Development of resilience index for safety critical organizations using a fuzzy synthetic evaluation approach

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Abstract

Resilient safety culture (RSC) model earlier developed by authors is defined and categorized into three groups: behavioral, psychological and managerial capabilities. These groups are further sub-divided based on various subcontracts and indicators as found in the literature. Resilient safety culture comprises of the static and the dynamic component which makes it challenging to understand and control. This model thus shows how resilience in organizations can help in defending against uncertainty and safety hazards. A resilience index is needed to quantify and rank the projects in organizations and for relative comparison between sites or projects.

In this paper, resilience index (RI) or safety culture index (SCI) is developed using a fuzzy synthetic evaluation method for safety critical organizations which helps measure the status of resilient safety culture in those organizations. Fuzzy synthetic evaluation (FSE) methodology follows the fuzzy set theory. The index is useful to evaluate various project sites or organizations and compare successfully as it takes care of the fuzziness information available. It can also help in disseminating resources to the weak RI projects. This paper also compares the fault tree analysis approach to fuzzy synthetic evaluation approach and finds that FSE approach is better.

Keywords

Safety, Resilience index, Fuzzy set theory, Maturity model, Safety culture index

1. Introduction

Risk is the potential of an event and activity to produce undesirable negative consequences (Rowe, 1975) and the definition of risk according to Lawrence was risk is the severity and probability of negative adverse effects (Lawrence, 1976). This shows that risk is combination of event's probability of occurrence and its consequences (Rai, Sharma, & Lohani, 2014). In the past, risk assessment, characterization and communication was dependent of traditional probabilistic risk assessment approach, which shows lot of limitations. By enhancing the resilience of the system, this limitation can be reduced (Aven, 2018). This resilience engineering approach does not need to look fully at traditional ways where hazards and uncertainty need to be identified before probabilities are calculated.

In the current approach, the methodology of using RSC uses the indicators or items using a survey which give an overall approach or holistic view of how the system is behaving. This system then gets the resilience level at the indicator, sub construct and the construct level. That resilience level shows the weak links and nodes which need resource allocation. It does not identify risks in a very local sense such as "how will this machine fail in interaction with the human behavior or how this hazard will be dealt with?" but it looks at how the organization as a system is behaving as well as its human resource management. How is the socio technical system behaving? There is off course a connectivity between risk and resilience engineering and that is the resilience engineering helps give pointers where the weak nodes and linkages need to be focused. The survey questions are not specific in nature but holistic in approach which gives it unique sense.

RSC model was generated as seen in earlier studies (A Garg & Mohamed, 2018; Arun Garg, Tonmoy, & Mohamed, 2019). These studies then showed how this model can be quantified. This took into consideration the risk approach where probability analysis was used using fault tree analysis (FTA) and also kept the indicators same throughout and not reducing them. This approach thus gave the probability numbers of those indicators, sub construct and constructs. This is more of the unified approach as described by (Aven, 2018).

1.1 Resilient Safety Culture Model

RSC is a new concept which has been proposed to cover the weaknesses of safety culture. It is a safety culture with resilience, learning, continuous improvements and cost effectiveness (Shirali, Shekari, & Angali, 2016). RSC is based on three factors: 1) Psychological/cognitive capability 2) Behavioral capabilities and 3) Managerial/contextual capabilities to anticipate, monitor, respond and learn in order to manage risks in a resilient organization. Resilience engineering (RE) is added in the safety culture to look at safety in safety-II way.

The psychological/ cognitive capabilities of an organization enable an organization to notice shifts, interpret unfamiliar situations, analyze options and figure out how to respond. It relates to sustaining pressures in a company environment and is a personality trait. Behavioral capabilities comprise of established behaviors and routines that enable an organization to learn more about the situation, implement new routines and fully use its resources. Managerial / contextual capabilities is combination of interpersonal connections, resource stocks and supply lines that provide a foundation of quick actions (Lengnick-Hall, Beck, & Lengnick-Hall, 2011). Figure 1 shows the overall system interaction and behavior of an independent system. Resilience is a characteristic which is added and defined for the system. It takes care of any uncertainty which arise along with safety issues.

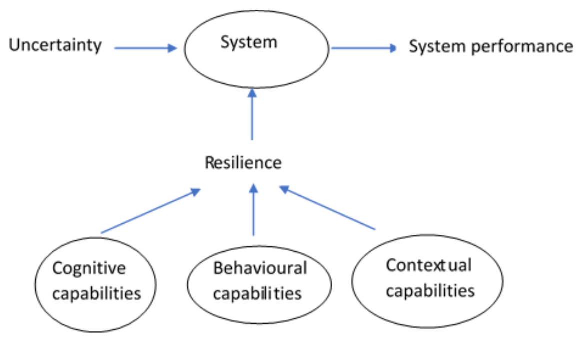

Fig. 1. A resilience incorporated system as perceived by authors

Till now these approaches were used to allocate resources. But we can't compare two different networks and different sites since for example remote site located surveyors may have different perception how they rank or express their views in a Likert scale from 1 to 5. This creates different fuzziness while giving the answers. Resilience index (RI) is calculated by using a fuzzy theory approach to take care of this fuzziness. There are two things to take care while using RI. One is the fuzziness which is there due to the ranking using the Likert scale and the other is the three capabilities (psychological, behavioral and managerial). The drawback using full version of the model without fuzziness as done in earlier studies is that indexing is not done in that scenario so the comparisons cannot be done between different sites and organizations. We use fuzzy synthetic approach to generate the RI.

