BJRS

BRAZILIAN JOURNAL
OF
RADIATION SCIENCES
10-03A (2022) 01-11

Decision Support Method in the Assessment of Nuclear Knowledge Management using Fuzzy Logic

Grecco[a] C.H.S., Souza[a,b] J.T.V., Carvalho[a] P. V. R., Cosenza[b] C. A. N.

[a] *Instituto de Engenharia Nuclear(IEN/CNEN)/ Departamento de Engenharia Nuclear/ Laboratório de Engenharia do Conhecimento(LABEC), 21941-906, Rio de Janeiro – RJ, Brasil, grecco@ien.gov.br*

[b] *Universidade Federal do Rio de Janeiro (UFRJ)/COPPE/ Programa de Engenharia de Produção/ Laboratório de Lógica Fuzzy (LABFUZZY), 21941-598, Rio de Janeiro – RJ, Brasil*

ABSTRACT

The knowledge of workers constitute as valuable resources, as they enable organizations to perform their functions successfully. However, there are conditions that favor the loss of this knowledge in organizations, as for example, the natural aging of workers and consequently the retirement and staff turnover. Then, it becomes important for organization to seek the preservation of this knowledge. For a successful implementation of Knowledge Management (KM), it is important to identify the barriers or critical factors that affect the success of the KM process.

From the perspective of the nuclear organizations, no systematic framework exists on characterizing a set of critical success factors (CSFs) for implementing KM. Furthermore, the CSFs assessment deals with uncertainty and imprecision of human judgments. In this context, this paper presents a decision support method using CSFs and fuzzy logic to access the KM in nuclear organizations. Fuzzy theory is essentially used in mapping quantitative models for decision support and representation methods in imprecise and uncertain environments. The decision support method was applied at the Laboratory of Human-Systems Interfaces of the Nuclear Engineering Institute. The results showed that the method is a good assessment tool for the elaboration of nuclear knowledge management strategies.

Keywords: **knowledge management, decision support method, fuzzy logic.**

ISSN: 2319-0612
DOI: https://doi.org/10.15392/2319-0612.2022.1785
Submitted: 2022-12-16
Accepted: 2022-11-26

1. INTRODUCTION

The knowledge of workers constitutes as a valuable resource, as they enable organizations to perform their functions successfully. Nuclear projects usually last for many years or decades, and can be divided into numerous phases involving different stakeholders. Nuclear equipment, installations and facilities may have long life cycles with changing operational conditions. The safe use of licensed nuclear facilities and technologies is dependent on the ongoing availability and maintenance of suitable knowledge and expertise, and an adequate understanding of related safety issues.

There is an evident risk that in the absence of knowledge transfer plans, essential knowledge can be lost between different phases of a nuclear facility lifetime, for a variety of reasons [1]. The most evident risk is that for every phase of a nuclear project, a different workforce is employed. Some competences needed during the design phase may not be required during operation, but at the operation stage, new competences will be needed. When moving from one phase of a nuclear facility lifetime to another, independently of other risk factors, knowledge gaps due to personnel attrition, diminishing job tenures, decreasing availability of skills on the market for the nuclear sector and reducing knowledge transfer between generations, can be created [1]. Organizational and workforce changes are not the only risks related to knowledge preservation in a nuclear organization. Some projects related to IT and data management might implement different information systems, with different media storage formats that require constant upgrades and are, in some cases, incompatible with each other, causing losses or not allowing information to be recovered from one system to another [2].

Furthermore, there are other conditions that favor the loss of this knowledge in organizations, as for example, the natural aging of workers and consequently the retirement and staff turnover. Then, it becomes important for organization to seek this knowledge preservation. For a successful implementation of Knowledge Management (KM), it is important to identify the barriers or critical factors that affect the success of the KM process.

From the perspective of the nuclear organizations, no systematic structure exists on characterizing a set of critical success factors (CSFs) for implementing KM. Additionally, the CSFs assessment deals with imprecision of human judgments. In this context, this paper presents a decision support method to assess the nuclear knowledge management based on: 1) the use of critical success factors in order to be able to monitor the success of a knowledge management initiative; 2) the approach of knowledge management in the development of critical success factors, which are on seven themes: top-level commitment, organizational culture, organizational structure, human resources management practices, measuring and results, information technology and learning culture; 3) the use of properties of decision support methods and fuzzy set theory to model of critical success factors. Fuzzy theory is essentially used in mapping quantitative models for decision support and representation methods in imprecise and uncertain environments.

