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Modified FUZZY ARAS Method for Application to Selection of Functional Improvement Plans for Surgical Light

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Keywords: surgical light, product function, modified FUZZY DANP, modified FUZZY ARAS

ABSTRACT

The paper applies a method, which combines the modified FUZZY DANP with the modified FUZZY ARAS, to select the prioritized function improvement plan for surgical light. First of all, the paper reviews the related patent literature and various patent analyses about the product of surgical light, and uses the functional words of the patents to screen out the criteria of product functions, which are divided into six functional fields. The paper takes these six functional fields as the criteria for function evaluation in selecting the improvement plans of a new surgical light product. The paper takes three product functional improvement plans of surgical light as the selection plans. These three functional improvement plans are: plan A: Enhancement of convenience of operation + Enhancement of lighting efficiency; plan B: Improvement of heat dissipation and service life + Enhancement of lighting efficiency; and plan C: Enhancement of convenience of operation + Improvement of heat dissipation and service life. Through combining product functions with the modified FUZZY DANP and the modified FUZZY ARAS, the prioritized weight values of the improvement plans can be obtained, and the prioritized product function improvement plan for surgical light can be selected.

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INTRODUCTION

Surgical lights are used as medical lighting equipment in the medical field, so all the possible unknown factors that may be detrimental to doctors' performance during surgery must be reduced. Surgical lights must possess sufficient brightness, color temperature and heat dissipation function, and must be as sterile as possible. Liang et al. (2017) mentioned that a surgical light included a suspension system or a support system, or multiple suspension support systems to hold the socket of a light bulb, from which light source is provided; and the light source was connected to a driving circuit for use as a light source driver; the driving circuit was connected to the operation interface to adjust the light intensity of the required light source.

Tzeng et als. (2017) mentioned that the main functions and characteristics of DEMATEL (Decision Making Trial and Evaluation Laboratory) were to observe the degree of influence among various criteria, and then obtain the causal relationship among all criteria through matrix and its mathematics-related theoretical calculations, and also use the matrix's numbers and Influential Network Relation Map (INRM) to express the intensity of influencing relationship and causal relationship among various criteria, so as to find the core issues and improvement directions from complicated issues. Ou Yang et al. (2008) proposed in a research a new decision-making method with multiple criteria mixed, called DANP method, which combines DEMATEL and ANP (Analytic Network Process) methods. Chang et al. (2012) used FUZZY DEMATEL and ANP methods to focus on modeling a high-performance project team. Lu et al. (2013) developed the fuzzy DANP (ANP-based fuzzy DEMATEL) to explore the relationship issue that managers should consider expanding their efforts to enhance practices of environmental protection, green products and processes, and design innovative networks following their green strategic direction. The Additive Ratio Assessment (ARAS) is Zavadskas and Turskis (2010) proposed the Additive Ratio Assessment (ARAS) method, which was a calculation method mainly used to select the optimal plan based on multiple criteria. The calculation of ARAS was conducted through the relative weight values of various plans and criteria. The results obtained could be used to determine the ranking of various plans. The ANP technology could calculate the relative weight values between the plans and criteria of a brand. The relative weight values between the plans and criteria obtained by ANP method could be substituted into the FUZZY ARAS method to further calculate the ranking of various plans for selection.

BRIEF INTRODUCTION OF SURGICAL LIGHT

Liang's patent (2005) mentioned that a surgical lamp needed to have an appropriate color temperature, and have a handle to fine-tune the illumination zone. Liang et al. (2017) proposed one or multiple control panels connected to the driving circuit for adjusting the light intensity of the light source as needed. As seen from the above patents, surgical light is the most principal equipment used to illuminate the area where surgery is performed, and is usually composed of a cantilever, a lampshade, a handle, a control panel, a reflector and a lamp assembly.

For the schematic diagram of surgical light in Figure 1, its detailed description is as follows. In Figure 1, (A) shows the schematic diagram of the overall structure of surgical light. It can be seen that there are: 1. Support bracket structure technology, which includes a cantilever, a rotating shaft, etc., and is used to support the entire light; 2. Light's handle and its peripheral structure technology, which includes a handle that can fine-tune the depth or range of light source illumination; 3. Light source arrangement and variation technology; 4. Light source heat dissipation and air flow technology, which includes air flow channel, etc., and is used to transfer and dissipate the heat generated by the light source; 5. Light source and power control technology, which includes 5a. Operation interface, which is used to adjust the color temperature, brightness or switch of the light source. Besides, Figures 1 (B) and (C) introduce two different components of 7. Surgical light body in (A) Schematic diagram of the overall structure of surgical light. In Figure 1 (B), it can be seen that there are 3. Light source arrangement and variation technology, which includes 3a. Light components, and 6. Light source illumination range and illumination technology, which includes 6a. Designated lighting area of reflector in the way of reflecting light. In Figure 1 (C), it can be seen that there is 3. Light source arrangement and variation technology, which includes multiple 3a. Light components, which illuminate the designated area in the way of direct illumination.

