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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.

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

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

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

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

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.

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

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

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

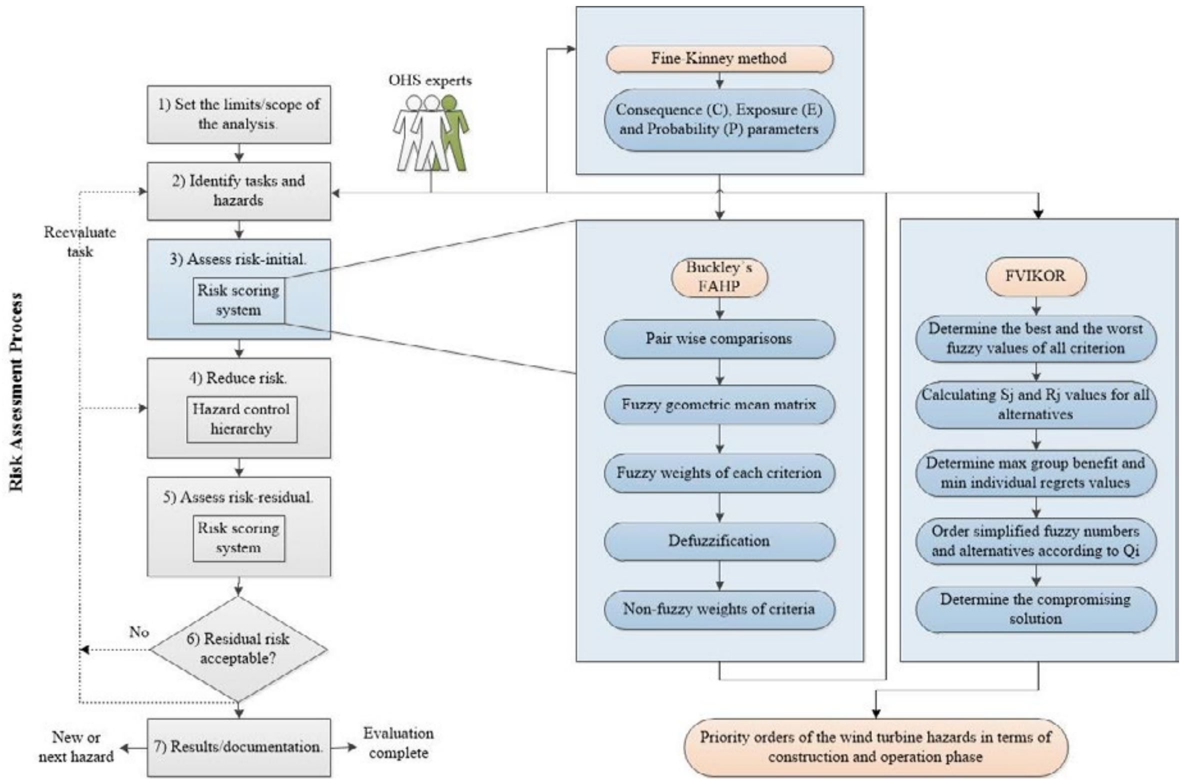

Fig. 1: The flow of the proposed combined risk assessment method

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

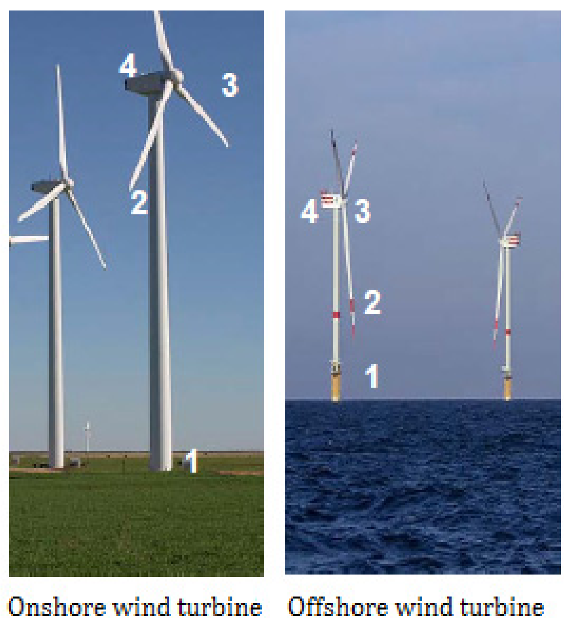

Fig. 2: Components of a wind turbine: (1) tower, (2) blades, (3) hub and (4) nacelle (EU-OSHA, 2013)

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

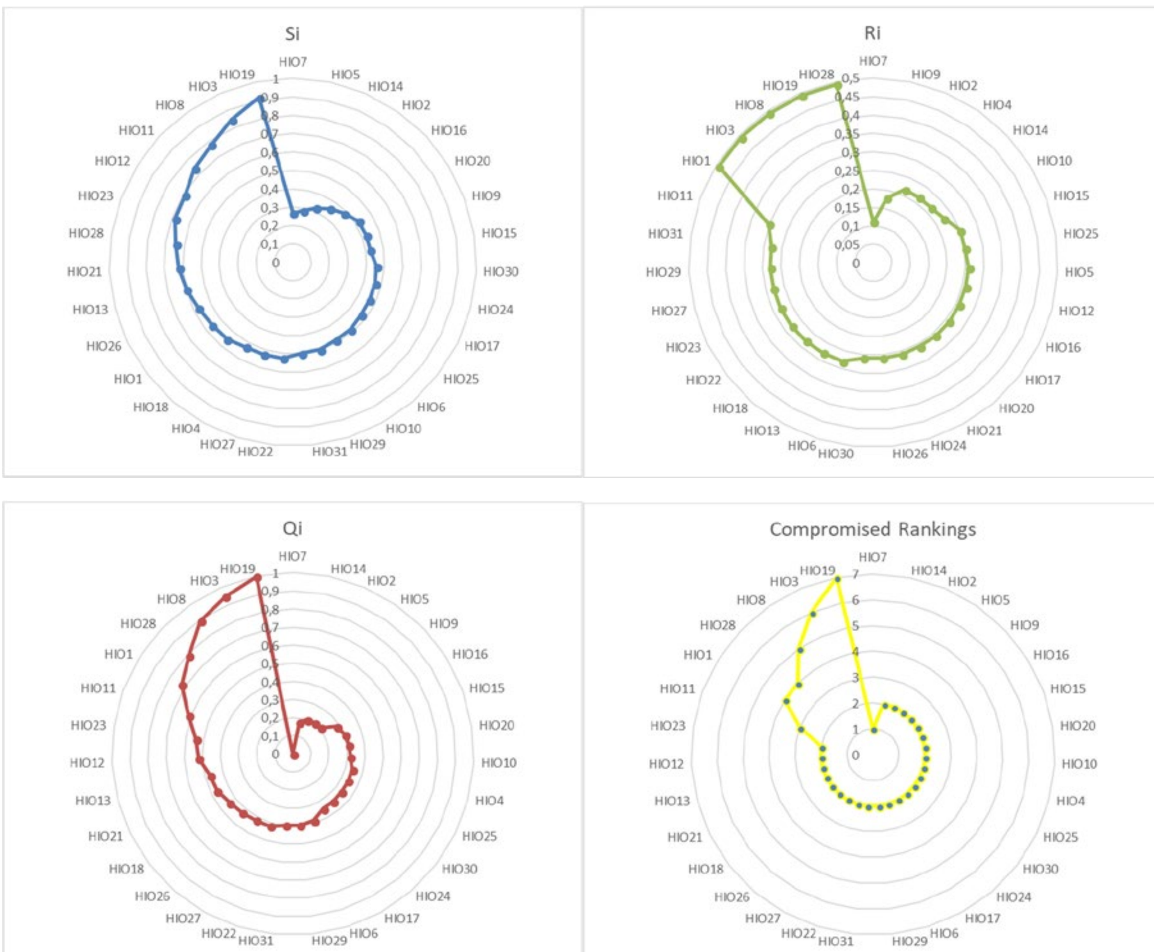

Fig. 3: Si, Ri and Qi values and compromised rankings for the hazards in the observed wind turbine in times of operation

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.