1.1. Critical Success Factors

The set of critical success factors can act as a list of items for organizations to address when adopting knowledge management. This helps to ensure that the essential issues and factors are covered during design and implementation phase. For academics, it provides a common language for them to discuss and study the factors crucial for the success of knowledge management program in an organization.

However, no systematic work exists on characterizing a collective set of CSFs for implementing KM in nuclear organizations. CSFs are critical areas of managerial planning and action that must be practiced in order to achieve effectiveness. In terms of KM, CSFs can be viewed as those activities and practices that should be addressed in order to ensure its successful implementation. These practices would either need to be nurtured if they already existed or be developed if they were still not in place [1].

1.2. Fuzzy Logic Basics

Fuzzy logic provides an appropriate mathematic-logical framework to handle complex problems [3], since: (1) it deals with uncertainty and imprecision of reasoning processes and situations; (2) it allows the modeling of the heuristic knowledge that cannot be described by traditional mathematical equations and; (3) it allows the computation of linguistic information. Several studies show important reasons to use fuzzy set theory (FST) [3][4][5]: reduction of human error, creation of expert knowledge and interpretation of large amount of vague data.

FST is an extension of classical set theory where elements have degrees of membership. Let X be the universe of discourse and x a generic element of X, a fuzzy subset $\tilde{A}$, defined in X, is one set of the dual pairs, as in (1):

$$\tilde{A}=\{(x,\mu_{\tilde{A}}(x)) \mid x\in X\} \quad (1)$$

Where $\mu_{\tilde{A}}(x)$ is the membership function or membership grade x in A. The membership function associates to each element x of X, a real number $\mu_{\tilde{A}}(x)$, in the interval [0, 1].

A fuzzy number is a special subset of real numbers (R). Its membership function is a continuous mapping of R closed interval [0, 1]. Triangular fuzzy numbers have continuous linear relevance function. The graphical representation of the triangular fuzzy number is shown in Figure 1.

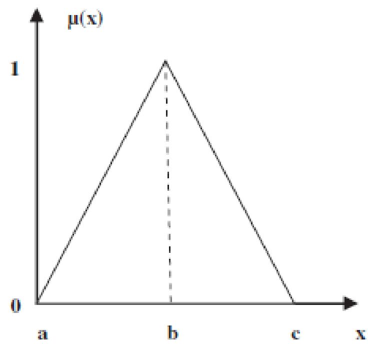


Figure 1: Membership function of a triangular fuzzy number A = (a, b, c)
Source: The authors

2. MATERIALS AND METHODS

The decision support method developed in this paper was structured according to the following steps:

1) Selection of CSFs;
2) Determination of an ideal pattern for nuclear knowledge management (NKM);
3) Assessment of the NKM.

The list of CSFs was developed in seven themes, based on the literature [1][2][6][7][8][9]: top-level commitment, organizational culture, organizational structures, human resources management practices and policies, measuring and results, information technology and learning culture. The Table 1 list the themes and exemplify some CSFs and the metrics used to assessment.

Table 1: Themes, CSFs and metrics

Themes	CSFs	Metric used
1 Top-level commitment	1.1 Mission and values 1.2 … 1.3 …	1.1.…clear definition of the mission and values of the facilitie. …
2 Organizational culture	2.1 Organizational climate 2.2 … 2.3 …	2.1 …positive environment, encouraging the knowledge sharing. …
3 Organizational Structures	3.1 Multidisciplinary groups 3.2 … 3.3 …	3.1 ...groups are multidisciplinary and they have autonomy in decisions. …
4 Human resources management practices	4.1 Training 4.2 … 4.3 …	4.1 …training is often offered and encouraged by managers. …
5 Measurement of results	5.1 Investment monitoring 5.2 … 5.3 …	5.1...adequate monitoring of results of investments in training. …
6 Information Technology	6.1Technological structure 6.2 … 6.3 …	6.1 …technological structure for the storage of knowledge... …
7 Learning culture	7.1 Context changes 7.2 … 7.3 …	7.1 …adequate learning to accept new practices… …

The second step of the method is to obtain from experts on KM the degree of importance of each CSF, so that the implementation of KM in organization can be considered good. This means that the degree of importance assigned to each CSF by the expert should show how the organization can achieve the maximum (ideal) KM level. Thus, this does not imply assessment of the organization but the ideal KM that should be obtained.

