A Fuzzy Model to Assess Resilience for Safety Management

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Abstract. The Most of methods to assess resilience cannot fully solve the subjectivity of resilience evaluation. In order to remedy this deficiency, the aim of this research is to adopt a Fuzzy Set Theory (FST) approach to establish a method for resilience assessment in organizations based on leading safety performance indicators, defined according to the resilience engineering principles. The method uses FST concepts and properties to model the indicators and to assess the results of their application. To exemplify the method we performed an exploratory study at the radiopharmaceuticals dispatch package sector of a radiopharmaceuticals production facility.

1 INTRODUCTION

Contemporary view on safety based on resilience engineering (RE) principles emphasizes that safety critical organizations should be able to proactively evaluate and manage safety of their activities. This new safety paradigm must be endorsed by the organizational safety management to be successful. Therefore we need new methods to measure safety according to RE principles, considering that safety is a phenomenon that is hard to describe measure, confirm, and manage.

Scientists in the field of safety critical organizations state that safety emerges when an organization is willing and capable of working according to the demands of their tasks, and when people understand the changing vulnerabilities of their work activities (Reiman & Odewald, 2007). Thus, safety management relies on a systematic anticipation, monitoring the evolution of trade-offs, in which various safety indicators play a key role in providing information on current organizational safety performance. An increasing emphasis has been placed also on the role of indicators in providing information to be used in anticipation and evolution of organizational performance. These indicators are called leading indicators.

The safety performance indicators that have commonly been used in traditional safety management have often been lagging indicators, measuring outcomes of activities or things and events that have already happened (e.g., injury rates, radiation doses and incidents). These indicators are reasonably objective, easy to quantify, and that they can be used requiring small changes in the existing system. However, it can be questioned whether they really indicate the actual safety of organization processes, because there is no sharp causal link between past events and the current safety performance. Lagging indicators may be more useful to confirm effects after a while, in long term, than to manage immediate changes in dynamic environments. Monitoring should not rely solely on lagging indicators but also on indicators of current activities and the potential of the organization to succeed in the future. To quickly monitor trade-offs, the effects of good work practices, as well as, to anticipate vulnerabilities, the organizations should define leading indicators. Those should be able to grasp organizational practices and processes that lead changes in safety performance of the people in the organization.

Several reasons for using leading indicators are: (a) they provide information on where to focus improvement efforts; (b) they direct attention to proactive measures of safety management rather than reactive follow up of negative occurrences or trending of events; (c) they provide early warning signs on potential weak areas or vulnerabilities in the organizational risk control system or technology; (d) they focus on precursors to undesired events rather than the undesired events themselves; (e) they provide information on the effectiveness of the safety efforts underway; and (f) they tell about the organizational health, not only sickness or absence of it.

The aim of this research is to adopt a Fuzzy Set Theory (FST) approach to establish a method for safety assessment in organizations based on resilience engineering using leading performance indicators, as the basis for a safety management system. To exemplify the method we performed an exploratory case study at the process of radiopharmaceuticals dispatch package in a radiopharmaceuticals production facility.

2 METHOD FOR RESILIENCE ASSESSMENT

The method has the following phases:

(1) Selection of the leading indicators;
(2) Determination of a resilience ideal pattern;
(3) Assessment of the actual resilience level compared with the pattern.

2.1 Selection of leading indicators

Selection of leading indicators should always start from the consideration of what are the key issues to monitor, manage and change (EPRI, 2000). The leading indicators are utilized as part of the resilience management process, not as an independent goal or function as such. The operationalization of an indicator is called “metric”. A metric denotes how the indicator is measured, whereas an indicator denotes something that one wishes to measure with the use of one or more metrics. The selection of the resilience themes addressed and leading indicators used in radiopharmaceuticals dispatch package sector was based on previous ergonomic study (Grecco et al., 2010) and are described in table 1.

Table 1. Themes and Leading indicators.

