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A Risk Analysis Method Based on Interval-Valued Fuzzy Numbers for Improving Patient Safety

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Abstract—As the importance of patient safety increases for hospital management, improvements in patient safety are needed to reduce this high incidence of medical error. Research on patient safety and medical errors shows that errors and the adverse events may mainly resulted by health care providers, equipment and the quality management system. Most studies focused their research on the risk of patient individual in health care, however, facing patient safety problems, a hospital manager must consider the risk of the organization while making improving decision. It will be relative with the cost-effectiveness of a health care organization. Here we used a TOPSIS (technique for order preference by similarity to ideal solution) approach to manage the risk of a health care organization in linguistic terms in the environment of interval-valued fuzzy numbers (IVFNs). Rather than calculating the distance between the alternatives and the positive/negative ideal solution in a TOPSIS approach, we use the similarity measure between IVFNs of the alternatives' risk and the risk of the positive/negative ideal solution to help hospital managers analyze risks in an uncertain and complex situation and more easily determine the best alternative.

Keywords—decision making; risk analysis; interval-valued fuzzy number; TOPSIS; patient safety; similarity measure

I. INTRODUCTION

All people requiring or receiving health care have a right to be safe — that is, the right to be kept free of danger or risk of injury while in health care domains [1]. This right carries with it a correlative duty on the part of health service providers to ensure that people who are receiving care are kept free from danger or risk of injury while receiving that care [1]. The risk of mortality among patients with iatrogenic complications was significantly higher than the risk of mortality among patients without iatrogenic complications [2]. Therefore, patient safety and quality health care are primary directives for those in health care [3]. The term patient safety is a relatively recent initiative in health care which encompasses systems of patient care, reporting of mistakes, and the initiation of new systems in order to reduce the risk of errors in patient care [7].

The main aim of patient safety efforts is to eliminate adverse events [8]. Recent studies denote that nurses are a critical component in the promotion of patient safety. Nurses have an innate capability to intercept near misses and errors of others in the health care team. Nurses have a pivotal role to play in clinical risk analysis and promoting patient safety in health care domains [1,3]. Accordingly, nurses need to be prepared educationally to manage clinical risk effectively when delivering patient care [1]. However, global nursing shortages have exacerbated time pressure and burnout among nurses [5]. Therefore, some researchers discussed nursing workload and the work environment [3,9].

In addition, most studies focused their research on the risk of patient individual in health care [3,11]. However, the risks of a health care organization should be considered in a decision making process while improving patient safety. Risk is composed of two factors: the probability of failure and the severity of loss. Many risk analysis approaches have been based on the use of linguistic assessments instead of numerical values [12]. The fuzzy set [13] is a mathematical tool for the analysis of data defined in imprecise linguistic terms based on subjective judgments such as low-risk, serious-impact, or high-probability events. The interval-valued fuzzy numbers (IVFNs) was thus defined by Zadeh [14] and Sambuc [15] and has been popularly adopted for handling subjective uncertainties arising from incomplete or imprecise information. It would appear to be a more applicable method for health care organizations to handle such variable and uncertain factors in risk analysis.

In this study, we analyzed the organization risk in patient safety based on IVFNs using a TOPSIS (technique for order preference by similarity to ideal solution) approach developed by Hwang and Yoon [17], a widely used multiple-attribute decision-making method. The basic concept of TOPSIS is that the chosen alternative should have the shortest distance from the positive-ideal solution and the farthest distance from the negative-ideal solution. To measure the risk of alternatives, we use TOPSIS to compare it with the smallest risk (positive-ideal solution) and the biggest risk (the negative-ideal solution). Rather than measuring the distance between the alternatives and the positive/negative ideal solution, we measured the similarity between IVFNs of risks of alternatives and the least risk (the positive ideal solution) and the greatest risk (the negative ideal solution) which can lead to intuitive results more than measuring the distance.