The relative importance of the expert were calculated on the basis of subjective attributes (experience, knowledge of KM). The team of experts comprised seventeen researchers with experience and knowledge of KM.

We used a questionnaire (Q) to identify the profile. Each questionnaire contains information of a single expert. The relative importance of expert (RIEx) Ex_i (i = 1, 2, 3,.., *n*), which is its relative importance degree compared to other experts, is a subset μ_i (k) Є [0,1] defined by Equation 2. According to the Equation 2, tsQ_i, is the total score of expert *i*.

$$RIEx_i = \frac{tsQ_i}{\sum_{i=1}^{n} tsQ_i} \quad (2)$$

Each CSF can be seen as a linguistic variable, related to a linguistic terms set associated with membership functions proposed by Lee [10]. These linguistic terms will be represented by triangular fuzzy numbers to represent the importance degree of each CSF (Figure 2). The linguistic terms will be: U (Unimportant), LI (Little Important), I (Important) and VI (Very Important) to evaluate the importance of each CSF. The importance degrees are assessed by requesting each expert to evaluate the CSFs based on their respective metrics.

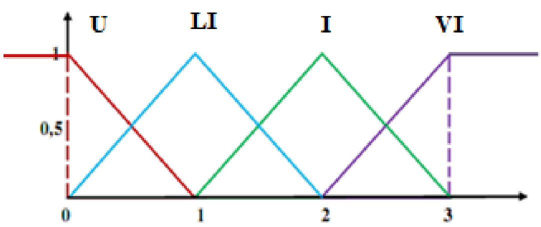


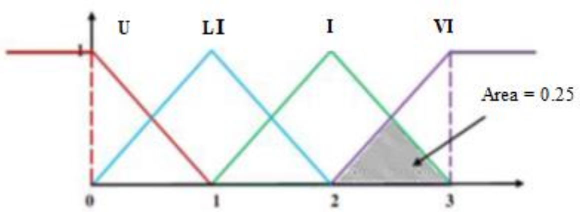
Figure 2: Membership functions for second step
Source: The authors

To combine the experts' opinions represented by triangular fuzzy numbers we used the similarity aggregation method proposed by Hsu e Chen [11].

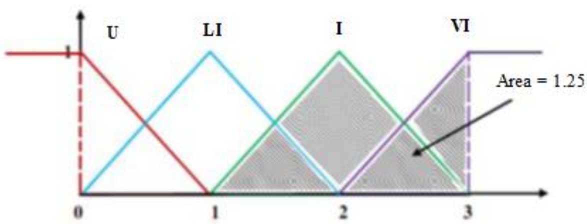
The agreement degree (A) between expert Ex_i and expert Ex_j will be determined by the proportion of intersection area to total area of the membership functions. The agreement degree (A) is defined by Equation 3.

$$A = \frac{\int_x \left(\min\left\{\mu_{\tilde{N}i}(x), \mu_{\tilde{N}j}(x)\right\}\right)dx}{\int_x \left(\max\left\{\mu_{\tilde{N}i}(x), \mu_{\tilde{N}j}(x)\right\}\right)dx} \tag{3}$$

If two experts have the same estimates, the agreement degree between them will be one. If two experts have completely different estimates, the agreement degree will be zero. The higher the percentage of overlap, the higher the agreement degree. Figure 3 shows the representation of the intersection area and the union area of two experts' opinions (I and VI).



(a)



(b)

Figure 3: Representation of two experts' opinions (I and VI): (a) intersection area; (b) union area.
Source: The authors

The relative agreement of expert (RAEx) Ex_i (i = 1, 2, 3, …, *n*) will be given by Equation 4.

$$RAEx_i = \sqrt{\frac{1}{n-1} \cdot \sum_{j=1}^{n} (A_{ij})^2} \tag{4}$$

To calculate the relative agreement degree of expert (RADEx) Ex_i (i = 1, 2, 3… *n*) Equation 5 will used.

$$RADEx_i = \frac{RAEx_i}{\sum_{i=1}^{n} RAEx_i} \quad (5)$$

The expert consensus coefficient (CCEx) Ex_i (i = 1, 2, 3… n) will be given by Equation 6.

$$CCEx_i = \frac{RADEx_i \cdot RIEx_i}{\sum_{i=1}^{n} \left(RADEx_i \cdot RIEx_i \right)} \quad (6)$$