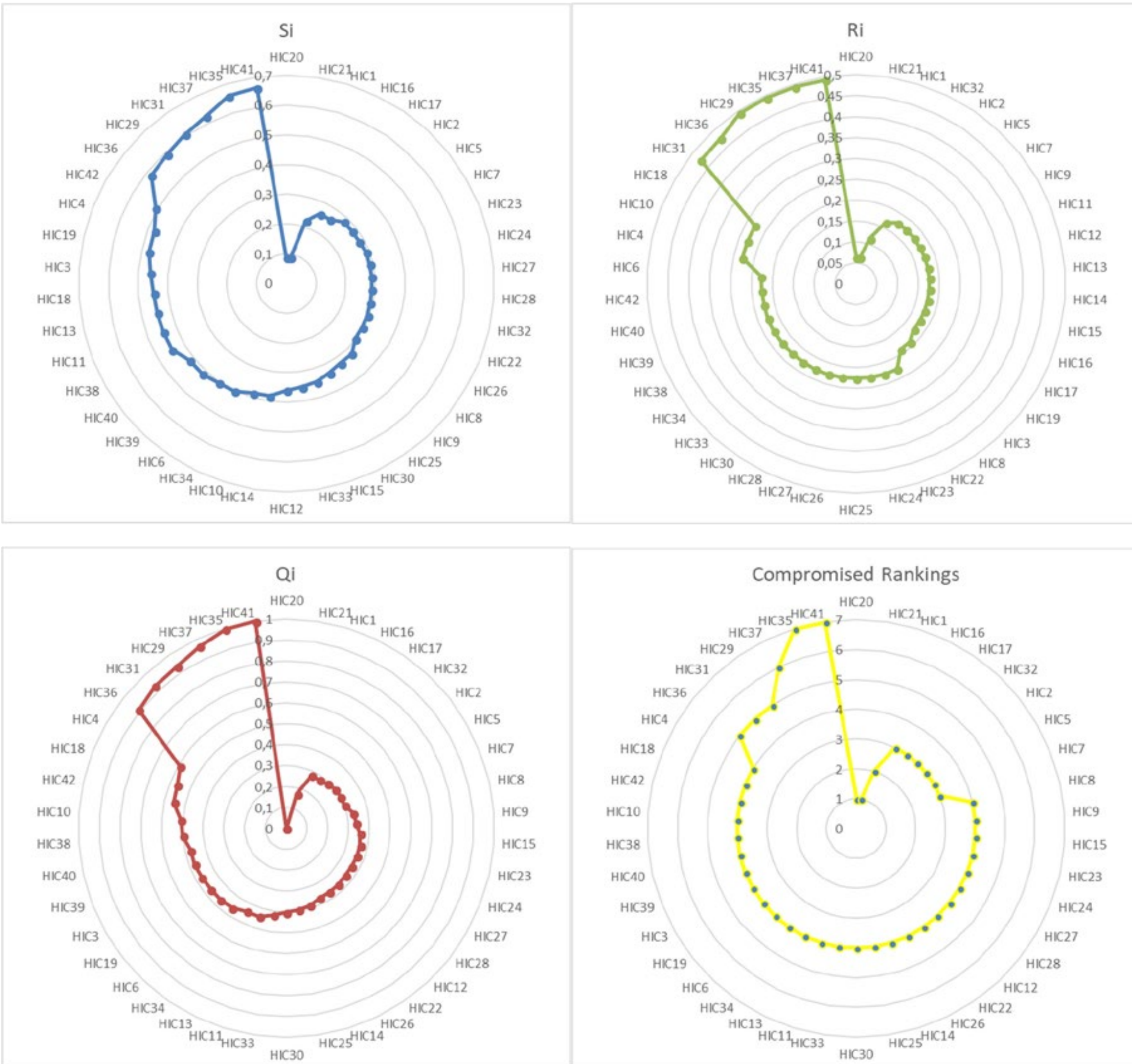

Fig. 4: S_i, R_i and Q_i values and compromised rankings for the hazards in the observed wind turbine in times of construction

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

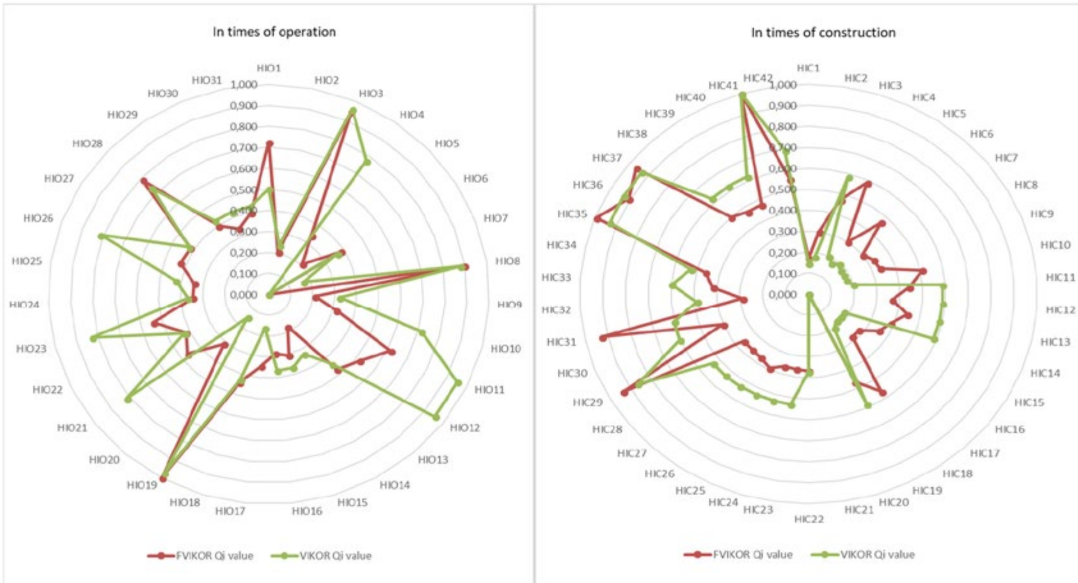

Fig. 5: Comparison of FVIKOR and VIKOR model results in terms of Q_i values

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.

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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

REFERENCES

Adem, A.; Çolak, A.; Dağdeviren, M., (2018). An integrated model using SWOT analysis and Hesitant fuzzy linguistic term set for evaluation occupational safety risks in life cycle of wind turbine. Saf. Sci., 106, 184-190 **(6 pages)**.

Aikhuele, D.O., (2018). Intuitionistic Fuzzy Model for Reliability Management in Wind Turbine System. Appl. Comput. Inform., 1-19 **(19 pages)**

Akyuz, E.; Celik, E., (2015). A fuzzy DEMATEL method to evaluate critical operational hazards during gas freeing process in crude oil tankers. J. Loss. Prevent. Proc., (38): 243-253 **(10 pages)**.

Akyuz, E.; Celik, M., (2016). A hybrid human error probability determination approach: The case of cargo loading operation in oil/chemical tanker ship. J. Loss. Prevent. Proc., (43): 424-431 **(7 pages)**.

Akyuz, E., (2017). A marine accident analysing model to evaluate potential operational causes in cargo ships. Saf. Sci., (92): 17-25 (**8 pages**).