This paper is organized as follows. In Section II, we proposed a new risk analysis method to solve risk-analysis
problems between IVFNs using a TOPSIS approach combined with a similarity measure. In Section III, we apply the proposed method to tackle risk of patient safety improving problems in health care organizations. The conclusions are presented in Section IV.

II. RISK-ANALYSIS METHOD FOR PATIENT SAFETY

We and Chen [16] presented a similarity measure between IVFNs that combined the concepts of the geometric distance, the perimeter, the height and the COG points of IVFNs to calculate the degree of similarity between IVFNs. They also provided proofs for three properties of the proposed similarity measure. We and Chen’s method can overcome the drawbacks of the existing similarity measures.

In this section, we use the TOPSIS approach and We and Chen’s similarity measure method to solve a risk-analysis problem. Assume that there are n alternatives A_1, A_2, ..., A_n. Each alternative has sub-risks center_R_1, center_R_2, ..., center_R_n. Decision makers are concerned not only with the severity of loss but also the probability of failure; thus, the integrated risk of each alternative is composed of these two sub-risk factors. We used a nine-member linguistic term set from Chen and Chen [6] to represent the linguistic terms and their corresponding IVFNs.

The proposed risk-analysis algorithm is presented in the following. The arithmetic operations between IVFNs are given in Chen [18] and We and Chen [16]. Based on the IVFN arithmetic operations, we first integrate the linguistic values \( \tilde{w}_i = (w_i^+; w_i^-; w_{si}^+; w_{si}^-, w_{si}^n) \) for the severity of loss and the values \( \tilde{p}_i = (p_i^+; p_i^-; p_{si}^+; p_{si}^-, p_{si}^n) \) for the probability of failure to obtain the integrated sub-risk \( \tilde{R}_i \) of each alternative, respectively, which can be calculated as follows:

\[
\tilde{R}_i = \tilde{w}_i \otimes \tilde{p}_i = \left[ \begin{array}{c} (w_i^+; w_i^-; w_{si}^+; w_{si}^-, w_{si}^n) \otimes (p_i^+; p_i^-; p_{si}^+; p_{si}^-, p_{si}^n) \end{array} \right] = \left[ \begin{array}{c} (w_i^+; w_i^-; w_{si}^+; w_{si}^-, w_{si}^n) \otimes (p_i^+; p_i^-; p_{si}^+; p_{si}^-, p_{si}^n) \end{array} \right]
\]

where \( 1 \leq i \leq n \).

Assume that \( \sigma_i \) is the importance of each sub-risk center_R_i. We modify the linguistic values \( \tilde{d}_i = (\sigma_i^+, \sigma_i^-, \sigma_i^{s+}, \sigma_i^{s-}, \sigma_i^n) \) for \( \tilde{d}_i \) with the arithmetic operation.

\[
\tilde{d}_i = \tilde{d}_i / \sum_{j=1}^{n} \tilde{d}_j = \left[ \begin{array}{c} (\sigma_i^+, \sigma_i^-, \sigma_i^{s+}, \sigma_i^{s-}, \sigma_i^n) \end{array} \right]
\]

where \( 1 \leq j \leq n \). The integrated risk \( \tilde{R}_i \) of each alternative is calculated as follows:

\[
\tilde{R}_i = \sum_{j=1}^{n} \left[ \tilde{d}_j \otimes \tilde{R}_j \right]
\]

\[
= \left[ (a_i^+, a_i^-, a_i^{s+}, a_i^{s-}, a_i^n), (b_i^+, b_i^-, b_i^{s+}, b_i^{s-}, b_i^n) \right]
\]

where \( 1 \leq i \leq n, 1 \leq j \leq k \).

