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**ORIGINAL RESEARCH PAPER**

# An occupational risk assessment approach for construction and operation period of wind turbines

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**ABSTRACT:** As wind energy is one of the most important renewable energy sources over the globe, need for increasing safety for this type of energy is gaining importance. Although this sector is not suffering an excessive amount of fatal injury accidents, there are many aspects open for improvements in occupational health and safety management. The construction and operation processes of wind turbines include several hazards that must be reduced. This study aims to present a risk assessment for the construction and operation period of wind tribunes using a new fuzzy based method. Fuzzy analytical hierarchy process, a common used multi criteria decision making method, is applied to assign weights to the parameters of Fine-Kinney risk analysis method. Then, fuzzy VIKOR method is used to prioritize hazards. A case study is carried out for an onshore wind turbine in Turkey by using occupational health and safety experts in weighting risk parameters and evaluating compromised rankings of the hazards. Results reveal the most important hazards both for construction and operation period of the wind tribune. On conclusion of the current study, control measures for those risks and possible corrective-preventive actions for improvement are also provided.

**KEYWORDS:** *Fine-Kinney method; Fuzzy analytic hierarchy process (FAHP); Fuzzy VIKOR (FVIKOR); Multi criteria decision making method (MCDM); Occupational health and safety (OHS); Risk assessment; Wind tribune.*

## INTRODUCTION

Wind turbines are devices with towers that have a large vanned wheel rotated by the wind to generate electricity (Guo *et al.,* 2009; Rideout *et al.,* 2010). They generate renewable and clean energy besides include non-greenhouse gas emissions (Çelik and Utlu, 2013). According to the official figures published by Global Wind Energy Council (GWEC), global annual installed wind capacity has reached 44,711 MW by the end of 2012 (Global Wind Statistics-2012 and 2013). Turkey, as well, is one of the fastest growing country over the globe in the context of renewable energy sector. By the wind statistic report of Turkish Wind Energy Association (TWEA), energy capacity is specified to be installed 4,718 Mega Watt (MW) over the year 2015 by taking 956 MW of plants into operation. It is stated in the report that Turkey had a total of 2.312 MW installed wind power capacity in 2012. This figure reached to 2.958 MW in 2013 and as 3.762 MW in 2014. By the end of 2015, installed total wind energy has reached to 4.718 MW (TWEA, 2015). However, besides its significance and installed capacity, wind energy investments such as wind turbines and wind farms involve various risks during their planning, construction and operation phases (Kucukali, 2016). Workers in wind energy sector are exposed to hazards resulting in loss of lives and fatal injuries in a wind turbine investment (European Agency for Safety and

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Health at Work, 2013). In order to create a safe and healthy work environment and ensure sustainability in wind turbines, determination of existing and external hazard sources and management of the risks occurred gain great importance. According to Rideout et al. (2010) the most frequent types of potential wind turbine hazards are related to sound/noise, low frequency sound, infrasound, electromagnetic fields, shadow flicker, ice throw/ ice shed and structural failure. Occupational safety risk assessment (OSRA) methods are common used in order to uncover causes and characteristics of accidents and workplace conditions in different sectors (Kaassis and Badri, 2018; Gul, 2018; Aneziris *et al.,* 2016). GWEC (2003), European Agency for Safety and Health at work (2013) and TWEA (2015) provide statistics and safety measures in the wind industry. Recently new quantitative methods have emerged versus traditional OSRA approaches to reveal occupational risk of workers. Multi criteria decision making (MCDM) based risk assessment methods are the ones of recent emerged quantitative OSRA methods (Gul, 2018). In MCDM methods, experts frequently face difficulty in evaluation of assigning an exact score to an alternative against the related criteria. In that case, fuzzy logic integrated MCDM is adopted to model this uncertainty. In this paper, the fuzzy MCDM methods such as fuzzy analytic hierarchy process (FAHP) and fuzzy VIKOR (FVIKOR) were applied in assessment of potential wind turbine hazards. Several attempts are available in the knowledge for MCDM approaches applied to OHS risk assessment (Aminbakhsh *et al.,* 2013; Akyuz, 2017; Akyuz and Celik, 2016) such as a hazard prioritization work in aluminum industry using Buckley's FAHP and fuzzy technique for order preference by similarity to ideal solution (FTOPSIS) by Gul and Guneri (2016), OHS risk assessment of hospitals by Gul *et al.* (2016), determination of risk levels on the workplaces in Serbian manufacturing industry using FAHP by Djapan *et al.* (2015), a fuzzy based method in a coal deposit of Iran using FTOPSIS by Mahdevari *et al.* (2014), seaport risk assessment using FAHP by John *et al.* (2014), a food production risk assessment in Italy using FTOPSIS by Grassi *et al.* (2009), risk evaluation of green components to hazardous substance using Failure Mode and Effects Analysis (FMEA) and FAHP by Hu *et al.* (2009), maritime safety evaluation using fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) by Akyuz and Celik (2015) and construction risk assessment by Liu and Tsai (2012) and Ebrahimnejad *et al.* (2010). In addition, traditional OSRA approaches have been used in OHS risk assessment, design and operation of wind turbines and wind farms. Adem *et al.* (2018) combined a strengths-weaknesses-opportunities-threats analysis and hesitant fuzzy sets in occupational safety of wind turbines. Aikhuele (2018) proposed a model for failure detection and safety management of wind turbines using intuitionistic fuzzy sets. Shafiee and Dinmohammadi (2014) proposed an FMEA based method for both onshore and offshore wind turbines. Aneziris *et al.* (2016) presented the calculation of risk for workers in the construction, operation and maintenance of an on-shore wind farm in Greece. Kucukali (2016) developed a risk assessment tool that quantifies economic, environmental, political, and societal risks in real time wind power plants located in Izmir, Turkey. Arabian-Hoseynabadi *et al.* (2010) applied FMEA to a wind turbine system using a proprietary software reliability analysis tool. Ashrafi *et al.* (2015) proposed a combined risk assessment approach to assess risk and reliability in a wind turbine using a Bayesian network and a cause and effect approach. Shafiee (2015) used fuzzy Analytic Network Process (ANP) to select the most appropriate risk mitigation strategy for an offshore wind farm. Results of ANP were compared to crisp AHP and ANP models. Dinmohammadi and Shafiee (2013) used fuzzy FMEA for offshore wind turbines incorporated with grey theory analysis. In the lights of the above-mentioned literature review, current study contributes a lot to the literature by some points: 1) A two-step fuzzy MCDM approach that eliminates drawbacks of risk score evaluation by crisp numbers is proposed. 2) The evaluations for risk parameters of Fine-Kinney method and for hazards with respect to these parameters are made by judgements of experienced OHS experts under full consensus. 3) Different from a classical Fine-Kinney method, experts assign weights for criteria by pairwise comparison of Buckley's FAHP. 4) To the best of authors' knowledge, this is the first attempt in OHS risk assessment for both construction and operation period of wind turbines that uses FAHP-FVIKOR hybrid approach. This study has been carried out in an onshore wind turbine located in Istanbul, Turkey in 2017.

## MATERIALS AND METHODS

*Fine-Kinney method*

This method was first released in the literature by the year of 1976 as a quantitative risk assessment method (Kinney and Wiruth, 1976). In this method, risk value is the product of three parameters as follows: severity of consequences for a worker in case of dangers and hazards (C), the exposure frequency of occurrence of dangers and hazards (E), and the probability of an accident (P) (Fine, 1971). Initially, ratings of these three parameters are determined (Tables 1-3). Then, the risk values are obtained. The ratings of parameters are expressed by 6, 6 and 7 classes for C, E and P, highlighted in Table 1. The classical Fine-Kinney method have several limitations. This method has an equal weighting manner for consequence, exposure and probability parameters. The new proposed fuzzy based method has some pluses: 1) It provides a group consensus in decision making of hazard assessment. 2) It deals with relative importance among the three risk parameters by pairwise comparison step of Buckley's FAHP. 3) Linguistic relations are used in the proposed method since there is difficulty in exactly evaluation of C, E and P.

The risk levels multiplying of three parameters allow to frame the risks into 5 levels, according to Table 2.

