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A Cumulative Belief-Degree Approach for Nuclear Safeguards Evaluation

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***Abstract*— Nuclear safeguards are a set of activities to verify that a State is living up to its international undertakings not to use nuclear programs for nuclear weapons purposes. International Atomic Energy Agency (IAEA) uses a hierarchical assessment system that is composed of critical activities in the nuclear fuel cycle, processes required for the activities, and the indicators to evaluate the processes. IAEA experts benefit from several sources to evaluate the indicators such as State declarations, on-site inspections, IAEA databases, and open sources. One of the most important problems in nuclear safeguards evaluation (NSE) is observed in the aggregation of the multiple expert evaluations. In this study, a methodology is proposed to solve this problem where fuzzy linguistic terms are proposed to represent the expert evaluations and cumulative belief degrees (CBDs) are applied to aggregate the evaluations. CBD is introduced based on belief structure, which is developed on the basis of decision theory and Dempster-Shafer theory of evidence. The study also presents a numerical example to show the applicability of the proposed methodology.**

***Keywords*—nuclear safeguards, fuzzy linguistic terms, cumulative belif degree, decision making**

I. INTRODUCTION

Nuclear safeguards are a set of activities by which IAEA seeks to verify that a State is living up to its international undertakings not to use nuclear programs for nuclear weapons purposes. The safeguards system is based on assessment of the correctness and completeness of the State's declarations to the IAEA concerning nuclear material and nuclear-related activities [1]. As a part of the efforts to strengthen international safeguards, including its ability to provide credible assurance of the absence of undeclared nuclear material and activities, IAEA makes use of increased amounts and types of information on States' nuclear and nuclear related activities. This information includes declarations provided by States, information collected by IAEA and other information available to IAEA.

The Physical Model [2] used by IAEA is a technical tool for the implementation of an enhanced information analysis. It includes all the main activities that may be involved in the nuclear fuel cycle from the source material acquisition to the production of weapons-usable material. It contains detailed narratives describing every known process for accomplishing each given nuclear activity represented in the fuel cycle. The Physical Model identifies and describes indicators of existence or development of a particular process. The indicators include especially designed and dual-use equipment, nuclear and non-nuclear materials, technology/training/R&D, other observables, and by-products/effluents. The specificity of each indicator is designated to a given nuclear activity and is used to determine the strength of an indicator. An indicator that is presented only if the nuclear activity exists or is under development, or whose presence is almost always accompanied by certain nuclear activity is a strong indicator of the activity. Conversely, an indicator that is present for many other reasons, or is associated with many other activities, is a weak indicator. In between are medium indicators [2].

Among the nine activities described in the Physical Model for the nuclear fuel cycle, every activity is structured by means of processes that may alternative or complimentary to each other. The existences of the processes are determined by the indicators. More than 900 indicators are defined in the Physical Model to make the final decision of existence of nuclear programs for nuclear weapons.

Evaluation of the indicators is conducted by the IAEA experts on the basis of their analysis of the available information sourced from declaration of States, on-site inspections, non-safeguards IAEA databases, and open sources such as Internet and newspapers. The evaluations are made in different time periods and by different experts. Therefore expert evaluations of the indicators for different periods are to be aggregated to make a final decision (see Fig. 1 for the steps of NSE). Since this process contains subjective judgments of the experts and aggregation of multiple evaluations, it is complicated under various uncertainties.

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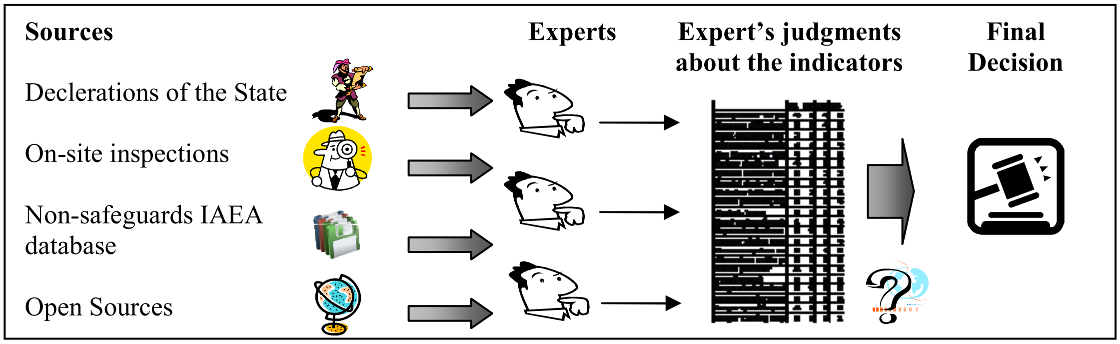

