Risk Management and Healthcare Policy

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ORIGINAL RESEARCH

Evaluating Surgical Risk Using FMEA and MULTIMOORA Methods under a Single-Valued Trapezoidal Neutrosophic Environment

This article was published in the following Dove Press journal:
Risk Management and Healthcare Policy

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Background: Human errors during operations may seriously threaten patient recovery and safety and affect the doctor–patient relationship. Therefore, risk evaluation of the surgical process is critical. Risk evaluation by failure mode and effect analysis (FMEA) is a prospective technology that can identify and evaluate potential failure modes in the surgical process to ensure surgical quality and patient safety. In this study, a hybrid surgical risk–evaluation model was proposed using FMEA and multiobjective optimization on the basis of ratio analysis plus full multiplicative form (MULTIMOORA) method under a single-valued trapezoidal neutrosophic environment. This work aimed to determine the most critical risk points during the surgical process and analyze corresponding solutions.

Methods: A team for FMEA was established from domain experts from different departments in a hospital in Hunan Province. Single-valued trapezoidal neutrosophic numbers (SVTNNs) were used to evaluate potential risk factors in the surgical process. Cmprehensive weights combining subjective and objective weights were determined by the best–worst method and entropy method to differentiate the importance of risk factors. The SVTNN–MULTIMOORA method was utilized to calculate the risk-priority order of failure modes in a surgical process.

Results: The hybrid FMEA model under the SVTNN–MULTIMOORA method was used to calculate the ranking of severity of 21 failure modes in the surgical process. An unclear diagnosis is the most critical failure in the surgical process of a hospital in Hunan Province.

Conclusion: The proposed model can identify and evaluate the most critical potential failure modes of the surgical process effectively. In addition, such a model can help hospitals to reduce surgical risk and improve the safety of surgery.

Keywords: failure mode and effect analysis, surgical process, MULTIMOORA, best–worst method, single-valued trapezoidal neutrosophic numbers

Introduction

Surgical operations are a key health-care service and an important means to cure patients effectively.[1] In general, surgery comprises a series of processes, such as diagnosis, preoperative preparation, surgical operation, and postoperative care. However, any surgical procedure has risks,[2] and various human errors, such as diagnosis and clinical errors, may occur during operation. Certain human errors may be unharmful to a patient, whereas other errors may lead to serious results or death.[3] Ensuring surgical safety by risk assessment and reduction during the operation is crucial for surgeons and patients.[4–6] Therefore, an effective risk-evaluation method

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submit your manuscript | www.dovepress.com
DovePress
http://doi.org/10.2147/RMHP.S243331

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should be determined to identify the most critical risks in the surgical process, and measures must be taken to reduce surgical risk.

Failure mode and effect analysis (FMEA) was initially adopted to assess complex processes in the aerospace industry to identify possible causes of damage and determine remedial measures.[7] FMEA is an available and effective instrument for identifying and evaluating potential or critical failures in a system. This analysis helps in developing risk-management strategies,[8] such as supplier selection[9] and yacht-system design.[10] FMEA is also used in medical fields to evaluate critical failures, such as surgical cancelation factors[11] and hazards in surgical wards[12] and health-care management,[13,14] and to take remedial measures before substantial damage or failure occurs, in order to improve patient safety.[15] Traditional FMEA assesses and prioritizes the risk of failure modes on the basis of the risk-priority number (RPN). RPNs can be computed by multiplying occurrence (O), severity (S) and detection (D) (RPN=$O\times S\times D$).[16] However, restricted to its practical application, FMEA has numerous shortcomings.[17–20] Risk factors in FMEA are estimated on the basis of their subjective quantification by the crisp number scale of 1–10. However, practical applications involve vague and uncertain information that cannot be described by quantified crisp numbers accurately. In the classical FMEA, risk factors O, S, and D are assumed to be equally important and discrepancies in relative weights among risk factors neglected, which is unreasonable in real life. Obtaining the risk-priority ranking by RPNs remains controversial.

Numerous researchers have incorporated the fuzzy theory into FMEA to express the vague and uncertain information in risk evaluation accurately.[21–23] In practical applications, risk-evaluation information is expressed in linguistic terms of a fuzzy set (FS),[24] such as triangular fuzzy numbers,[25] trapezoidal fuzzy numbers,[26,27] intuitionistic fuzzy numbers,[28,29] and interval-valued intuitionistic fuzzy numbers.[30] As the extension of traditional FSs[31] and intuitionistic FSs,[32] single-valued trapezoidal neutrosophic fuzzy sets (SVTNFSs) can express additional uncertain information. Given the complexity of the surgical environment, various experiences and expertise of experts, the assessment information provided by experts is usually uncertain and vague. The evaluation information provided by experts in a limited time may be neutral, uncertain or inconsistent because their knowledge, attention or information processing capacities are distinctive.[33] Using SVTN numbers (SVTNNs) to express risk-evaluation information for the surgical process is suitable, because SVTNFSs can effectively describe uncertain and inconsistent information.[34–36]

Several researchers have emphasized the importance of risk factors in risk ranking of failure modes to consider discrepancies in risk factors in FMEA.[18] By contrast, FMEA is modified by calculating the weights of risk factors in different ways.[37,38] The analytic hierarchy process is commonly used to determine the subjective weight.[39,40] A new method for calculating subjective weight, ie, the best–worst method (BWM), has been examined by Rezaei.[41] Compared with the analytic hierarchy–process method, the BWM can provide more consistent comparisons and requires less information and computation.[42–44] Moreover, numerous studies have determined the comprehensive weights of risk factors by integrating subjective and objective weights.[45] In the FMEA case, objective weights of risk factors can be determined by a powerful multicriteria decision-making (MCDM) technique, ie, the entropy method.[46] Therefore, on the basis of the aforementioned discussion, the comprehensive weights of risk factors were obtained by the BWM and entropy method in this study.

Multiple risk factors should be considered, given the difficulty and complexity of defining the risk of potential failure modes by FMEA team members. Determining the risk priority of failure modes can be considered an MCDM problem.[42] Numerous MCDM techniques have been adopted to resolve risk-priority ranking. Examples of such techniques include *visekriterijumska optimizacija I kompromisno resenje* (VIKOR), preference-ranking organization methods for enrichment evaluations, and technique for order preference by similarity to ideal solution (TOPSIS).[37,42,47,48] Multiobjective optimization on the basis of ratio analysis plus full multiplicative form (MULTIMOORA) method[49,50] was derived from multiobjective optimization by ratio analysis (MOORA).[51] MULTIMOORA determines ranking results on the basis of the three perspectives (ie, the ratio system, reference point, and full multiplicative form).[52] This method can effectively solve multiobjective and MCDM problems. Compared with other methods, MULTIMOORA is simple, effective, and can easily compare and select alternatives.[49,51,53,54] The MULTIMOORA method has been widely used in decision-making in such topics as climate,[55] economies,[56] and electronics,[57] due to its flexibility, simplicity, and robustness.[58,59] The risk-assessment environment of the surgical process is complex. Risk evaluation of the surgical process by FMEA not only has multiple

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criteria but also multiple objectives, including maximizing O and S while minimising D. As such, the MULTIMOORA method can be used to obtain the risk-priority ranking of the surgical process to simplify the evaluation and enhance the robustness of ranking results.