*Buckley's Fuzzy analytic hierarchy process*

FAHP is a frequently applied method for MCDM in fuzzy environment. Classical AHP with crisp numbers cannot reflect the subjectivity entirely. Hence, AHP is extended under fuzzy environment in order to reflect uncertainty and vagueness. Several versions of FAHP are proposed in fuzzy MCDM literature (Buckley, 1985; Chang, 1996). For the current work, Buckley's (1985) method was preferred. However, Chang's extent analysis method has a limitation. There is an irrational zero weight assignment problem for criteria weighting (Chan and Wang, 2013). The steps of Buckley's FAHP method followed in this study was given as below (Tzeng and Huang, 2011; Gumus *et al.,* 2013; Gul and Guneri, 2016):

*Step 1:* This step is regarding building pairwise comparison of each criterion in the hierarchy. Linguistic relations are used in determining relative importance of each two criteria, based on Eqs. 1 and 2.

$$\tilde{M} = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{pmatrix} = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{pmatrix} \quad (1)$$

$$\tilde{a}_{ij} = \begin{cases} \tilde{1},\tilde{3},\tilde{5},\tilde{7},\tilde{9} & \text{criterion } i \text{ is favored with criterion } j \\ 1 & i = j \\ \tilde{1}^{-1},\tilde{3}^{-1},\tilde{5}^{-1},\tilde{7}^{-1},\tilde{9}^{-1} & \text{criterion } j \text{ is favored with criterion } i \end{cases} \quad (2)$$

*Step 2:* In this step, fuzzy geometric mean matrix is constructed using geometric mean technique by Eq. 3.

$$\tilde{r}_i = \left(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in}\right)^{1/n} \quad (3)$$

Table 1: Ratings of three parameters (Kinney and Wiruth, 1976)

| Rating | Description of C | Rating | Description of E | Rating | Description of P |
|---|---|---|---|---|---|
| 100 | Catastrophic (many fatalities) | 10 | Continuous (multiply a day) | 10 | To be expected |
| 40 | Disaster (few fatalities) | 6 | Frequent (daily) | 6 | Possible |
| 15 | Very serious (fatality) | 3 | Occasional (weekly) | 3 | Unusual but possible |
| 7 | Serious (serious injury) | 2 | Unusual (monthly) | 1 | Unlikely, but possible in the long term |
| 3 | Important (disability) | 1 | Rare (approximately a year) | 0.5 | Highly unlikely, but conceivable |
| 1 | Noticeable | 0.5 | Very rare (less than one year) | 0.2 | Almost unimaginable |
| | | | | 0.1 | Next to impossible |

Table 2: Risk levels (Kinney and Wiruth, 1976)

| Risk score (R) | Risk classification |
|---|---|
| Higher than 400 | Too high risk; consider stopping operations |
| Between 200 and 400 | High risk; apply immediate large corrective actions |
| Between 70 and 200 | Moderate risk; apply simple corrective actions |
| Between 20 and 70 | Little risk; attention required |
| Lower than 20 | Slight risk; acceptable |

*Step 3:* For each criterion, the fuzzy weights are obtained by the Eq. 4 below.

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} \quad (4)$$

Here, $\tilde{w}_i$ is the fuzzy weight of criterion *i*. and $\tilde{w}_i = (lw_i, mw_i, uw_i)$.

Here, $lw_i$, $mw_i$, $uw_i$ show lower, middle and upper value of the fuzzy weight of criterion *i*.

*Step 4:* The best non-fuzzy weight is calculated using Center of gravity method, according to the Eq. 5.

$$w_i = [(uw_i - lw_i) + (mw_i - lw_i)]/3 + lw_i \quad (5)$$

*FVIKOR*

VIKOR is stand for multi-criteria optimization and compromise solution. It is one of the useful MCDM methods and developed by Opricovic (1998). It ranks alternatives and determines a compromise solution. For the current work, VIKOR method was preferred under a fuzzy environment in assessments of hazards. The steps of FVIKOR are provided in details as below (Gul *et al.,* 2016):

*Step 1:* This step is regarding defuzzification of the elements of fuzzy decision matrix into crisp values. Transformation of a fuzzy number $\tilde{a} = (a_1, a_2, a_3)$ into a crisp number *a* can be expressed by the Eq. 6.

$$a = \frac{a_1 + 4a_2 + a_3}{6} \quad (6)$$

*Step 2:* Second step is about determination of the best and worst values of all criteria ratings (j=1,2,.., n) and alternatives (i=1,2,.., m) using Eqs. 7 and 8.

$$f_j^* = \max_i \{x_{ij}\}; f_j^- = \min_i \{x_{ij}\} (\textit{Benefit criteria}) \quad (7)$$

$$f_j^* = \min_i \{x_{ij}\}; f_j^- = \max_i \{x_{ij}\} (\textit{Cost criteria}) \quad (8)$$

*Step 3:* The third step is the computation of two of three VIKOR specific indexes ($S_i$ and $R_i$ values) using Eqs. 9 and 10.

$$S_i = \sum_{j=1}^{n} w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \quad (9)$$

$$R_i = \max_j w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \quad (10)$$

*Step 4:* The forth step is about $Q_i$ value calculation using Eq. 11.

$$Q_i = v \frac{S_i - S^*}{S^- - S^*} + (1-v) \frac{R_i - R^*}{R^- - R^*} \quad (11)$$

Where, $S^* = \min_i S_i; S^- = \max_i S_i; R^* = \min_i R_i; R^- = \max_i R_i$. and *v* is the value between 0 and 1 and called as the strategy of maximum group utility and (1-*v*) is the value of the individual regret.

*Step 5:* In the fifth step, alternatives are ranked sorting by the values S, R and Q in ascending order.

*Step 6:* The last step is about compromised solution. For a compromise solution, two conditions in (Awasthi and Kannan, 2016) should be satisfied.

*The proposed combined risk assessment method*

Fig. 1 shows the proposed combined risk assessment method for wind turbine risk management. At the left side of the Fig. 1, an overall risk assessment frame is given. This frame comprises seven main steps. The first one is regarding setting of assessment scope. Secondly, tasks and hazards are identified by using different approaches. In this method, data of hazards are provided from OHS experts who make risk analysis for wind turbines. Thirdly, assessment of risks in both construction and operation periods of the observed wind turbine is performed. The focal point at this paper is within this step. This step is given in details at the right side of the figure. Buckley's FAHP is used in weighting C, E and P derived from Fine-Kinney method taking into consideration pairwise comparison manner. The priority orders of hazards are obtained by FVIKOR method. Linguistic ratings are used for evaluation of criteria and alternatives in both MCDM methods. The forth step deals with reducing risks. This step enables significant risks be eliminated rapidly by using hazard control hierarchy (Main, 2012). Following the risk reduction, a residual risk analysis is performed to confirm whether the suggested actions reduce the risks successfully or not (Fig. 1).

## RESULTS AND DISCUSSION

*Case study in a wind turbine*

*Environment of a wind energy turbine system*

The aim of wind turbine systems is to generate electricity. In a wind turbine system, the kinetic energy of the wind is initially transformed into mechanical energy and then into electricity (Guo *et al.,* 2009). Wind turbines are classified into two types as onshore and offshore. A typical wind turbine system consists