Figure 1. The Nuclear Safeguards Evaluation Procedure

In this paper, a CBD approach is proposed to aggregate the expert evaluations of indicators in the NSE context. Fuzzy linguistic terms are assumed for the expert judgments. Section II reviews the current literature about NSE. The proposed methodology is presented in Section III. Section IV is devoted to a numerical example for the proposed methodology. Finally, the paper is concluded in Section V.

II. State of the Art on NSE

Being one of the earlier papers dealing with NSE, [3] uses a linguistic assessment approach to handle nuclear safeguards relevant information. The hierarchical structure of the IAEA's Physical Model is considered to solve the problem step by step from lower levels to overall evaluation. The symbolic approach is employed in [3] by the direct computation on linguistic values instead of the approximation approach using the associated membership function. Ordinal linguistic terms and 2-tuple representation approaches are used as the symbolic approaches [11-12].

The hierarchical approach in [3] satisfies a useful tool to analyze the large problem in small and less complex levels. The use of symbolic linguistic terms let the experts make the evaluation with natural languages. However, [3] does not offer an appropriate aggregation function for the NSE problem. Neither the compensatory natures nor the information losses of the aggregation functions are taken into consideration.

Reference [4] provides detailed information about the NSE problem and uses an enhanced belief rule-based inference methodology to solve it. It mainly deals with the incomplete, imprecise, not fully reliable, conflicting, in short uncertain information. For this aim the paper uses a newly developed belief rule-base inference methodology (RIMER), which handles hybrid uncertain information in NSE process. RIMER is developed on the basis of the Dempster-Shafer theory of evidence, decision theory and fuzzy rule based systems.

The level of the specific nuclear activity (output) and the indicator (input) that is used to the activity are represented by a distributed representation of linguistic terms with beliefs (i.e., belief distribution) in the methodology of [4]. The relations between the inputs and the outputs are defined by a belief rule-base. Then the rule inference that depends on the evidential reasoning algorithm [5-7] is introduced.

Using the belief distribution representation is one of the strong features of [4], because it gives a chance of defining different probabilities for the different states of an indicator, which is also the case in real life experiences. However to construct the rule base for all activities, processes and indicators in NSE is very hard. Besides, it is almost impossible to guarantee the correctness of the rule base.

In [8-9] a fuzzy decision support system was developed for open source information analysis in a non-proliferation framework. The study structures the flow of information from open sources to indicators, synthesis indicators and the output. It uses linguistic values that are characterized by Gaussian membership functions for the existence of the indicators. The aggregation module of the work, which is used to synthesis all kinds of open source information to a unique value, includes the aggregation of the information according to the reliability of their sources and the strength of the indicators. Fuzzy inference system is used in this module. This work focuses only on the handling of the open source information.

As can be seen from the existing literature, there is a need for a methodology that can be easily applicable to the NSE problem with a more general rule base, handles all kinds of available information, and offers a reliable aggregation procedure. The methodology given in the following section is proposed to meet this need.

III. Proposed Methodology

The proposed methodology aims to aggregate expert judgments about the indicators with easily definable rules. Additionally the model will also give results for different aspiration levels of decision makers. For these purposes, the model uses fuzzy linguistic terms for the expert evaluations of the indicators and utilizes CBDs to aggregate the evaluations according to the linguistic terms.