Next, we rank the alternatives according to the decision-making criteria and give the risk of the ideal alternative for "excellence":

\[
\tilde{R} = \left[ (a^+, a^-, a^{s+}, a^{s-}, a^n), (b^+, b^-, b^{s+}, b^{s-}, b^n) \right]
\]

\[
= \left[ (0.0, 0.0, 0.0, 0.0, 1.0), (0.0, 0.0, 0.0, 0.0, 1.0) \right]
\]

We use the proposed similarity measure [16] to evaluate the degree of similarity between the IVFNs of \( \tilde{R} \) and the risk of the ideal alternative, \( \tilde{R} \).

\[
s(\tilde{R}, \tilde{R}) = \left[ \frac{S(\tilde{R}, \tilde{R}) \times S(\tilde{R}, \tilde{R})}{2} \right] \times \left[ \left( \frac{1}{\tilde{w}_{i}^{+} \tilde{w}_{i}^{-} \tilde{w}_{si}^{+} \tilde{w}_{si}^{-} \tilde{w}_{si}^{n}} \right) \right]^{\frac{1}{2}}
\]

\[
= \left[ \frac{S(\tilde{R}, \tilde{R}) \times S(\tilde{R}, \tilde{R})}{2} \right] \times \left[ \left( \frac{1}{\tilde{w}_{i}^{+} \tilde{w}_{i}^{-} \tilde{w}_{si}^{+} \tilde{w}_{si}^{-} \tilde{w}_{si}^{n}} \right) \right]^{\frac{1}{2}}
\]

\[
i = \begin{cases} 1, & \text{if } A(\tilde{R}) - A(\tilde{R}^a) = 0 \text{ and } A(\tilde{R}) - A(\tilde{R}^a) = 0, \\ 0, & \text{otherwise.} \end{cases}
\]

\[
u = \begin{cases} 1, & \text{if } a_i^+ = a_i^+ \text{ and } a_i^- = a_i^-, \\ 0, & \text{otherwise.} \end{cases}
\]

\( A(\tilde{R}) \) and \( A(\tilde{R}^a) \) denote the areas of the lower trapezoidal fuzzy number \( \tilde{R} \) and the upper trapezoidal fuzzy number \( \tilde{R}^a \), and \( A(\tilde{R}) \) and \( A(\tilde{R}^a) \) denote the areas of the lower trapezoidal fuzzy number \( \tilde{R} \) and the upper trapezoidal fuzzy number \( \tilde{R}^a \).

To calculate the degree of similarity \( s(\tilde{R}, \tilde{R}) \), we must first calculate the degrees of similarity \( s(\tilde{R}, \tilde{R}) \) and \( s(\tilde{R}, \tilde{R}) \) between the lower trapezoidal fuzzy numbers \( \tilde{R} \) and \( \tilde{R}^a \) and the upper trapezoidal fuzzy numbers \( \tilde{R} \) and \( \tilde{R}^a \).

After calculating the degrees of similarity between the lower trapezoidal fuzzy numbers \( \tilde{R} \) and \( \tilde{R}^a \) and the upper trapezoidal fuzzy numbers \( \tilde{R}^a \) and \( \tilde{R}^a \), respectively, we then calculate the COG points \( \left( x_{i}^+, x_{i}^- \right), \left( y_{i}^+, y_{i}^- \right), \left( x_{i}^+, y_{i}^- \right) \) and \( \left( x_{i}^+, y_{i}^- \right) \) of \( \tilde{R} \), \( \tilde{R}^a \), \( \tilde{R}^a \) and \( \tilde{R}^a \), respectively.

\[
\tilde{R}_k = \frac{y_k \times (x_k^+ + x_k^-)}{2w_k}, \text{ if } a_i^+ = a_i^- \text{ and } 0 \text{ or } w_k \leq 1,
\]

\[
y_k = \frac{w_k}{2}, \text{ if } a_i^+ = a_i^- \text{ and } 0 \text{ or } w_k \leq 1,
\]
To rank the alternatives according to the decision-making criteria, we take the risk of negative ideal alternative for "harful":

$$\tilde{R} = \left[\begin{array}{c} r^H_1, r^H_2, r^H_3; u^H_1, u^H_2, u^H_3; w^H_1, w^H_2, w^H_3 \end{array}\right] = \left[\begin{array}{c} (1, 1, 1, 1, 0, 0, 1, 1, 0, 0) \end{array}\right]$$