This study investigated an effective surgical risk–evaluation method using the FMEA and MULTIMOORA methods under the SVTN environment. The most critical failures during a surgical process in a hospital were systematically identified and evaluated to reduce surgical risk and ensure operational security, using a hospital in Hunan Province as an example. The extended MULTIMOORA method overcomes the drawbacks of traditional FMEA in evaluation information, differentiation in importance of risk factors, and priority of failure modes. This study included the following work to achieve the objectives mentioned previously. Firstly, the potential failure modes of surgical processes were listed, and the causes and potential effects of the listed failure modes were analyzed systematically. Secondly, given the complex surgical environment and the distinct experiences and expertise of experts, SVTNN was used to represent the uncertain or inconsistent linguistic evaluation of risk factors provided by experts. Thirdly, comprehensive weights were obtained by combining the BWM with the entropy method to distinguish importance weights and deal with the same importance of risk factors in the classical FMEA. Finally, an extended MULTIMOORA method was applied to obtain the risk priority of the identified failure modes in FMEA.

Methods

At a hospital (denoted "X") in Hunan Province, potential risks in the surgical process were evaluated to improve the quality and safety of the operating room. A cross-functional team for FMEA was established from domain experts from different departments, including inpatient wards, operating rooms, and the anesthesiology department. The multidisciplinary FMEA team comprised a surgeon, the head nurse of the operating room, an anesthesiologist, and a deputy head nurse. The surgeon (TM_1) is a professor who has worked in the field for nearly 30 years. The head nurse of the operating room (TM_2) is an associate professor who has worked in the field for 27 years. The anesthesiologist (TM_3) is an associate professor who has worked in the field for 20 years. The deputy head nurse (TM_4) is an associate professor who has worked in the field for 25 years. Given that the surgeon has a deep understanding of the harm caused by mistakes during an operation, he carried large weight in assessing the O, S, and D of surgical failure modes. Therefore, given the qualifications and distinct experience of the four experts, the weight vector was assigned and denoted $\lambda = (0.3, 0.26, 0.2, 0.24)$. All experts completed the questionnaire related to surgical risk assessment independently.

Potential failure modes and their causes and effects during operations in the hospital were listed on the basis of the literature and expert opinions. A questionnaire was sent to each expert to collect information related to the importance of each failure mode and the linguistic evaluation of risk factors O, S, and D. Then, a hybrid FMEA method using MULTIMOORA was used to determine the most likely contributors to severe surgical failure by the ranking of failure modes. The specific steps involved in such stages are described in the following sections. Figure 1 shows the flowchart of the proposed hybrid risk-evaluation model.

Identifying and Evaluating Risk of Failure Modes

In general, surgery comprises a series of processes, ie, diagnosis, preoperative preparation, surgical operation, and postoperative care. Various risks may occur in each phase of the surgical process. Risk assessment subjective and FMEA scope should be determined to evaluate the risk of the surgical process. m potential failure modes $FM_i(i = 1, 2, \ldots, m)$ with respect to n risk factors $RF_j(j = 1, 2, \ldots, n)$ in surgery should be evaluated by l cross-functional experts $TM_k(k = 1, 2, \ldots, l)$ in the FMEA team. The linguistic evaluation of risk factors provided by FMEA team members was transformed into SVTNNs, and the decision matrix was obtained. The specific steps are given as follows.

Identifying and Listing Risk of Failure Modes

Based on previous studies, failures that may occur during operations include infection, adverse reactions to anesthetics and medicine used in surgical operations,[2] laboratory-test errors, delayed diagnosis,[4] improper scheduling, unrealistic operating rooms, insufficient medicine, insufficient required instruments and materials, insufficient staff, unavailable equipment, facility malfunctions, unavailable instruments and materials, incorrect sterilization,[11] errors in disinfection, isolation of infection, vital signs, medication delivery, ward rounds, surgical-site marking, postoperative care,[12,60–63] and missing information, nonexistent severity labels,[64] improper

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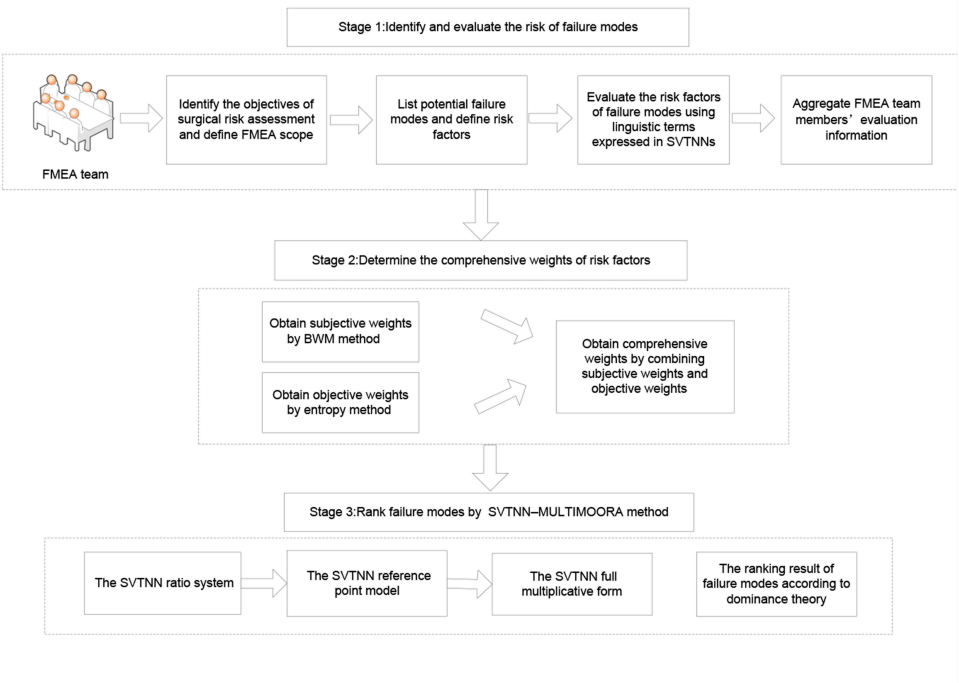

Figure 1 Flowchart of the proposed surgical risk evaluation model.

transport of patients, poor intraoperative management of surgical tools, and poor surgical record-keeping.[65] Figure 2 shows the hierarchical structure of the surgical process risk–analysis problem in accordance with the failures of the surgical process in previous studies and expert opinions of the FMEA team. Table 1 shows the failure modes and their relative failure causes and effects.

Evaluating Risk Factors of Failure Modes

In the traditional FMEA method, risk values of failure modes are evaluated by crisp numbers, which are inadequate or insufficient for assessing risks in real life.[30] FMEA team members tend to use linguistic terms to express evaluation information. SVTNNs can depict indeterminate and inconsistent information well.[34,35] As such, the proposed model adopts linguistic variables expressed in SVTNNs to evaluate the ratings of failure modes with regard to various risk factors. The definitions of neutrosophic set[66,67] and SVTNN[68] are presented in Appendix A. Each FMEA team member (TM_k) should give their opinion on the basis of a seven-point scale. Linguistic variables can be represented by SVTNNs (Table 2). Individual evaluation matrices are characterized by $R^{(k)} = \left(\tilde{a}_{ij}\right)_{m\times n}$.