A. Fuzzy linguistic terms

Reference [10] characterizes a linguistic variable by a quintuple (H, $T(H)$, U, G, M) in which H is the name of the variable; $T(H)$ (or simply T) denotes the term set of H, i.e., the set of names of linguistic values of H, with each value being a fuzzy variable denoted generically by X and ranging across a universe of discourse U, which is associated with the base variable u; G is a syntactic rule (which usually takes the form of grammar) for generating the names of values of H; and M is a semantic rule for associating its meaning with each H, $M(X)$, which is a fuzzy subset of U.

The first priority ought to establish is what kind of term set to use. Let S = $\{s_i\}$, $i \in \{0,...,m\}$ be a finite and totally ordered term set. Any label, s_i, represents a possible value for a linguistic variable. The semantics of the finite term set S is given by fuzzy numbers defined in a [0, 1] interval, which are described by their membership functions. Moreover, it must have the following characteristics:

- The set is ordered: $s_i \leq s_j$ if $i \leq j$.
- There is a negation operator: Neg(s_i) = s_j such that $j = m - i$.
- There is a maximization operator: Max(s_i, s_j)=s_i if $s_j \leq s_i$.
- There is a minimization operator: Min(s_i, s_j)=s_i if $s_i \leq s_j$.

Linguistic term sets can be defined according to the nature of the problem. For the NSE problem, for instance, the existence of the indicators can be evaluated with a seven-term set, S = $\{s_i\}$, $i \in \{0,...,6\}$, in which the following meanings to the terms are assigned. s_0: definitely does not exist, s_1: strong belief to non-existence, s_2: quite belief to non-existence, s_3: undetermined about the existence/non-existence, s_4: quite belief to existence, s_5: strong belief to existence, s_6: definitely exists. On the other hand, experts may define numerical set definitions for the term sets where the measurable indicators are available.

Once the expert evaluations are gathered with the linguistic terms, they have to be aggregated to make the final decision of the existence of the process that will lead to make judgment about existence of non-peaceful nuclear programs. In this study, a belief structure based approach is used to represent expert evaluations.

B. The belief structure

The belief structure, which is the same as the belief distribution structure discussed in [4], is represented by an expectation to model multiple attribute decision analysis problems [7]. An expectation was originally designed to model qualitative assessments with uncertainty in the evidential reasoning approach developed on the basis of decision theory and Dempster-Shafer theory of evidence [5-6].

In the proposed methodology, the belief structure is used to represent general belief of the existence of an indicator as a result of expert evaluations. Such that, to evaluate an indicator of a process, for example, 20% of the experts may say it is s_1, 50% of them say it is s_2, and 30% of them say it is s_3. In this statement s_1, s_2, and s_3 are linguistic evaluation grades and percentage values of 20%, 50%, and 30% are referred to as the degrees of belief, which indicate the extents that the corresponding grades are assessed to. The above assessment can be expressed as the following expectation:

$$B(I_1) = \{ (s_1, 0.2), (s_2, 0.5), (s_3, 0.3) \} \quad (1)$$

where B(I_1) stands for the state of the existence of the first indicator. To assess the process on the other indicators, other linguistic evaluation grades may also be used such as s_0, s_4, s_5, s_6, resulting with a seven-term set, i.e., S = $\{s_i\}$, $i \in \{0,...,6\}$. Suppose that the other assessments of the indicators related to the process are as the given in (2-4):

$$B(I_2) = \{ (s_0, 0.6), (s_1, 0.1), (s_6, 0.3) \}, \quad (2)$$

$$B(I_3) = \{ (s_3, 0.2), (s_6, 0.8) \}, \quad (3)$$

$$B(I_4) = \{ (s_0, 0.1), (s_1, 0.25), (s_2, 0.05), (s_3, 0.3), (s_4, 0.1), (s_5, 0.15), (s_6, 0.05) \}. \quad (4)$$

In a general, the belief degree can be defined as follows:

$$B(I_k) = \{ (s_i, \beta_{ik}), i = 1,\ldots,m) \} ,\forall k, \quad \sum_{i=0}^{m} \beta_{ik} \leq 1, \forall k \quad (5)$$

If the sum of the belief degrees in (5) is smaller than 1 then it shows a kind of incompleteness in the belief structure. In the proposed methodology, this value is always equal to 1.