Aminbakhsh, S.; Gunduz, M.; Sonmez, R., (2013). Safety risk assessment using analytic hierarchy process (AHP) during planning and budgeting of construction projects. J Safety. Res., (46): 99-105 **(6 pages)**.

Aneziris, O.N.; Papazoglou, I.A.; Psinias, A., (2016). Occupational risk for an onshore wind farm. Saf. Sci., (88): 188-198 **(10 pages)**.

Arabian-Hoseynabadi, H.; Oraee, H.; Tavner, P.J., (2010). Failure modes and effects analysis (FMEA) for wind turbines. Int. J. Elec. Power., 32(7): 817-824 **(7 pages)**.

Ashrafi, M.; Davoudpour, H.; Khodakarami, V., (2015). Risk assessment of wind turbines: Transition from pure mechanistic paradigm to modern complexity paradigm. Renew. Sust. Energ. Rev., (51): 347-355 **(8 pages)**.

Awasthi, A.; Kannan, G., (2016). Green supplier development program selection using NGT and VIKOR under fuzzy environment. Comput. Ind. Eng., (91): 100-108 **(8 pages)**.

Buckley, J.J.; (1985). Fuzzy hierarchical analysis, Fuzzy. Set. Syst., 17(3): 233–247 **(14 pages)**.

Çelik, Ö.; Utlu, Z., (2013). Rüzgar enerji santrallerinde iş sağlığı ve güvenliği uygulamaları. Istanbul Aydin Üniversitesi Dergisi (İAÜD)., (19):57-64 **(7 pages)**.

Chan, H.K.; Wang, X., (2013). Fuzzy extent analysis for food risk assessment. In Fuzzy Hierarchical Model for Risk Assessment. Springer., 89-114 **(25 pages)**.

Chang, D.Y., (1996). Applications of the extent analysis method on fuzzy AHP, Eur. J. Oper. Res., 95(3): 649-655 **(6 pages)**.

Chen, C.T., (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy. Set. Syst. 114(1): 1-9 **(9 pages)**.

Dinmohammadi, F.; Shafiee, M., (2013). A fuzzy-FMEA risk assessment approach for offshore wind turbines. Int. J. Prog. Health. Manag., (4): 1-10 **(10 pages)**.

Djapan, M.J.; Tadic, D.P.; Macuzic, I.D.; Dragojovic, P.D., (2015). A new fuzzy model for determining risk level on the workplaces in manufacturing small and medium enterprises. Proc. Inst. Mech. Eng. O., 229(5): 456-468 **(12 pages)**.

Ebrahimnejad, S.; Mousavi, S.M.; Seyrafianpour, H., (2010). Risk identification and assessment for build–operate–transfer projects: A fuzzy multi attribute decision making model. Expert. Syst. Appl., 37(1): 575-586 **(11 pages)**.

EU-OSHA – European Agency for Safety and Health at Work, (2013). Occupational safety and health in the wind energy sector: European Risk Observatory Report.

Fine, W.T., (1971). Mathematical evaluations for controlling hazards (No. NOLTR-71-31). NAVAL ORDNANCE LAB WHITE OAK MD.

Global Wind Energy Council, (2013). Global wind statistics | 2012.

Grassi, A.; Gamberini, R.; Mora, C.; Rimini, B., (2009). A fuzzy multi-attribute model for risk evaluation in workplaces. Saf. Sci., 47(5): 707-716 **(19 pages)**.

Gul, M.; Ak, M.F.; Guneri, A.F., (2016). Occupational health and safety risk assessment in hospitals: A case study using two-stage fuzzy multi criteria approach. Hum. Ecol. Risk. Assess., 23(2): 187-202 **(15 pages)**.

Gul, M.; Celik, E.; Aydin, N.; Gumus, A.T.; Guneri, A.F., (2016). A state of the art literature review of VIKOR and its fuzzy extensions on applications. Appl. Soft. Comput., 46: 60-89 **(29 pages)**.