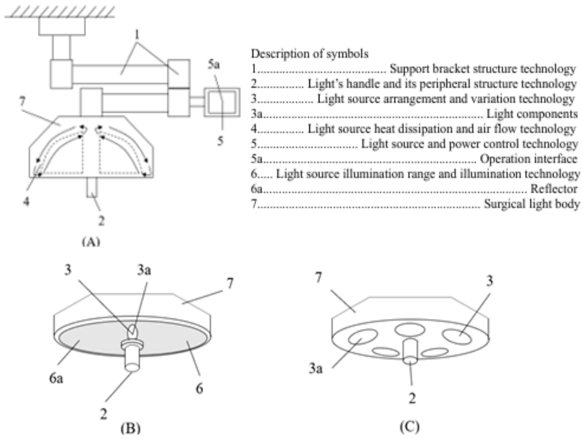

Figure 1. Schematic diagram of surgical light,

When exploring the patent contents and their engineering knowledge, the paper defines the first layer of technical field of surgical light, which is divided into three technical fields, namely 1. Overall bracket structure technology, 2. Lampshade structure technology, and 3. Lamp control technology. They are further subdivided into six technologies in the second layer of technology, namely 1. Support bracket structure technology, 2. Light's handle and its peripheral structure technology, 3. Light source arrangement and variation technology, 4. Light source heat dissipation and air flow technology, 5. Light source and power control technology, 6. Light source illumination range and illumination technology. These six technologies shall be the important basis for the subsequent analysis of technology/function matrix.

USING PRODUCT FUNCTIONS TO COMBINE THE MODIFIED FUZZY DANP AND THR MODIFIED FUZZY ARAS DECISION-MAKING PROCESSES TO SELECT PRIORITIZED IMPROVEMENT PLAN FOR SURGICAL LIGHT

Using Functional Words of Surgical Light Patents to Screen Out the Product Technology/Function Criteria

The paper explores the related literature and various patents of surgical light products. Through the term and word segmentation system, the paper screens out from the surgical light-related patents six product function criteria, namely a. Enhancement of convenience and stability of operation, b. Improvement of heat dissipation and air flow quality, c. Reduction of costs and extension of service life, d. Improvement of shadow effect and visual clarity to the eyes, and reduction of eyestrain, e. Improvement of light uniformity and brightness, and f. Adjustment of illumination range. The paper also establishes a product technology/function matrix. In the technology/function matrix, the first-layer technologies and the second-layer technologies are just what are described in the above contents of the technical fields. Subsequently, according to the searched surgical light-related patents, the paper establishes the six functional fields' functional word and part/component word groups, as shown in Table 1 (Liu,2021). The six functional fields in Table 1 are taken as the six function criteria of the paper.

Table 1 Functional word groups of functional fields of surgical light-related patents (Liu,2021)

Functional field	Functional word group
a. Enhancement of convenience and stability of operation	handle, rotation, light source, illumination, control … etc.
b. Improvement of heat dissipation and air flow quality	illumination, air flow, heat dissipation, light source, fixed … etc.
c. Reduction of costs and extension of service life	disposable, brightness, sterile, handle cover, energy-saving … etc.
d. Improvement of shadow effect and visual clarity to the eyes, and reduction of eyestrain	light source, illumination, color temperature, reflection, light spot … etc.
e. Improvement of light uniformity and brightness	light source, intensity, illumination, rotation, light spot … etc.
f. Adjustment of illumination range	light source, illumination zone, illumination, adjust, beam … etc.

Establishment of Three Design Plans of Surgical Light for its Product Functions

The paper proposes three interdependent functional plans for "surgical light". Each of these plans contains two functional improvement groups to make the three plans interdependent. Plans A, B and C are explained as follows:

plan A: "Enhancement of convenience of operation + Enhancement of lighting efficiency"

plan B: "Improvement of heat dissipation and service life + Enhancement of lighting efficiency"

plan C: "Enhancement of convenience of operation + Improvement of heat dissipation and service life"

For plan A, "Enhancement of convenience of operation + Enhancement of lighting efficiency", the functional group of "Enhancement of convenience of operation" contains one function criterion, which is a. Enhancement of convenience and stability of operation, whereas the functional group of "Enhancement of lighting efficiency" contains three function criteria, which are d. Improvement of shadow effect and visual clarity to the eyes, and reduction of eyestrain, e. Improvement of light uniformity and brightness, and f. Adjustment of illumination range.

For plan B, "Improvement of heat dissipation and service life + Enhancement of lighting efficiency", the functional group of "Improvement of heat dissipation and service life" contains two function criteria, which are b. Improvement of heat dissipation and air flow quality, and c. Reduction of costs and extension of service life, whereas the functional group of "Enhancement of lighting efficiency" contains three function criteria, which are d. Improvement of shadow effect and visual clarity to the eyes, and reduction of eyestrain, e. Improvement of light uniformity and brightness, and f. Adjustment of illumination range.

And for plan C, "Enhancement of convenience of operation + Improvement of heat dissipation and service life", as mentioned above, these two functional groups contain three function criteria, which are a. Enhancement of convenience and stability of operation, b. Improvement of heat dissipation and air flow quality, and c. Reduction of costs and extension of service life.

Steps and Processes of Combining Product Functions with the Modified FUZZY DANP and the Modified FUZZY ARAS Methods for Ranking of Various Plans of Surgical Light for Selection

The following description shows the steps to select the prioritized improvement plan for surgical light by combining product functions with the FUZZY DANP and FUZZY ARAS methods. [Step 1] to [Step 9] are steps of the modified FUZZY DANP method, whereas [Step 10] to [Step 15] are steps of the modified FUZZY ARAS method for selection of prioritized improvement plan.