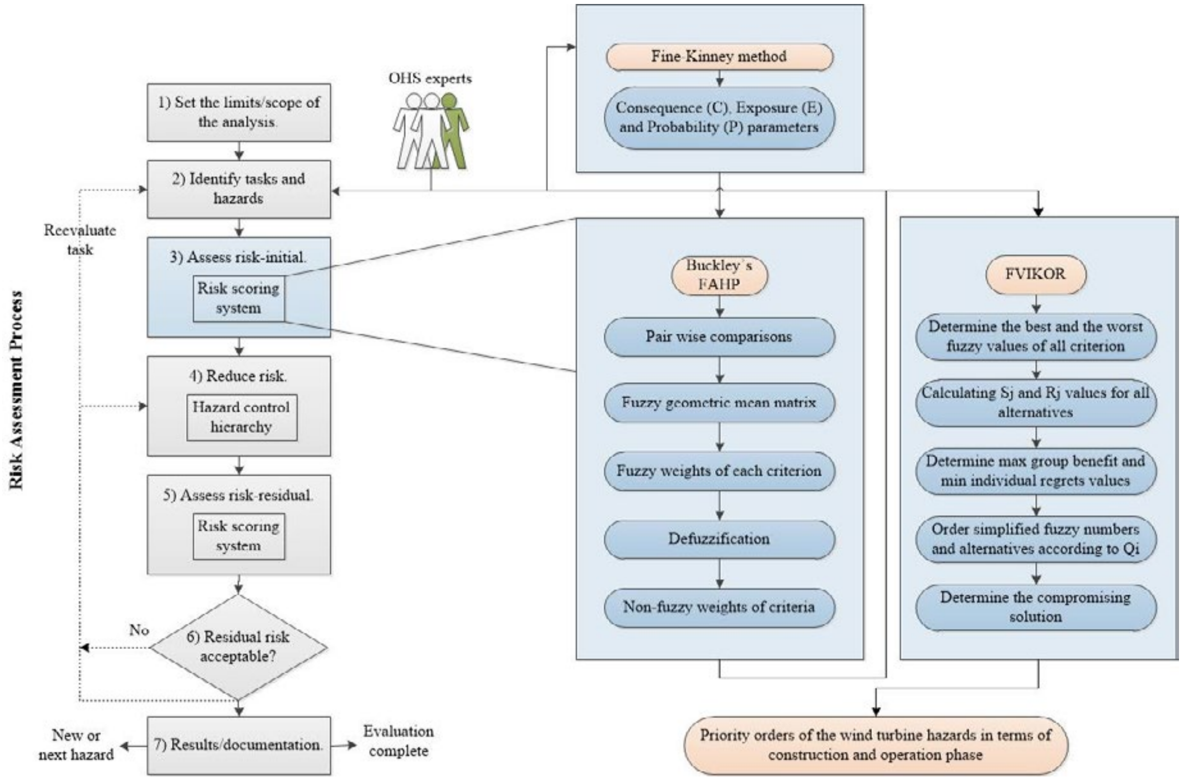

Fig. 1: The flow of the proposed combined risk assessment method

of the components identified in Fig. 2.

Prior to making risk assessment by the proposed method, the most important hazard sources and risks defined by safety managers and OHS experts in the observed wind turbine are classified in terms of operation and construction periods. The classification is given in Table 3 and Table 4.

*Risk scoring and prioritizing using proposed approach*

Following the hazard identification, with the aid of Buckley's fuzzy AHP, OHS experts compare Fine-Kinney parameters (P, C and E) in a pairwise manner using linguistic relations in Table 5 and determine the weight values. Linguistic variables in evaluating risk parameters referenced in this paper is based on the scale in Kutlu and Ekmekçioğlu (2012). The pairwise questionnaire form for the three-parameter evaluation is given in Table 5. As an example, when compared the probability and consequence parameters, the replies of three experts are TW, TW, and CW, respectively. Using the steps of fuzzy AHP explained in Eqs. 1 to

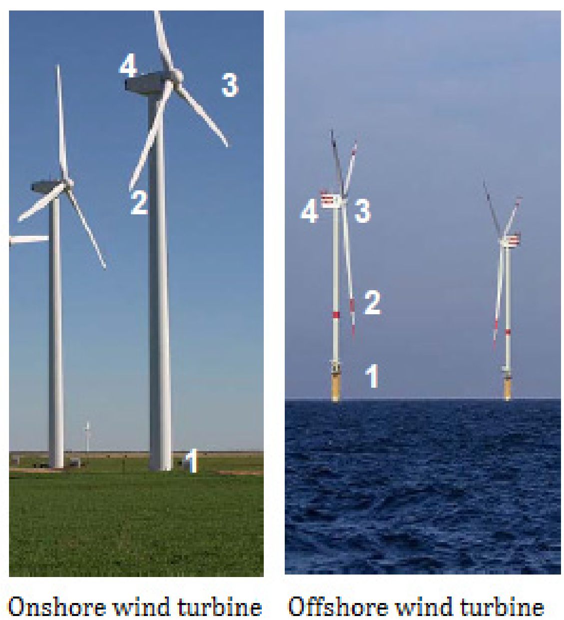

Fig. 2: Components of a wind turbine: (1) tower, (2) blades, (3) hub and (4) nacelle (EU-OSHA, 2013)

Table 3: Descriptions of the hazard sources and risks in the observed wind turbine in times of operation

| Code | Identified hazard in times of operation ($HIO_i$) | Unit | Definition of hazard | Definition of risk |
|---|---|---|---|---|
| DR | HIO1 | Administrative building - Dressing room | Lockers | Fall risk of lockers |
| GR1 | HIO2 | Administrative Building - Guest Rooms | Fire | Risk of fire |
| GR2 | HIO3 | | Dress cabinet | Fall of dress cabinet |
| PA1 | HIO4 | Administrative building environment-Public areas | Using stairs | Wet floor |
| PA2 | HIO5 | | Internal transformer | Explosion risk of internal transformer |
| PA3 | HIO6 | | Human factor | Entry of unauthorized persons to the areas where diesel generator and internal transformer are placed |
| PA4 | HIO7 | | Septic and water tank | Drowning |
| PA5 | HIO8 | | Pests and insects | Pest and insect bites |
| PA6 | HIO9 | | Spraying engaged staff | Electric shock |
| P | HIO10 | Security - Patrolling | Electric shock possibility as a result of using of electrical equipment | Possibility of receiving electric shock of security personal |
| CWA | HIO11 | Contaminated waste area | Access of unauthorized persons to waste containers | Poisoning as a result of contact of unauthorized persons to chemicals |
| WWA1 | HIO12 | Warehouse and Waste area | Access of unauthorized persons to storage area | Aimless movement of unauthorized persons in warehouse and waste area |
| WWA2 | HIO13 | | Access of unauthorized persons to storage area | Touching and climbing of unauthorized persons to the high voltage towers |
| TC1 | HIO14 | Tranche channels (Medium voltage cable route) | Agriculture in the agricultural lands of operational area | Electric shock as a result of plowing the fields and excavations by farmers in the cable route |
| TC2 | HIO15 | | Opening of the water trenches on the roadside and studies with work machine in the operational area | Electric shock by contacting the MV cables during the works on opening of the water trenches on the roadside and with work machines |
| TC3 | HIO16 | | Damaging of the heavy rainfall to trench channel | Damage risk of cables as a result of disclosure of the trench channels due to heavy rainfall |
| WT | HIO17 | Wind turbine | Lightning, Ice fall, Overthrow of turbines as a result of the natural disasters | Lightning, Wounding risk as a result of skidding down of ice blocks when moving of iced tower, Wound or death risk as a result of overthrow of wind turbines during natural disasters |
| TA1 | HIO18 | Turbine areas | The entry of unauthorized persons | Exposure to electric current as a result of entry of unauthorized persons |
| TA2 | HIO19 | | Works in the turbine area | Entering of unauthorized persons to the turbine working areas |
| TT1 | HIO20 | 34.5 kV Turbine Step Up Transformer | Transformer | High temperature and pressure that may occur in the transformer |
| TT2 | HIO21 | | Transformer | Spreading of oil as a result of explosion |
| TT3 | HIO22 | | Transformer | The entry of unauthorized persons |
| TT4 | HIO23 | | Transformer | Accident resulting in material damage and spreading |
| RMU1 | HIO24 | 34.5 kV RMU (Ring Main Unite) cell | RMU cell | Exposure to electric current, Explosion burns |
| RMU2 | HIO25 | | RMU cell | The arcing in the explosion during the maneuver |
| RMU3 | HIO26 | | RMU cell | The entry of unauthorized persons |
| RMU4 | HIO27 | | RMU cell | Low voltage electric shock during operation and intervene in the control panel |
| K1 | HIO28 | Kiosks | Concrete kiosk | Damages of insects and rodents to the cable systems |
| K2 | HIO29 | | Concrete kiosk | Entry of unauthorized persons |
| K3 | HIO30 | | Concrete kiosk | Damage as a result of fire |
| K4 | HIO31 | | Rectifiers | Exposure to electric current |