Gul, M.; Guneri, A.F., (2016). A fuzzy multi criteria risk assessment based on decision matrix technique: A case study for aluminum industry. J. Loss. Prevent. Proc., (40): 89-100 **(11 pages).**

Gul, M., (2018). A review of occupational health and safety risk assessment approaches based on multi-criteria decision-making methods and their fuzzy versions. Hum. Ecol. Risk. Assess., 1-38 **(38 pages)**.

Gumus, A.T.; Yayla, A.Y.; Çelik, E.; Yildiz, A., (2013). A combined fuzzy-AHP and fuzzy-GRA methodology for hydrogen energy storage method selection in Turkey. Energies., 6(6): 3017-3032 **(15 pages)**.

Guo, H.; Watson, S.; Tavner, P.; Xiang, J., (2009). Reliability analysis for wind turbines with incomplete failure data collected from after the date of initial installation. Reliab. Eng. Syst. Saf., 94(6): 1057-1063 **(6 pages)**.

Hu, A.H.; Hsu, C.W.; Kuo, T.C.; Wu, W.C., (2009). Risk evaluation of green components to hazardous substance using FMEA and FAHP. Expert. Syst. Appl., 36(3): 7142-7147 **(5 pages)**.

John, A.; Paraskevadakis, D.; Bury, A.; Yang, Z.; Riahi, R.; Wang, J., (2014). An integrated fuzzy risk assessment for seaport operations. Saf. Sci., (68): 180-194 **(14 pages)**.

Kaassis, B.; Badri, A., (2018). Development of a Preliminary Model for Evaluating Occupational Health and Safety Risk Management Maturity in Small and Medium-Sized Enterprises. Saf., 4(1): 1-5 **(5 pages)**.

Kinney, G.F.; Wiruth, A.D., (1976). Practical risk analysis for safety management [Final Report].

Kucukali, S., (2016). Risk scorecard concept in wind energy projects: An integrated approach. Renew. Sust. Energ. Rev., (56): 975-987 **(12 pages)**.

Kutlu, A.C.; Ekmekçioğlu, M., (2012). Fuzzy failure modes and effects analysis by using fuzzy TOPSIS-based fuzzy AHP. Expert. Syst. Appl., 39(1): 61-67 **(6 pages)**.

Liu, H.T., Tsai, Y.L., (2012). A fuzzy risk assessment approach for occupational hazards in the construction industry. Saf. Sci., 50(4): 1067-1078 **(11 pages)**.

Mahdevari, S.; Shahriar, K.; Esfahanipour, A., (2014). Human health and safety risks management in underground coal mines using fuzzy TOPSIS. Sci. Total. Environ., (488): 85-99 **(14 pages)**.

Opricovic, S., (1998). Multicriteria optimization of civil engineering systems. Faculty of Civil Engineering., 2(1): 5-21 **(16 pages)**.

Rideout, K.; Copes, R.; Bos, C., (2010). Wind turbines and health. National Collaborating Centre for Environmental Health.

Samantra, C.; Datta, S.; Mahapatra, S.S., (2016). Analysis of occupational health hazards and associated risks in fuzzy environment: a case research in an Indian underground coal mine. Int. J. Inj. Contr. Saf. Promot., 24(3): 311-327 **(16 pages)**.

Shafiee, M.; Dinmohammadi, F., (2014). An FMEA-based risk assessment approach for wind turbine systems: a comparative study of onshore and offshore. Energies., 7(2): 619-642 **(23 pages)**.

Shafiee, M., (2015). A fuzzy analytic network process model to mitigate the risks associated with offshore wind farms. Expert. Syst. Appl., 42(4): 2143-2152 **(9 pages)**.

TWEA., (2015). Turkish Wind Energy Statistics Report.

Tzeng, G.H.; Huang, J.J., (2011). Multiple attribute decision making: methods and applications. CRC Press.

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