Let *W* be a fuzzy number for combining expert's opinions. *W* is the fuzzy value of each CSF which is also a triangular fuzzy number. By definition of the consensus coefficient of expert (CCEx) Ex_i (i = 1, 2, 3… n), *W* can be defined by Equation 7. According to the Equation 7, w_i, is the triangular fuzzy number relating to the linguistic terms, U (Unimportant), LI (Little Important), I (Important) and VI (Very Important).

$$W = \sum_{i=1}^{n} \left(CCEx_i \cdot w_i \right) \quad (7)$$

The ideal NKM pattern as a reference for assessing NKM was established by calculating the normalized importance degree (NID) of each CSF that make up each property relevant to NKM. The normalized importance degree (NID) of each CSF will be given by defuzzification of its triangular fuzzy number *W* (a_i, b_i, c_i), where b_i represents the importance degree. Defuzzification is the process of obtaining a single number from the output of the fuzzy set. Then, NID will be defined by Equation 8.

$$NID_i = \frac{NID_i}{\text{the largest numerical value of bi}} \quad (8)$$

The third step of the method is to obtain the actual level of NKM as perceived by each worker and to compare it to the ideal NKM pattern. In this step, the linguistic terms are used to assess the values of CSFs in an organizational domain of the nuclear area, using a questionnaire. It is suggested that the workers employ the linguistic terms SD (Strongly Disagree), PD (Partially Disagree), NAND (Neither Agree Nor Disagree), PA (Partially Agree), and SA (Strongly Agree). In Figure 4 we show the graphic presentations of membership functions for these linguistic terms.

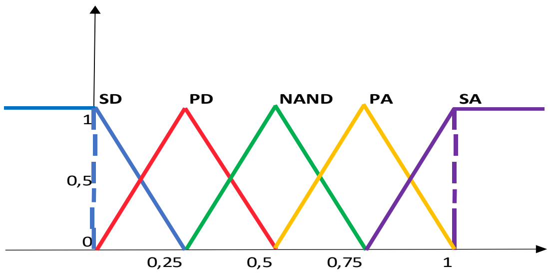


Figure 4: Membership functions for third step
Source: The authors

Using the center of area defuzzification method [12] we calculate the compliance degree (CD) with the NKM pattern by Equation 9.

$$\mathrm{CDi} = \frac{\sum_{j=1}^{k} \mathrm{NID}_j . \mathrm{cd}_j}{\sum_{j=1}^{k} \mathrm{NID}_j} \tag{9}$$

Referring to equation 9, cd_j, is the compliance degree of the CSF j of the theme i in the organization. Yager and Filev [11] provide a comprehensive discussion of this defuzzification method.

3. RESULTS AND DISCUSSION

The decision support method was implemented at the Laboratory of Human-Systems Interfaces (LHSI) of the Nuclear Engineering Institute. In LHSI research and projects are carried out in the areas of development and evaluation of advanced interfaces for control rooms, evaluation of human performance in emergency situations, human reliability analysis and human factors engineering.

We selected seventeen experts for determination of the degree of importance of each CSF, so that the implementation of NKM in the Laboratory of Human-Systems Interfaces can be considered good (ideal pattern for NKM). Afterwards, the relative importance score assigned to each expert were determined by a questionnaire with ten questions, whose items were associated with a score. Table 2 shows the relative importance of each expert calculated by equation 2. Expert E_{13} has the highest relative importance, $RIEx_{13}$ = 0.0812, and expert E_{17} has the lowest relative importance, $RIEx_{17}$ = 0.0333.

As an example, we present the assessment of CSF 1.3 (interaction between people) of theme 1 (top-level commitment) in Table 2. Table 2 shows the relative importances, the relative agreements, the relative agreement degrees and the consensus coefficients of the experts.