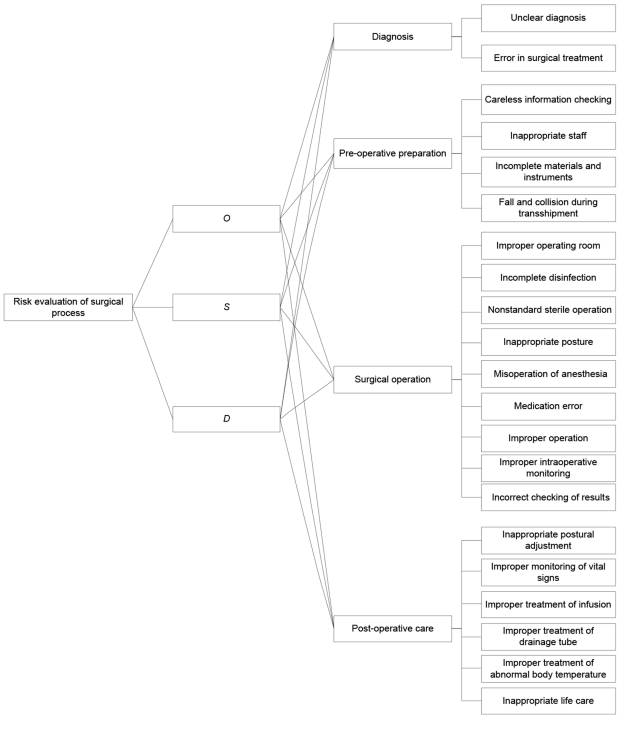

Figure 2 Hierarchical structure of surgical process risk analysis.

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Table 1 FMEA of the Surgical Process

Failure Modes	Failure Cause	Failure Effects	Corrective and Effective Measures
FM_1 Unclear diagnosis	Unclear examination Misjudgement of etiology	Unreasonable treatment	Multiaspect examination Careful recording
FM_2 Error in surgical treatment	Misdiagnosis Recording error	Affects the recovery of patients	Medical team consultation Communication with patients
FM_3 Careless information-checking	Medical record–information error Information-checking error	Inaccurate preparation Wrong patient	Careful checking of information
FM_4 Inappropriate staff	Shortage of operative nurses Strict requirements Contradictions in staffing	Increased surgical risk	Additional skills training Coordination with staff
FM_5 Incomplete materials and instruments	Imperfect equipment-preparation system Poor responsibility Untimely handover	Surgery interruption Long operative time	Improvement in preoperative equipment-preparation process Enhancement of responsibility Checking of equipment
FM_6 Fall and collision during transshipment	Decreased capacity Error in transport mode Imperfect emergency response	Fall Crush	Ensuring perfect transport mode Improvement of quality of nurses Improvement of emergency management
FM_7 Improper operating room FM_8 Incomplete disinfection	Careless information-checking Improper disinfectant Insufficient disinfection scope Incorrect disinfection method	Operational failure Infection	Checking of information Careful disinfection
FM_9 Nonstandard sterile operation	Nonstandard manner Delayed replacement of pollutants Disinfection without rigor	Infection	Strict disinfection
FM_{10} Inappropriate posture	Improper communication between doctors and patients Underappreciation	Soft-tissue injury Thrombosis in lower - Nerve injury	Emphasis of importance of posture Good physician–patient communication
FM_{11} Misoperation of anesthesia	Poor instrument status Insufficient vocational skill	Inaccurate monitoring of vital signs Endangerment of patient's life	Careful checking of the instrument Strict manipulation regulations
FM_{12} Medication error	Mistaken drug label Improper dosage Mistaken medication record	Endangerment of patient's life	Multiple checking Strict manipulation regulations Dosage following the doctor's advice
FM_{13} Improper operation	Improper identification of a surgical site Poor posture Inadequate specialized skills of a doctor	Excessive blood loss Shock	Careful checking of information Correct position Additional skills training
FM_{14} Improper intraoperative monitoring	Insufficient awareness of medical staff	Endangerment of patient's life	Strict monitoring of surgical operation
FM_{15} Incorrect checking of results	Unclear checking of instrument dressings Nonstandard instrument checking system Poor quality of nursing staff	Omission of operative foreign body	Strict implementation of the surgical instrument–checking system Careful recording of apparatus used Improvement of the quality of medical staff

(*Continued*)

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Table 1 (Continued).

Failure Modes	Failure Cause	Failure Effects	Corrective and Effective Measures
FM_{16} Inappropriate postural adjustment	Low safety awareness of nursing care Improper physician–patient communication	Influenced wound-healing Pain	Adjusting position based on surgical condition
FM_{17} Improper monitoring of vital signs	Careless monitoring Poor responsibility	Complication	Observation at regular intervals Full communication with patients
FM_{18} Improper treatment of infusion	Insufficient drug knowledge among medical staff Poor responsibility Self-regulation of patient	Influenced treatment effect Drug side effects Endangerment of patient's life	Improvement of knowledge in drug use Strengthening sense of responsibility Full communication with patients
FM_{19} Improper treatment of drainage tube	Indeterminate mark Improper replacement of drainage tube Careless checking	Unsmooth drainage Complication Infection	Strengthening sense of responsibility Implementation of aseptic technology Proper implementation of drainage-tube nursing
FM_{20} Improper treatment of abnormal body temperature	Untimely temperature testing Irrational cooling mode	Complication Infection	Timely monitoring of body temperature Cooling down following the doctor's advice
FM_{21} Inappropriate life care	Noisy environment Improper dietary care Insufficient care for patient	Influenced recovery Discomfort	Timely communication with patients Implementation of nursing procedures

Table 2 Linguistic Variables of SVTNNs for Linguistic Terms[69]

Linguistic Variables	SVTNNs
Very low (VL)	<[0.1,0.1,0.1,0.1],(0.5,0.3,0.3)>
Low (L)	<[0.2,0.2,0.4,0.5],(0.6,0.2,0.2)>
Medium low (ML)	<[0.3,0.4,0.5,0.6],(0.7,0.1,0.1)>
Medium (M)	<[0.4,0.5,0.6,0.7],(0.8,0.0,0.1)>
Medium high (MH)	<[0.5,0.6,0.7,0.8],(0.8,0.1,0.1)>
High (H)	<[0.7,0.8,0.9,1.0],(0.8,0.2,0.2)>
Very high (VH)	<[1.0,1.0,1.0,1.0],(0.9,0.1,0.1)>

From the SVTNN evaluation of risk factors provided by the FMEA team, the weight $\lambda = (\lambda_1, \lambda_2, \ldots, \lambda_l)^T$ vector of team members can be utilized to aggregate all individual evaluation matrices into the group-evaluation matrix $R = (\tilde{r}_{ij})_{m\times n}$.

Determining Comprehensive Weights of Risk Factors

Without weighting information for risk factors, traditional FMEA risk assessment may lead to an inaccurate risk ranking of failure modes. Therefore, weights of risk factors should be calculated to obtain an accurate risk ranking. Using a method proposed in a prior study,[41] weighting information for risk factors from subjective and objective perspectives can be computed using the BWM and entropy method. Therefore, comprehensive weights can be determined.

Calculating Subjective Weights Using BWM

Step 1: Determine a set of decision criteria.