We then use the proposed similarity measure to evaluate the degree of similarity between the IVFNs of $\tilde{R}$ and the risk of the negative ideal alternative, $\tilde{R}^H$.

$$s(\tilde{R}, \tilde{R}^H) = \left[\frac{S(\tilde{R}, \tilde{R}^H) - S(\tilde{R}, \tilde{R}^H)_{\Delta}}{2\Delta}\right] \times (1-\Delta) \times (1-\Delta)$$

Finally, calculated the difference $\Delta x$ on the x-axis and the difference $\Delta y$ on the y-axis of the COG points of the IVFNs $\tilde{R}$ and $\tilde{R}^H$ are:

$$\Delta x = \begin{cases} x^*_R - x^*_H & \text{if } A(\tilde{R}_x) - A(\tilde{R}^H_x) \neq 0, \\ 0 & \text{otherwise,} \end{cases}$$

$$\Delta y = \begin{cases} y^*_R - y^*_H & \text{if } A(\tilde{R}_y) - A(\tilde{R}^H_y) \neq 0, \\ 0 & \text{otherwise,} \end{cases}$$

\[
y_{st}^{j} = \begin{cases} 
\frac{w_{st} + (r_{st}^{u} - r_{st}^{l})}{r_{st}^{u} - r_{st}^{l}} + 2, & \text{if } r_{st}^{u} \neq r_{st}^{l} \text{ and } 0 < w_{st} \leq 1, \\
\frac{w_{st}}{2}, & \text{if } r_{st}^{u} = r_{st}^{l} \text{ and } 0 < w_{st} \leq 1.
\end{cases} = 0.5 
\] (29)

Now, we can calculate the COG points \((x_{st}, y_{st})\) and \((x_{st}^{*}, y_{st}^{*})\) of the IVFN \(\tilde{R}\) and \(\tilde{K}\), respectively. The COG point \((x_{st}^{*}, y_{st}^{*})\) of the IVFN \(\tilde{K}\) was calculated from Eqs. (16)–(17).

The COG point \((x_{st}^{*}, y_{st}^{*})\) of the IVFN \(\tilde{K}\) is shown as follows

\[
x_{st}^{*} = \begin{cases} 
\frac{A(\tilde{R}^{u}) \times x_{st}^{u} - A(\tilde{R}^{l}) \times x_{st}^{l}}{A(\tilde{R}^{u}) - A(\tilde{R}^{l})}, & \text{if } A(\tilde{R}^{u}) - A(\tilde{R}^{l}) \neq 0, \\
0, & \text{otherwise},
\end{cases} \quad = 0 \] (30)

\[
y_{st}^{*} = \begin{cases} 
\frac{A(\tilde{R}^{u}) \times y_{st}^{u} - A(\tilde{R}^{l}) \times y_{st}^{l}}{A(\tilde{R}^{u}) - A(\tilde{R}^{l})}, & \text{if } A(\tilde{R}^{u}) - A(\tilde{R}^{l}) \neq 0, \\
0, & \text{otherwise},
\end{cases} \quad = 0 \] (31)

The difference \(\Delta x\) on the x-axis and the difference \(\Delta y\) on the y-axis of the COG points of the IVFNs \(\tilde{R}\) and \(\tilde{K}\) are now calculated as:

\[
\Delta x = \begin{cases} 
x_{st}^{*} - x_{st}^{*}, & \text{if } A(\tilde{R}^{u}) - A(\tilde{R}^{l}) \neq 0 \text{ and } A(\tilde{R}^{u}) - A(\tilde{R}^{l}) \neq 0, \\
0, & \text{otherwise}
\end{cases} \quad = 0 \] (32)

\[
\Delta y = \begin{cases} 
y_{st}^{*} - y_{st}^{*}, & \text{if } A(\tilde{R}^{u}) - A(\tilde{R}^{l}) \neq 0 \text{ and } A(\tilde{R}^{u}) - A(\tilde{R}^{l}) \neq 0, \\
0, & \text{otherwise}
\end{cases} \quad = 0 \] (33)