There are many heuristic techniques such as probabilistic reasoning, neural networks, genetic algorithms, AHP (Analytic hierarchy process) and fuzzy logic which try to find solutions to real world complex problems (Bonissone, 1997). This study uses fuzzy synthetic evaluation (FSE) approach because the resilience or inversely hazard or risk is related to uncertainty and complexity. This FSE method is used in various applications specially in civil engineering such as structural health monitoring, engineering quality, performance evaluation etc.(Wang, Mo, He, & Yan, 2017).

Working with a complex real-world problem require this kind of methodology because there can be qualitative and quantitative indices which can be interacting with each other such is the case in this study. So, one level FSE approach is not possible. Multi-level FSE approach is more suitable to evaluate the complex problems (Wang et al., 2017).

Various authors have used fuzzy synthetic approach. Grecco et al. looked at safety culture assessment using fuzzy set theory (dos Santos Grecco, Vidal, Cosenza, dos Santos, & de Carvalho, 2014). They acknowledged that safety culture concept is hard to measure confirm and manage. The traditional methods used have been lagging indicators measuring activities that have happened already like incidents or accidents. These are all lagging indicators which cannot be used in dynamic environments. Resilience engineering provide the concepts of using the leading as well as lagging indicators together.

Wu et. Al studied the fuzzy synthetic approach to formulate a risk assessment index of electric vehicles supply chain (Wu et al., 2019). Rai et. al developed framework using the fuzzy synthetic evaluation technique to facilitate the identification of the transboundary river basins at risk (Rai et al., 2014). Fugar et al. used FSE to study and quantify job satisfaction level of construction professionals. Boateng et. al formulated a safety culture index using the FSE to quantify the level of safety culture on construction projects in developing countries. It is used in determining the status of safety culture index and it can also be used to compare the relative safety culture levels of different projects for benchmarking purposes (Boateng, Pillay, & Davis, 2020).

2. Fuzzy synthetic evaluation methodology

Fuzzy approach deals with fuzzy logic and membership function. This idea was first introduced by Dieter Klaua in 1965 and L.A Zadeh (Akter et al., 2019). There are three steps to implement the fuzzy logic technique. Fuzzification, fuzzy inference and defuzzification. The relationships between a parameter and the membership function is described by a fuzzy number (Rai et al., 2014). The value of membership function ranges between 0 to 1. The fuzzy number can assume any justified shape according to the information available. Most common functions used to represent linguistic variable are triangular and trapezoidal (Huey-Ming Lee, 1996). Fuzzification coverts the crisp data into fuzzy data or membership function, fuzzy inference combines the membership function with control rules to get the output and defuzzification lead to crisp output of the fuzzy number. Centroid and center of area method are the two most commonly used defuzzification methods (Yager, 1980).

2.1. Model Application

Multiple organizations with sites located remotely and urban areas were surveyed. The surveys were completed by different employees including engineers, supervisors, and managers. There was no limitation on who could fill the survey since the goal is to gauge the perception of all employees working in these organizations along with other attributes about the safety culture. There were 42 items in the survey. Nine items were for "psychological capability", fifteen items were for "behavioral capability" and eighteen items were for "managerial capability". Total forty two items or safety culture attribute (SCA) were inferred using the various indicators of RSC model (A Garg & Mohamed, 2018). Appendix A shows the breakdown of indicators, constructs and sub constructs. Likert scale from 1-5 was used to rate these items, where 1 on the low side or lower expectancy and 5 on the higher side or higher expectancy.

It is difficult to determine the exact probability of occurrence between events (Pan & Yun, 1997). The fuzzy numbers are thus used to deal with imprecise and vague information such as extremely likely, likely, extremely unlikely etc. In our Likert scale, the survey gives five options starting from 1 which denotes very low expectancy (VLE), 2 denotes low expectancy (LE), 3 denotes medium expectancy (ME), 4 denote high expectancy (HE) and 5 denotes very high expectancy (VHE). These linguistic expressions describe the probability of the indicator's occurrence. These linguistic values can be represented by various forms of fuzzy numbers.

3. Methodology

The FSE model follows the following approach (Xu et al., 2010).

Step 1: Establish a basic set of criteria $\pi = \{f_1, f_2, f_3 \dots \dots . . f_n\}$; where n is number of criteria

Step 2: Label the set of grade alternatives as $g = \{g_1, g_2, g_3, \dots . g_n\}$. This is the scale measurement categories such as Likert scale of 1 means VLE (very low expectancy).

Step 3: Set the weight for each factor component. The weight (W) is found or calculated from the survey using the equation : $w_i = \frac{M_i}{\sum_{i=1}^{5} M_i}, 0 < w_i < 1, \sum_{i=1}^{n} w_{i=1}$ where w_i is weight function of SCA or SCG and M_i is the mean score value of the SCA or SCG, the limit of M is 5 in this study which is the grade

Step 4: Apply fuzzy evaluation matrix for each factor where the matrix is expressed as $R_i = (r_{ij})_{mxn,}$ where r_{ij} is the degree to which gj satisfies the criteria fj.