【Step 1】Pairwise comparison results of various product function criteria (W_1)

For the functional word group of each function criterion, the paper calculates the normalized numerical value of each function criterion, and the equation for calculating the above normalized numerical values is expressed as equation (1). After that, the normalized numerical values of the functional word groups relating to the functional field in the technology/function matrix of surgical light in Table 1 are added up to obtain the total normalized numerical value. Then, divide the normalized numerical value of each function criterion by the total normalized numerical value to obtain each function criterion's ratio of normalized numerical value, as shown in Table 2. After that, the ratios of normalized numerical values of various product function criteria are mutually subtracted to obtain the interval in between. With this interval, and using the triangular fuzzy theory and the concept of α-cut, the relative level of importance is calculated. The obtained fuzzy level of importance is used to establish a pairwise comparison matrix for various product function criteria. Finally, analysis and calculation of numerical values are made, and the weight value of the pairwise comparison matrix is calculated.

$$\text{Normalized numerical value} = \frac{\text{Appearance frequency of keywords of important functional words}}{\text{Total number of words in the full text of the related patent groups}} \quad (1)$$

Table 2 Normalized numerical values and ratio of normalized numerical values of the patents' key functional word groups for judging the levels of importance of various product function criteria

Important functional word group	Normalized numerical value of each product function criterion	Ratio of normalized numerical value
a. Enhancement of convenience and stability of operation	0.039882	13.12%
b. Improvement of heat dissipation and air flow quality	0.035874	11.80%
c. Reduction of costs and extension of service life	0.034629	11.39%
d. Improvement of shadow effect and visual clarity to the eyes, and reduction of eyestrain	0.065099	21.41%
e. Improvement of light uniformity and brightness	0.063640	20.93%
f. Adjustment of illumination range	0.064892	21.34%
Total	0.304017	100.00%

Example: The normalization ratio of criterion e is 20.93%, and the normalization ratio of criterion a is 13.12%. The difference between the ratios of normalized numerical values of the two criteria obtained in Table 2 is 7.81%, which is at the range of 7~9%, and triangular fuzzy numbers are used for planning membership function. When two triangles intersect, two triangular membership functions are substituted into the triangle fuzzy equation to obtain μ_A and μ_B. With the concept of α-cut, if the membership function α ≧ 0.5, it belongs to 1; but if the membership function α < 0.5, it belongs to 0

As shown in Figure 2, its level of importance is 7, implying that when taking criterion a as the major one, the level of importance of criterion e is 7; and when taking criterion e as the major one, the level of importance of criterion a is 1/7. And the values on the diagonal lines of the pairwise comparison matrix of various function criteria are all 1, indicating that the relative importance between functional words are the same.

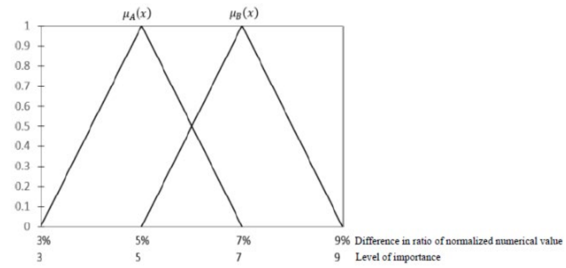

Figure 2 Fuzzy range of interval of the difference in ratio of normalized numerical value at 5~7%

The relative level of importance value of other product function criteria are all obtained by this calculation method. Therefore, using the above calculation method for Table 2, the fuzzy pairwise comparison matrix of each product function criterion after fuzzification can be further obtained, as shown in Table 3.

After that, the paper proposes a method for calculating the weight value of the pairwise comparison matrix. First of all, the geometric mean value is calculated, and the value obtained in Table 3 are substituted into equation (2):

$$Y_i = \sqrt[n]{X_{i1} \cdot X_{i2} \cdots X_{in}} \tag{2}$$

$$Y_a = \sqrt[6]{1 \cdot 1 \cdot 3 \cdot (\frac{1}{9}) \cdot (\frac{1}{7}) \cdot (\frac{1}{9})} = 0.417$$

Here, Y_i = geometric mean value; Y_i = comparative value of relative level of importance; i = a, b, c, d, e, f. Add up the geometric mean values calculated by the criteria for product function evaluation. Divide the calculated geometric mean values of the criteria for product function evaluation by the sum of geometric mean values to obtain the weight value W_{1i}, as shown in equation (3):

$$\text{Weight value } W_{1i} = \frac{Y_i}{\sum_{i=1} Y_i} \quad , \quad i = a \cdot b \cdot c \cdot d \cdot e \cdot f \tag{3}$$

$$W_{1a} = \frac{0.147}{\sum_{n=1}^{6} Y_n} = \frac{0.417}{0.417 + 0.333 + 0.278 + 3.000 + 2.877 + 3.00} = 0.042$$

Table 3 Pairwise comparison matrix of the criteria of various product functions

	a	b	c	d	e	f	Geometric mean value	Weight value
a	1	1	3	1/9	1/7	1/9	0.417	0.042
b	1	1	1	1/9	1/9	1/9	0.333	0.034
c	1/3	1	1	1/9	1/9	1/9	0.278	0.028
d	9	9	9	1	1	1	3.000	0.303
e	7	9	9	1	1	1	2.877	0.290
f	9	9	9	1	1	1	3.000	0.303

The values on the diagonal lines of the pairwise comparison matrix of various most important functional words are all 1, indicating an agreement to the statement that the importance of the functional words being mutually compared are the same. Using the above calculation method, other weight values can be obtained, including W_{1b}, W_{1c}, W_{1d}, W_{1e} and W_{1f}. All the calculated weight values are used to form a weight matrix W_1 as follows:

$$W_1 = \begin{bmatrix} W_{1a} \\ W_{1b} \\ W_{1c} \\ W_{1d} \\ W_{1e} \\ W_{1f} \end{bmatrix} = \begin{bmatrix} 0.042 \\ 0.034 \\ 0.028 \\ 0.303 \\ 0.290 \\ 0.303 \end{bmatrix}$$

【Step 2】Comparison of relative importance of various function criteria to various plans

Establish the criteria of various product functions as well as comparison of relative importance of each plan. For the three plans A, B, and C, add up the normalized numerical ratios of the key functional word groups of the product function criteria relating to the three functional improvement groups, including enhancement of convenience of operation, Improvement of heat dissipation and service life, and enhancement of lighting efficiency. After that, calculate the ratio of normalized numerical value of each function criterion to the normalized value of each functional word in each plan, and then judge the relative level of importance according to the ratios of normalized values, and finally calculate the weight value.

