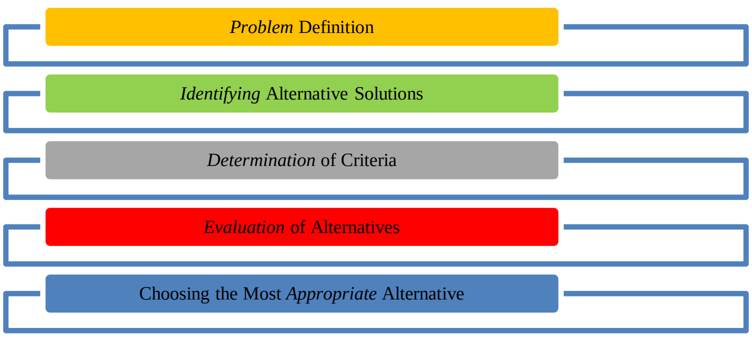

Figure 1. Decision Making Process

Within the scope of this study, four criteria have been determined in the protection measures to be determined for the works carried out at height. These criteria were evaluated with three decision makers. Decision makers determined the order of importance and ratings of the criteria.

Evaluation and weighting of the criteria were done with the SWARA method. Then, the most suitable alternatives were evaluated according to these criteria. Five alternatives were considered. These alternatives represent the most appropriate protection measures for work at height. The SAW method was used to evaluate the alternatives and determine their priorities. Table 1 includes the criteria and Table 2 contains the alternatives.

Table 1. Criteria

Criteria	***Number of Criterion***
Cost	*C1*
Safety	*C2*
Technical Specifications	*C3*
Ease of Use	*C4*

Table 2. Alternatives

Alternatives	***Number of Alternative***
Exterior Railings	*A1*
Capture Nets	*A2*
Closing Gaps	*A3*
Health and Safety Signs	*A4*
Parachute Type Seat Belt	*A5*

2.1. SWARA Method

SWARA is known as the Step-Wise Weight Assessment Ratio Analysis Method. It consists of the initials of these words. In the SWARA method, criterion weights can be determined in five steps.

Step 1: The criteria are ordered from the most important to the most important.

Step 2: Relative relevance levels are defined for each criterion, beginning with the second. In order to determine this, criteria j is compared to the prior criterion (j-1). Keršulienė et al. (2010) called this ratio “comparative significance of the mean value” and represented it with the symbol sj (Veršuliene et al., 2010).

Step 3: The coefficient (kj) is determined by the following equation.

$$k_j = \begin{cases} 1 \ , \ j = 1 \\ s_j + 1, \ j > 1 \end{cases} \tag{1}$$

The notation s_j shows proportionally how important the one above criterion is than the one below.

Step 4: Significance vector q_j, with the following equation calculated:

$$q_j = \begin{cases} 1 \ , \ \ j = 1 \\ \frac{x_{j-1}}{k_j}, \ j > 1 \end{cases} \tag{2}$$

The notation x_{j-1} points to q_{j-1}.

Step 5: Calculation of the weights (w_j) of the criteria is provided by the following equation:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{3}$$

w_j shows the relative importance of the j criterion.

2.1. SAW Method

SAW is known as the Simple Additive Weighting method. It consists of the initials of these words. (Hwang, 1981; Pimerol, 2000). In the SAW method, alternative weights can be determined in four steps (Savitha, 2011).

Step 1: It is constructed a decision matrix. The decision matrix is built as shown in Equation (4).

$$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \quad i = 0, m \, ; j = 1, n \tag{4}$$

Here; x_{ij} indicates the value of the ith alternative according to the jth criterion. n indicates the number of alternatives to be compared, while m indicates the number of criteria.

Step 2: The decision matrix is normalized. In the normalization process, the decision matrix is standardized by using Equation (5) or (6), depending on whether the criteria are maximization or minimization oriented.

$$r_{ij} = \frac{x_{ij}}{max\, x_{ij}} \quad i = 1, 2, \dots m; j = 1,2, \dots n \qquad (5)$$

$$r_{ij} = \frac{min\, x_{ij}}{x_{ij}} \quad i = 1, 2, \dots m; j = 1,2, \dots n \qquad (6)$$

Step 3: Alternatives are listed. The performance value of each alternative is calculated using Equation (7) from the normalized matrix. Performance values are ordered from largest to smallest.

$$S_i = \sum_{j=1}^{m} w_j r_{ij} \qquad (7)$$

Step 5: Alternatives are listed. Using Equation (8), the percentages of each alternative are calculated.

$$S_j^{\%} = \frac{S_j}{\sum_{j=1}^{n} S_j} \qquad (8)$$

3. Results and Discussion

As stated in the previous sections, the weighting of the criteria with the SWARA method, the ranking of the alternatives with the SAW method and the determination of the best alternative were made. Decision makers scored between 0-100 for alternatives. In the same way, they scored for the criteria. Information on the criteria for decision makers is given in Table 3.