Step 5. Reach a final FSE results by considering the weight vector and fuzzy evaluation matrix using equation: $D = w_i o\ R_i$ where $w_i$is the weight function for SCA for each SCG, o is fuzzy composite operation and R_i is fuzzy matrix

Step 6. The final FSE matrix is normalized and resilient safety culture index (SCI) for the particular factor is computed using the equation: $SCI = \sum_{i=1}^{5} D * g$

4. Result and discussion

Several preliminary tests were conducted (Osei-Kyei & Chan, 2017) including reliability for internal consistency, correlation matrix, KMO, and Bartlett's test of sphericity to check the appropriateness of the data used in this technique. First, reliability test is conducted using the Cronbach's alpha model. Cronbach's alpha developed by Lee Cronbach in 1951 to measure the reliability or internal consistency. The overall alpha value for the 42 items is 0.945, which is above the threshold of 0.70 (Chan et al. 2010). This indicates high reliability among the survey responses (Chan, Lam, Chan, Cheung, & Ke, 2010).

The correlation matrix measures the relationship among factors based on the partial correlation coefficients. Appendix B shows this matrix. The matrix calculated indicates a strong correlation because their correlation coefficients exceed 0.30 for more than one other variable (Li et al. 2005b; Norusis 2008). The KMO statistic and Bartlett's test of sphericity measure the sampling adequacy. KMO test measure how suited the data is for factor analysis. The test measures sampling adequancy for each variable and for complete model as well. The KMO statistic values vary between 0 and 1, where a value of 0.50 is considered acceptable for a satisfactory factor analysis (Norusis 2008). A KMO value of 0.895 was recorded, which exceeds the threshold (Field, 2013). A KMO value of less than 0.5 is not used, 0.5 to 0.6 is termed "poor", 0.6 to 0.7 is "mediocre", 0.7 to 0.8 is "middling", 0.8 to 0.9 is "good", and 0.9 and above is "excellent" (Chan et al., 2010). This again signifies the appropriateness of the survey data for factor analysis (Chan et al. 2010).

Further, Bartlett's test of sphericity compares the correlation matrix (pearson correlations) to identity matrix . The value of Bartlett's test is large with chi-square value of 3477.6 and its associated significance value is less than 0.05 which is 0.000, indicating that the population correlation matrix is not an identity matrix (Norusis 2008). The principal factor extraction with eigenvalues greater than 1.0, explaining 65.14% of the variance in responses as shown in Table 1. Varimax rotation was used because it simplifies interpretation. Again, this reaffirms the appropriateness of the survey data (Ahadzie et al. 2008).

Table 1. Principal factor extraction for the whole data

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	13.781	32.811	32.811	13.781	32.811	32.811
2	4.698	11.185	43.996	4.698	11.185	43.996

3	2.118	5.044	49.040	2.118	5.044	49.040
4	1.871	4.455	53.495	1.871	4.455	53.495
5	1.399	3.332	56.827	1.399	3.332	56.827
6	1.261	3.002	59.830	1.261	3.002	59.830
7	1.167	2.778	62.608	1.167	2.778	62.608
8	1.067	2.541	65.148	1.067	2.541	65.148
9	0.981	2.335	67.483			
10	0.893	2.127	69.610			
11	0.877	2.089	71.699			
12	0.817	1.945	73.644			
13	0.782	1.863	75.507			
14	0.701	1.669	77.175			
15	0.667	1.587	78.762			
16	0.601	1.430	80.192			
17	0.595	1.416	81.608			
18	0.566	1.349	82.957			
19	0.550	1.310	84.267			
20	0.530	1.262	85.530			
21	0.491	1.170	86.700			
22	0.474	1.128	87.827			
23	0.442	1.051	88.879			
24	0.417	0.993	89.871			
25	0.387	0.922	90.794			
26	0.359	0.854	91.648			
27	0.352	0.838	92.486			
28	0.310	0.739	93.225			
29	0.290	0.691	93.916			
30	0.286	0.682	94.598			
31	0.267	0.636	95.235			
32	0.266	0.633	95.867			
33	0.241	0.575	96.442			
34	0.213	0.507	96.949			
35	0.200	0.477	97.426			
36	0.189	0.451	97.877			
37	0.179	0.426	98.303			
38	0.174	0.415	98.718			
39	0.158	0.377	99.095			
40	0.155	0.368	99.463			
41	0.127	0.302	99.765			
42	0.099	0.235	100.000			

Mean score analysis was used to rank the safety culture attributes in Table 2. Further, to determine the critical attributes of resilient safety culture among the list, normalization was used. Normalized attributes greater than or equal to 0.50 are retained. This selection mechanism has been used by many previous studies to establish the most significant factors (Osei-Kyei and Chan, 2017). With this criterion, out of total 42 indicators or attributes, 15 attributes were deemed critical as presented in Table 3. In this tabulation, we don't use resilience enhancement or weights based on constructs, some studies have used the probability of occurrence with severity to get the significant values of mean and then ranked them. We don't have the severity data thus giving a severity number would create problems. Indexing gives a unbiased outlook of the indicators, later the resources can be allocated based on the psychological, behavioral and managerial approach as found in the earlier studies (A Garg & Mohamed, 2018).