Example: In plan A, the two functions for improvements, "Enhancement of convenience of operation + Enhancement of lighting efficiency" contains these function criteria: a. Enhancement of convenience and stability of operation, d. Improvement of shadow effect and visual clarity to the eyes, and reduction of eyestrain, e. Improvement of light uniformity and brightness, f. Adjustment of illumination range. Since other functions do not belong to those in plan A, the normalized numerical values of other product function criteria are not considered. This paper proposes to add up the normalized numerical values of the key functional word groups of all product function criteria included in plan A, and then recalculate the ratios of the normalized numerical values of the key functional words of the related function criteria of various product functions in plan A. The equations for calculating the ratios of the normalized numerical values of the key functional words of various product function criteria in each plan can be obtained, and are expressed as equation (4) and equation (5):

Example: Since criteria a, d, e and f are the related criteria in plan A, the sum of the normalized numerical values of the various plan A-related criteria is n_A.

$$n_A = n_a + n_d + n_e + n_f \;) \tag{4}$$

$$\text{Then } n_{a1} = \frac{n_a}{n_A},\ n_{a2} = \frac{n_d}{n_A},\ n_{a3} = \frac{n_d}{n_A},\ n_{a4} = \frac{n_f}{n_A} \tag{5}$$

where n_A = Sum of normalized numerical values na、d、e、f = original normalized numerical values of various criteria for product function evaluation.

n_{a1}= Ratio of normalized numerical value of criterion a after calculation in plan A

n_{a2}= Ratio of normalized numerical value of criterion d after calculation in plan A

n_{a3}= Ratio of normalized numerical value of criterion e after calculation in plan A

n_{a4}= Ratio of normalized numerical value of criterion f after calculation in plan A

From Table 2, the n_A of plan A can be obtained:

n_A = 13.12% + 21.41% + 20.93% + 21.34% = 76.81%

$$n_{a1} = \frac{n_a}{n_A} = \frac{13.12}{76.81} = 17.08\%\text{，} n_{a2} = \frac{n_d}{n_A} = \frac{21.41}{76.81} = 27.88\%\text{，}$$
$$n_{a1} = \frac{n_e}{n_A} = \frac{20.93}{76.81} = 27.25\%\text{，} n_{a2} = \frac{n_f}{n_A} = \frac{21.34}{76.81} = 27.79\%$$

Similarly, plan B: $n_B = n_b + n_c + n_d + n_e + n_f$,

$$n_{b1} = \frac{n_b}{n_B},\ n_{b2} = \frac{n_c}{n_B}, n_{b3} = \frac{n_d}{n_B},\ n_{b4} = \frac{n_e}{n_B},\ n_{b5} = \frac{n_f}{n_B}$$

Similarly, plan C: $n_C = n_a + n_b + n_c$,

$$n_{c1} = \frac{n_a}{n_C}, n_{c2} = \frac{n_b}{n_C}, n_{c3} = \frac{n_c}{n_C}$$

The criteria of various product functions are compared in pairs to find out the weight of influence of each product function criterion on the target, and the weight vector of each product function criterion is expressed as W_2. Using the above calculation method, the ratio of normalized numerical value of each product function criterion in the plan is shown in Table 4.

Table 4 Ratio of various product function criteria to the normalized numerical values for judging the importance of various plans

Ratio of various product function criteria to the normalized numerical values for judging the importance of various plans							
		a	b	c	d	e	f
plan	A	17.08%	0.00%	0.00%	27.88%	27.25%	27.79%
	B	0.00%	13.58%	13.11%	24.65%	24.09%	24.57%
	C	36.13%	32.50%	31.37%	0.00%	0.00%	0.00%

Based on the results obtained by the above equation for calculation of the ratio of normalized numerical value, the ratios of normalized numerical value of the most important functional words in various criteria appeared in plans A, B and C for product function evaluation can be seen in Table 4. Since the interval between the ratios of normalized numerical values in Table 4 is great, the difference in ratio of normalized numerical value, at an interval of 9%, is taken to determine the relative level of importance. Triangular fuzzy theory and the concept of α-cut are introduced to conduct planning of membership. Then, a comparison table of the relative level of importance of various product function criteria after fuzzification to various plans is established, as shown in Table 5.

Table 5 Levels of importance of various product function criteria to various plans

	a	b	c	d	e	f	Weight value
A	5	1	1	7	7	7	0.341
B	1	3	3	7	7	7	0.376
C	9	9	7	1	1	1	0.283

Example: The eigenvector value $W2aA$ of criterion a's Enhancement of convenience of operation to plan A is expressed as equations (6) and (7) as follows:

$$W_{2aA} = \frac{W_{aA}}{W} \tag{6}$$

$$\text{where W} = W_{aA} + W_{aB} + W_{aC} \tag{7}$$

W = Sum of values of relative levels of importance of criterion a. Enhancement of convenience of operation to various plans.

W_{aA} = Value of relative level of importance of criterion a. Enhancement of convenience of operation to plan A. As obtained from Table 5, W_{aA}= 5.

W_{aB} = Value of relative level of importance of criterion a. Enhancement of convenience of operation to plan B. As obtained from Table 5, W_{aB} = 1.

W_{aC} = Value of relative level of importance of criterion a. Enhancement of convenience of operation to plan C. As obtained from Table 5, W_{aC}= 9.