Table 2: Values of the relative importance (RIEx), relative agreement (RAEx), relative agreement degree (RADEx) and consensus coefficient (CCEx) of the experts

Experts	$RIEx_i$	$RAEx_i$	$RADEx_i$	$CCEx_i$
1	0.0390	0.8016	0.0627	0.0417
2	0.0796	0.6801	0.0532	0.0722
3	0.0455	0.6801	0.0532	0.0412
4	0.0561	0.6801	0.0532	0.0508
5	0.0699	0.8016	0.0627	0.0747
6	0.0439	0.6801	0.0532	0.0398
7	0.0496	0.6801	0.0532	0.0449
8	0.0601	0.8016	0.0627	0.0642
9	0.0455	0.8016	0.0627	0.0486
10	0.0739	0.8016	0.0627	0.0790
11	0.0682	0.8016	0.0627	0.0729
12	0.0561	0.8016	0.0627	0.0599
13	0.0812	0.6801	0.0532	0.0737
14	0.0569	0.8016	0.0627	0.0608
15	0.0731	0.8016	0.0627	0.0781
16	0.0682	0.6801	0.0532	0.0619
17	0.0333	0.8016	0.0627	0.0356

The result of the CSF 1.3 assessment is a triangular fuzzy number W (*1.62, 2.62, 3.00*) calculated by Equation 7. Figura 5 shows the membership function of CSF 1.3.

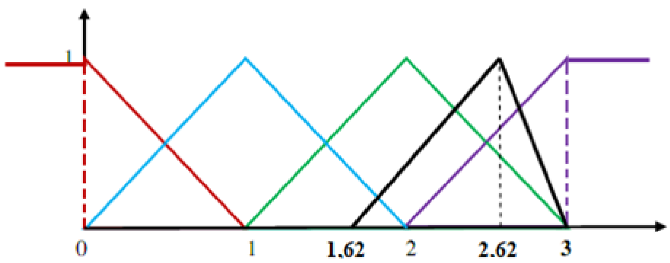


Figure 5: Membership function of CSF 1.3
Source: The authors

In Table 3 we show the result of all CSFs assessment. The ideal NKM was established by calculating the normalized importance degree (NID) of each CSF (Table 3).

Table 3: Result of all CSFs assessment e the NID value of each CSF

CSF	Fuzzy number			NID
Top-level commitment	**a**	**b**	**c**	
1.1 Mission and values: There is a clear definition of the mission and values of the facilitie.	1.57	2.57	2.98	0.874
1.2 Goals and Objectives: The goals and objectives of the facilitie are clearly defined.	1.82	2.82	3.00	0.959
1.3 Interaction between people: There is freedom of interaction between people and working groups.	1,62	2,62	3,00	0.891
1.4 Knowledge sharing: Managers provide support for sharing knowledge between the groups.	1,94	2,94	2,98	1.000
1.5 Knowledge dissemination: The managers motivate and create internal conditions for the dissemination of knowledge.	1.87	2.87	2.98	0.976
1.6 Investments to knowledge dissemination: There are investments for knowledge dissemination in the facilitie.	1.54	2.54	2.90	0.864
Organizational culture				
2.1 Organizational climate: There is a positive environment, encouraging the knowledge sharing.	1.78	2.78	3.00	1.000
2.2 Incentive Program: There is an incentive for the ideas used by the institution.	1.67	2.67	2.97	0.960
2.3 Meetings: People realized meetings to disseminate successful practices.	1.21	2.21	2.93	0.795
2.4 Documentation: There is a practice of elaboration and disseminationof project/research documents reporting positive and negative aspects.	1.17	2.17	2.93	0.781
2.5Relationship of Trust: There is a relationship of trust between people.	1.27	2.27	2.89	0.817
2.6 Commitment: The workers are committed to the facilitie.	1.43	2.43	2.93	0.874
2.7 Learning: The facilitie has an internal culture aligned to the learning process, that is, there is a learning environment in the institution.	1.67	2.67	3.00	0.960
2.8 Positive environment: There is a positive environment for communication, cooperation and negotiation.	1.41	2.41	2.94	0.867
Organizational Structures				
3.1 Multidisciplinary groups: The groups are multidisciplinary and they have autonomy and decision action.	1.24	2.24	2.92	0.922
3.2 Project/Research groups: Groups are organized by projects/research (processes).	1.12	2.12	2.79	0.872
3.3 Cooperation between groups: There is cooperation between physically distributed groups.	1.43	2.43	2.93	1.000
3.4 Formation of groups: There is freedom in the formation of groups.	1.37	2.37	2.90	0.975
3.5 Administrative structure: There is a specific group responsible for knowledge management.	1,29	2,29	2,98	0.942
Human resources management practices and policies				
4.1 Training: Appropriate training for activities is often offered and encouraged by managers.	1.49	2.49	2.97	1.000
4.2 Time pressure: There is no pressure for time and excessive goals.	0.99	1.99	2.88	0.799
4.3 Additional efforts: Additional efforts related to knowledge and	1.03	2.03	2.78	0.815