Table 2. Ranking of safety culture attributes-SCA (level 1)

Safety culture attributes	Mean	Rank	Standard deviation	Normalization
P1	3.35	1	0.83	1.00
P2	3.06	11	0.90	0.57
P3	3.01	15	0.86	0.48
P4	3.01	14	0.90	0.50
P5	3.07	9	0.71	0.58
P6	2.87	27	0.85	0.28
P7	2.99	17	0.93	0.46
P8	2.76	38	1.08	0.11
P9	2.78	36	0.91	0.13
B1	3.07	9	0.78	0.58
B2	2.96	20	0.88	0.41
B3	3.06	12	0.69	0.56
B4	2.75	39	0.89	0.09
B5	2.77	37	0.92	0.12
B6	2.72	41	0.93	0.04
B7	3.32	2	0.81	0.96
B8	3.24	4	0.88	0.85
B9	3.24	4	1.03	0.85
B10	3.23	6	0.97	0.82
B11	3.20	7	0.85	0.78
B12	2.98	18	0.78	0.44
B13	2.81	33	0.88	0.19
B14	2.69	42	0.92	0.00
B15	2.88	26	0.92	0.30
M1	3.32	2	0.74	0.96
M2	3.09	8	0.93	0.60
M3	2.86	28	0.85	0.26

M4	3.01	15	0.90	0.48
M5	2.89	25	0.91	0.31
M6	2.73	40	1.12	0.07
M7	2.97	19	0.89	0.43
M8	2.86	31	0.90	0.25
M9	2.86	28	0.85	0.26
M10	2.81	34	0.86	0.18
M11	2.94	23	0.88	0.37
M12	2.86	28	0.96	0.26
M13	2.96	20	0.97	0.41
M14	2.80	35	0.96	0.17
M15	2.94	22	0.78	0.39
M16	3.06	12	0.84	0.56
M17	2.90	24	1.02	0.32
M18	2.85	32	0.90	0.24

Normalized value= (Actual value- minimum value)/ (Maximum value-minimum value)

Table 3 shows the selected indicators which has normalized score of 0.5 and above. There are four indicators from the psychological capability, five from behavioral and four from managerial constructs. This shows the resilience information selection using these critical 15 indicators.

Table 3. Attributes mean higher than 0.5 (level 2)

Indicator Naming (SCA) safety culture attribute	Constructs
Sense of purpose	P1
Strong core value	P2
Highly visible moral purpose	P4
Having Attitude	P5
Disciplined creativity	B1
Ability to follow different course of action	B3
Development of useful practical habits	B7
Develop habits of investigation	B8
Develop habits of collaboration	B9
Develop habit of flexibility	B10
Creating robust responses	B11
Respectful interactions within organization	M1
Face to face honest interaction	M2
Exchanging resources	M4
Creating organization structure	M16

4.1 Formulating FSE tool for evaluating resilient safety culture

The multi-level FSE is used to analyze this multilevel decision problem (Ameyaw & Chan, 2015). The first level is the safety culture groupings (SCA) and the second level is the SCG looking at the lower to higher levels. The proposed fuzzy model consists of two levels of membership functions (MFs). Thus membership grades level to level from the lowest indicators and then determines the project resilience index (SCI). The FSE tool is used to determine the objective weightings of each SCG considering the 15 attributes as input variables in the evaluation expression. Subsequent sections illustrate the application of the FSE in developing the SCI.

4.2 Calculating the weights for each SCA and SCG (multi-level)

The weightings for each SCA and SCG are calculated using Eq. (1) based on the mean scores from the survey:

$$w_i = \frac{M_i}{\sum_{i=1}^{5} M_i}, 0 < w_i < 1, \sum_{i=1}^{n} w_{i=1} \quad (1)$$

Where w_i is weight function of SCA or SCG and M_i is the mean score value of the SCA or SCG. For example if we have to calculate the weight of P_1, equation 1 is used.

$$W_1 = \frac{3.35}{3.35+3.06+3.01+3.07} = 0.38$$

Similarly, the same procedure is adopted to compute the weights for SCA and SCG. Same approach is used to calculate the weightings for the remaining SCAs and SCGs.

Table 4. Weights of SCA and SCG for 15 indicators selected

SCA	Mean of SCA	Weight SCA	Total mean of SCG	Weight of SCG
P1	3.35	0.38		
P2	3.06	0.22		
P4	3.01	0.19		
P5	3.07	0.22		
Psychological capability (P)			12.50	0.26
B1	3.07	0.11		
B3	3.06	0.10		
B7	3.32	0.18		
B8	3.24	0.16		
B9	3.24	0.16		
B10	3.23	0.15		
B11	3.20	0.14		
Behavioral capability (B)			22.37	0.47
M1	3.32	0.37		
M2	3.09	0.23		
M4	3.01	0.19		
M16	3.06	0.22		
Managerial capability (M)			12.47	0.26

4.3 Define the membership function (MF) for each level

The MF are calculated to determine the resilient safety culture index. The MF of the SCA are calculated to get the second level MF of the SCG. We have 5 point Likert scale rating system where 1 is low expectancy and 5 is highest. Using equation 2, we calculate the MF for each SCA. Taking example of P_1 where 1% VLE, 5% LE, 58% ME, 26% HE and 9% VHE.

$$MF_{P1} = (0.01/VLE) + (0.05/LE) + (0.58/ME) + (0.26/HE) + (0.09/VHE) \quad (2)$$

The MF can be defined as (0.01, 0.05, 0.58, 0.26, 0.09). The MF for the remaining SCA are calculated using the same approach. Table 5 shows the MF for level 1. To calculate the level 2 MF, equation 3 is used.

$$D = w_i o\ R_i \quad (3)$$

Where w_i is the weight function for SCA for each SCG, o is fuzzy composite operation and R_i is fuzzy matrix. Using the example of Psychological capability SCG, following MF for the SCG is calculated.

$$D_P = w_p \text{ o } R_p = (w_{p1}, w_{p2}, w_{p4}, w_{p5}) \text{ x } \begin{vmatrix} MFp1 \\ MFp2 \\ MFp4 \\ MFp5 \end{vmatrix} = (0.38, 0.22, 0.19, 0.22) \text{ x } \begin{vmatrix} (0.01, 0.05, 0.58, 0.26, 0.09) \\ (0.01, 0.29, 0.38, 0.26, 0.06) \\ (0.01, 0.29, 0.43, 0.20, 0.06) \\ (0.00, 0.17, 0.63, 0.16, 0.04) \end{vmatrix} = (0.01, 0.17, 0.52, 0.23, 0.07)$$

The remaining SCG are calculated in the same way.