Finally, we calculate the relative closeness to the positive ideal solution. The relative closeness \(C_{r}\) of \(\tilde{K}\) with respect to \(\tilde{K}\) is defined as:

\[
C_{r} = \frac{S(\tilde{K}, \tilde{K})}{S(\tilde{R}, \tilde{K}) + S(\tilde{K}, \tilde{K}) + S(\tilde{R}, \tilde{R})} \quad 0 < C_{r} < 1 \quad i = 1, 2, ..., n \] (34)

A set of alternatives can now be preference ranked in descending order of \(C_{r}\).

The proposed fuzzy risk-analysis algorithm steps are as follows:

- **Step 1:** Integrate the linguistic values \(\tilde{W}_{s}\) of the severity of loss and the linguistic values \(\tilde{P}_{q}\) of the probability of failure to obtain the IVFNs of sub-risk \(\tilde{K}_{i}\) of each alternative (Eq. (1)).

- **Step 2:** Modify the linguistic values \(\tilde{S}_{q}\) of importance in each risk \(\tilde{K}_{i}\) to \(\tilde{S}_{q}\) (Eq. (2)).

- **Step 3:** Integrate the sub-risk \(\tilde{K}\) and importance \(\tilde{S}_{q}\) of each alternative (Eq. (3)).

- **Step 4:** Use the proposed similarity measure to evaluate the degrees of similarity between the IVFNs of \(\tilde{K}\) and the risk of the ideal alternative \(\tilde{K}\) (Eqs. (4)–(21)).

- **Step 5:** Use the proposed similarity measure to evaluate the degrees of similarity between the IVFNs of \(\tilde{K}\) and the risk of the negative ideal alternative \(\tilde{K}\) (Eqs. (22)–(33)).

- **Step 6:** Calculate the relative closeness to the ideal solution (Eq. (34)).

- **Step 7:** Rank the preference order.

### III. ILLUSTRATION OF THE PROPOSED METHOD IN IMPROVING PATIENT SAFETY

Giraud et al. [2] found that forty-four percent of all iatrogenic complications in their study were associated with either human errors (insufficient surveillance, inadequate experience) or equipment-related problems (equipment failure, inadequate equipment). A human error was defined as a deviation from standard conduct, as well as addition or omission of actions related to standard operational instructions or routines of the unit [19]. Thus, organizations in the healthcare sector acknowledged the fact that human errors must be managed and controlled. However, several studies identified that nurse-patient ratios impact on adverse outcomes, task completion, medication errors, falls and staff retention and costs [10]. Since workload per nurse may decrease as overall staffing size increases, a large staff is likely to have reduced workload, and therefore reduced nursing time pressure [5].

Patient safety is also affected by the work environment. In the matter of employee well-being, recent studies of quality of working life have been carried out to measure job stress, job dissatisfaction, and burnout experienced by the professions in a health care organization [20]. Time was not the only factor when nurses were stressed, it was also important how other co-workers reacted. Nurses were preoccupied with their relationship to other professions and how this can have a negative effect on their work. Therefore, a good relationship with other professions was felt to be important for patient safety. In a demanding work environment, such as in caring for critically ill patients, participation in decisions and support from colleagues can have a very positive effect in relation to patient safety [21]. Therefore, providing a pleasant work environment may improve the relationships between nurses with other professions and may positive influence patient safety.

To decrease the possibility of litigation, risk analysis focuses on maintaining minimum standards. Risk managers want to make sure that the standard of care is followed and that health care providers obtain informed consent, document thoroughly, communicate clearly, and act in compliance with regularity and accreditation [22]. Some researchers also found that the patient safety should be integrated into quality management system [8]. Quality management systems are defined as all processes were explicitly designed to monitor, assess and improve the quality of care [8]. Kalra [4] suggested that adopting intelligent systems approaches to promote
efficiency and enhancing team coordination to facilitate optimal outcomes in patient care is a necessity.