In this step, the criteria $\{c_1, c_2, \ldots, c_n\}$ is considered to obtain a decision.

$$R = \sum_{k=1}^{l} \lambda_k R^k = (\tilde{r}_{ij})_{m\times n} R^{(k)} (k = 1, 2, \ldots, l) = \begin{bmatrix} \left\langle \left[a^1{}_{11}, a^2{}_{11}, a^3{}_{11}, a^4{}_{11}\right], (T_{11}, I_{11}, F_{11}) \right\rangle & \cdots & \left\langle \left[a^1{}_{1n}, a^2{}_{1n}, a^3{}_{1n}, a^4{}_{1n}\right], (T_{1n}, I_{1n}, F_{1n}) \right\rangle \\ \vdots & \vdots & \vdots \\ \left\langle \left[a^1{}_{m1}, a^2{}_{m1}, a^3{}_{m1}, a^4{}_{m1}\right], (T_{m1}, I_{m1}, F_{m1}) \right\rangle & \cdots & \left\langle \left[a^1{}_{mn}, a^2{}_{mn}, a^3{}_{mn}, a^4{}_{mn}\right], (T_{mn}, I_{mn}, F_{mn}) \right\rangle \end{bmatrix} \quad (1)$$

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Step 2: Determine the best (eg, most desirable, most important) and the worst (eg, least desirable, least important) criterion.

Step 3: Determine the preference of the best criterion over all other criteria using a number between 1 and 9. The resulting best-to-others vector would be $A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$, where a_{Bj} indicates the preference of the best criterion B over criterion j. Therefore, $a_{BB} = 1$.

Step 4: Determine the preference of all criteria over the worst criterion by using a number between 1 and 9. The resulting others-to-worst vector would be $A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})$, where a_{jW} indicates the preference of the criterion j over the worst criterion W. Therefore, $a_{WW} = 1$.

Step 5: Find the optimal weights $(w_1{}^*, w_2{}^*, \ldots, w_n{}^*)$.

The optimal weight for the criteria is that which for each pair of w_B/w_j and w_j/w_W, we have $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$. A solution where the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_w} - a_{jw}\right|$ for all j are minimal should be sought to satisfy these conditions for all j. Given the nonnegativity and condition for the weights, the problem results are presented as:

$$\begin{aligned} &minmax_j\left\{\left|\tfrac{w_B}{w_j} - a_{Bj}\right|, \left|\tfrac{w_j}{w_w} - a_{jw}\right|\right\} \\ &s.t. \\ &\sum_j w_j = 1 \\ &w_j \geq 0, \text{for } all\ j. \end{aligned} \tag{2}$$

Equation 2 is equivalent to:

$$\begin{aligned} &\min \xi \\ &s.t. \\ &\left|\tfrac{w_B}{w_j} - a_{Bj}\right| \leq \xi, for\ all\ j \\ &\left|\tfrac{w_j}{w_w} - a_{jw}\right| \leq \xi, for\ all\ j \\ &\sum_j w_j = 1 \\ &w_j \geq 0, \text{for } all\ j. \end{aligned} \tag{3}$$

Solving Equation 2), the optimal weights $(w_1{}^*, w_2{}^*, \ldots, w_n{}^*)$ and ξ^* are obtained.

Then, the consistency ratio (CR) is calculated using ξ^* and the corresponding consistency index:

$$CR = \frac{\xi^*}{Consistency\ Index} \tag{4}$$

Table 3 shows the maximum values of ξ (consistency index) for different values of a_{BW}.

If CR is ≤0.1, then the consistency is good and acceptable. Otherwise, a_{Bj} and a_{jW} can be revised to achieve a consistent solution.

The BWM is limited in deriving a unique optimum weight vector when the number of criteria is more than three, which may lead to multiple optimal solutions. An improved method[70] was used to obtain the optimal weights with n criteria. If $\left\{\left|w_B - a_{Bj}w_j\right|, \left|w_j - a_{jw}w_w\right|\right\}$ is used instead of $\left\{\left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_w} - a_{jw}\right|\right\}$, then the problem can be solved:

$$\begin{aligned} &minmax_j\left\{\left|w_B - a_{Bj}w_j\right|, \left|w_j - a_{jw}w_w\right|\right\} \\ &s.t. \\ &\sum_j w_j = 1 \\ &w_j \geq 0,\ for\ \text{all}\ j. \end{aligned} \tag{5}$$

Equation 5 can be transferred to this linear programming problem:

$$\begin{aligned} &\min \xi^L \\ &s.t. \\ &\left|w_B - a_{Bj}w_j\right| \leq \xi^L, for\ \text{all}\ j \\ &\left|w_j - a_{jw}w_w\right| \leq \xi^L, for\ all\ j \\ &\sum_j w_j = 1 \\ &w_j \geq 0, for\ all\ j. \end{aligned} \tag{6}$$

Computing Objective Weights

The main idea of the entropy method is that if the information entropy of the index is small, then the amount of information provided is large and the weight high. Therefore, the weight-determination method was performed on the basis of entropy under an SVTNN environment:[71]

$$H(A) = -1 \sum_{i=1}^{m\sum_i} f_i ln \tag{7}$$

$$f_i = \frac{Ex(\tilde{a}_i)}{\sum_{i=1}^{m} Ex(\tilde{a}_i)} \tag{8}$$

Table 3 Consistency-Index Values for Different Values of a_{Bw}

a_{Bw}	1	2	3	4	5	6	7	8	9
Consistency Index (max ξ)	0	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

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Then, the entropy weight can be computed:

$$w_j = \frac{\sum_{j=1}^{n} H(A_j) + 1 - 2H(A_j)}{\sum_{j=1}^{n}\left(\sum_{j=1}^{n} H(A_j) + 1 - 2H(A_j)\right)} \quad (9)$$

Obtaining Comprehensive Weights of Risk Factors

From the subjective and objective weight vectors derived from the above two steps, the synthetic weight of each risk factor was calculated:

$$w_j = \varepsilon w_j^s + (1-\varepsilon) w_j^o \quad (10)$$

where ε ($\varepsilon \in [0,1]$) is the adjustment parameter.

Ranking of Failure Modes by SVTNN–MULTIMOORA

The classical MULTINOORA method consists of three parts: the ratio system, the reference-point model, and the full multiplicative form.[30,54] It was extended into an SVTNN environment to rank failure modes in this study. The steps are:

Step 1: SVTNN ratio system.

The SVTNN group decision matrix R can be translated into the normalized decision matrix $\tilde{X} = [\tilde{x}_{ij}]_{m\times n}$ using the vector-normalization method:

$$\tilde{x}_{ij} = \langle [a^1{}_{ij}, a^2{}_{ij}, a^3{}_{ij}, a^4{}_{ij}], (T_{ij}, I_{ij}, F_{ij})\rangle = \left\langle \left[\frac{w_j a^1{}_{ij}}{d_j}, \frac{w_j a^2{}_{ij}}{d_j}, \frac{w_j a^3{}_{ij}}{d_j}, \frac{w_j a^4{}_{ij}}{d_j}\right], (T_{ij}, I_{ij}, F_{ij})\right\rangle \quad (11)$$

where $d_j = \frac{1}{4}\sqrt{\sum_{i=1}^{m}((a^1{}_{ij})^2 + (a^2{}_{ij})^2 + (a^3{}_{ij})^2 + (a^4{}_{ij})^2)}$.

After standardization, the summarising ratio $\tilde{y}_i$ of each failure mode was computed.Normalized ratios were added or subtracted to optimize

$$\tilde{y}_i = \sum_{j=1}^{g} \tilde{x}_{ij} - \sum_{j=g+1}^{n} \tilde{x}_{ij} \quad (12)$$

where $g = 1, 2, \ldots, n$ stands for the number of risk factors to be minimized and $\tilde{y}_i$ the normalised assessment of the ith failure mode with respect to all risk factors. If the value of $\tilde{y}_i$ is small, then the risk ranking is high.