Belief degrees can be derived from the expert evaluations. Such that, if X_{ke} indicates the evaluation of expert e, for any e, for the indicator k, for any k (X_{ke} takes values from the set S), and w_e, for any e, shows the importance of expert e, then the belief degree associated to linguistic term i, and indicator k can be calculated as follows:

$$\beta_{ik} = \frac{\left(\sum w_e \mid X_{ke} = s_i\right)}{\left(\sum w_e \mid X_{ke} \geq s_0\right)} \quad (6)$$

Numerator of (6) sums up the weights of experts who assign i to the existence of the indicator and the denominator is the summation of the weights of all the experts who make assignments. Notice that if an expert evaluation is missing then belief degrees can also be calculated without considering it in the denominator.

Suppose that four experts with their importance of $w_1 = 3$, $w_2 = 5$, $w_3 = 4$, and $w_4 = 2$ indicate s_3, s_2, s_3, and s_6 respectively for the existence of an indicator (say, indicator 5) (i.e., $X_{51} = s_3$, $X_{52} = s_2$, $X_{53} = s_3$, $X_{54} = s_6$). Then the belief structure related to the existence of indicator 5 can be expressed as follows:

$$B(I_5) = \{ (s_2, 5/14), (s_3, 7/14), (s_6, 2/14) \}$$

where, for instance, β_{35} is found according to (6) as follows:

$$\beta_{35} = \frac{\left(\sum w_e \mid X_{5e} = s_3\right)}{\left(\sum w_e \mid X_{5e} \geq s_0\right)} = \frac{w_1 + w_3}{w_1 + w_2 + w_3 + w_4} = \frac{3+4}{3+5+4+2} = \frac{7}{14}$$

To clarify the calculations for the missing value case, assume that the third expert does not make evaluation about the indicator (i.e., X_{53} is missing) then belief degrees are formed as follows:

$$B(I_5) = \{ (s_2, 5/10) (s_3, 3/10), (s_5, 2/10) \}$$

where β_{35} is found according to (6) as follows:

$$\beta_{35} = \frac{\left(\sum w_e \mid X_{5e} = s_3\right)}{\left(\sum w_e \mid X_{5e} \geq s_0\right)} = \frac{w_1}{w_1 + w_2 + w_4} = \frac{3}{3+5+2} = \frac{3}{10}$$

C. Cumulative belief degrees

The CBD of an element in a linguistic term set can be defined as the aggregated belief degrees of greater terms of the element. For the case of safeguards, suppose that the final existence of an indicator is determined according to a threshold value that is determined as one of the linguistic terms. Then the belief degrees of the terms that are greater than the threshold have to be taken into account. For instance, when s_3 is determined as the threshold, s_3, s_4,…,s_m indicate the existence of the indicator. Therefore the belief degrees of these terms can be summed up to find the CBD at this threshold level. Consider the fourth belief degree set, (4), for s_3 as the threshold CBD will be equal to 60% (=0.3+0.1+0.15+0.05).

The cumulative belief structure can be defined as follows:

$$C(I_k) = \{ (s_i, \gamma_{ik}), i = 1,\ldots,m) \} , \forall k, \quad (7)$$

where $\gamma_{ik} = \sum_{j=i}^{m} \beta_{jk}$ is CBD related to indicator k at the threshold level i. For instance, by using the belief degrees in (4), corresponding cumulative belief structure can be formed as $C(I_4)$ = { (s_0,1.0), (s_1,0.9), (s_2,0.65), (s_3,0.60), (s_4,0.30), (s_5,0.2), (s_6,0.05) }.