Table 4: Descriptions of the hazard sources and risks in the observed wind turbine in times of construction

| Code | Identified hazard in times of construction ($HIC_i$) | Scope | Hazard definition | Risk definition |
|---|---|---|---|---|
| FST6 | HIC1 | Field security - Transportation | Lack of communication within the work site | Not able to respond to the emergency cases in the work site |
| EC3 | HIC2 | Emergency cases | Not determining dangerous work sites | Entries of unauthorized people to the work sites |
| ELECT | HIC3 | Work with electricity | Lack of safety signs of electrical panels | Electric shock and wrong response |
| ADW1 | HIC4 | Work in adverse weather conditions | Unsuitable weather conditions | Improper working situations |
| NW3 | HIC5 | Night works | Insufficiency of lighting | Visual disturbances and undesirable behavior |
| LORRY | HIC6 | Trucks | The uncontrolled movement of excavation trucks | The tipping risk of trucks and mechanical failures as a result of uncontrolled movement |
| ME2 | HIC7 | Machine and Equipment | Lack of yardman in excavation and dump site and lack of barrier on the dump site | Not be directed by the yardman and exposure to the accidents |
| VU3 | HIC8 | Vehicle using | Availability of persons inside the cabinet of truck excluding driver | Occupational accidents as a result of availability of persons inside the cabinet of truck excluding driver |
| WM6 | HIC9 | Working methods | Unsuitable slope in the excavation roads | Traffic accident as a result of the slope |
| ACT | HIC10 | Activity of foreign people in the fields | Unwanted entries | Occupational accidents as a result of entries of non-official personnel into the borders of excavation field |
| CW1 | HIC11 | Cleaning works | Not making water analysis | Improper use of water |
| DH2 | HIC12 | Dining hall works | Lack of hygiene education of food staff | Work of staff without attention to hygiene |
| FW | HIC13 | Field works | Toxic wild animals | Unawareness against animal attacks |
| CONT | HIC14 | Control | Works of suppliers | Lack of specific risk assessment works |
| TT1 | HIC15 | Transportation of turbines | Lack of road signs | Not know the hazard, accident |
| TT3 | HIC16 | Transportation of turbines | Making of tree pruning | Fall from height |
| TA2 | HIC17 | Turbine assembly | Use of crane, Fall of equipment | Fall of load and hand tools |
| HU2 | HIC18 | Hytork use | High pressure oil, excessive sound | Flashing of high pressure oil, Hearing loss |
| PATR | HIC19 | Patrolling | Sabotage and theft | Assault of staff as a result of initial response |
| FORM1 | HIC20 | Formwork related works | The absence of appropriate port for attaching a seat belt | Not use of seat belts, fall from heights |
| FORM2 | HIC21 | Formwork related works | Ignoring employment measures at height | Fall from heights |
| FIRE1 | HIC22 | Fire and emergency cases | Not prepared of emergency action plan, not created of an emergency team | The panic in emergency situations, Inability to quickly intervene in case of emergency |
| C1 | HIC23 | Concreting | Do concreting at height | Not use of parachute-type safety belt, fall from height |
| CM2 | HIC24 | Concrete mixer | Making works in the back-maneuver area of the mixer or being out of order of back signal of the mixer | Crash into the construction equipment and employees |
| WCO2 | HIC25 | Weather condition | Work at height in extreme rainy and windy weathers | Fall from heights, Landslides and floods, Hitting of flying and blown materials to employees |
| AAD1 | HIC26 | Accidents and diseases | Employment of workers who has no professional competence certificate in very dangerous works | Increase in occupational accident occurrence rate |

Continue Table 4: Descriptions of the hazard sources and risks in the observed wind turbine in times of construction

| Code | Identified hazard in times of construction (HIC$_i$) | Scope | Hazard definition | Risk definition |
|---|---|---|---|---|
| WHW | HIC27 | Work in hot weather | Work under the hot sun | Sun stroke |
| VP3 | HIC28 | Vehicles of the plant | Driving vehicles at night and dark weather conditions | Restrictive sight distance |
| EXW4 | HIC29 | Excavation works | Excavation | Shifting of excavation soil |
| SHIP | HIC30 | Shipping | Exceed the speed limit in the work site | Traffic accident |
| PA1 | HIC31 | Post assembly | Skin up or down | Fall from height |
| GW1 | HIC32 | General works | No maintenance of hand tools | Damages of hand tools to the employees by being broken and splashing parts |
| MHE1 | HIC33 | Manual handling and ergonomics | Heavy loads that cannot be moved by hand | Carrying of the loads alone by employees |
| LU1 | HIC34 | Ladder using | Working with hand ladders on the edge | Lose his/her balance and falling |
| CP3 | HIC35 | Conductor pulling | Deflection-offset studies | Fall from height, Manual Handling, Hardware material damages, Material falls |
| INS | HIC36 | Insulator installation | Installing of spool and insulator ring to the poles in the stage | Working at height, Material falls, Manual handling, Skinning up and down the poles |
| GUP1 | HIC37 | Guidewire pulling | Pulling over a guide wire | Squashing of hands into spool or wire and injuring, Miscommunication, Wire whisking |
| PPE | HIC38 | PPE using | Not use of personal protective equipment | Not recognizing of staff |
| MH4 | HIC39 | Material handling | Unstable stacking of materials | Tipping of stack on employees |
| WS1 | HIC40 | Warning signs | Insufficiency of warning signs | Inadequate informing of employees about hazards |
| BWD | HIC41 | Brake and wire drawing | Incorrect replacement of brake and wire drawing machine | Choosing the wrong place for machines and not fixing them |
| HEQ | HIC42 | Hand equipment | Hand tools accidents | Damaged hand tools using |

Table 5: Pairwise comparison of Fine-Kinney parameters

| Parameter | CS | TS | JS | LS | EA | LW | JW | TW | CW | Parameter |
|---|---|---|---|---|---|---|---|---|---|---|
| P | | | | | | | | √,√ | √ | C |
| P | | | | | √ | √ | √ | | | E |
| C | | √, √ | √ | | | | | | | E |

√ refers to the evaluations of OHS experts. Other abbreviations are as follows: Completely strong (CS); Too strong (TS); Just strong (JS); Little strong (LS); Equal (EA); Little weak (LW); Just weak (JW); Too weak (TW); Completely weak (CW)

5, the weights are determined as (0.228, 0.493, 0.279) for P, C and E, respectively. Finally, a consistency computation is performed. The consistency index CI and random consistency index (RI) are obtained as 0.0279 and 0.58. The consistency ratio is "CR=CI/RI=0.0481". Since the CR value is less than 10%, the pairwise evaluation matrix is found consistent.

By injecting the assigned weight values of three risk parameters obtained from Buckley's FAHP, FVIKOR is used to prioritize hazards in both operation and construction times of the observed wind turbine. In the paper, the OHS experts evaluate hazards using

Table 6: Linguistic relations and related triangular fuzzy values used for hazard ranking (Chen, 2000)

| Linguistic relation | Corresponding triangular fuzzy number |
|---|---|
| Too poor (TP) | (0,0,1) |
| Poor (PR) | (0,1,3) |
| Moderate poor (MP) | (1,3,5) |
| Fair (F) | (3,5,7) |
| Moderate good (MG) | (5,7,9) |
| Good (G) | (7,9,10) |
| Too good (TG) | (9,10,10) |

linguistic relations given in Table 6. The linguistic evaluations of 31 hazards by OHS experts (indicated with "Exp." in Table 7) with respect to C, E and P are demonstrated in Table 7.

Transformation of these linguistic relations into triangular fuzzy numbers and aggregation are performed as made by Awasthi and Kannan (2016). A small example that explains the calculations is as follows:

Experts assess the hazard "HIO1" with respect to consequence parameter by giving the linguistic terms of (PR, PR, MP). According to the scale in Table 6, PR and MP are corresponded to the triangular fuzzy number of (0, 1, 3) and (1, 3, 5), respectively. The fuzzy rating of HIO1 with respect to parameter C is calculated by taking minimum value of expert ratings for lower value, arithmetic mean for middle value and maximum value of expert ratings for upper value. Lower value of triangular fuzzy rating of HIO1 with respect to parameter C is computed as min(0,0,1)=0. Middle value is computed as (1/3)*(1+1+3) =1.667. Upper value is computed as max(3,3,5)=5. Therefore, the fuzzy rating of HIO1 with respect to parameter C is obtained as (0,1.667,5). Then this value is

Table 7: Linguistic assessment for the hazard sources in the observed wind turbine in times of operation