Table 5. Membership functions (MF) for selective SCA and SCG

SCA	Weight SCA	MF for selective SCA from lowest to highest (1 to 5)					MF for SCG from lowest to highest (1 to 5)				
P1	0.38	0.01	0.05	0.58	0.26	0.09					
P2	0.22	0.01	0.29	0.38	0.26	0.06					
P4	0.19	0.01	0.29	0.43	0.20	0.06					
P5	0.22	0.00	0.17	0.63	0.16	0.04					
Psychological capability (P)							0.01	0.17	0.52	0.23	0.07
B1	0.11	0.01	0.19	0.57	0.18	0.05					
B3	0.10	0.01	0.15	0.61	0.21	0.01					
B7	0.18	0.01	0.08	0.48	0.40	0.03					
B8	0.16	0.00	0.13	0.46	0.38	0.04					
B9	0.16	0.01	0.15	0.37	0.43	0.05					
B10	0.15	0.01	0.18	0.33	0.45	0.03					
B11	0.14	0.01	0.13	0.46	0.40	0.01					
Behavioral capability (B)							0.01	0.14	0.46	0.36	0.03
M1	0.37	0.01	0.09	0.55	0.30	0.06					
M2	0.23	0.01	0.28	0.42	0.21	0.09					
M4	0.19	0.00	0.28	0.43	0.26	0.04					
M16	0.22	0.03	0.15	0.57	0.20	0.04					

Managerial capability (M)	0.01	0.18	0.50	0.25	0.06

Afterwards the MF of level 2 are substituted in equation 4 to calculate the SCI for each category. Where g is the grades from the Likert scale from 1 to 5.

$$SCI = \sum_{i}^{5} D \ x \ g \qquad (4)$$

Using Psychological capability as example, the SCI is calculated as follows.

$$SCI_{P} = (1*0.01)+(2*0.17)+(3*0.52)+(4*0.23)+(5*0.07) =0.33$$

Table 6 shows the SCI for each construct along with the ranking and coefficients. Behavioral capability is ranked first, then psychological then managerial. Coefficient is calculated as follows (equation 6).

$$\text{Coefficient} = (\text{SCI for SCG}/ \sum SCI\ for\ SCG) \qquad (5)$$

Table 6. Resilience index for each safety culture group (constructs)

Safety culture group (SCG) or construct	Safety culture index or Resilience index	Ranking	Coefficients
Psychological capability (P)	3.17	2	0.330
Behavioural capability (B)	3.27	1	0.340
Managerial capability (M)	3.16	3	0.329
Total	9.61		1

From this study, the SCI for evaluating the resilience index (RI) levels can be expressed as follows as shown in equation 6:

$$SCI = (0.33 \text{ x } P) + (0.34 \text{ x } B) + (0.329 \text{ x } M) \qquad (6)$$

These findings show that most important aspect of resilience in behavioral, then psychological and then managerial. It shows the resource allocation first should go to psychological then behavioral then managerial as per the earlier studies. In this case, behavioral is already highest so the first allocation is psychological and then managerial.

5. Conclusions

The resilience index is designed to create a baseline to enable organizations to monitor the multiple factors that contribute to their resilience. Its primary function is to diagnose strengths and weaknesses and measure the relative performance over time. The resilience index follows a nonlinear relationship where resilience starts with the resilience index from 3.3 and it goes to a 15 maximum. No resilience in the system shows a resilience index of zero value. A company without too much effort and time can jump from a very low base from 3.3 to say 8 then it may take much more effort and time to improve and say reach 12 and perhaps it will take them lifetime to move from 12 to reach 14 or higher. If there is no data from either of the three constructs, then the resilience index is zero. This is how the method functions. The resilience index developed can be deemed flexible in operation at the normalization steps when the user chooses to have a threshold, the threshold can be there or not depending upon the number of calculations the user wants to achieve. The user can choose to select the group in the data for normalization irrespective of the threshold which can be a flexibility to the calculation. Resilience index can help the companies make strategy in dealing with risk. If the company finds a low resilience index, it can see where the level is low and work to enhance the resilience by strengthening that area.

The FSE approach has the ability to do initial filtering to establish critical indicators that requires further analysis (Ameyaw & Chan, 2015). The main goal of this study is resource allocation and ranking the constructs based on the fuzziness information available and also for project comparisons. It takes care of the fuzziness better than any probabilistic techniques (Lo, 1999). Behavioral capability has the highest ranking followed by psychological and managerial. This shows that the resilience information is recorded most for behavioral capability. If we use the fault tree methodology as used in earlier studies for all the data of remote and urban sites together, the following order emerges (Arun Garg et al., 2019). First resilience ranking in psychological then behavioral and then managerial as shown in Appendix C. This shows that indexing is better approach since the fuzziness is cleared between the data available and thus the ranking between the construct changes.