Table 3. Information on the Criteria for Decision Makers

Decision Maker-1					
Criteria	**Rank of Importance**	***sj***	***kj***	***qj***	***wj***
C2	*1*		*1*	*1*	*0,289805*
C4	*2*	*0,15*	*1,15*	*0,869565*	*0,252005*
C1	*3*	*0,05*	*1,05*	*0,828157*	*0,240004*
C3	*4*	*0,1*	*1,1*	*0,75287*	*0,218186*
Decision Maker-2					
Criteria	***Rank of Importance***	***sj***	***kj***	***qj***	***wj***
C2	*1*		*1*	*1*	*0,325165*
C1	*2*	*0,25*	*1,25*	*0,8*	*0,260132*
C3	*3*	*0,15*	*1,15*	*0,695652*	*0,226202*
C4	*4*	*0,2*	*1,2*	*0,57971*	*0,188501*
Decision Maker-3					
Criteria	***Rank of Importance***	***sj***	***kj***	***qj***	***wj***
C3	*1*		*1*	*1*	*0,30039*
C2	*2*	*0,1*	*1,1*	*0,909091*	*0,273082*
C4	*3*	*0,25*	*1,25*	*0,727273*	*0,218466*
C1	*4*	*0,05*	*1,05*	*0,692641*	*0,208062*

Average information regarding the criteria is given in Table 4.

Table 4. Average Information Regarding the Criteria

Final Weights					
Criteria	***Decision Maker-1***	***Decision Maker-2***	***Decision Maker-3***	***Final Criterion Weight***	***Rank***
C1	*0,240004*	*0,260132*	*0,208062*	***0,235073***	*3*
C2	*0,289805*	*0,325165*	*0,273082*	***0,295235***	*1*
C3	*0,218186*	*0,226202*	*0,30039*	***0,245661***	*2*
C4	*0,252005*	*0,188501*	*0,218466*	***0,218123***	*4*

C1 and C4 criteria were determined as maximum, and C2 and C3 criteria as minimum. The weights were made in this way. Information on the decision matrix is given in Table 5.

Table 5. Decision Matrix

Decision Matrix				
Criteria	***C1***	***C2***	***C3***	***C4***
Alternatives	***max***	***min***	***min***	***max***
A1	*100*	*60*	*60*	*50*
A2	*70*	*85*	*40*	*65*
A3	*60*	*90*	*70*	*70*
A4	*90*	*100*	*80*	*85*
A5	*80*	*65*	*90*	*90*

Table 6 contains information about the normalized decision matrix.

Table 6. Normalized Decision Matrix

Normalized Decision Matrix				
Criteria	**C1**	**C2**	**C3**	**C4**
Alternatives	***max***	***min***	***min***	***max***
A1	1	1	0,666667	*0,555556*
A2	0,7	0,705882	1	*0,722222*
A3	0,6	0,666667	0,571429	*0,777778*
A4	0,9	0,6	0,5	*0,944444*
A5	0,8	0,923077	0,444444	*1*

Table 7 contains information about the weighted normalized decision matrix.

Table 7. Weighted Normalized Decision Matrix

Weighted Normalized Decision Matrix				
Criteria	**C1**	**C2**	**C3**	**C4**
Alternatives	***max***	***min***	***min***	***max***
A1	*0,235073*	*0,295235*	*0,163774*	*0,12118*
A2	*0,164551*	*0,208401*	*0,245661*	*0,157533*
A3	*0,141044*	*0,196823*	*0,140378*	*0,169651*
A4	*0,211565*	*0,177141*	*0,12283*	*0,206005*
A5	*0,188058*	*0,272524*	*0,109183*	*0,218123*

Performance values and their percentages were calculated as a result of all alternative values. The ranking of the alternatives is given in Table 8.