Themes	Indicators	Themes	Indicators
Top-level commitment	1.1 Human resources 1.2 Material resources 1.3 Safety commitment 1.4 Safety policy 1.5 Procedure management 1.6 Training programs 1.7 Competence selection	**Awareness**	4.1 Reports of problems 4.2 Information security 4.3 Communication 4.4 Team work 4.5 Workload 4.6 People relations 4.7 Tasks and skills 4.8 Awareness of limitations 4.9 Preventive maintenance 4.10 Proactive actions
Learning culture	2.1 Information dissemination 2.2 Information flow 2.3 Work management 2.4 Actual working practices 2.5 Local adaptations 2.6 Content of the documentation 2.7 Availability of the documentation 2.8 Analysis of incidents 2.9 Investigations of incidents and accidents	**Just culture**	5.1 Reporting of deviations/worries 5.2 Understanding of errors 5.3 Perception of errors 5.4 Actions are not punitive 5.5 Peer assessments 5.6 Professional recognition

Flexibility	3.1 Ability to cope with unexpected 3.2 Capacity for flexibility 3.3 Safe working limits 3.4 Reports on adaptations 3.5 Incorporation of adaptations	**Preparedness**	6.1 Emergency plan 6.2 Identification of risks 6.3 Safety equipments 6.4 Alarm system 6.5 Proactive procedures 6.6 Emergency training

2.2 Resilience ideal pattern

The second phase of the method is to obtain from experts in radiopharmaceuticals production and resilience engineering issues the degree of importance of each indicator metric, so that the organization sector can be considered resilient. This means that the degree of importance assigned to each indicator by the specialist, should show how the sector should be to achieve an ideal resilience level. Thus, it is not evaluating the sector, but the ideal of resilience that it should have. The phase has the following steps: 1) Experts selection, 2) Calculation of each expert relative importance, based on knowledge and experience, 3) Choice of linguistic terms and membership functions, 4) Determination of the importance degree of each indicator, 4) Aggregation of fuzzy opinions, 5) Resilience pattern.

Calculation of experts' relative importance. The relative importance of the expert was calculated on the basis of experts' attributes (experience, knowledge of radiopharmaceuticals production safety and knowledge of the dispatch package radiopharmaceuticals). We used a questionnaire (Q) to identify the profile. Each questionnaire contains information of a single expert. The relative importance (RI) of expert Ei (i = 1, 2, 3, …, n) is a subset μi (k) ∈ [0,1] defined by equation 1. Referring to equation 1, *tQi*, is the total score of the expert *i*.

$$RI_i = \frac{tQ_i}{\sum_{i=1}^{n} tQ_i} \qquad (1)$$

Choice of linguistic terms and membership functions. Each leading indicator can be seen as a linguistic variable, related to a linguistic terms set associated with membership functions. These linguistic terms are represented by triangular fuzzy numbers to represent the importance degree of each indicator. It is suggested that the experts employ the linguistic terms, U (Unimportant), LI (Little Important), I (Important) and VI (Very Important) to evaluate the importance of each indicator.

Aggregation of the fuzzy opinions. The similarity aggregation method proposed by Hsu and Chen [21] is used to combine the experts' opinions which are represented by triangular fuzzy numbers. The agreement degree (AD) between expert Ei and expert Ej is determined by the proportion of intersection area to total area of the membership functions. The agreement degree (AD) is defined by equation 2.

$$AD = \frac{\int_x \left(\min\left\{\mu_{\tilde{N}i}(x), \mu_{\tilde{N}j}(x)\right\}\right)dx}{\int_x \left(\max\left\{\mu_{\tilde{N}i}(x), \mu_{\tilde{N}j}(x)\right\}\right)dx} \qquad (2)$$

If two experts have the same estimates, that is, AD =1. In this case, the two experts' estimates are consistent, and then the agreement degree between them is one. If two experts have completely different estimates, the agreement degree is zero. If the initial estimates of some experts have no intersection, then we use Delphi method to adjust the opinion of the experts and to get the common intersection at a fixed α – level cut (Hsu & Chen, 1996). The higher the percentage of overlap, the higher the agreement degree. After all the agreement degrees between the experts are calculated, we can construct an agreement matrix (AM), which give us insight into the agreement between the experts.