performance are recognized by the leadership.				
4.4. Identification of competencies: There is an appropriate procedure for identifying skills and selecting people to work on the site.	1.19	2.19	2.94	0.880
4.5. Human Resources: The capacity of workers in the facilitie is sufficient to ensure the sharing of information.	1.19	2.19	2.94	0.880
4.6 Responsibilities: The responsibilities attributed to persons are accompanied by criteria for the valuation.	1.41	2.41	2.97	0.968
Measurement of results				
5.1 Investment monitoring: There is a monitoring of the results of investments in training.	0.85	1.83	2.64	0.796
5.2 Performance assessment: There is an evaluation of the results (performance) of activities of the workers.	1.07	2.07	2.70	0.900
5.3 Alignment identification: The activities developed by the people are evaluated regarding the alignment with the objectives of the facilitie.	1.32	2.30	2.86	1.000
Information Technology				
6.1 Technological structure: There is a technological structure for the storage and sharing of knowledge.	1.54	2.54	3.00	0.937
6.2 Information access policy: There is a portal (local network) of dissemination and search for knowledge.	1.61	2.61	3.00	0.963
6.3 Training: People are trained to use the technological resources of information.	1.54	2.54	3.00	0.937
6.4 Availability of information technology: The technological resources of information are available to people when needed.	1.68	2.68	3.00	0.989
6.5 Quality of technological resources: The information technology resources are efficient for storing and disseminating information.	1.54	2.54	3.00	0.937
6.6. Access information: The information is centralized in a system of easy access.	1.71	2.71	2.98	1.000
Learning culture				
7.1. Context changes: People are encouraged to learn, participate and accept new practices and innovative technologies.	1.60	2.60	2.92	1.000
7.2 Contents of the Documentation: The procedures, instructions or documentation are updated and easy to understand.	1.45	2.45	2.97	0.942
7.3 Information content: The information exchanged during the communication processes is sufficient.	1.20	2.20	2.97	0.846
7.4 Communication: Communication mechanisms are efficient for disseminating information about work activities (knowledge).	1.30	2.30	3.00	0.885

The assessment of NKM in Laboratory of Human-Systems Interfaces was performed by five workers. Each assessment was performed according to the third step of the method.

The average assessment of the NKM is shown in Figure 6. We consider as satisfactory a compliance degree greater than 0.8, because this value represents agreement with the KNM pattern. The result of the average assessment showed that the Laboratory of Human-Systems Interfaces was satisfactory for all the themes.

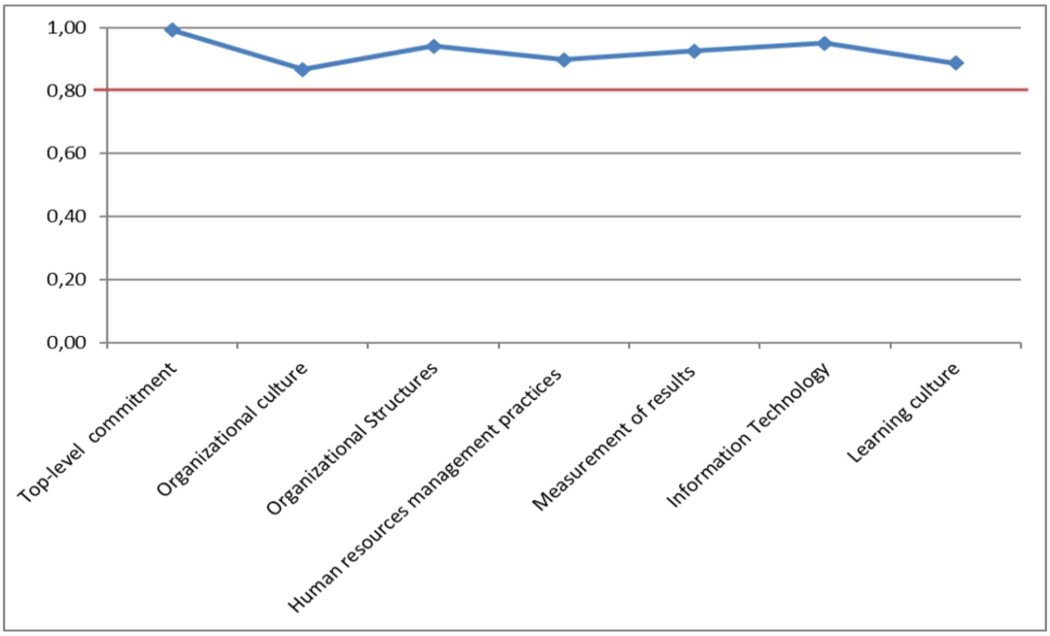


Figure 6: Assessment of NKM in Laboratory of Human-Systems Interfaces
Source: The authors