Table 8. Ranking of Alternatives

Alternatives	*Si*	*Si (%)*	*Ranking*
A1	*0,815261*	*0,217709*	*1*
A2	*0,776146*	*0,207263*	*3*
A3	*0,647896*	*0,173015*	*5*
A4	*0,717542*	*0,191614*	*4*
A5	*0,787889*	*0,210399*	*2*
Total	*3,744734*	*1*	

As can be seen in Table 8, there are alternative Si values and Rank values. The values are respectively; A1 alternative; 0.815261 (22%), A2 alternative; 0.776146 (21%), A3 alternative; 0.647896 (17%), A4 alternative; 0.717542 (19%) and A5 alternative; It is seen that it is 0.787889 (21%). In Figure 2, there is a bar chart of the comparison of the alternatives. The values 1, 2, 3, 4 and 5 on the alternatives axis in Figure 2 represent the alternatives A1, A2, A3, A4 and A5, respectively. In Table 1 and Table 2, explanations of alternatives and criteria are given.

In line with these values, a decision can be made about the best alternative measure. Precautionary precaution was determined in the works at height from the best alternative to the last alternative. In Figure 3, there is a pie chart showing the percentiles of the alternatives.

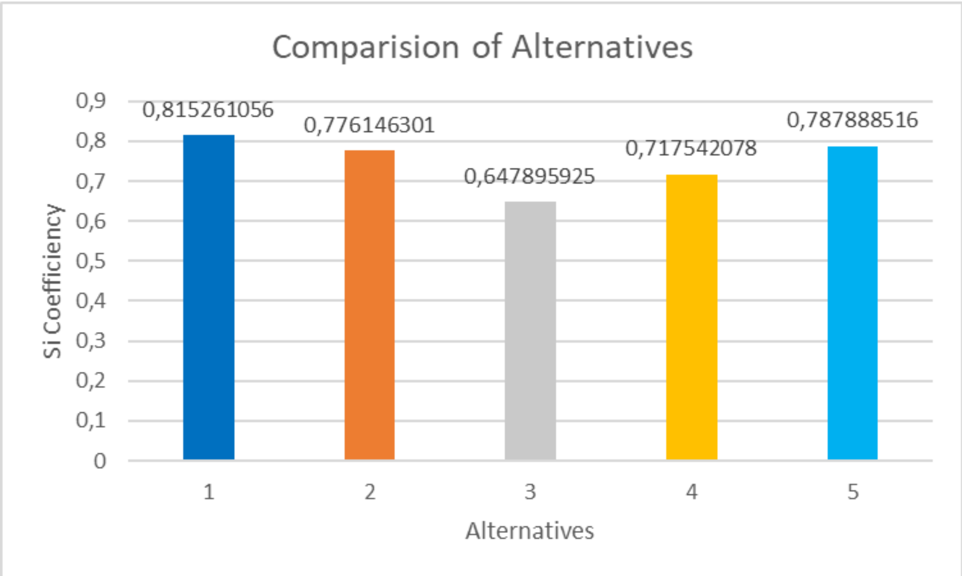

Figure 2. Comparision of Alternatives

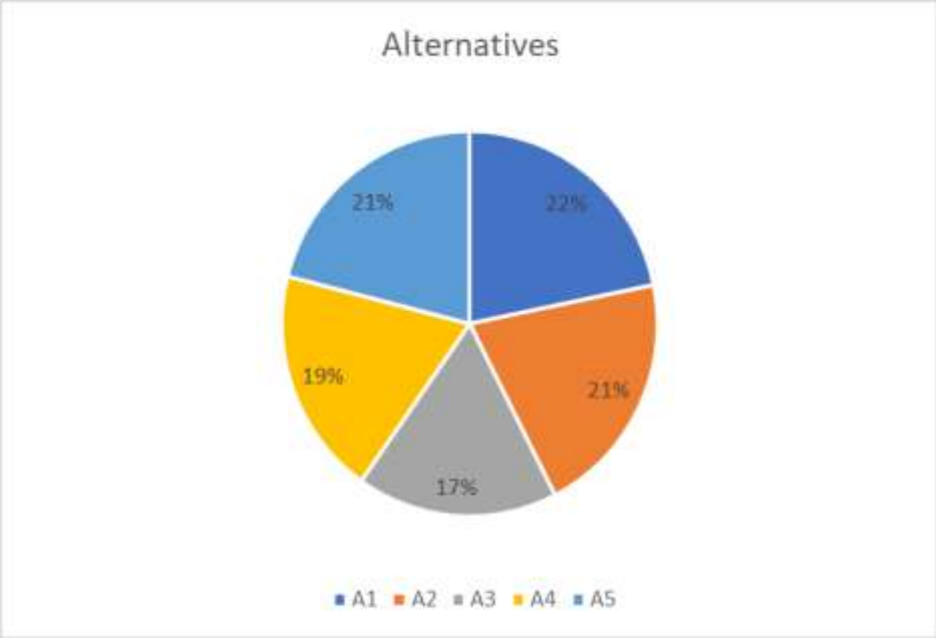

Figure 3. Percentages of Alternatives

Alternatives based on the Si coefficients' magnitudes; The criteria show that A1 (Exterior railings) is the most appropriate alternative measure because it is given as A1- A5 - A2 -A4 -A3. The following solutions are mentioned in order: A5 (Parachute type seat belt), A2 (Capture nets), A4 (Health and safety signage), and A3 (Closing gaps). A1 is the top substitute technique for working at heights dangers. The most effective defense against these hazards is the A1 alternative.

4. Conclusions and Recommendations

A more effective solution has emerged in the evaluation of the measures to be taken in working at heights, in the calculation of the best alternatives to the criteria, the measurements and weights of the decision makers. The weighting and ranking of the criteria were made by applying SWARA, and the weighting and ranking of the alternatives was done by applying the SAW Method.

The best protection measures have been considered according to the criteria of cost (C1), safety (C2), technical specifications (C3) and ease of use (C4) against the risks of falling that may occur while working at height. In this study, considering these criteria, the best alternative protection measure was found in line with the decisions of the three decision makers. Based on the information in Table 4, it is possible to comment on the ranking of the criteria. As a result of the values given by the three decision makers to the criteria, it is seen that the general average is in the form of C2-C3-C1-C4, respectively. Respectively, safety (C2), technical specifications (C3), cost (C1) and ease of use (C4) criteria are listed. The values are respectively; C1 criterion; 0,235073 (23,5%), C2 criterion; 0,295235 (29,5%), C3 criterion; 0,245661 (25%) and C4 criterion; It is seen that it is 0,218123 (22%).