The resilience index is a great tool which can help the industry in reducing incidents and enhance its safety records. More research needs to be done in this area and future studies will look into longitudinal studies where the resilience index predictions of weak areas if rectified can it bring less incidents and higher resilience levels.

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References

Akter, M., Jahan, M., Kabir, R., Karim, D. S., Haque, A., Rahman, M., & Salehin, M. (2019). Risk assessment based on fuzzy synthetic evaluation method. *Science of The Total Environment*, *658*, 818–829.

Ameyaw, E. E., & Chan, A. P. C. (2015). Evaluation and ranking of risk factors in public–private partnership water supply projects in developing countries using fuzzy synthetic evaluation approach. *Expert Systems with Applications*, *42*(12), 5102–5116.

Aven, T. (2018). The Call for a Shift from Risk to Resilience: What Does it Mean? *Risk Analysis*, risa.13247.

Boateng, E. B., Pillay, M., & Davis, P. (2020). Developing a Safety Culture Index for Construction Projects in Developing Countries: A Proposed Fuzzy Synthetic Evaluation Approach. In P. M. Arezes (Ed.), *Advances in Safety Management and Human Factors* (Vol. 969, pp. 167–179).

Bonissone, P. P. (1997). Soft computing: The convergence of emerging reasoning technologies. *Soft Computing*, *1*(1), 6–18.

Chan, A. P. C., Lam, P. T. I., Chan, D. W. M., Cheung, E., & Ke, Y. (2010). Critical Success Factors for PPPs in Infrastructure Developments: Chinese Perspective. *Journal of Construction Engineering and Management*, *136*(5), 484–494.

dos Santos Grecco, C. H., Vidal, M. C. R., Cosenza, C. A. N., dos Santos, I. J. A. L., & de Carvalho, P. V. R. (2014). Safety culture assessment: A fuzzy model for improving safety performance in a radioactive installation. *Progress in Nuclear Energy*, *70*, 71–83.

Field, A. (2036). *Discovering Statistics using IBM SPSS Statistics* (Fourth edition). SAGE Publications Limited.

Garg, A, & Mohamed, S. (2018). Resilient safety culture: A modelling perspective. *1st International Conference on Construction Project Management and Construction Engineering*, 116–127.
Garg, Arun, Tonmoy, F., & Mohamed, S. (2019). Reliability Evaluation of Resilient Safety Culture Using Fault Tree Analysis. *8th International Conference on Construction Engineering and Project Management*, 9.
Huey-Ming Lee. (1996). Applying fuzzy set theory to evaluate the rate of aggregative risk in software development. *Fuzzy Sets and Systems*, *79*(3), 323–336.
Lawrence, W. W. (1976). Of acceptable risk. *William Kaufmann, Los Altos, CA*.
Lengnick-Hall, C. A., Beck, T. E., & Lengnick-Hall, M. L. (2011). Developing a capacity for organizational resilience through strategic human resource management. *Human Resource Management Review*, *21*(3), 243–255.
Lo, S. M. (1999). A Fire Safety Assessment System for Existing Buildings. *Fire Technology*, *35*(2), 131–152.
Osei-Kyei, R., & Chan, A. P. C. (2017). Developing a Project Success Index for Public–Private Partnership Projects in Developing Countries. *Journal of Infrastructure Systems*, *23*(4), 04017028.
Pan, H., & Yun, W. (n.d.). *Fault Tree Analysis with Fuzzy Gates*. 4.
Rai, S. P., Sharma, N., & Lohani, A. K. (2014). Risk assessment for transboundary rivers using fuzzy synthetic evaluation technique. *Journal of Hydrology*, *519*, 1551–1559.
Rowe, W. D. (1975). *An "anatomy" of risk /*. Retrieved from http://hdl.handle.net/2027/uc1.d00003630142
Shirali, Gh. A., Shekari, M., & Angali, K. A. (2016). Quantitative assessment of resilience safety culture using principal components analysis and numerical taxonomy: A case study in a petrochemical plant. *Journal of Loss Prevention in the Process Industries*, *40*, 277–284.
Wang, B., Mo, C., He, C., & Yan, Q. (2017). Fuzzy Synthetic Evaluation of the Long-Term Health of Tunnel Structures. *Applied Sciences*, *7*(2), 203.
Wu, Y., Jia, W., Li, L., Song, Z., Xu, C., & Liu, F. (2019). Risk assessment of electric vehicle supply chain based on fuzzy synthetic evaluation. *Energy*, *182*, 397–411.
Xu, Y., Yeung, J. F. Y., Chan, A. P. C., Chan, D. W. M., Wang, S. Q., & Ke, Y. (2010). Developing a risk assessment model for PPP projects in China—A fuzzy synthetic evaluation approach. *Automation in Construction*, *19*(7), 929–943.
Yager, R. R. (1980). On a general class of fuzzy connectives. *Fuzzy Sets and Systems*, *4*(3), 235–242.