If the expert evaluations are available then CBD related to indicator k at threshold level i can be calculated directly by combining (6) and (7) as:

$$\gamma_{ik} = \frac{\left(\sum w_e \mid X_{ke} \geq s_i\right)}{\left(\sum w_e \mid X_{ke} \geq s_0\right)} \quad (8)$$

D. Aggregations

Once the CBDs of all indicators are specified for a process, the decision about the existence of the process can be made at the different threshold term values. Aggregation is made according to the general rules that depend on the type of the indicators (e.g., strong, medium, and weak indicators).

In NSE, existence of solely one strong indicator is enough to make the decision of existence of non-peaceful nuclear program [2]. Since combinations of medium and weak indicators can be considered as to be equal to a strong indicator [3-4] the following rule system can be used for NSE.

Suppose that R_1, R_2,…,R_P, are the rules one of which is sufficient to make the final decision of the existence of the process. A rule is characterized with the existence of the number of different types of the indicators. Assume that T_1, T_2,…,T_U, are the types of different indicators. Then rules are defined as follows:

$$R_p = \{ [T_u, \alpha_{pu}], u = 1,\ldots,U \}, \quad p = 1,\ldots,P. \quad (9)$$

where α_{pu} indicates the number of indicators with type u that is required to make the existence decision of the process.

For the actual NSE problem, there are three types of indicators such as strong (T_1), medium (T_2), and weak (T_3). In this study, types of indicators are described in general manner for the possible need of defining new types of indicators to make a more reliable rule system. For instance, semi-strong indicators can be defined in accord with the partial existence of strong indicators.

For example, if the rules of "One of the strong indicators" (Rule 1), OR "Two medium and three weak indicators" (Rule 2) are considered, they can be formed as follows:

R_1 ={ [Strong, 1], [medium, 0], [Weak, 0] }

R_2 ={ [Strong, 0], [medium, 2], [Weak, 3] }

In this example the first rule indicates that the existence of one strong indicator is enough to make the existence decision of the related process. On the other hand, the second rule shows that the existence of two medium indicators and three week indicators is also sufficient to make the existence decision.

To make the decision related to the existence of a process, initially, the CBD of fulfillment of each rule is found. For this, firstly, existence of the required numbers of indicators for the process is calculated. Suppose that there are z_u indicators with type T_u, and α_{pu} out of z_u indicators should exist to confirm the fulfillment of rule R_p. Then all possible combinations of α_{pu} indicators with z_u indicators are made and the CBD of existence of each is calculated with the minimum operator. Secondly since one combination is satisfactory, existence of required number of indicators is found by using the maximum operator. Thus, the CBD of existence of α_{pu} indicators (with type T_u) for rule R_p at threshold i is found as follows.

$$EI_{pi}(T_u, \alpha_{pu}) = \max_{p_1, p_2, \ldots, p_{\alpha_{pu}} \in T_u} \left(\min_{y=1,\ldots,\alpha_{pu}} \gamma_{ip_y} \right) \quad (10)$$

where $p_1, p_2, \ldots, p_{\alpha_{pu}}$ are systematically selected type T_u indicators to form all possible combinations.

To clarify (10), suppose the second rule (R_2) and medium (type 2) indicators where required number of indicators is equal to 2 (i.e., α_{22} = 2) and indicators indexed as 6, 7, 8, 9 are medium indicators. Then (10) is formed as follows:

$$EI_{2i}(T_2, 2) = \max_{p_1, p_2 \in T_2} \left(\min_{y=1,2} \gamma_{ip_y} \right)$$

$$EI_{2i}(T_2, 2) = \max \left\{ \begin{array}{l} \min(\gamma_{i6}, \gamma_{i7}), \min(\gamma_{i6}, \gamma_{i8}), \min(\gamma_{i6}, \gamma_{i9}), \\ \min(\gamma_{i7}, \gamma_{i8}), \min(\gamma_{i7}, \gamma_{i9}), \min(\gamma_{i8}, \gamma_{i9}) \end{array} \right\}$$

The CBD of fulfillment of rule p is found by utilizing the minimum operator because the required numbers of all types of indicators should exist in a rule.

$$ER_{pi} = \min_{\substack{u=1,\ldots,U \\ \alpha_{pu} \neq 0}} \left\{ EI_{pi}(T_u, \alpha_{pu}) \right\} \quad (11)$$