| Hazards (HIO$_i$ $i$=1 to 31) | Codes | Consequence | | | Exposure | | | Probability | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Exp. 1 | Exp. 2 | Exp. 3 | Exp. 1 | Exp. 2 | Exp. 3 | Exp. 1 | Exp. 2 | Exp. 3 |
| HIO1 | DR | PR | PR | MP | G | G | MG | MG | MG | MG |
| HIO2 | GR1 | G | MG | G | PR | PR | MP | G | G | MG |
| HIO3 | GR2 | PR | PR | MP | PR | PR | MP | F | F | F |
| HIO4 | PA1 | MG | MG | MG | PR | MP | PR | F | F | F |
| HIO5 | PA2 | TG | TG | TG | TP | PR | TP | G | G | MG |
| HIO6 | PA3 | G | MG | G | TP | TP | TP | MG | F | MG |
| HIO7 | PA4 | G | MG | G | MG | MG | F | MG | MG | F |
| HIO8 | PA5 | PR | PR | MP | MP | MP | F | F | F | F |
| HIO9 | PA6 | G | MG | G | MP | F | F | MP | F | MP |
| HIO10 | P | MG | F | MG | PR | PR | MP | G | MG | MG |
| HIO11 | CWA | F | F | F | TP | PR | TP | MP | MP | F |
| HIO12 | WWA1 | F | F | MG | TP | PR | TP | MP | F | MP |
| HIO13 | WWA2 | MG | G | G | TP | TP | TP | MP | MP | MP |
| HIO14 | TC1 | G | G | G | MP | PR | PR | MG | MG | G |
| HIO15 | TC2 | G | MG | G | PR | PR | TP | MG | MG | MG |
| HIO16 | TC3 | G | G | G | TP | PR | TP | MG | MG | MG |
| HIO17 | WT | TG | TG | TG | TP | PR | TP | MP | MP | MP |
| HIO18 | TA1 | G | MG | G | TP | TP | TP | F | MP | F |
| HIO19 | TA2 | PR | PR | MP | PR | PR | MP | MP | MP | MP |
| HIO20 | TT1 | TG | TG | TG | TP | PR | TP | MP | F | F |
| HIO21 | TT2 | F | MG | MG | TP | PR | TP | F | F | F |
| HIO22 | TT3 | MG | G | G | TP | TP | TP | F | F | F |
| HIO23 | TT4 | MG | MG | MG | TP | TP | TP | MP | PR | MP |
| HIO24 | RMU1 | G | MG | G | TP | PR | TP | MG | F | MG |
| HIO25 | RMU2 | MG | G | G | PR | PR | TP | F | MG | F |
| HIO26 | RMU3 | MG | MG | MG | TP | PR | TP | F | F | F |
| HIO27 | RMU4 | G | G | MG | TP | TP | TP | F | F | F |
| HIO28 | K1 | MP | PR | PR | MP | MP | F | G | G | G |
| HIO29 | K2 | G | MG | G | TP | TP | TP | F | F | MG |
| HIO30 | K3 | G | G | G | TP | PR | TP | F | F | F |
| HIO31 | K4 | G | G | MG | TP | TP | TP | F | MG | F |

transformed into crisp number using Eq. 6 as follows: (0+4*1.667+5)/6=1.944.

All results for 31 hazards with respect to parameters of C, E and P are presented in Table 8. Also, the $f_j^*$ and $f_j^-$ values are computed using Eqs. 2 and 3 (Table 8). Then, $S_i$, $R_i$ and $Q_i$ values are calculated using Eqs. 4-6 and the values of $S^*= 0.268$, $S^-= 0.916$, $R^*= 0.111$, $R^-= 0.493$.

Fig. 3 shows the values of $S_i$, $R_i$ and $Q_i$ for each hazard that indicate the ranking in ascending order. The lowest value reflects highest risk. $S_i$, $R_i$ and $Q_i$ values closest to 1 reflect lowest risk. It can be seen from the results of Fig. 3 that alternative HIO7 is the most serious hazard with a minimum $Q_i$ value. However, the two acceptability conditions are checked in order to show compromised rankings (Awasthi and Kannan, 2016). The first condition is named as acceptable advantage. According to this condition, $Q(H^{(2)})- Q(H^{(1)})\geq DQ$ and $DQ=1/(M-1)$, where $H^{(1)}$ and $H^{(2)}$ is the alternatives with first and second positions in the ranking list by Qi value respectively and M is the total number of alternatives. Using this, DQ=1/(31-1)=0.033. Q(HIO14)-Q(HIO7)=0.178-0=0.178>0.033, hence the first condition is satisfied. The second condition is acceptable stability in decision making. The alternative $H^{(1)}$ must also be the best ranked by $S_i$ value or/and $R_i$ value. This condition is also satisfied. Therefore, the ultimately ranking order is HIO7> HIO14. The most

Table 8: Aggregated crisp ratings for operation risk assessment of the observed wind turbine

| Codes | Hazards (HIO*i* i=1 to 31) | Risk parameters | | |
|---|---|---|---|---|
| | | C | E | P |
| DR | HIO1 | 1.944 | 8.056 | 7.000 |
| GR1 | HIO2 | 8.056 | 1.944 | 8.056 |
| GR2 | HIO3 | 1.944 | 1.944 | 5.000 |
| PA1 | HIO4 | 7.000 | 1.944 | 5.000 |
| PA2 | HIO5 | 9.833 | 0.722 | 8.056 |
| PA3 | HIO6 | 8.056 | 0.167 | 6.222 |
| PA4 | HIO7 | 8.056 | 6.222 | 6.222 |
| PA5 | HIO8 | 1.944 | 3.778 | 5.000 |
| PA6 | HIO9 | 8.056 | 4.222 | 3.778 |
| P | HIO10 | 6.222 | 1.944 | 7.611 |
| CWA | HIO11 | 5.000 | 0.722 | 3.778 |
| WWA1 | HIO12 | 5.778 | 0.722 | 3.778 |
| WWA2 | HIO13 | 8.056 | 0.167 | 3.000 |
| TC1 | HIO14 | 8.833 | 1.944 | 7.611 |
| TC2 | HIO15 | 8.056 | 0.944 | 7.000 |
| TC3 | HIO16 | 8.833 | 0.722 | 7.000 |
| WT | HIO17 | 9.833 | 0.722 | 3.000 |
| TA1 | HIO18 | 8.056 | 0.167 | 4.222 |
| TA2 | HIO19 | 1.944 | 1.944 | 3.000 |
| TT1 | HIO20 | 9.833 | 0.722 | 4.222 |
| TT2 | HIO21 | 6.222 | 0.722 | 5.000 |
| TT3 | HIO22 | 8.056 | 0.167 | 5.000 |
| TT4 | HIO23 | 7.000 | 0.167 | 2.389 |
| RMU1 | HIO24 | 8.056 | 0.722 | 6.222 |
| RMU2 | HIO25 | 8.056 | 0.944 | 5.778 |
| RMU3 | HIO26 | 7.000 | 0.722 | 5.000 |
| RMU4 | HIO27 | 8.056 | 0.167 | 5.000 |
| K1 | HIO28 | 1.944 | 3.778 | 8.833 |
| K2 | HIO29 | 8.056 | 0.167 | 5.778 |
| K3 | HIO30 | 8.833 | 0.722 | 5.000 |
| K4 | HIO31 | 8.056 | 0.167 | 5.778 |
| fj* | | 9.833 | 8.056 | 8.833 |
| fj- | | 1.944 | 0.167 | 2.389 |

serious hazard rankings in the observed wind turbine in times of operation are stemmed from drowning (HIO7), explosion risk of internal transformer (HIO5), electric shock as a result of plowing the fields and excavations by farmers in the cable route (HIO14), the fire risk in administrative building-guest rooms (HIO2), and electric shock in administrative building environmental-public areas (HIO9). The followed risk assessment methodology cannot eradicate risks entirely. It may suggest some corrective-preventive actions. Therefore, each risk should be controlled or reduced to an acceptable level (Mahdevari *et al.,* 2014). The compromise ranking of the hazards is also shown in Fig. 3.

Secondly, linguistic assessment for the most important hazard sources in the observed wind turbine in times of construction is made. In the analysis, 42 hazard sources are considered as given in Table 4. Similar calculations are performed before as in evaluating hazards in times of operation. The linguistic evaluations of 42 hazards by OHS experts with respect to C, E and P are provided in Table 9. These linguistic terms are converted to triangular fuzzy numbers then aggregated following the procedure as in operation risk assessment of the observed wind turbine. The aggregated crisp ratings for the 42 hazards in construction period are given in Table 10. Using Eqs. 2 and 3, the best $f_j^*$ and the worst values $f_j^-$ are computed (Table 10). $S_i$, $R_i$ and $Q_i$ values that are specific indexes for FVIKOR are provided for each hazard using Eqs. 4-6. Fig. 4 shows the values of $S_i$, $R_i$ and $Q_i$ and compromised rankings. In the lights of obtained results, the most vital hazards in the observed wind turbine in times of construction