To summarize again; alternatives, according to the magnitudes of the Si coefficients; Since it is listed as A1 - A5 - A2 -A4 - A3, considering the criteria, it is seen that the most suitable alternative measure is A1 (Exterior railings). Then, respectively; A5 (Parachute type seat belt), A2 (Capture nets), A4 (Health and safety signs) and A3 (Closing gaps) alternatives are listed. The best alternative method for working at height risks is A1. The A1 alternative is the most successful measure against these risks. Criterion and alternative based methods can be used for many fields. Multi-criteria decision making methods can be used for the precautions to be taken especially in large industrial fires such as BLEVE. For example, a study was conducted using Quality Function Deployment (QFD) for noise-canceling equipment design (Cinar, 2020). Different methods can be integrated in the assessment of risks. A risk assessment model was developed with Dematel, Fuzzy AHP, and QFD methods (Cinar, 2022).

There are some artificial intelligence studies available. Negative effects have been estimated with artificial neural networks (Barisik, 2022). In another study, he investigated the environmental effects of BLEVE (Barisik, 2021). Different studies can be created by integrating these methods with artificial neural network models. It is possible to choose more reasonable alternatives and apply measures corresponding to the risks identified. Especially in risk assessment studies, this etc. More accurate alternative measurements can be listed by using multi-criteria decision making methods. Also, the best solution can be calculated. This study will shed light on risk assessment studies fall risks in working at height in the future.

This study will contribute to the priority given to deaths occurring in work at height, especially in the construction sector, while taking precautions, and to determine the best way when giving priority.

References

Abdelhamid, T.S., Everett, J.G. (2000). Identifying Root Causes of Construction Accidents, Journal of Construction Engineering and Management, 126(1), 52–60.

Barisik, T., Guneri, A.F. (2021). Calculation The Environmental Impacts of BLEVE Using Artificial Neural Networks, Fresenius Environmental Bulletin, 40, 9611-9616.

Barisik, T., Guneri, A.F. (2022). BLEVE Risk Effect Estimation Using The Levenberg-Marquardt Algorıthm in An Artificial Neural Network Model, Sigma Journal of Engineering and Natural Sciences, 40(4), 877-893.