Consider the second rule again. E_{2i} is calculated as follows:

$$ER_{2i} = \min_{\substack{u=1,\ldots,3 \\ \alpha_{pu} \neq 0}} \left\{ EI_{2i}(T_u, \alpha_{pu}) \right\}$$

$$ER_{2i} = \min\{ EI_{2i}(T_2, 2), EI_{2i}(T_3, 3) \}$$

To make the final decision related to the existence of the process, an evidence of existence according to a rule is sufficient. Therefore rules are combined via the maximum operator on the CBDs of the rules as follows:

$$EP_i = \max_{p=1,\ldots,P} ER_{pi} \tag{12}$$

where EP_i is the combined belief degree of the existence of the process at s_i threshold level.

As a result, CBDs for different threshold terms are gathered. The final decision can be made with two approaches. In the first one, the graphical representation of the result can be analyzed to determine a cut-off point. The other approach is to assign expectation values for the linguistic terms to aggregate them. For this, suppose that v_i indicates an expectation value for the term i, then the aggregated result (AR) that gives the total expectation can be found by the following formula:

$$AR = \sum_{i=0}^{m} v_i \left(ER_i - ER_{i+1} \right) \tag{13}$$

In (13) CBDs are decomposed to belief degrees to make the summation of the expectation values.

IV. A Numerical Example

To show the validity of the proposed model it is applied to the example given in [3] which is for gaseous diffusion enrichment process. In Table I, evaluations by the four experts using the linguistic terms S = $\{s_i\}$, $i \in \{0,\ldots,6\}$ are given. The importance weights of the experts are supposed to be 3, 5, 4, 2 for e_1, e_2, e_3, e_4, respectively.

It is concluded from the IAEA report [2] that there can be four rules to conduct the evaluation:

Rule 1: One of the strong indicators;
Rule 2: Three of the medium indicators;
Rule 3: Two medium and three weak indicators;
Rule 4: One medium and six weak indicators;

TABLE I. Expert Evaluations in the Example

Indicator			**Expert evaluations**			
ID	***Type***	***Definition***	e_1	e_2	e_3	e_4
1	Strong	Compressor for pure UF 6	s_4	s_2	s_4	s_6
2	Strong	Gaseous diffusion barrier	s_6	s_5	s_4	s_6
3	Strong	Heat Exchange for cooling pure UF6	s_5	s_3	s_6	s_6
4	Medium	Diffuser housing/vessel	s_3	s_3	s_5	s_4
5	Medium	Gas blower for UF6	s_3	s_2	s_3	s_6
6	Medium	Rotary shaft seal	s_4	s_3	s_5	s_3
7	Medium	Special control value (large aperture)	s_3	s_2	s_5	s_5
8	Medium	Special shut-off value (large aperture)	s_6	s_1	s_4	s_5
9	Medium	Chlorine trifluoride	s_3	s_2	s_5	s_4
10	Medium	Nickel powder, high purity	s_2	s_2	s_3	s_4
11	Weak	Gasket, large	s_2	s_3	s_5	s_3
12	Weak	Feed system/product and tails withdrawal	s_1	s_3	s_2	s_4
13	Weak	Expansion bellows	s_6	s_6	s_6	s_5
14	Weak	Header piping system	s_5	s_3	s_6	s_4
15	Weak	Vacuum system and pump	s_3	s_2	s_1	s_2
16	Weak	Aluminum oxide powder	s_2	s_2	s_2	s_3
17	Weak	Nickel powder	s_4	s_3	s_6	s_4
18	Weak	PTFE (teflon)	s_3	s_3	s_3	s_2
19	Weak	Large electrical switching yard	s_3	s_6	s_5	s_5
20	Weak	Large heat increase in air or water	s_6	s_3	s_6	s_4
21	Weak	Larger specific power consumption	s_4	s_3	s_5	s_6
22	Weak	Larger cooling requirements (tower)	s_3	s_1	s_2	s_1

Notice that these rules are the principle and obvious ones. For a real problem, any new rule system with different indicator types and different rules can be established.