Therefore, W = $W_{aA} + W_{aB} + W_{aC} = 9 + 1 + 5 = 15$，$W_{2aA} = 5/15 = 0.333$

After calculation by the above method, the eigenvector $W2a$ can be obtained.

$$\begin{bmatrix} W_{2aA} \\ W_{2aB} \\ W_{2aC} \end{bmatrix} = \begin{bmatrix} 0.333 \\ 0.067 \\ 0.600 \end{bmatrix} = W_{2a}$$

Calculate the eigenvector W_2 of all criteria for product function evaluation to form a weight value matrix W_2.

$$W_2 = \begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{cccccc} W_{2a} & W_{2b} & W_{2c} & W_{2d} & W_{2e} & W_{2f} \end{array} \\ \begin{bmatrix} 0.333 & 0.077 & 0.091 & 0.467 & 0.467 & 0.467 \\ 0.067 & 0.231 & 0.273 & 0.467 & 0.467 & 0.467 \\ 0.600 & 0.692 & 0.636 & 0.067 & 0.067 & 0.067 \end{bmatrix} \end{array}$$

【Step 3】Pairwise comparison of internal interdependence among various most important function criteria (W_3)

FUZZY ANP considers the internal interdependence among various criteria for product function evaluation. Therefore, the paper analyzes the functional word groups in various function criterion, observes various important functional words in the functional word group of a certain function criterion, and compares the important functional words of the functional word groups of other criteria with the important functional words found previously. The important functional words that appear repetitively and relatively more frequently would combine with engineering knowledge to determine which function criteria are related to a certain criterion of this function. Therefore, the functional word groups of various function criteria are established for selection of words for comparison, and the internal interdependence among the following function criteria can be known.

The interdependence among the function criteria is shown as follows:

Criterion a is related to criteria b, c, d, e and f.
Criterion b is related to criteria a, c, d and e.
Criterion c is related to criteria a, b and f.
Criterion d is related to criteria a, b, e and f.
Criterion e is related to criteria a, b, d and f.
Criterion f is related to criteria a, c, d and e.

The equation of the normalized numerical value of the total number of words in the full text of the patents of each important functional word and the related product function criteria is expressed as equation (8):

$$\text{Normalized numerical value} = \frac{\text{Appearance frequency of words relating to important functional words}}{\text{Total number of words in the full text of each patent of related criteria}} \tag{8}$$

Example: As criterion b is related to criteria a, c, d and e, calculate the normalized numerical value of each criterion, and then calculate the ratio of normalized numerical value of each criterion, and compare them with the relative levels of importance of the relatively important criteria, as shown in Table 6 and Table 7.

Table 6 Normalized numerical values and the ratios of normalized numerical values of the internal interdependent criteria of criterion b

Criteria	Normalized numerical value of product function and each criterion	Ratio of normalized numerical value
a. Enhancement of convenience and stability of operation	0.039882	16.68%
b. Improvement of heat dissipation and air flow quality	0.035874	15.00%
c. Reduction of costs and extension of service life	0.034629	14.48%
d. Improvement of shadow effect and visual clarity to the eyes, and reduction of eyestrain	0.065099	27.22%
e. Improvement of light uniformity and brightness	0.063640	26.61%

Table 7 Comparison between criterion b and relative levels of importance of the internal interdependent criteria

Criterion b	a	b	c	d	e
a	0.00%	1.68%	2.20%	-10.55%	-9.94%
b	-1.68%	0.00%	0.52%	-12.22%	-11.61%
c	-2.20%	-0.52%	0.00%	-12.74%	-12.31%
d	10.55%	12.22%	12.74%	0.00%	0.61%
e	9.94%	11.61%	12.13%	-0.61%	0.00%

Calculate the difference in the ratio of normalized numerical value between the related functions of various criteria. Take 3% as a level of interval. Substitute the triangular fuzzy theory and concept of α-cut for planning the membership, so as to establish the value of level of importance of internal interdependence among various product function criteria, and calculate the weight. The values of relative levels of importance and weight values of criterion b to criteria a, c, d and e are shown in Table 8.

Table 8 Values of relative levels of importance and weight values of criterion b to criteria a, c, d and e

Criterion b	a	b	c	d	e	Geometric mean	Weight value
a	1	3	3	1/9	1/7	0.678	0.078
b	1/3	1	1	1/9	1/9	0.333	0.039
c	1/3	1	1	1/9	1/9	0.333	0.039
d	9	9	9	1	1	3.737	0.433
e	7	9	9	1	1	3.554	0.412

The weight values in Table 8 are calculated using equations (1) and (2). The weight value of internal interdependence among various criteria for product function evaluation is calculated. For example:

$$Y_a = \sqrt[5]{1 \cdot 3 \cdot 3 \cdot \left(\frac{1}{9}\right) \cdot \left(\frac{1}{7}\right)} = 0.678 \tag{9}$$

$$\text{Weight value } W_{3ba} = \frac{Y_a}{\sum_{i=1} Y_i}, i = a, b, c, d, e \tag{10}$$

$$\text{Weight value } W_{3ba} = \frac{0.678}{0.678 + 0.333 + 0.333 + 3.737 + 3.554} = 0.078$$

Calculate the weight values of various criteria for product function evaluation to form a weight matrix of various criteria for product function evaluation. The value that has no internal interdependence with the criteria for product function evaluation is 0. Let us take criterion b. Improvement of heat dissipation and air flow quality, for explanation. The criteria having internal interdependence with Improvement of heat dissipation and air flow quality are criteria a. Enhancement of convenience and stability of operation, c. Reduction of costs and extension of service life, d. Improvement of shadow effect and visual clarity to the eyes, and reduction of eyestrain, and e. Improvement of light uniformity and brightness. And the key functional word criterion having no internal interdependence with criterion b is criterion f. Adjustment of illumination range, and its weight value is 0. After calculation, the obtained weight values are W_{3ba}= 0.078, W_{3bb}= 0.039, W_{3bc}= 0.039, W_{3bd}= 0.433, W_{3be}= 0.412 and W_{3bf}= 0. Therefore, the weight value matrix formed for criterion b. Improvement of heat dissipation and air flow quality is:

W_{3b}=(0.078, 0.039, 0.039, 0.433, 0.412, 0)

According to the calculation process aforesaid, W_3 can be obtained as follows:

$$W_3 = \begin{array}{c c} & \begin{array}{cccccc} a & b & c & d & e & f \end{array} \\ \begin{array}{c} a \\ b \\ c \\ d \\ e \\ f \end{array} & \begin{bmatrix} 0.042 & 0.034 & 0.028 & 0.303 & 0.290 & 0.303 \\ 0.078 & 0.039 & 0.039 & 0.433 & 0.412 & 0 \\ 0.148 & 0.065 & 0.065 & 0 & 0 & 0.722 \\ 0.042 & 0.036 & 0 & 0.307 & 0.307 & 0.307 \\ 0.053 & 0.029 & 0 & 0.311 & 0.296 & 0.311 \\ 0.052 & 0 & 0.029 & 0.307 & 0.306 & 0.306 \end{bmatrix} \end{array}$$

【Step 4】Establishment of fuzzy direct-relation matrix Z

According to the total normalized numerical value of functional words of patents of various criteria, using the ratios of normalized numerical values of patents' functional words that are repeated or defined the same in various criteria, through the physical meaning and a range, and through matching the fuzzy set with the triangular membership function, it is determined that the difference in ratio value is located at the fuzzy area where the two triangles intersect. When the concept of α-cut is adopted, if the membership function α ≧ 0.5, it belongs to 1; and if the membership function α < 0.5, it belongs to 0, as shown in the equation below. It is used to evaluate and decide the degree of mutual influence among the criteria, being 0~4; and this value is used to evaluate the level of importance:

$$\mu_A(\mathrm{x}) = \begin{cases} 1 & \text{if } \mathrm{x} \in A \\ 0 & \text{if } \mathrm{x} \notin A \end{cases}$$

Example: The ratio of normalized numerical value of criterion b. Improvement of heat dissipation and air flow quality to criterion a. Enhancement of convenience and stability of operation is 39.7%. Take 21% as a unit of relative level of importance, as shown in Figure 3. The calculation method of the relative level of importance ratios of various criteria is shown as follows:

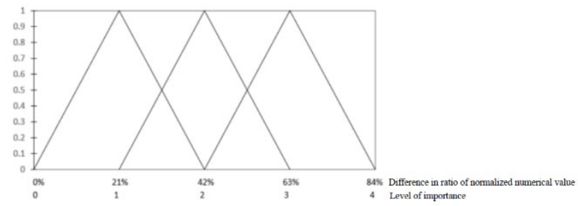

Figure 3 Relative level of the ratio of normalized numerical value at an interval of 21%

Substitute the numerical values into the following equation to obtain:

$$\mu_A(\chi) = \begin{cases} 0 & \text{For } \chi < 0 \\ \frac{\chi - 0}{21 - 0} & \text{For } 0 \le \chi < 21 \\ 1 & \text{For } \chi = 21 \\ \frac{42 - \chi}{42 - 21} & \text{For } 21 < \chi \le 42 \\ 0 & \text{For } 42 < \chi \end{cases} ; \mu_B(\chi) = \begin{cases} 0 & \text{For } \chi < 21 \\ \frac{\chi - 21}{42 - 21} & \text{For } 21 \le \chi < 42 \\ 1 & \text{For } \chi = 42 \\ \frac{63 - \chi}{63 - 42} & \text{For } 42 < \chi \le 63 \\ 0 & \text{For } 63 < \chi \end{cases}$$

$$\mu_A = \frac{42 - 39.7}{42 - 21} = 0.109 \quad ; \quad \mu_B = \frac{39.7 - 21}{42 - 21} = 0.890$$

Since μ_A (χ) = 0.109, which is smaller than 0.5, 0 is taken as its value. Since μ_B (χ) = 0.890, which is greater than 0.5, 1 is taken as its value. Its level of importance is 2.

The relative level of importance among various criteria is represented by different numbers, where 0 represents "no influence", 1 represents "low influence", 2 represents "medium influence", 3 represents "great influence" and 4 represents "extremely great influence". The difference in ratio value of normalized numerical value is located in the fuzzy area where two triangles intersect. When the concept of α-cut is adopted, if the membership function α ≧ 0.5, it belongs to 1, and if the membership function α < 0.5, it belongs to 0. The equation below is used to evaluate and decide the degree of mutual influence among the criteria, being 0~4; and this value is used to evaluate the level of importance. Through the above method, the direct relation matrix Z can be further obtained, as shown below.

$$\text{direct relation matrix } Z=\begin{bmatrix}0&3&4&2&2&2\\2&0&2&2&2&1\\2&2&0&2&0&2\\2&2&2&0&3&3\\3&2&1&4&0&3\\4&2&3&4&3&0\end{bmatrix}$$

【Step 5】Establishment of normalized direct relation matrix.