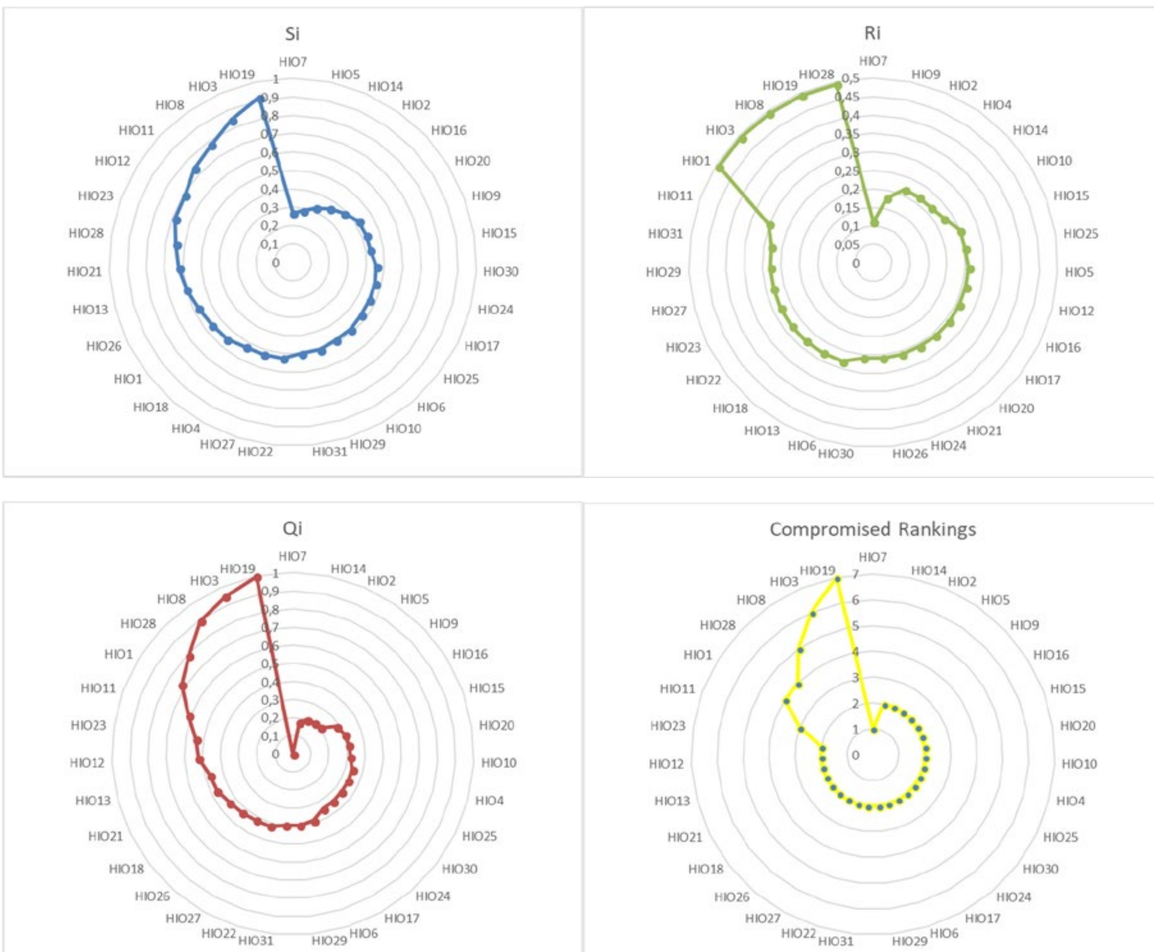


Fig. 3: Si, Ri and Qi values and compromised rankings for the hazards in the observed wind turbine in times of operation

are HIC20, HIC21, HIC1, HIC16, HIC17, HIC32, HIC2, HIC5 and HIC7.

*Comparison of the results*

To compare the results of the FVIKOR with the other methods, we also use the ranking of the hazards in terms of $S_i$, $R_i$ and $Q_i$ values and the correlation coefficient. The comparative analysis is conducted with the results of crisp VIKOR method. The ranking results of the hazards yielded by VIKOR method and a closeness coefficient approach show how well the relationship between two methods' results. Fig. 5

Table 9: Linguistic assessment for the hazard sources in the observed wind turbine in times of construction

| Hazards (HIC$_i$ $i$=1 to 42) | Codes | Consequence | | | Exposure | | | Probability | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Exp.1 | Exp.2 | Exp.3 | Exp.1 | Exp.2 | Exp.3 | Exp.1 | Exp.2 | Exp.3 |
| HIC1 | FST6 | MG | MG | MG | MG | MG | F | MG | MG | MG |
| HIC2 | EC3 | MG | MG | MG | F | F | MP | MG | MG | MG |
| HIC3 | ELECT | F | F | F | MP | MP | F | MG | MG | MG |
| HIC4 | ADW1 | MG | MG | F | PR | TP | PR | MG | MG | F |
| HIC5 | NW3 | MG | MG | MG | F | F | MP | MG | MG | MG |
| HIC6 | LORRY | MG | F | MG | MG | MG | F | MP | F | MP |
| HIC7 | ME2 | MG | MG | MG | F | F | MP | MG | MG | MG |
| HIC8 | VU3 | MG | MG | MG | MP | MP | F | MG | MG | MG |
| HIC9 | WM6 | F | MG | MG | F | F | MP | MG | G | MG |
| HIC10 | ACT | MG | MG | MG | PR | TP | P | MG | MG | MG |
| HIC11 | CW1 | F | F | F | F | F | MP | MG | MG | MG |
| HIC12 | DH2 | F | F | MG | F | F | MP | MG | G | MG |
| HIC13 | FW | F | F | F | MP | MP | F | MG | MG | MG |
| HIC14 | CONT | F | F | MG | MP | MP | F | MG | MG | MG |
| HIC15 | TT1 | MG | MG | F | MP | MP | F | MG | MG | MG |
| HIC16 | TT3 | MG | MG | MG | F | F | MP | MG | MG | G |
| HIC17 | TA2 | MG | MG | MG | F | F | MP | MG | MG | G |
| HIC18 | HU2 | MG | MG | F | PR | TP | PR | MG | MG | MG |
| HIC19 | PATR | F | F | F | F | F | MP | MG | F | MG |
| HIC20 | FORM1 | MG | MG | F | G | TG | G | TG | TG | TG |
| HIC21 | FORM2 | MG | MG | F | G | G | TG | TG | TG | TG |
| HIC22 | FIRE1 | F | F | MP | TG | TG | TG | MG | G | G |
| HIC23 | C1 | MP | F | F | TG | G | G | G | G | G |
| HIC24 | CM2 | F | F | MP | TG | G | G | G | G | G |
| HIC25 | WCO2 | F | F | MP | G | G | G | G | MG | G |
| HIC26 | AAD1 | F | F | MP | G | G | G | G | G | G |
| HIC27 | WHW | F | F | MP | TG | G | G | G | G | G |
| HIC28 | VP3 | MP | F | F | G | G | TG | G | G | G |
| HIC29 | EXW4 | PR | TP | PR | G | G | G | MG | G | G |
| HIC30 | SHIP | F | MP | F | TG | G | G | MG | G | MG |
| HIC31 | PA1 | PR | PR | PR | TG | G | G | MG | MG | MG |
| HIC32 | GW1 | F | F | F | MG | MG | MG | G | G | G |
| HIC33 | MHE1 | F | MP | F | MG | MG | MG | G | G | G |
| HIC34 | LU1 | F | F | MP | F | MP | F | TG | TG | TG |
| HIC35 | CP3 | PR | TP | PR | G | G | G | MG | MG | F |
| HIC36 | INS | PR | PR | PR | TG | G | G | MG | G | MG |
| HIC37 | GUP1 | TP | PR | PR | G | TG | G | MG | MG | MG |
| HIC38 | PPE | F | F | MP | F | F | F | G | G | MG |
| HIC39 | MH4 | F | F | MP | F | F | F | G | G | G |
| HIC40 | WS1 | F | F | MP | F | F | F | G | G | G |
| HIC41 | BWD | TP | PR | PR | MG | MG | MG | MG | G | MG |
| HIC42 | HEQ | F | F | MP | F | MP | F | MG | MG | MG |