Appendix A

Indicator #	Constructs (SCG)	Safety culture attribute (SCA)	Constructs (SCG)	Sub constructs
1	P	Sense of purpose	P1	Conceptual Orientation
2		Strong core value	P2	
3		Prevailing vocabulary	P3	
4		Highly visible moral purpose	P4	
5		Having Attitude	P5	Constructive Sense making
6		Mindset	P6	
7		Ingenuity to develop new skills	P7	
8		Common language	P8	
9		Situation specific interpretations	P9	
10	B	Disciplined creativity	B1	Learned resourcefulness
11		Combine originality and initiative	B2	
12		Ability to follow different course of action	B3	Counterintuitive agility
13		Engaging in non-conforming repertoires	B4	
14		Have varied and complex action inventory	B5	
15		Have diverse competitive actions	B6	

16		Development of useful practical habits	B7	
17		Develop habits of investigation	B8	
18		Develop habits of collaboration	B9	
19		Develop habit of flexibility	B10	
20		Creating robust responses	B11	Practical habits
21		Ability to spot an opportunity	B12	
22		Developing new competencies	B13	
23		Unlearning obsolete information	B14	
24		Benefit from situations that emerge	B15	Behavioral preparedness
25	M	Respectful interactions within organization	M1	
26		Face to face honest interaction	M2	
27		Disclosure oriented intimacy	M3	
28		Exchanging resources	M4	
29		Sharing tacit information	M5	
30		Cross-functional collaboration	M6	Deep social capital
31		Forging relationships	M7	
32		Relationships with strategic alliances	M8	
33		Bond with various environmental agents	M9	
34		Promote organizational slack	M10	Broad resource network
35		Communicating without getting ignorant label	M11	
36		Communicating without getting incompetent label	M12	
37		Communicating without getting negative label	M13	
38		Communicating without getting time water label	M14	Psychological safety
39		Sharing decision making	M15	
40		Creating organization structure	M16	
41		Members have discretion and responsibility	M17	
42		Replying on self-organization	M18	Diffused power and accountability