To solve the problem with the proposed methodology, first CBDs are calculated for each linguistic term based on the experts' importance by using (8). The results are given in Table II. For instance, γ_{48} is calculated as follows:

$$\gamma_{48} = \frac{\left(\sum w_e \mid X_{8e} \geq s_4 \right)}{\left(\sum w_e \mid X_{8e} \geq s_0 \right)} = \frac{w_1 + w_3 + w_4}{w_1 + w_2 + w_3 + w_4} = \frac{9}{14} = 0.643$$

Then fulfillment of the rules and the combined results of the rules are calculated based on CBDs by (10-12) (see Table III). E.g., the second rule can be defined by (9) as R_2 = { [T_1,0], [T_2,3], [T_3,0] }. The CBD of existence of 3 medium indicators at threshold s_4 for this rule can be calculated by (10) as follows:

$$EI_{24}(T_2,3) = \max_{p_1,p_2,\ldots,p_{\alpha_{pu}} \in T_2} \left(\min_{y=1,2,3} \gamma_{4p_y} \right)$$

To calculate this formula, we make such a combination of three medium indicators (i.e., among the indicators indexed 4 to 10) that minimum of their CBDs would be maximum.

$$EI_{24}(T_2,3) = \max \left\{ \begin{array}{l} \min(\gamma_{44},\gamma_{45},\gamma_{46}), \min(\gamma_{44},\gamma_{45},\gamma_{47}), \\ \min(\gamma_{44},\gamma_{45},\gamma_{48}), \ldots, \min(\gamma_{44},\gamma_{46},\gamma_{48}), \\ \ldots, \min(\gamma_{47},\gamma_{49},\gamma_{4,10}), \min(\gamma_{48},\gamma_{49},\gamma_{4,10}) \end{array} \right\}$$
$$= \max\{0.143, 0.143, 0.143, \ldots, 0.429, \ldots, 0.143, 0.143\}$$
$$= 0.429$$

When (11) is applied to the second rule at i = 4, the result is:

$$ER_{24} = \min_{\substack{u=1,\ldots,3 \\ \alpha_{pu} \neq 0}} \left\{ EI_{24}(T_u, \alpha_{2u}) \right\} = \min_{u=2} \left\{ EI_{24}(T_u, \alpha_{2u}) \right\}$$
$$= EI_{24}(T_2,3) = 0.429$$

TABLE II. CBDs for the Example

Indicator ID	s_0	s_1	s_2	s_3	s_4	s_5	s_6
1	1.000	1.000	1.000	0.643	0.643	0.143	0.143
2	1.000	1.000	1.000	1.000	1.000	0.714	0.357
3	1.000	1.000	1.000	1.000	0.643	0.643	0.429
4	1.000	1.000	1.000	1.000	0.429	0.286	0.000
5	1.000	1.000	1.000	0.643	0.143	0.143	0.143
6	1.000	1.000	1.000	1.000	0.500	0.286	0.000
7	1.000	1.000	1.000	0.643	0.429	0.429	0.000
8	1.000	1.000	0.643	0.643	0.643	0.357	0.214
9	1.000	1.000	1.000	0.643	0.429	0.286	0.000
10	1.000	1.000	1.000	0.429	0.143	0.000	0.000
11	1.000	1.000	1.000	0.786	0.286	0.286	0.000
12	1.000	1.000	0.786	0.500	0.143	0.000	0.000
13	1.000	1.000	1.000	1.000	1.000	1.000	0.857
14	1.000	1.000	1.000	1.000	0.643	0.500	0.286
15	1.000	1.000	0.714	0.214	0.000	0.000	0.000
16	1.000	1.000	1.000	0.143	0.000	0.000	0.000
17	1.000	1.000	1.000	1.000	0.643	0.286	0.286
18	1.000	1.000	1.000	0.857	0.000	0.000	0.000
19	1.000	1.000	1.000	1.000	0.786	0.786	0.357
20	1.000	1.000	1.000	1.000	0.643	0.500	0.500
21	1.000	1.000	1.000	1.000	0.643	0.429	0.143
22	1.000	1.000	0.500	0.214	0.000	0.000	0.000