4. CONCLUSION

In this paper we described a research study in which a decision support method for assessment of a nuclear knowledge management was proposed and used. The method uses CSFs and the concepts and properties of fuzzy set theory. This study, performed in the Laboratory of Human-Systems Interfaces, showed that the method made it possible to identify of compliance degrees for the themes, higher than the acceptance level (0.8) specified in this work. This shows that LABIHS has good knowledge management. It was clear that, as it is a laboratory for carrying out advanced research in ergonomics and human factors, similar to the research carried out in developed countries, LABIHS has practices that allow both the preservation and sharing of existing knowledge for efficient use in the development and evaluation of new technologies for control rooms and human-system interfaces, as well as for the production of new knowledge.

This method offers interesting perspectives for the implementation of KM process and can be applied in any safe-critical organization (e.g., nuclear industry, aviation, pharmaceutical) with adjustments in terms of the CSFs and their metrics according to the characteristics of these organizations.

As suggestions for future research, we highlight: (1) the development of a computational system in order to automate the use of the method to assess an organization's NKM online; (2) the periodic application of the method to estimate how new corrective actions change NKM levels; (3) the use of the method in other safe-critical organizations in order to test its universality.

REFERENCES

[1] IAEA - Intenational Atomic Energy Agency. **Nuclear Energy Series NG-T-6.11: Knowledge Loss Risk Management in Nuclear Organizations.** Viena: IAEA, 2007.

[2] WONG, K. Y. Critical Success Factors for Iimplementing Knowledge Management in Small and Medium Enterprises. **Industrial Management & Data Systems 3**, v. 105, p. 261-279, 2005.

[3] GRECCO, C. H. S., VIDAL, M. C., COSENZA, C. A. N., SANTOS, I. J.A. L., CARVALHO, P. V. R. Safety culture assessment: A fuzzy model for improving safety performance in a radioactive installation. **Progress in Nuclear Energy**, v. 70, p. 71-83, 2014.

[4] GENTILE, M., ROGERS, W., MANNAN, M. Development of an inherent safety index based on fuzzy logic. **AIChE Journal**, v. 49, p. 959-968, 2003.

[5] Nunes I. L. ERGO X – The model of a fuzzy expert system for workstation ergonomic analysis, In: **INTERNATIONAL ENCYCLOPEDIA OF ERGONOMICS AND HUMAN FACTORS**, Karwowski W. (Ed.), CRC Press, p. 3114-3121, 2006.

[6] TAKEUCHI, H., NONAKA, I**. Gestão do Conhecimento**, 1. ed., Porto Alegre, Brasil , 2008.

[7] TERRA, J. A. **Gestão do Conhecimento: O Grande Desafio Empresarial**, 5. Ed., Rio de Janeiro, Brasil, 2005.

[8] WANG, J., PETERS, H. P., GUAN, J. Factors Influencing Knowledge Productivity in German Research Groups: lessons for developing countries. **Journal of Knowledge Management,** v.10, p. 113-126, 2006.

[9] GRECCO, C. H. S., AUGUSTO, S. C., SOUZA, J. T. V., CARVALHO, P. V. R., DAVILA, A. L. A method for the evaluation of knowledge management systems. **Brazilian Journal of Radiation Sciences**, v. 9, p. 1-12, 2021.

[10] LEE, H. M. Group decision making using fuzzy theory for evaluating the rate of aggregative risk in software development. **Fuzzy Sets and Systems**, v. 80, p. 261-271, 1996.

[11] HSU, H. M., CHEN, C. T. Aggregation of fuzzy opinions under group decision making. **Fuzzy Sets and Systems**, v. 79, p. 279-285, 1996.

[12] YAGER, R. R., FILEV, D. P. On the issue of defuzzification and selection based on a fuzzy set. **Fuzzy Sets and Systems**, v. 55, p.255-272, 1993.