Step 2: SVTNN reference-point model.

The SVTNN maximal objective reference point (SVTNN–MORP) vector $\tilde{r}_* = (\tilde{x}_1^*, \tilde{x}_2^*, \ldots, \tilde{x}_n^*)$ was found in accordance with the normalised SVTNN decision matrix $\tilde{X} = [\tilde{x}_{ij}]_{m\times n}$. In consideration of the SVTNNs, SVTNN–MORP was defined:

$$\tilde{x}_j^* = \begin{cases} \langle [max_i a^1{}_{ij}, max_i a^2{}_{ij}, max_i a^3{}_{ij}, max_i a^4{}_{ij}], (max_i T_{ij}, min_i I_{ij}, min_i F_{ij})\rangle, \\ \quad j \le g \\ \langle [min_i a^1{}_{ij}, min_i a^2{}_{ij}, min_i a^3{}_{ij}, min_i a^4{}_{ij}], (min_i T_{ij}, max_i I_{ij}, max_i F_{ij})\rangle, \\ \quad j > g \end{cases} \quad (13)$$

Then, the distance of each failure mode from the SVTNN-MORP can be calculated:

$$d_i = \max_j d(\tilde{x}_j^*, \tilde{x}_{ij}) \quad (14)$$

Therefore, the ranking orders of all failure modes can be determined in accordance with the deviation from the reference point and the min–max metric of Tchebycheff. If the value of d_i is large, then the risk ranking is high.

Step 3: SVTNN full multiplicative form.

The overall utility of the ith failure mode can be expressed as an SVTNN using the formula:

$$U_i = \frac{\tilde{A}_i}{\tilde{B}_i} \quad (15)$$

where $\tilde{A}_i = \prod_{j=1}^{g} \tilde{x}_{ij}$ denotes the product of factors of the ith failure mode to be minimized, with $g = 1, 2, \ldots, n$ being the number of factors to be minimized, $\tilde{B}_i = \prod_{j=g+1}^{n} \tilde{x}_{ij}$ denoting the product of factors of the ith failure mode to be maximized, and n-g being the number of factors to be maximized. If the value of U_i is small, then the risk ranking is high.

Step 4: Determine the risk level of each failure mode.

On the basis of the three ranking lists derived from the previous steps of SVTNN–MULTIMOORA, the final ranking of all failure modes was obtained by utilizing the dominance theory (for more details, please refer to Brauers et al[49]).

Results

Evaluation of Risk Factors

The FMEA team members $TM_k (k = 1, 2, 3, 4)$ in hospital X evaluated the ratings of failure modes for each risk factor using the linguistic variables described in Table 2. Then, the original evaluation information provided by the team members for these failure modes with respect to each risk factor was obtained (Table 1 in Appendix B). Table 2 shows that linguistic evaluations were converted into SVTNNs. Then, the SVTNWAA operator[35] was utilized to aggregate the evaluation of the individual FMEA team members with the weight vector of the FMEA team members $\lambda = (0.3, 0.3, 0.2, 0.2)$. The group-evaluation matrix was obtained (Table 4).

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Table 4 Group-Evaluation Matrix

FMs	O	S	D
FM_1	<[0.664,0.684,0.704,0.724], (0.8,1,0.9)>	<[0.838,0.892,0.946,1], (0.8,0.8,0.8)>	<[0.48,0.58,0.68,0.78], (0.8,0.92,0.9)>
FM_2	<[0.254,0.354,0.454,0.554], (0.654,0.854,0.854)>	<[1,1,1,1], (0,0,0)>	<[0.29,0.36,0.43,0.5], (0.6686,0.8,0.8)>
FM_3	<[0.19,0.26,0.33,0.4], (0.6286,0.8286,0.8286)>	<[1,1,1,1], (0,0,0)>	<[0.64,0.74,0.84,0.94], (0.8,0.83,0.83)>
FM_4	<[0.25,0.35,0.45,0.55], (0.65,0.85,0.85)>	<[0.23,0.33,0.43,0.53], (0.63,0.83,0.83)>	<[0.56,0.66,0.76,0.86], (0.8,0.87,0.87)>
FM_5	<[0.202,0.278,0.354,0.43], (0.6342,0.8342,0.8342)>	<[0.4,0.5,0.6,0.7], (0.8,1,0.9)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>
FM_6	<[0.226,0.326,0.426,0.526], (0.626,0.826,0.826)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>	<[0.3,0.4,0.5,0.6], (0.7,0.9,0.9)>
FM_7	<[0.202,0.278,0.354,0.43], (0.6342,0.8342,0.8342)>	<[0.3,0.4,0.5,0.6], (0.7,0.9,0.9)>	<[0.3,0.4,0.5,0.6], (0.7,0.9,0.9)>
FM_8	<[0.15,0.2,0.25,0.3], (0.6,0.8,0.8)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>
FM_9	<[0.232,0.308,0.384,0.46], (0.6737,0.8737,0.8737)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>	<[0.4,0.5,0.6,0.7], (0.8,1,0.9)>
FM_{10}	<[0.254,0.354,0.454,0.554], (0.654,0.854,0.854)>	<[0.4,0.5,0.6,0.7], (0.8,1,0.9)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>
FM_{11}	<[0.214,0.284,0.354,0.424], (0.6629,0.8629,0.8629)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>
FM_{12}	<[0.214,0.284,0.354,0.424], (0.6629,0.8629,0.8629)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>
FM_{13}	<[0.314,0.414,0.514,0.614], (0.714,0.914,0.87)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>
FM_{14}	<[0.226,0.326,0.426,0.526], (0.626,0.826,0.826)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>
FM_{15}	<[0.186,0.242,0.298,0.354], (0.6536,0.8536,0.8536)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>
FM_{16}	<[0.286,0.386,0.486,0.586], (0.686,0.886,0.856)>	<[0.4,0.5,0.6,0.7], (0.8,1,0.9)>	<[0.2,0.3,0.4,0.5], (0.6,0.8,0.8)>
FM_{17}	<[0.256,0.356,0.456,0.556], (0.656,0.856,0.856)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>	<[0.7,0.8,0.9,1], (0.8,0.8,0.8)>
FM_{18}	<[0.588,0.688,0.788,0.888], (0.8,0.856,0.856)>	<[0.4,0.5,0.6,0.7], (0.8,1,0.9)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>
FM_{19}	<[0.588,0.688,0.788,0.888], (0.8,0.856,0.856)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>	<[0.5,0.6,0.7,0.8], (0.8,0.9,0.9)>
FM_{20}	<[0.312,0.412,0.512,0.612], (0.712,0.912,0.856)>	<[0.4,0.5,0.6,0.7], (0.8,1,0.9)>	<[0.3,0.4,0.5,0.6], (0.7,0.9,0.9)>
FM_{21}	<[0.268,0.324,0.38,0.436], (0.8,1,0.9)>	<[0.2,0.3,0.4,0.5], (0.6,0.8,0.8)>	<[0.2,0.3,0.4,0.5], (0.6,0.8,0.8)>

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Comprehensive Weight Information on Risk Factors

Rating vectors of the most and least important criteria were determined by FMEA team members in accordance with the BWM (Table 2 in Appendix B). Subjective weights provided by the team members were determined using Equation 6. Synthetic subjective weights of the risk factors were obtained by utilizing the weighted averaging operator with consideration of the importance weights of team members $\lambda = (0.3, 0.3, 0.2, 0.2)$. Table 5 shows the optimal weight and the *CR* of comparisons. The reliability of the BWM can be indicated by checking the consistency of pairwise comparisons.[72] Table 5 shows that the *CR* values are close to 0, indicating the consistency of comparisons provided by team members. As such, the consistency results indicate the reliability of the subjective weights calculated from the BWM.