TABLE III. RESUTLS FOR THE RULES AND AGGREGATED RESULT

	s_0	s_1	s_2	s_3	s_4	s_5	s_6
Rule 1	1.000	1.000	1.000	1.000	1.000	0.714	0.429
Rule 2	1.000	1.000	1.000	0.643	0.429	0.286	0.000
Rule 3	1.000	1.000	1.000	1.000	0.500	0.357	0.143
Rule 4	1.000	1.000	1.000	1.000	0.643	0.286	0.143
E_i	1.000	1.000	1.000	1.000	1.000	0.714	0.429

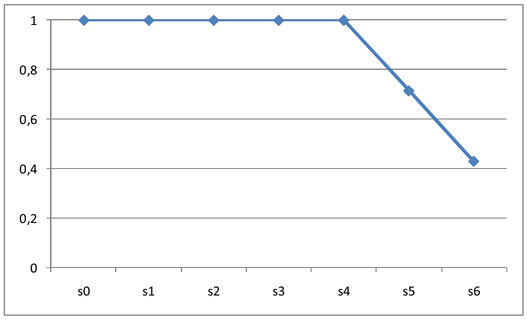

Figure 2. Combined result of the example

The combined result in Fig. 2 indicates that if the threshold term is specified as s_0, s_1, s_2, s_3, s_4 then the belief degree to the existence of the process is 100%. If the threshold term is specified as s_5 and s_6, then the belief degree is 71.4% and 42.9% respectively. From these results we conclude that there is strong belief on the existence of the process.

If expectation values associated to the linguistic terms are considered as $v_i = \{0, 1, 2, 3, 4, 5, 6\}$ for i=0,…,6, respectively, then the aggregated result is found as 5.14 by using (13):

$$AR = \sum_{i=0}^{m} v_i \left(ER_i - ER_{i+1}\right) = 0(1-1) + 1(1-1) + 2(1-1) + 3(1-1)$$
$$+ 4(1-0.714) + 5(0.714-0.429) + 6(0.429-0) = 5.14$$

The results of the same problem in [3] are 4.64, 4.74, 4.76, and 4.77 for different operators. The proposed methodology gives higher existence of the process than these results. When the high evaluation values assigned to the strong indicators are considered, the result of the proposed method can be counted as more reliable. However it is noticed that more experiments are required to justify the superiority of the proposed model.

V. CONCLUSIONS

In this study, a new approach based on the belief degrees, called CBDs, is suggested to aggregate the evaluations in NSE problem. Fuzzy linguistic terms are used to represent the expert evaluations. Another newly proposed approach is a rule system that is defined on the types and numbers of indicators in a general manner to make the characterization of the rules easily, and understandably.

The advantage of the proposed model over the existing methods can be summarized as follows. The rule base of the method is easier to apply in the real problem. The problem owners may define the rules in a general manner for all processes or the different rule sets can be defined for each process if required. The methodology can be applied in the NSE problem if the classification of the indicators is changed. The model can be used to evaluate the state declarations, verification data, and other open source information as soon as they are evaluated by the experts. The methodology is transparent and back-traceable. Such that the result obtained for a linguistic term can be back-tracked and the reason of high/low values can be understood easily.

One of the most important features of the method is that it can be used when some data are missing. In the real problem it is evident that some of the experts do not indicate judgment for some indicators because of lack of expertise for a particular topic or lack of available information. By using available expert evaluations, the methodology can be run without any complex procedure such as generating a value for the missing datum. However, the methodology does not supply any reliability degree for the concluded result at this time. A further study can be conducted for this purpose.

Other further studies for improving the proposed model may be about making more experiments on different cases. Effects of various missing data can be analyzed and the results can be compared with the other methods dealing with missing values. The model can be adapted for different rule definitions such as "two of the strong indicators with low belief degrees indicates the existence" by introducing new types of indicators.

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