$$AM = \begin{bmatrix} 1 & AD_{12} & \cdots & AD_{1j} & \cdots & AD_{1n} \\ \vdots & \vdots & & \vdots & \vdots & \\ AD_{i1} & AD_{i2} & \cdots & AD_{ij} & \cdots & AD_{in} \\ \vdots & \vdots & & \vdots & \vdots & \\ AD_{n1} & AD_{n2} & \cdots & AD_{nj} & \cdots & 1 \end{bmatrix}$$

The relative agreement (RA) of expert Ei (i = 1, 2, 3, …, n) is given by equation 3.

$$RA_i = \sqrt{\frac{1}{n-1} \cdot \sum_{j=1}^{n} (AD_{ij})^2} \qquad (3)$$

Then we calculate the relative agreement degree (RAD) of expert Ei (i = 1, 2, 3, …, n) by equation 4 and the consensus coefficient (CC) of expert Ei (i = 1, 2, 3, …, n) by equation 5.

$$RAD_i = \frac{RA_i}{\sum_{i=1}^{n} RA_i} \qquad (4) \qquad\qquad CC_i = \frac{RAD_i \cdot RI_i}{\sum_{i=1}^{n} \left(RAD_i \cdot RI_i\right)} \qquad (5)$$

Let Ñ be a fuzzy number of combining expert's opinions. So, Ñ is the fuzzy value of each leading indicator which is also triangular fuzzy number. By definition of the consensus coefficient (CC) of expert Ei (i = 1, 2, 3, …, n), Ñ can be defined by equation 6. Referring to equation 6, ñi, is the triangular fuzzy number relating to the linguistic terms, U (Unimportant), LI (Little Important), I (Important) and VI (Very Important).

$$\tilde{N} = \sum_{i=1}^{n} \left(CC_i \cdot \tilde{n}_i \right) \qquad (6)$$

Resilience pattern. The resilience pattern as a reference for assessing organizational resilience of the is established by calculating the normalized importance degree (NID) of each leading indicator that make up each property relevant to resilient organizations. The normalized importance degree (NID) of each leading indicator is given by deffuzification of its triangular fuzzy number Ñ (ai, bi, ci), where bi represents the importance degree. Then, NID can be defined by equation 7.

$$NID_i = \frac{NID_i}{high \quad value \quad of \quad b_i} \qquad (7)$$

2.3. Resilience assessment

This third phase of the method is to assess resilience level compared to the resilience pattern. In this phase, the linguistic values are used to assess the attendance degrees of the leading indicators to the radiopharmaceuticals dispatch package sector given by workers. It is suggested that the workers employ the linguistic terms, SD (Strongly Disagree), PD (Partially Disagree), NAND (Neither Agree Nor Disagree), PA (Partially Agree), SA (Strongly Agree). Table 4 shows the attendance degrees and triangular fuzzy numbers for linguistic terms. Using center of area defuzzification method we calculate the attendance degree (AD) to the resilience pattern by equation 8. Referring to equation 8, adj, is the attendance degree of the leading indicator j of the theme i in the dispatch package radiopharmaceuticals sector.

$$ADi = \frac{\sum_{j=1}^{k} NID_j .ad_j}{\sum_{j=1}^{k} NID_j} \qquad (8)$$

3. RESULTS

The resilience assessment of the radiopharmaceuticals dispatch package sector was performed by seven workers and results are presented in figure 1. The average evaluation of the resilience based on each indicator was computed and showed in figure 2. We consider satisfactory an attendance degree greater than or equal to 0.6. The result of the average evaluation showed that the radiopharmaceuticals dispatch package sector presented satisfactory learning culture, flexibility awareness, just culture and preparedness. However, this sector presented problems related to the top-level commitment.