Table 10: Aggregated crisp ratings for construction risk assessment of the observed wind turbine

| Hazards (HIC$_i$ i=1 to 42) | | HIC1 | HIC2 | HIC3 | HIC4 | HIC5 | HIC6 | HIC7 | HIC8 | HIC9 | HIC10 | HIC11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Codes | | FST6 | EC3 | ELECT | ADW1 | NW3 | LORRY | ME2 | VU3 | WM6 | ACT | CW1 |
| Three risk parameters | C | 7.000 | 7.000 | 5.000 | 6.222 | 7.000 | 6.222 | 7.000 | 7.000 | 6.222 | 7.000 | 5.000 |
| | E | 6.222 | 4.222 | 3.778 | 0.944 | 4.222 | 6.222 | 4.222 | 3.778 | 4.222 | 0.944 | 4.222 |
| | P | 7.000 | 7.000 | 7.000 | 6.222 | 7.000 | 3.778 | 7.000 | 7.000 | 7.611 | 7.000 | 7.000 |
| Hazards (HIC$_i$ i=1 to 42) | | HIC12 | HIC13 | HIC14 | HIC15 | HIC16 | HIC17 | HIC18 | HIC19 | HIC20 | HIC21 | HIC22 |
| Codes | | DH2 | FW | CONT | TT1 | TT3 | TA2 | HU2 | PATR | FORM1 | FORM2 | FIRE1 |
| Three risk parameters | C | 5.778 | 5.000 | 5.778 | 6.222 | 7.000 | 7.000 | 6.222 | 5.000 | 6.222 | 6.222 | 4.222 |
| | E | 4.222 | 4.222 | 4.222 | 4.222 | 4.222 | 4.222 | 0.944 | 4.222 | 9.056 | 9.056 | 9.833 |
| | P | 7.611 | 7.000 | 7.000 | 7.000 | 7.611 | 7.611 | 7.000 | 6.222 | 9.833 | 9.833 | 8.056 |
| Hazards (HIC$_i$ i=1 to 42) | | HIC23 | HIC24 | HIC25 | HIC26 | HIC27 | HIC28 | HIC29 | HIC30 | HIC31 | HIC32 | HIC33 |
| Codes | | C1 | CM2 | WCO2 | AAD1 | WHW | VP3 | EXW4 | SHIP | PA1 | GW1 | MHE1 |
| Three risk parameters | C | 4.222 | 4.222 | 4.222 | 4.222 | 4.222 | 4.222 | 0.944 | 4.222 | 1.167 | 5.000 | 4.222 |
| | E | 9.056 | 9.056 | 8.833 | 8.833 | 9.056 | 9.056 | 8.833 | 9.056 | 9.056 | 7.000 | 7.000 |
| | P | 8.833 | 8.833 | 8.056 | 8.833 | 8.833 | 8.833 | 8.056 | 7.611 | 7.000 | 8.833 | 8.833 |
| Hazards (HIC$_i$ i=1 to 42) | | HIC34 | HIC35 | HIC36 | HIC37 | HIC38 | HIC39 | HIC40 | HIC41 | HIC42 | fj* | fj- |
| Codes | | LU1 | CP3 | INS | GUP1 | PPE | MH4 | WS1 | BWD | HEQ | | |
| Three risk parameters | C | 4.222 | 0.944 | 1.167 | 0.944 | 4.222 | 4.222 | 4.222 | 0.944 | 4.222 | 7.000 | 0.944 |
| | E | 4.222 | 8.833 | 9.056 | 9.056 | 5.000 | 5.000 | 5.000 | 7.000 | 4.222 | 9.833 | 0.944 |
| | P | 9.833 | 6.222 | 7.611 | 7.000 | 8.056 | 8.833 | 8.833 | 7.611 | 7.000 | 9.833 | 3.778 |

shows the ranking of hazards by $Q_i$ values. According to Fig. 5, the similar ranking results were obtained from both methods (FVIKOR and VIKOR). In addition, we applied the Pearson correlation coefficient to measure the correlation between two methods. This measure is a ratio of statistical dependence between the results of the two methods. The correlation coefficients are obtained nearly 75% and 77% for operation and construction period risk assessment, respectively. The correlation coefficients in terms of $S_i$, and $R_i$ values are also obtained as 66% & 73% and 67% & 82% for operation and construction periods. Therefore, the relationships between ranking results are strong. According to this analysis, it can be proved that the FVIKOR is consistent with the other methods in risk assessment like VIKOR.

*Risk control measures*

In this subsection, discussions on the measures are provided that should be taken to control risks in the observed wind turbine. Regarding the hazards in times of operation, HIO7, HIO5, HIO14, HIO2, and HIO9 are the most important ones. For hazard H7, two main control measures should be taken as follows:

1) Caution signs should be placed in septic and water tanks;

2) Water and septic tank lid must be locked. With respect to HIO5, daily maintenance and checks should be made. In tranche channels (Medium Voltage Cable Route), electric shock as a result of plowing the fields and excavations by farmers in the cable route (HIO14) is the most important risk. In order to struggle with this kind of hazards, there should be warning signs along the route. Moreover, a protection system to leave itself off as a result of contact with the cable system is available. According to the plant safety instructions patrolling is carried out. In administrative building guest rooms, there is a risk of fire severely (HIO2). Since there are no fire detectors currently, it is a serious need to place the fire tube in the rooms. Workers are faced with an electric shock risk (HIO9) that exposures to death, severely injuries and property damages in public areas of administrative building environmental. The control measures that should be followed are 1) to utilize PPE; 2) spraying engaged staff should apply pesticide to switchyard and electrical shock risky regions with guidance of the operation and maintenance technician.

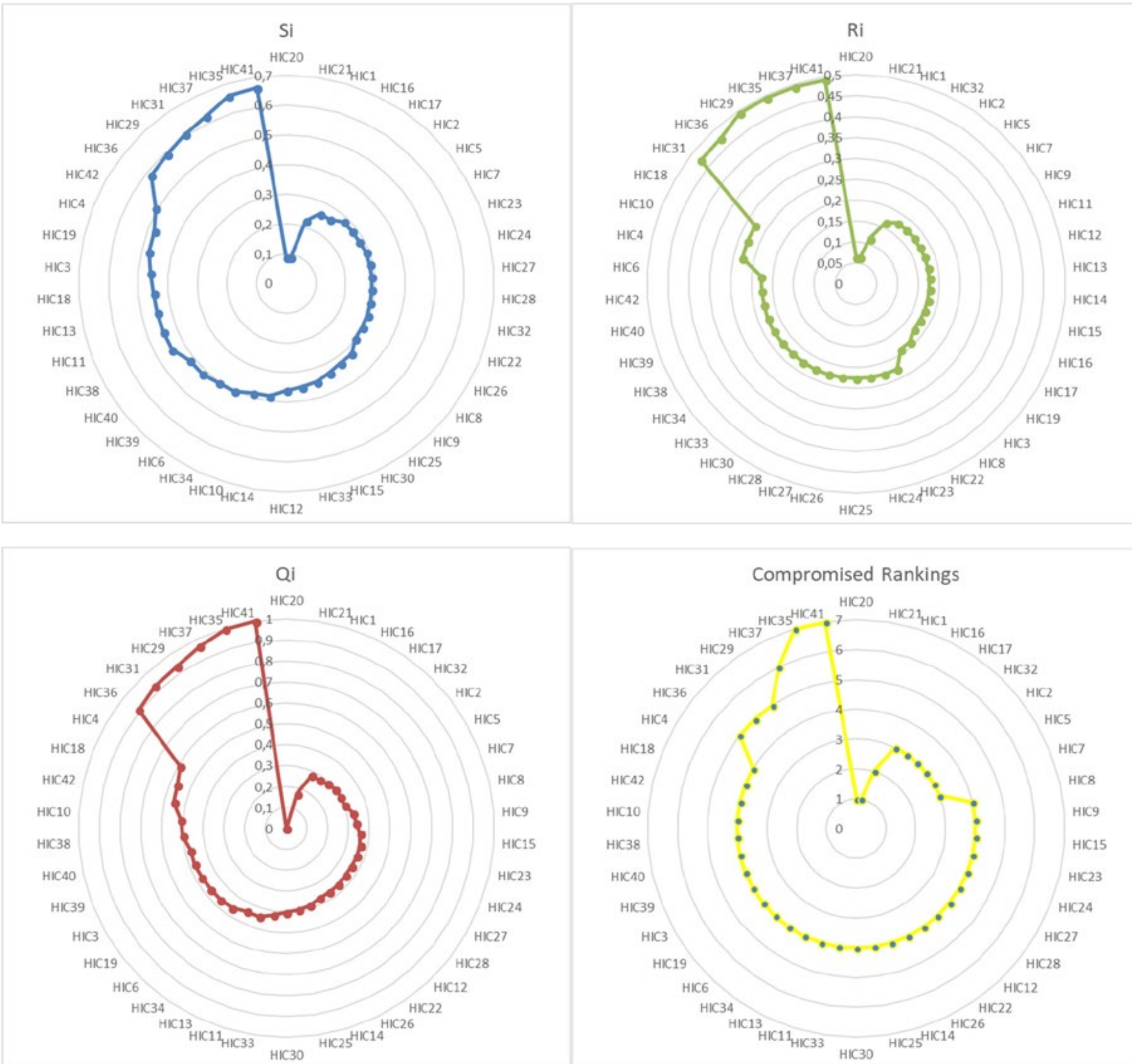


Fig. 4: $S_i$, $R_i$ and $Q_i$ values and compromised rankings for the hazards in the observed wind turbine in times of construction