The objective weights of risk factors can be determined using Equation 7–Equation 9), as shown in

Table 6. Comprehensive weights of risk factors can be obtained using Equation 10 by combining the subjective and objective weights derived from the BWM and entropy method. Without losing the generality, we let $\varepsilon = 0.5$. Table 6 shows the comprehensive weights of risk factors.

Ranking of Failure Modes

The ranking of failure modes during the surgical process in hospital X was determined using the SVTNN–MULTIMOORA method in accordance with three perspectives: the ratio system, reference-point model, and full multiplicative form. Firstly, the normalized SVTNN evaluation matrix $\tilde{X} = [\tilde{x}_{ij}]_{21\times 3}$ was computed using Equation 11 (Table 3 in Appendix B). Then, the summarizing ratio $\tilde{y}_i$ of each failure mode was obtained utilising Equation 12. The SVTNN maximal objective reference point of each risk factor was determined using Equation 13. The distance (d_i) between the maximal objective reference point and each failure mode was calculated using Equation 14. The overall utility (U_i) of the $i(i = 1, 2, \ldots, 21)$st failure mode can be expressed as an SVTNN using Equation 15. Following the aforementioned steps, the results computed by the ratio system, reference-point approach, and full multiplicative form are obtained, as shown in Table 7.

The final ranking was obtained by aggregating the three ranking lists yielded by different parts of SVTNN–MULTIMOORA in accordance with the dominance theory. The last column in Table 8 shows the final ranking of the 21 failure modes acquired by the proposed FMEA model. The results demonstrate that the five most serious failures of hospital X are unclear diagnosis, careless information-checking, improper treatment of drainage tubes, improper administration of infusions, and improper operations, which require urgent and corrective action. Inappropriate life care is the least important failure during the surgical process in hospital X, and requires less improvement. Based on the ranking results, the hospital should adopt measures for the most serious failure modes to avoid surgical risk and improve the safety of operations.

Analysis of causes, effects, and prevention methods showed that an unclear diagnosis results from unclear examination and misjudgement of etiology. An incorrect diagnosis may seriously affect the safety and healing of patients. The probability of diagnosis error was high, and should be emphatically improved. A suggested solution to the problem is to adopt the consultation model of multidisciplinary teams to explore suitable treatment plans. The second most serious failure in the surgical process was error in information-matching, which leads to erroneous preoperative preparation. As such, medical staff should be required to check the patient's medical records, surgical treatments, surgical site, anesthesia methods, surgical instruments, and other information. This solution may be time-consuming and require improved personnel quality. Improper usage of drainage tubes and administration of infusions is caused by the poor professional quality of medical staff. Promoting professional knowledge, strong responsibility, sufficient communication, and strict guidelines for procedures are suggested to solve these

Table 5 Subjective Weights

	O	S	D	CR
TM_1	0.0909	0.7121	0.197	0.0203
TM_2	0.0909	0.6909	0.2182	0.0001
TM_3	0.2255	0.0588	0.7157	0.0365
TM_4	0.1429	0.2857	0.5714	0
w_j^s	0.12822	0.4898	0.38198	

Table 6 Objective and Comprehensive Weights

	O	S	D
Objective weights	0.3428	0.3304	0.3268
Comprehensive weights	0.2355	0.4101	0.3544

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Table 7 Ranking Indices $\tilde{y}_i$, d_i and U_i for Failure Modes

FMs	$\tilde{y}_i$	d_i	U_i
FM_1	<[0.474,0.516,0.558,0.6], (0.8,0.547,0.541)>	0.130981	<[0.004,0.005,0.006,0.008], (0.512,0.26,0.352)>
FM_2	<[0.376,0.415,0.455,0.494], (0.655,0.68,0.68)>	0.099926	<[0.001,0.002,0.003,0.004], (0,1,1)>
FM_3	<[0.443,0.482,0.522,0.561], (0.703,0.557,0.557)>	0.099926	<[0.002,0.0.003,0.004,0.005], (0,1,1)>
FM_4	<[0.246,0.317,0.388,0.46], (0.67,0.7,0.7)>	0.119976	<[0.004,0.001,0.002,0.003], (0.325,0.386,0.386)>
FM_5	<[0.31,0.376,0.441,0.507], (0.746,0.774,0.728)>	0.119236	<[0.001,0.001,0.003,0.004], (0.405,0.333,0.4)
FM_6	<[0.297,0.369,0.44,0.511], (0.713,0.673,0.673)>	0.124185	<[0.001,0.001,0.003,0.004], (0.35,0.406,0.406)>
FM_7	<[0.191,0.257,0.323,0.389], (0.679,0.706,0.706)>	0.118121	<[0.000,0.001,0.001,0.002], (0.31,0.325,0.325)>
FM_8	<[0.276,0.334,0.396,0.456], (0.752,0.682,0.682)>	0.119497	<[0.000,0.001,0.002,0.003], (0.384,0.352,0.352>
FM_9	<[0.272,0.338,0.403,0.469], (0.757,0.696,0.717)>	0.119497	<[0.001,0.001,0.002,0.003], (0.427,0.22,0.298)>
FM_{10}	<[0.275,0.346,0.418,0.489], (0.742,0.766,0.724)>	0.119236	<[0.001,0.001,0.003,0.004], (0.416,0.235,0.312)>
FM_{11}	<[0.387,0.452,0.516,0.581], (0.759,0.688,0.688)>	0.124185	<[0.001,0.002,0.004,0.006], (0.427,0.445,0.445)>
FM_{12}	<[0.341,0.405,0.47,0.534], (0.759,0.666,0.666)>	0.124185	<[0.001,0.002,0.003,0.005], (0.427,0.376,0.376)>
FM_{13}	<[0.364,0.435,0.507,0.578], (0.771,0.712,0.692)>	0.124185	<[0.001,0.003,0.004,0.007], (0.464,0.334,0.37)>
FM_{14}	<[0.34,0.412,0.483,0.554], (0.732,0.734,0.734)>	0.119497	<[0.001,0.002,0.004,0.006], (0.4,0.406,0.406)>
FM_{15}	<[0.381,0.442,0.503,0.565], (0.761,0.672,0.672)>	0.124185	<[0.001,0.002,0.003,0.005], (0.416,0.456,0.456)>
FM_{16}	<[0.213,0.284,0.355,0.427], (0.713,0.796,0.744)>	0.119236	<[0.000,0.001,0.002,0.003], (0.324,0.3,0.388)>
FM_{17}	<[0.347,0.419,0.49,0.561], (0.742,0.744,0.744)>	0.119497	<[0.001,0.002,0.004,0.006], (0.416,0.388,0.388)>
FM_{18}	<[0.352,0.424,0.495,0.566], (0.8,0.766,0.724)>	0.119236	<[0.002,0.003,0.004,0.007], (0.512,0.235,0.312)>
FM_{19}	<[0.377,0.448,0.52,0.591], (0.8,0.724,0.724)>	0.119497	<[0.002,0.003,0.005,0.008], (0.512,0.312,0.312)>
FM_{20}	<[0.242,0.313,0.385,0.456], (0.742,0.786,0.724)>	0.119236	<[0.001,0.001,0.002,0.003], (0.392,0.19,0.312)>
FM_{21}	<[0.158,0.22,0.281,0.342], (0.652,0.711,0.685)>	0.121848	<[0.000,0.000,0.001,0.001], (0.288,0.36,0.424)>