P= Psychological capability, B=Behavioral capability, M=Managerial capability

Appendix B

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
1	1	.540**	.496**	.487**	.437**	.330**	.501**	.342**	.285**	.455**	.425**	.256**	0.098	0.133	0.145	0.117	.308**	0.163	0.099	0.095	.416**	.296**	0.046	.385**	.502**	.459**	.476**	.230**	.348**	.294**	.189*	.252**	.271**	.348**	0.061	.242**	.180*	.214*	.445**	.479**	.436**	.438**
2		1	.450**	.641**	.469**	.493**	.502**	.320**	.389**	.541**	.531**	.309**	.236**	.175*	.220**	0.041	.207*	0.092	0.058	0.077	.375**	.179*	0.120	.394**	.434**	.521**	.492**	.259**	.292**	.462**	0.155	.352**	.445**	.446**	.170*	.296**	.334**	.315**	.511**	.348**	.378**	.458**
3			1	.470**	.382**	.370**	.338**	.433**	.291**	.457**	.451**	.270**	0.135	0.057	.193*	0.018	0.094	0.014	-0.002	-0.101	.262**	.194*	0.012	.333**	.419**	.355**	.418**	.170*	.300**	.259**	-0.028	0.162	.319**	.367**	.213*	.267**	.350**	.353**	.327**	.382**	.392**	.387**
4				1	.487**	.485**	.581**	.361**	.411**	.516**	.583**	.326**	.320**	0.135	.229**	0.113	.205*	0.035	-0.029	0.138	.457**	.277**	.206*	.467**	.448**	.553**	.531**	.179*	.366**	.413**	0.064	.343**	.418**	.425**	.175*	.456**	.366**	.312**	.477**	.372**	.445**	.441**
5					1	.449**	.540**	.354**	.340**	.596**	.445**	.437**	.326**	.181*	.250**	0.137	.192*	0.115	0.007	0.048	.425**	.219**	.178*	.481**	.370**	.464**	.460**	.204*	.373**	.380**	0.061	.256**	.340**	.392**	.206*	.367**	.405**	.467**	.389**	.419**	.312**	.392**
6						1	.430**	.455**	.469**	.519**	.456**	.322**	.319**	.212*	.292**	0.028	0.110	0.037	0.045	0.046	.271**	.248**	.235**	.371**	.353**	.446**	.565**	.210*	.339**	.428**	.291**	.298**	.475**	.521**	.280**	.397**	.442**	.445**	.471**	.315**	.379**	.467**
7							1	.381**	.487**	.433**	.406**	.272**	.277**	.278**	.357**	0.051	0.152	0.070	-0.071	0.029	.362**	.282**	0.116	.382**	.403**	.421**	.511**	.191*	.378**	.388**	.175*	.338**	.282**	.453**	0.133	.415**	.362**	.330**	.421**	.418**	.368**	.441**
8								1	.440**	.340**	.346**	.252**	0.148	0.083	.214*	0.004	0.061	0.111	0.053	0.044	.262**	.181*	0.078	.272**	.221**	.288**	.334**	0.121	.240**	.337**	0.121	0.092	.271**	.379**	0.144	.319**	.336**	.329**	.389**	.366**	.387**	.402**
9									1	.372**	.376**	.275**	.260**	0.077	.285**	0.047	0.123	0.082	0.026	0.068	.281**	.210*	0.012	.343**	.223**	.358**	.493**	.277**	.270**	.254**	0.001	.227**	.306**	.482**	0.136	.289**	.342**	.362**	.402**	.263**	.305**	.357**
10										1	.564**	.412**	.329**	.287**	.178*	0.044	.228**	.178*	0.113	0.087	.315**	.242**	.193*	.500**	.350**	.464**	.573**	.259**	.340**	.447**	0.097	.254**	.496**	.488**	.304**	.452**	.408**	.542**	.546**	.415**	.422**	.420**
11											1	.302**	.289**	0.104	.258**	0.009	.171*	0.060	0.071	0.089	.422**	.278**	.206*	.477**	.430**	.588**	.636**	.247**	.392**	.479**	0.145	.367**	.521**	.581**	.230**	.387**	.471**	.415**	.513**	.511**	.423**	.529**
12												1	.436**	.341**	.352**	.214*	.191*	.195*	.176*	0.153	.382**	0.054	0.108	.331**	.233**	.253**	.309**	0.093	0.149	.170*	-0.009	-0.033	.186*	0.154	0.162	.199*	.362**	.290**	.290**	.332**	0.081	.201*
13													1	.441**	.575**	.292**	.290**	.289**	.168*	.181*	.327**	.409**	.370**	.336**	0.154	.280**	.240**	.255**	.342**	.186*	.254**	.271**	.192*	.276**	.376**	.324**	.380**	.403**	.292**	.183*	0.084	.286**
14														1	.549**	.206*	.480**	.436**	.362**	.291**	0.166	.403**	.436**	.243**	0.044	0.074	0.107	.336**	.231**	0.039	.478**	.372**	0.107	0.099	.403**	0.129	0.143	0.086	.316**	.186*	0.076	0.124
15															1	.359**	.488**	.458**	.346**	.327**	.262**	.535**	.428**	.377**	.192*	.196*	.197*	.514**	.401**	.219**	.373**	.454**	0.152	.212*	.447**	0.152	.275**	.219**	.337**	.353**	0.138	.320**
16																1	.378**	.412**	.343**	.433**	0.161	.216*	0.142	.186*	0.098	0.002	0.032	.277**	.265**	0.022	0.043	0.163	0.042	-0.120	0.131	0.028	0.027	-0.029	0.029	0.112	-0.005	-0.063
17																	1	.548**	.477**	.579**	0.114	.525**	.324**	.259**	0.069	0.160	0.122	.510**	.359**	0.118	.340**	.392**	0.016	0.063	.329**	-0.003	-0.013	-0.027	.242**	.205*	0.108	0.065
18																		1	.571**	.506**	0.070	.379**	.218*	0.153	0.097	0.023	0.047	.462**	.285**	0.026	.213*	.290**	0.014	-0.028	.226**	-0.039	-0.011	-0.038	.181*	.177*	0.086	0.025
19																			1	.542**	-0.022	.204*	0.154	0.071	.181*	0.083	0.100	.442**	.219**	-0.050	.226**	.264**	0.021	0.002	.308**	0.019	0.057	-0.059	0.105	.207*	0.068	-0.026
20																				1	-0.004	.282**	.218*	0.076	0.047	0.051	0.058	.339**	0.131	0.011	.217*	.275**	0.048	-0.134	.288**	0.007	-0.060	-0.144	0.094	0.054	0.032	-0.083
21																					1	.280**	.213*	.455**	.402**	.405**	.401**	.167*	.285**	.252**	0.156	0.110	.302**	.364**	0.030	.289**	.346**	.343**	.310**	.324**	.209*	.359**
22																						1	.534**	.394**	0.158	.286**	.255**	.451**	.519**	.265**	.353**	.561**	.216*	.258**	.415**	.279**	.253**	.237**	.344**	.230**	.238**	.293**
23																							1	.308**	0.028	.209*	.167*	.274**	.315**	.235**	.297**	.427**	.213*	.243**	.404**	.222**	.220**	.198*	.247**	0.088	0.075	0.153
24																								1	.341**	.514**	.471**	.292**	.386**	.400**	0.120	.279**	.387**	.367**	.207*	.452**	.442**	.408**	.417**	.431**	.430**	.488**
25																									1	.643**	.538**	.301**	.406**	.337**	0.145	.254**	.366**	.381**	.187*	.388**	.351**	.322**	.383**	.505**	.388**	.365**
26																										1	.555**	.286**	.545**	.531**	.213*	.380**	.546**	.557**	.336**	.584**	.439**	.376**	.539**	.541**	.439**	.553**
27																											1	.181*	.412**	.523**	0.147	.334**	.462**	.597**	.249**	.394**	.492**	.416**	.523**	.435**	.302**	.483**
28																												1	.491**	0.096	.353**	.497**	.191*	.256**	.424**	0.153	0.150	0.161	.323**	.345**	.255**	.271**
29																													1	.385**	.354**	.551**	.271**	.410**	.474**	.375**	.308**	.290**	.433**	.436**	.342**	.433**
30																														1	0.137	.308**	.424**	.413**	.277**	.432**	.390**	.332**	.498**	.393**	.186*	.492**
31																															1	.474**	0.147	.220**	.395**	0.165	0.107	0.044	.300**	.215*	0.109	.301**
32																																1	.324**	.387**	.466**	.306**	.184*	.217*	.434**	.299**	.286**	.341**
33																																	1	.537**	.230**	.563**	.457**	.468**	.479**	.375**	.377**	.435**
34																																		1	.204*	.488**	.521**	.547**	.558**	.437**	.417**	.505**
35																																			1	.421**	.473**	.412**	.355**	.300**	0.139	.299**
36																																				1	.665**	.559**	.476**	.469**	.388**	.497**
37																																					1	.649**	.410**	.412**	.246**	.466**
38																																						1	.477**	.417**	.319**	.449**
39																																							1	.592**	.552**	.608**
40																																								1	.473**	.586**
41																																									1	.435**
42																																										1

Appendix C

Construct Group #	RSC constructs	Total data
1	Psychological capability	0.600
2	Behavioral capability	0.596
3	Managerial capability	0.584
	Total resilience level probability (RL)	**0.209**