Here, we provide three alternatives \( (A_1, A_2, \text{ and } A_3) \) to illustrate the risk analysis process of the proposed method in a health care organization to improve patient safety.

Assume that there is a hospital \( H \) whose managements found that there were several medical errors which were harmful to patients happened in this organization, continuously. The managements want to improve the quality and safety of care provided to patients. After considering the causes of patient safety problem as mentioned in literatures and as happened in hospital \( H \), they brought several alternatives to improve patient safety. However, the alternatives could not be executed entirely since the cost budget was limited. Managements in hospital \( H \) decided to chose one of the alternatives described below which has the lowest risk in the organization to be the first to improve patient safety. The first alternative \( (A_1) \) is to hire more nurses to reduce workload and provide periodical training simultaneously. The second alternative \( (A_2) \) is to build a saloon for employees and attend to improve employee well-being. The third alternative \( (A_3) \) is to establish a risk management unit overseeing regularity and accreditation compliance for patient safety.

To analyze the risks, there are two evaluating items used to derive the probability of failure of the alternative selected by the hospital. We use the linguistic term set from Chen and Chen [6] to represent the linguistic terms and their corresponding IVFNs. The linguistic values of evaluating items and of the alternative and the importance of sub-risk are shown in Table I.

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<th>Items</th>
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<th>Operating risk</th>
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<td></td>
<td>Linguistic values of the severity of loss</td>
<td>Probability of failure</td>
</tr>
<tr>
<td>( A_1 )</td>
<td>( \hat{w}_1 = \text{high} )</td>
<td>( \hat{p}_1 = \text{low} )</td>
</tr>
<tr>
<td>( A_2 )</td>
<td>( \hat{w}_1 = \text{low} )</td>
<td>( \hat{p}_1 = \text{medium} )</td>
</tr>
<tr>
<td>( A_3 )</td>
<td>( \hat{w}_1 = \text{fairly low} )</td>
<td>( \hat{p}_1 = \text{low} )</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>( \hat{a}_1 = \text{high} )</td>
<td>( \hat{a}_2 = \text{very high} )</td>
</tr>
</tbody>
</table>

In the following, we use the proposed algorithm to solve the risk analysis problem.

- **Step 1**: Based on Eq. (1), we integrate the evaluating items \( \hat{w}_1 \) and \( \hat{p}_1 \) of alternative \( A_1 \) as follows:

\[
\bar{R}_{A_1} = \left[ \begin{array}{c} (0.0352, 0.0543, 0.086, 0.1036; 0.5), \\ (0.0128, 0.041, 0.1044, 0.1495; 1.0) \end{array} \right], \\
\bar{R}_{A_2} = \left[ \begin{array}{c} (0.0936, 0.1154, 0.1747, 0.2029; 0.5), \\ (0.0544, 0.0902, 0.2088, 0.273; 1.0) \end{array} \right], \\
\bar{R}_{A_3} = \left[ \begin{array}{c} (0.0203, 0.036, 0.052, 0.0652; 0.5), \\ (0.0068, 0.022, 0.0648, 0.0966; 1.0) \end{array} \right], \\
\bar{R}_{A_4} = \left[ \begin{array}{c} (0.0352, 0.0543, 0.086, 0.1036; 0.5), \\ (0.0128, 0.041, 0.1044, 0.1495; 1.0) \end{array} \right].
\]