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Table 8 Final Ranking of Failure Modes

FMs	SVTNN Ratio System	SVTNN Reference-Point Model	SVTNN Full Multiplicative Form	Final
FM_1	1	8	1	1
FM_2	9	1	20	11
FM_3	2	1	21	2
FM_4	17	5	15	18
FM_5	15	3	11	12
FM_6	11	7	14	16
FM_7	19	2	18	19
FM_8	13	4	16	17
FM_9	14	4	12	14
FM_{10}	16	3	9	12
FM_{11}	4	7	6	7
FM_{12}	7	7	8	9
FM_{13}	6	7	4	5
FM_{14}	12	4	7	8
FM_{15}	3	7	10	9
FM_{16}	20	3	17	20
FM_{17}	10	4	5	6
FM_{18}	8	3	3	4
FM_{19}	5	4	2	3
FM_{20}	18	3	13	15
FM_{21}	21	6	19	21

failures. Improper procedures may cause serious consequences, but the possibility of procedural errors in hospital X is small. The staff in the operating room should carefully check information and correctly mark the operational siteto solve this problem.

Discussion

Surgery is one of the important methods of treating diseases and comprises a series of processes, including diagnosis, preoperative preparation, surgical operation, and postoperative care. Each process has accompanying risks and may seriously affect operation quality and patient safety. Therefore, the risk assessment of each segment of the surgical process is critical for the safety and quality of surgery, along with improvement in the physician–patient relationship.

The International Organization for Standardization suggests that FMEA is a prospective risk-analysis technology for high-risk processes.[73,74] FMEA can be used systematically to define and evaluate potential risk-failure modes in the surgical process, analyze the causes and effects of potential failures, and implement effective measures to control them. However, the classical FMEA has limitations. The proposed hybrid FMEA in this study overcomes these shortcomings. The hybrid FMEA can identify several potential failures in the surgical process and consider linguistic evaluation of information provided by experts, instead of crisp ratings. The final risk ranking of failure modes obtained by the extended SVTNN–MULTIMOORA method helps the hospital's medical team to focus on major surgical-process failures. Several critical failure modes that needed to be solved were obtained by evaluating the risk points in the surgical process of a hospital in Hunan Province.

Risk Factors

Among the MCDM techniques used in the proposed hybrid FMEA model, the BWM was used to determine the subjective weights of risk factors. Table 5 shows the importance of risk-factor rankings obtained by four experts. Three experts believed that the severity-of-failure mode is the most important factor, whereas another expert believed that its detectability is the most important factor. After the opinions of four experts had been comprehensively considered, the importance of risk factors was ranked as $S>D>O$. Risk factor S with, a weight of 0.4898, was the most important factor. As such, the S of failures is a concern in surgical-risk evaluation for effectively improving operation quality and security. The O of failures was the least important among the three risk factors. Experts agreed that the S of errors in the surgical process was more important than O. In generating subjective weights, inconsistencies may occur because of the complex judgment of experts.[43] All CR values were close to 0, suggesting that the importance of risk factors provided by experts was consistent.

The basic principle of the entropy method is that if the information entropy of the index is small, the index may provide additional information and the weight should be high. The importance ranking of risk factors based on entropy weight was $O>S>D$ according to the evaluation of information provided by the experts. As such, the risk factor O provides more information than the others, but small differences exist among the entropy weights of the three risk factors.

The comprehensive importance of risk factors was ranked as $S>D>O$ on the basis of the principle of combining the subjective and objective weights. Considering the subjective judgment of experts and the amount of information provided by risk factors, S is more important than the other risk factors. If the S of failure mode is high, then additional attention should be given to this factor.

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Failure-Mode Ranking

According to the proposed hybrid FMEA model, the ranking result of failure modes was directly influenced by the comprehensive weight information of risk factors. The ranking result depends considerably on the proportion of ε for subjective and objective weights. ε is the adjustment parameter and was set to 0.5 in this work, with a value range of [0, 1]. Different values of ε, ie, $\varepsilon = (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1)$, were used to analyze the impact of ε on failure-modes ranking. Figure 3 presents the influence of the ranking of each failure mode with various ε values.

Figure 3 shows that based on the variable value of ε, slight changes in the most critical failure modes can be observed under various circumstances. If ε is < 0.8, then FM_1 is the most critical failure mode. Otherwise, FM_3 is deemed the most critical. Given that the weight of the risk factor S was considerably higher than the other risk factors and the S of FM_3 was higher than that of FM_1, FM_3 was more critical than FM_1 when subjective weights account for a large proportion. When ε<0.3, all ranking results changed slightly, and when ε was near 1, the ranking results were stable. Conclusively, each failure mode produced a minor change in the risk ranking when ε changed from 0 to 1. A robust ranking result of failure modes was obtained, and the five most severe failures in the hospital comprised unclear diagnosis, careless information-checking, improper treatment of drainage tubes and improper infusion procedures.

In summary, the professional skills and moral quality of the operating-room staff should be emphatically improved. Measures should be implemented, even given the high cost of manpower, money, and time. In modern society, medical errors and doctor–patient relationship problems often occur in hospitals. Highly professional and responsible staff should ensure that each patient and operation process is taken seriously to improve the quality and safety of operations and ease the relationship between doctors and patients.

Comparative Analysis with Other MCDM Methods

The proposed FMEA method was compared with the classical FMEA method, the crisp MULTIMOORA method,[50] and the SVTNN–TOPSIS method[75] to demonstrate its effectiveness and reliability further. Rankings are presented in Table 9 and Figure 4.

Although the risk rankings of failure modes were unidentical, the most critical failure mode in all methods was FM_1 and the least serious FM_{21}. This finding is consistent with the results of the proposed model. Therefore, the proposed model is effective in properly ranking the failure modes.