Cinar, U., Ugurlu, O.F., Cebi, S. (2020). Design of Noise-Canceling Earmuff with Quality Function Deployment, Customer Oriented Product Design, 279, 23-34.

Cinar, U., Cebi, S. (2022). A Novel Approach to Assess Occupational Risks and Prevention of Hazards: The House of Safety & Prevention, Journal of Intelligent & Fuzzy Systems, 42(1), 517-528.

Choi, B., Ahn, S., Lee, S. (2017). Construction Workers' Group Norms and Personal Standards Regarding Safety Behavior: Social Identity Theory Perspective, Journal of Management in Engineering, 33(4).

Choi, B., Lee, S. (2022). The Psychological Mechanism of Construction Workers' Safety Participation: The Social Identity Theory Perspective, Journal of Safety Research, 82, 194–206.

Choo, H., Lee, B., Kim, H., Choi, B., (2023). Automated Detection of Construction Work at Heights and Deployment of Safety Hooks Using IMU with A Barometer, Automation in Construction, 147.

Erdem, I. (2013). Operational Research and WinQSB Practices, Seçkin Publishers, Ankara.

Gavcar, E., Coşkun, E., Paksoy, T., Eleren, A., Sulak, H., Özdemir, M., Aytemiz, T., Özceylan, E., Keskin, R. (2011). Operational Research, Lisans Publishers, Istanbul.

Hwang, C.L., Yoon, K. (1981). Multiple Attribute Decision Making – Methods and Applications – A State-of-the-Art Survey, Berlin, Heidelberg, New York.

Keršuliene, V., Zavadskas, E. K., Turskis, Z. (2010). Selection of Rational Dispute Resolution Method by Applying New Step-Wise Weight Assessment Ratio Analysis (Swara), Journal of Business Economics and Management, 11(2),243–258.

Khan, M., Khalid, R., Anjum, S., Khan, N., Cho, S., Park, C. (2022). Tag and IoT Based Safety Hook Monitoring for Prevention of Falls from Height, Automation in Construction, 136.

Khosravi, Y., Asilian-Mahabadi, H., Hajizadeh, E., Hassanzadeh-Rangi, N., Bastani, H., Behzadan, A.H. (2014). Factors Influencing Unsafe Behaviors and Accidents on Construction Sites: A Review, International Journal of Occupational Safety and Ergonomics, 20(1), 111–125.

Loosemore, M., Malouf, N. (2019). Safety Training and Positive Safety Attitude Formation in the Australian Construction Industry, Safety Science, 113, 233–243.

Pimerol, J.C., Romero, S.B. (2000). Multi Criteria Decision in Management: Principles and Practic, Kluwer Academic Publishers.

Reason, J. (1990). Human Error, Cambridge University Press, BO9781139062367.

Savitha, K., Chandrasekar, C. (2011). Vertical Handover Decision Schemes Using SAW and VPM for Network Selection in Heterogeneous Wireless Networks, Global Journal of Computer Science and Technology, 11(9), 21-22.

Shin, M. Lee, H.S., Park, M., Moon, M., Han, S. (2014). A System Dynamics Approach for Modeling Construction Workers' Safety Attitudes Behaviors, Accident Analysis & Prevention, 68, 95–105.

Tekin M. (2008). Numerical Methods, Faculty of Economics and Administrative Sciences, Selcuk University, Konya.

Timor, M. (2010). Operational Research, Türkmen Bookstore, Istanbul.

Umer, W., Li, H., Lu, W., Szeto, G.P.Y., Wong, A.Y. (2018). Development of A Tool to Monitor Static Balance of Construction Workers for Proactive Fall Safety Management, Automation in Construction, 94, 438–448.

Wong, T.K.M., Man, S.S., Chan, A.H.S. (2020). Critical Factors for The Use or Non-Use of Personal Protective Equipment Amongst Construction Workers, Safety Science, 126.

Yang, K., Ahn, C.R., Vuran, M.C., Aria, S.S. (2016). Semi-Supervised Near Miss Fall Detection for Ironworkers with a Wearable Inertial Measurement Unit, Automation in Construction, 68, 194–202.

Yang, K., Ahn, C.R., Vuran, M.C., Kim, H. (2017). Collective Sensing of Workers' Gait Patterns to Identify Fall Hazards in Construction, Automation in Construction, 82, 166–178.