- **Step 2**: Based on Eq. (2), we modify the importance \( \hat{a}_j \) of each sub-risk \( \hat{R}_j \) to \( \tilde{a}_j \):

\[
\tilde{a}_1 = \left[ \begin{array}{c} (0.4523, 0.4528, 0.4714, 0.4776; 0.5), \\ (0.4364, 0.4432, 0.4792, 0.4924; 1.0) \end{array} \right], \\
\tilde{a}_2 = \left[ \begin{array}{c} (0.5224, 0.5286, 0.5472, 0.5477; 0.5), \\ (0.5076, 0.5208, 0.5568, 0.5636; 1.0) \end{array} \right].
\]

- **Step 3**: Based on Eq. (3), we calculate the risk \( \tilde{R} \) as follows:

\[
\tilde{R}_1 = \left[ \begin{array}{c} (0.1156, 0.1526, 0.2249, 0.2555; 0.5), \\ (0.0646, 0.1221, 0.2667, 0.348; 1.0) \end{array} \right], \\
\tilde{R}_2 = \left[ \begin{array}{c} (0.0648, 0.0856, 0.1361, 0.1606; 0.5), \\ (0.0332, 0.0652, 0.1663, 0.2275; 1.0) \end{array} \right], \\
\tilde{R}_3 = \left[ \begin{array}{c} (0.0276, 0.0426, 0.0716, 0.0878; 0.5), \\ (0.0095, 0.0312, 0.0892, 0.1319; 1.0) \end{array} \right].
\]

- **Step 4**: Based on Eqs. (4) – (21), we use the proposed similarity measure to evaluate the degrees of similarity between the IVFNs of \( \tilde{k} \) and the risk of the positive ideal alternative \( \tilde{k} \), respectively. The results are shown as follows:

\[
S(\tilde{k}, \tilde{k}^+)=0.5817; S(\tilde{k}, \tilde{k}^-)=0.6427; S(\tilde{k}, \tilde{k}^-)=0.6903
\]

- **Step 5**: Use the proposed similarity measure to evaluate the degrees of similarity between the IVFNs of \( \tilde{k} \) and the risk of the negative ideal alternative \( \tilde{k} \) (Eqs. (22) – (33)).

\[
S(\tilde{k}, \tilde{k}^-)=0.1410; S(\tilde{k}, \tilde{k}^-)=0.0867; S(\tilde{k}, \tilde{k}^-)=0.0461
\]

- **Step 6**: Calculate the relative closeness to the ideal solution.

\[
C=0.8049; C_p=0.8811; C_p=0.9374
\]
• Step 7: Rank the preference order. According to the descending order of the $C_i$ values, the preference order is: $A_1 > A_2 > A_3$.

Without doubt, hospital $H$ will be a health care organization with high quality in patient safety, if all feasible alternatives are taken action by the managements. According to the limited budget, in the above risk analysis method for a health care organization in patient safety, we obtained the alternative $A_1$, we consider the hospital $H$ among the alternatives. To improve patient safety in the lower management risk, hospital $H$ should establish a risk management unit overseeing regularity and accreditation compliance for patient safety first. If there are remaining budget after executing alternative $A_1$, the managements in hospital $H$ may consider to execute alternative $A_3$. Using the proposed method, management can easily choose the alternative most appropriate for their organization’s situation using their own opinions of the risk in linguistic terms.

IV. CONCLUSION

In this study, we used the TOPSIS approach to manage the risk of a health care organization in the IVFN environment while improving patient safety. Rather than measuring the risk in patient individual, we measured the risks in the health care organizations. Considering the communication patterns, we used linguistic terms to represent their corresponding IVFNs because IVFNs are more appropriate for expert opinions in some complex situations. Generally, the risk of patient safety is affected by some factors, such as health care providers (nurse et al.), equipments and the quality management system which were discussed in past several decades. However, limiting to the cost-effectiveness of a health care organization, it may not take actions to improve all factors which will affect patient safety, simultaneously. A health care organization should consider the decision making risk while reducing patient safety risk. The proposed method provides a useful way for decision makers in a health care organization to handle risks in a variable, complex and uncertain environment. Moreover, it may reduce the cost to the organization in determining these risks.

REFERENCES