However, the risk rankings among classical FMEA, crisp MULTIMOORA, and SVTNN–TOPSIS and the proposed method present several differences. Table 9 shows that the ranking results of crisp MULTIMOORA were consistent with those of the classical FMEA. The ranking order of FM_3, FM_9, FM_{10}, FM_{12}, FM_{13}, FM_{14}, FM_{17}, FM_{18}, and FM_{19} obtained using the two methods differed from those of the

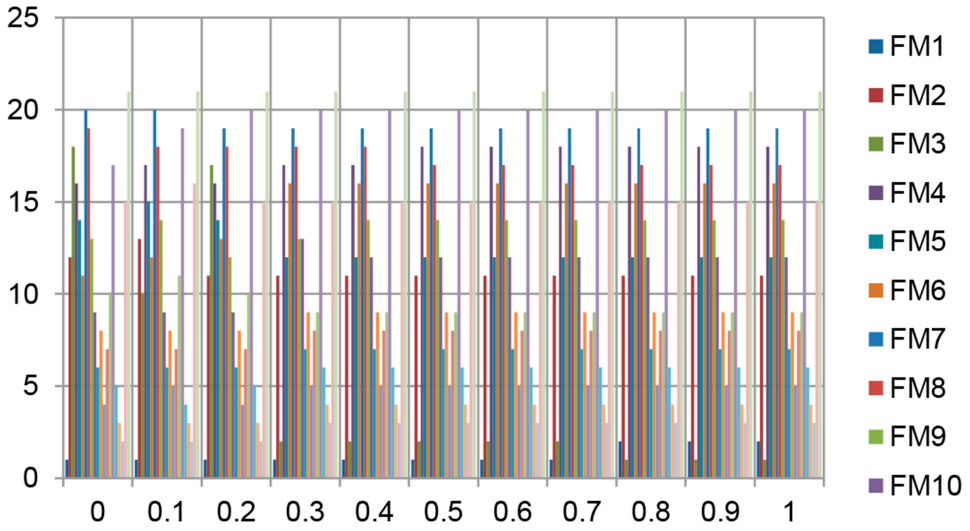

Figure 3 Ranking of failure modes for different ε-values.

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Table 9 Comparison of different methods

FMs	SVTNN–MULTIMOORA	Classical FMEA	Crisp MULTIMOORA	SVTNN–TOPSIS
FM_1	1	1	1	1
FM_2	11	14	13	15
FM_3	2	8	8	9
FM_4	18	18	16	13
FM_5	12	12	12	10
FM_6	16	16	17	16
FM_7	19	20	18	20
FM_8	17	15	19	17
FM_9	14	11	11	14
FM_{10}	12	13	13	12
FM_{11}	7	7	7	5
FM_{12}	9	10	10	11
FM_{13}	5	4	4	6
FM_{14}	8	6	6	7
FM_{15}	9	9	9	8
FM_{16}	20	19	20	19
FM_{17}	6	5	5	4
FM_{18}	4	3	3	3
FM_{19}	3	2	2	2
FM_{20}	15	17	15	18
FM_{21}	21	21	21	21

proposed model. A deviation in ranking results was observed because the imprecise and uncertain information in failure-mode evaluation was not considered in the classical FMEA or the crisp MULTIMOORA method. Therefore, the SVTNN–MULTIMORA method can provide more information for decision-makers than classical FMEA or crisp MULTIMOORA.

In the classical FMEA, assuming that the weights of risk factors are equal is unreasonable. For example, the evaluation information of FM_2 under risk factor S is considerably larger thanunder the other two risk factors. FM_2 ranked 14 in the classical FMEA. Given that the weight of S was higher than O in the proposed method, FM_2 ranked 11, three places above that in the classical FMEA. These results were caused by the same weight of risk factors assigned in classical FMEA. Therefore, comprehensive weighting of risk factors by the BWM and entropy method is reasonable and applicable.

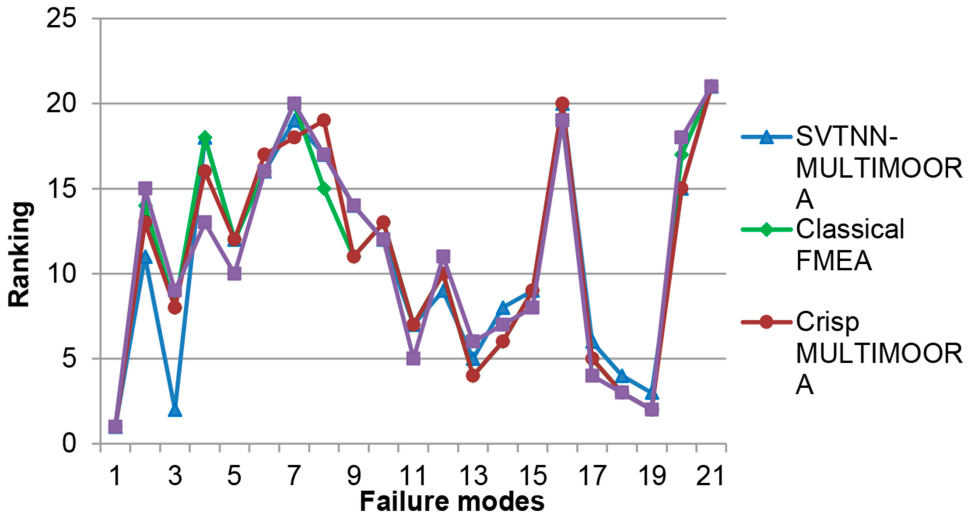

Figure 4 Ranking results of different methods.

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Figure 4 shows that the risk ranking obtained by SVTNN–TOPSIS differed from that acquired using the method proposed in this paper. This result is attributed to the failure mode that is close to the positive ideal value in TOPSIS, but may also be close to the negative ideal value. Moreover, the SVTNN–TOPSIS method considers only objective entropy weight and disregards the effect of experts' subjective opinions on ranking results. Therefore, SVTNN–TOPSIS cannot fully reflect the risk of failure modes, thus affecting the accuracy of decision-making results. In the proposed SVTNN–MULTIMOORA method, the ranking of failure modes was determined in accordance with ranking results obtained by three decision-making methods: the SVTNN ratio system, the SVTNN reference-point method, and the SVTNN full multiplication model. Compared with other MCDM methods, the proposed method exhibits better applicability, potential, and ease of implementation. The proposed method also integrates subjective and objective weights and can obtain reasonable risk priority. The proposed hybrid SVTNN–MULTIMOORA model can obtain effective rankings.

Future Research Orientation

The hybrid FMEA method was used to analyze risks in surgical processes of a hospital in Hunan Province systematically, identify all potential failures, and determine the most critical failures. This method proposes corresponding solutions and is superior to other risk-assessment methods. Although the proposed FMEA model can effectively assess the risk of the surgical process, several points, such as changes in the surgical environment and certain risk factors not considered in this study, should be studied in future. In addition, through communication with hospitals, data on surgical errors before and after intervention measures should be collected and corresponding changes compared and analyzed.

Conclusion

A reliable and practical risk-assessment model can reduce risks during surgery and disease treatment. FMEA is widely used to evaluate failure modes in many fields, although such a method has shortcomings. However, few studies have systematically assessed the risk of the surgical process by FMEA. A hybrid risk-assessment model of the surgical procedure was proposed in this study on the basis of extended FMEA. The method was helpful in identifying high-risk failure modes in the operation process and suggesting corresponding measures in advance to prevent the occurrence of surgical errors. Improving the quality of surgery and safety management and alleviating the doctor–patient relationship are conducive strategies.

Acknowledgments

This work was supported by the Human Philosophy Social Science Fund Projects (No. 18YBA150), the Key Project of Hunan Education Department (No. 18A201), Project of Hunan Federation of Social Sciences (No. XSP20YBC318), and the Hunan Provincial Natural Science Fund (Nos. 2018JJ5004, 2019JJ40088, and 2019JJ40479).

Disclosure

Peng-Fei Cheng reports grants and personal fees from the Department of Science and Technology of Hunan Province, Social Science Planning Office of Hunan Province, and the Department of Education of Hunan Province. Ji-Qun He reports grants and personal fees from the Hunan Provincial Natural Science Fund and Hunan Federation of Social Sciences during the study. The authors declare that they have no other possible conflicts of interest.

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