Normalize the direct relation matrix obtained in the previous step. Using the equation, find from matrix Z the maximum column sum S, and then divide matrix "Z" by S to obtain the normalized direct relation matrix X.

$$S=max\left(\max_{1\le i\le n}\sum_{j=1}^{n}Z_{ij},\max_{1\le j\le n}\sum_{i=1}^{n}Z_{ij}\right)=4+2+3+4+3+0=16$$

$$X=\frac{Z}{S}=\begin{bmatrix}0&0.188&0.250&0.125&0.125&0.125\\0.125&0&0.125&0.125&0.125&0.063\\0.125&0.125&0&0.125&0&0.125\\0.125&0.125&0.125&0&0.188&0.188\\0.188&0.125&0.063&0.250&0&0.188\\0.250&0.125&0.188&0.250&0.188&0\end{bmatrix}$$

【Step 6】Establishment of total influence matrix

$$\mathrm{T}=\mathrm{X}(\mathrm{I}-\mathrm{X})^{-1} \qquad (11)$$

The total influence matrix T obtained using equation (11) is shown as follows: T = X(I − X) −1 where 1 denotes unit matrix, and X denotes normalized direct relation matrix.

$$\mathrm{T}=\begin{bmatrix}0.355&0.477&0.597&0.421&0.380&0.387\\0.379&0.241&0.408&0.352&0.320&0.276\\0.259&0.248&0.168&0.136&0.120&0.167\\0.500&0.451&0.579&0.350&0.459&0.446\\0.584&0.487&0.580&0.594&0.339&0.502\\0.669&0.525&0.673&0.624&0.524&0.374\end{bmatrix}$$

【Step 7】Normalization of total influence matrix T and transposition of the total influence matrix to obtain T_c.

With the total influence matrix T obtained in the above step, and using the following equation, calculate the sum of each column, and divide each sum by each criterion of each column to obtain the normalized total influence matrix T_c as follows:

$$\text{Total influence matrix } T=\begin{bmatrix}t_{11}&\cdots&t_{1j}&\cdots&t_{1m}\\\vdots&&\vdots&&\vdots\\t_{i1}&\cdots&t_{ij}&\cdots&t_{im}\\\vdots&&\vdots&&\vdots\\t_{m1}&\cdots&t_{mj}&\cdots&t_{mm}\end{bmatrix}$$

$$T_C=\begin{bmatrix}t_{11}/d_1&\cdots&t_{1j}/d_1&\cdots&t_{1m}/d_1\\\vdots&&\vdots&&\vdots\\t_{i1}/d_i&\cdots&t_{ij}/d_i&\cdots&t_{im}/d_i\\\vdots&&\vdots&&\vdots\\t_{m1}/d_m&\cdots&t_{mj}/d_m&\cdots&t_{mm}/d_m\end{bmatrix}=\begin{bmatrix}t_{11}^1&\cdots&t_{1j}^1&\cdots&t_{1m}^1\\\vdots&&\vdots&&\vdots\\t_{i1}^1&\cdots&t_{ij}^1&\cdots&t_{im}^1\\\vdots&&\vdots&&\vdots\\t_{m1}^1&\cdots&t_{mj}^1&\cdots&t_{mm}^1\end{bmatrix}$$

Example:

$$\because T=\begin{bmatrix}0.355&0.477&0.597&0.421&0.380&0.387\\0.379&0.241&0.408&0.352&0.320&0.276\\0.259&0.248&0.168&0.136&0.120&0.169\\0.500&0.451&0.579&0.350&0.459&0.466\\0.584&0.487&0.580&0.594&0.339&0.502\\0.669&0.525&0.673&0.624&0.524&0.374\end{bmatrix}$$

$$d_1=0.355+0.477+0.597+0.421+0.380+0.387=2.612$$

di denotes the normalized value, which is the sum of numerical values of the ith column of this influence matrix T.

$\therefore \frac{t_{11}}{d_1}=\frac{0.355}{2.612}=0.136$，Therefore, T_C can be obtained as follows:

$$T_C=\begin{bmatrix}0.136&0.182&0.228&0.161&0.145&0.148\\0.192&0.122&0.206&0.178&0.162&0.140\\0.235&0.225&0.153&0.123&0.110&0.154\\0.178&0.161&0.206&0.125&0.164&0.166\\0.189&0.158&0.188&0.193&0.110&0.163\\0.198&0.155&0.199&0.184&0.155&0.110\end{bmatrix}$$

【Step 8】Transposition of the normalized matrix T_c, and multiplication of it and the weight value matrix.

Normalized total influence matrix T_c is transposed to be T_c^T. Multiply T_c^T and the pairwise comparison matrix W_3 to obtain a new matrix W_3^D, which is expressed as equation (12), and the calculation result is shown as follows:

$$T_c^T\cdot W_3=W_3^D \qquad (12)$$

$$\begin{bmatrix}0.136&0.192&0.235&0.178&0.189&0.198\\0.182&0.122&0.225&0.161&0.158&0.155\\0.228&0.206&0.153&0.206&0.188&0.199\\0.161&0.178&0.123&0.125&0.193&0.184\\0.145&0.162&0.110&0.164&0.110&0.155\\0.148&0.140&0.154&0.166&0.163&0.110\end{bmatrix}\begin{bmatrix}0.042&0.034&0.028&0.303&0.290&0.303\\0.078&0.039&0.039&0.433&0.412&0\\0.148&0.065&0.065&0&0&0.722\\0.042&0.036&0&0.307&0.307&0.307\\0.053&0.029&0&0.311&0.296&0.311\\0.052&0&0.029&0.307&0.306&0.306\end{bmatrix}$$

$$=\begin{bmatrix}0.083&0.039&0.032&0.298&0.290&0.385\\0.074&0.036&0.029&0.254&0.247&0.364\\0.077&0.038&0.030&0.341&0.331&0.362\\0.064&0.030&0.025&0.280&0.272&0.292\\0.056&0.027&0.022&0.246&0.239&0.255\\0.061&0.031&0.023&0.241&0.234&0.291\end{bmatrix}=W_3^D$$

【Step 9】Calculation of matrix W_C^D after adding in DEMATEL.