One of the most important moderate hazards in the observed wind turbine in times of operation is stemmed from extreme weather conditions (HIO17). Lightning strikes and thunderstorms can be frightening and dangerous for workers of a wind turbine, particularly if they are working within the nacelle itself (EU-OSHA, 2013). Lightning, wounding risk as a result of skidding down of ice blocks when moving of iced tower, wound or death risk as a result of overthrow of wind turbines during natural disasters are the main risks regarding wind turbine operation. To reduce these risks into an acceptable level a number of control measures are taken into consideration. They are as follows: 1) The change of weather conditions should be monitored in real time. 2) Adverse weather operating procedures must be applied. 3) During the lightning risks, workers should pass into a safer place from the turbine tower. All parts must be grounded from top to bottom of the turbine. (4) While wandering around the turbines, PPEs must be utilized. 5) People and vehicles are not allowed to enter around the turbine in snowy and icy weather conditions. 6) When a risk of ice falling is detected, no working should be performed around the turbine. 7) It should be ensured that the visibility is clear and

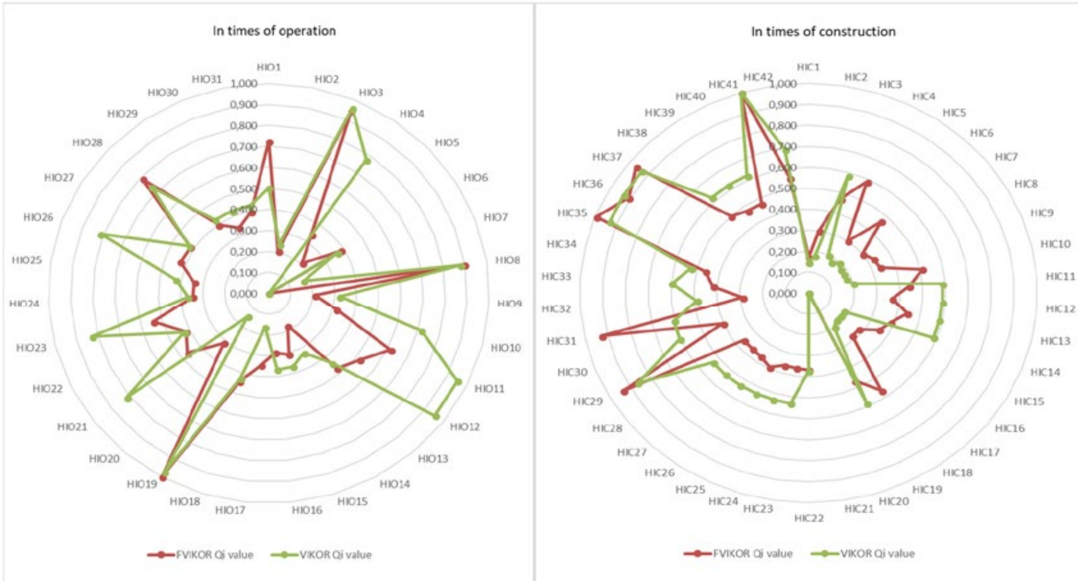


Fig. 5: Comparison of FVIKOR and VIKOR model results in terms of $Q_i$ values

understandable. In excessive foggy weathers, high visibility jackets must be preferred to wear. 8) For extreme heat weather conditions, it should be used skin protective cream against skin burns.

Regarding the hazards in times of construction, three of the most important hazards are HIC20, HIC21 and HIC1. Adem *et al.* (2018) also determined "falling from the height while assembling the blades" as the most serious risk with the highest score. The same result is obtained in this study. To reduce the risks related to these three factors, the operating process must be stopped and continuous improvement activities must be implemented. Strong points should be determined about working at heights to fasten the seat belts for HIC20. On the other way, the seat belt should be connected to the lifeline. For HIC21, appropriate working platforms must be built. Parachute type safety belts must be provided for all workers and their utilization must be controlled. A training should be carried out on working at heights, utilizing PPEs and seat belts. Instructions on working at height and mold making should be prepared. Lack of communication within the work site (HIC1) is the third most important hazard type. Some practices and training for security staff should be carried out by giving them walkie-talkies. For hazards HIC16, HIC17, HIC2, HIC5 and HIC7, a short-term correction action plan should be activated and some control measures should be taken respectively as follows: Seat belts should be fastened in order to overcome HIC16. For HIC17, the used lifting equipment must have a CE certificate and periodic control documents must be valid. Suitability of the used equipment should be under control with daily control check lists. Since HIC2 is about emergency cases, work sites should be determined as safety which they do not pose dangers for other employees and visitors. HIC5 is regarding of insufficiency of lighting especially at night working conditions. To eliminate risks, night lighting measurements of working areas should be performed. Maneuver of trucks should be made by the aid of yardman in excavation and dump site and a barrier should be situated on the dump site. The operating process must be stopped and continuous improvement activities must be implemented to reduce the risks related to HIC32. Since the hand tools have no maintenance, prior to using by employees they should be checked and the damaged broken of them should be repaired by informing the chief of the unit. Risk assessment process is obviously an ongoing process and taking control measures for this process should be handled together with nonstop improvement, review and revision if necessary (Samantra *et al.,* 2016; Mahdevari *et al.,* 2014).

## CONCLUSION

This paper proposes a new OSRA approach including FAHP and FVIKOR. The proposed approach is employed to the construction and operation period of a wind turbine. First, Buckley's FAHP is used in order to weight three risk parameters of Fine-Kinney method. Then in prioritizing hazards in terms of operation and construction period of the wind turbine, FVIKOR is applied. The proposed fuzzy based approach allows the interpretation of the risks more realistically by giving pairwise comparisons among consequence, exposure, and probability parameters. The proposed method identifies the potential hazards and provides control measures for early warning. Results demonstrate that the most vital hazards during the period of construction are stemmed from unavailability of seat belts, falls from height, panic in an emergency case and inability to quickly response in case of emergency. The ones arisen during the period of operation of the wind turbine are emerged as damaged and bumpy road due to a road accident, the risk of shock as a result of making unauthorized excavation and accident as a result of the apparent lack of the road. However, risk assessment process is a continuing review, the OHS executives should track risks and control in certain periods. For forthcoming works, other MCDM methods (ANP, TOPSIS and their fuzzy versions) and/or their combinations can also be considered as applicable tools for wind energy industry stakeholders to struggle with hazards. Although the application case is for an onshore wind turbine this combined approach can be also applied to an offshore wind turbine or a wind farm during for risk analysis of construction and operation periods.

## CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript.

## ACKNOWLEDGMENT

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## ABBREVIATIONS

| | |
|---|---|
| *ANP* | Analytic network process |
| *C* | Consequence |
| *CI* | Consistency index |
| *CR* | Consistency ratio |
| *CS* | Completely strong |
| *CW* | Completely weak |
| *DEMATEL* | Decision making trial and evaluation laboratory |
| *DQ* | Difference between $Q_i$ values of two alternatives |
| *E* | Exposure |
| *EA* | Equal |
| *Eq.* | Equation |
| *Exp.* | Expert |
| *F* | Fair |
| *FAHP* | Fuzzy analytic hierarchy process |
| *FMEA* | Failure mode and effects analysis |
| *FTOPSIS* | Fuzzy technique for order preference by similarity to ideal solution |
| *FVIKOR* | Fuzzy VIKOR |
| *G* | Good |
| *GWEC* | Global Wind Energy Council |
| $H^{(1)}$ | Any hazard with first position in the ranking list |
| $H^{(2)}$ | Any hazard with second position in the ranking list |
| $HIO_i$ | Identified hazards in times of operation |
| $HIC_i$ | Identified hazards in times of construction |
| *JS* | Just strong |
| *JW* | Just weak |
| *LS* | Little strong |
| *LW* | Little weak |
| *M* | Total number of alternatives assessed |
| *MCDM* | Multi criteria decision making |
| *MG* | Moderate good |
| *MP* | Moderate poor |
| *MW* | Mega Watt |
| *OHS* | Occupational health and safety |
| *OSRA* | Occupational safety risk assessment |
| *P* | Probability |
| *PR* | Poor |
| *R* | Risk score |
| *RI* | Random consistency index |
| $S_i$, $R_i$, $Q_i$ | Three different ranking values (VIKOR index value) that are specific to the VIKOR |

| | |
|---|---|
| *TG* | Too good |
| *TP* | Too poor |
| *TS* | Too strong |
| *TW* | Too weak |
| *TWEA* | Turkish Wind Energy Association |

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