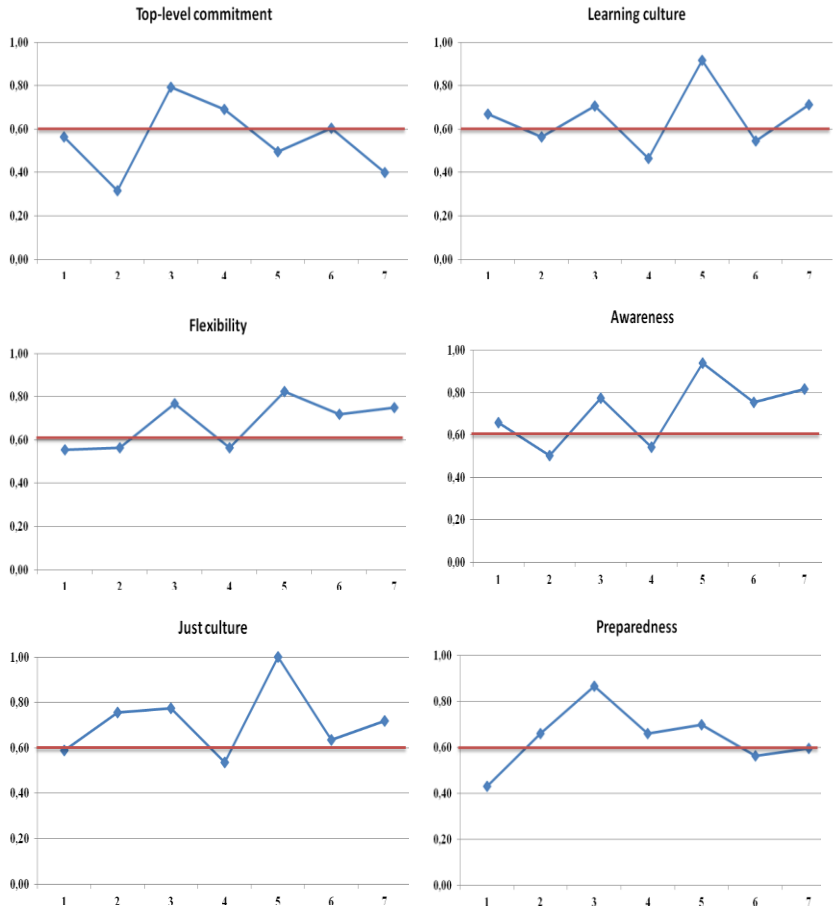

Fig. 1. Result of the evaluation of the resilience by the seven workers.

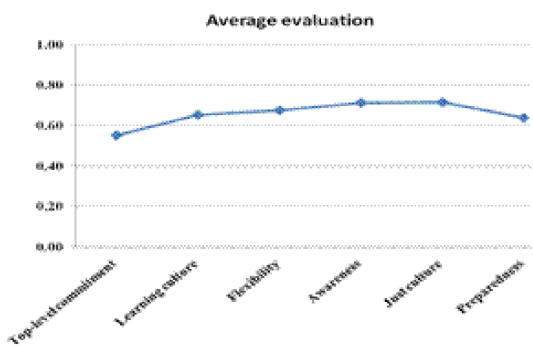

Fig. 2. Average evaluation of the resilience performed by the seven workers.

4. CONCLUSIONS

In this paper we described a method for organizational resilience assessment was used. We proposed a method that uses leading indicators and concepts and properties of Fuzzy Sets Theory. We develop a resilience pattern using a similarity aggregation method to aggregate fuzzy individual opinions, considering the difference of importance of each expert. A pilot study in the radiopharmaceuticals production facility shows that this method based on leading indicators and fuzzy logic offers interesting perspectives for the implementation of resilience engineering principles. This assessment method can be a proactive tool to provide a basis for action without waiting for events. Through the use of the method we identify problems related to leading indicator metrics of the top-level commitment theme. These problems can be investigated in order to implement actions to make the process of radiopharmaceuticals dispatch package more efficient and secure besides to improve the resilience in this sector.

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