But this paper follows the decision-making procedure of FUZZY DANP method, and uses the calculation method of matrix to replace the super matrix, with the calculation shown below. First of all, multiply the W_3^D obtained in the previous step and W1 to obtain a new internally interdepending prioritized weight value W_C^D, which is expressed as equation (13), and the calculation result is shown as follows:

$$W_3^D \cdot W_1 = W_C^D \quad (13)$$

$$\begin{bmatrix} 0.083 & 0.039 & 0.032 & 0.298 & 0.290 & 0.385 \\ 0.074 & 0.036 & 0.029 & 0.254 & 0.247 & 0.364 \\ 0.077 & 0.038 & 0.030 & 0.341 & 0.331 & 0.362 \\ 0.064 & 0.030 & 0.025 & 0.280 & 0.272 & 0.292 \\ 0.056 & 0.027 & 0.022 & 0.246 & 0.239 & 0.255 \\ 0.061 & 0.031 & 0.023 & 0.241 & 0.234 & 0.291 \end{bmatrix} \begin{bmatrix} 0.042 \\ 0.034 \\ 0.028 \\ 0.303 \\ 0.290 \\ 0.303 \end{bmatrix} = \begin{bmatrix} 0.297 \\ 0.264 \\ 0.315 \\ 0.257 \\ 0.225 \\ 0.233 \end{bmatrix}$$

The steps from【Step 10】to【Step 11】are the selection steps of prioritized improvement plan using the modified FUZZY ARAS method.

【Step 10】Establishment of a decision-making matrix to find the weight value of each plan to each criterion.

In this step, the equation of ARAS decision matrix is expressed as equation (14) below. In this equation, x_{ij}^* is the weight value of plan i to criterion j. This paper proposes that x_{ij}^* is the matrix value of plan i to criterion j after fuzzification of the ratios of various product function criteria in W_2 after fuzzification to the normalized numerical values for judging the levels of importance of various plans. And in equation (15), x_{0j}^* represents the optimal attribute value of criterion j. If the optimal value of the criterion is unknown, the maximum plan value i of each criterion j is set to be x_{0j}^*:

$$X^* = \begin{bmatrix} x_{01}^* & \cdots & x_{0j}^* & \cdots & x_{0n}^* \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1}^* & \cdots & x_{ij}^* & \cdots & x_{in}^* \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1}^* & \cdots & x_{mj}^* & \cdots & x_{mn}^* \end{bmatrix} ;\ i = 0,1,\ldots,m\text{,}\ j = 1,\ldots,n \quad (14)$$

$$x_{0j}^* = max_i\, x_{ij}^*\big|_{i=1,\ldots,m} \quad ;\quad i = 0,1,\ldots,m\text{,}\ j = 1,2,\ldots,n \quad (15)$$

Here, $max_i\, x_{ij}^*\big|_{i=1,\ldots,m}$ is the maximum value of each criterion j in plan i.

Fuzzified W_2 in Table 5

$$X^* = \begin{bmatrix} x_{i1}^* & \cdots & x_{ij}^* & \cdots & x_{in}^* \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1}^* & \cdots & x_{mj}^* & \cdots & x_{mn}^* \end{bmatrix} ;\ i = 1,\ldots,m\text{,}\ j = 1,\ldots,n$$

$$= \begin{bmatrix} 5 & 1 & 1 & 7 & 7 & 7 \\ 1 & 3 & 3 & 7 & 7 & 7 \\ 9 & 9 & 7 & 1 & 1 & 1 \end{bmatrix}$$

The above equation W_2 shows the matrix value of plan i to criterion j in W_2 after fuzzification of the ratios of various product function criteria to the normalized numerical values for judging the level of importance of various plans.

According to equation (15), i = 0, and $maxi\ x_{ij}^*$ is the maximum value.

Therefore, for plan A, i = 1; for plan B, i = 2; for plan C, i = 3;

and for criterion a, j = 1; for criterion b, j = 2; for criterion c, j = 3;

for criterion d, j = 4; for criterion e, j = 5; for criterion f, j = 6.

In criterion a, its j = 1; and in plan A, its i = 1; so its x_{11}^*= 5. Similarly, in plan B, its i = 2; so its x_{21}^*= 1. And in plan C, its i = 3; so its x_{31}^*= 9. Therefore, in criterion a, when j = 1, the x_{31}^*= 9 in in plan C with i = 3 is the maximum value. As a result, $x_{01}^* = maxi\ x_{i1}^*|\ i$=1−3 = 9.

According to the above method, the following are obtained: $maxi\ x_{i2}^* = 9$, $maxi\ x_{i3}^* = 7$, $maxi\ x_{i4}^* = 7$, $maxi\, x_{i5}^* = 7$, and $maxi\ x_{i6}^* = 7$. Therefore, $maxix_{ij}^* = [9\ 9\ 7\ 7\ 7\ 7]$; $i = 1, \ldots, m$, $j = 1, \ldots, n$.

After calculation of each column is completed, X^* can be further obtained as follows:

$$X^* = \begin{array}{r} i=0 \\ i=1 \\ i=2 \\ i=3 \end{array} \begin{bmatrix} 9 & 9 & 7 & 7 & 7 & 7 \\ 5 & 1 & 1 & 7 & 7 & 7 \\ 1 & 3 & 3 & 7 & 7 & 7 \\ 9 & 9 & 7 & 1 & 1 & 1 \end{bmatrix}$$

【Step 11】 Normalized decision matrix

Normalize x_{ij}^* of the decision matrix X^* of equation (16). The matrix obtained after normalization is $\bar{X}$, and the matrix $\bar{X}$ is as follows:

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \cdots & \bar{x}_{0j} & \cdots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix} ;\ i = 0,1,\ldots,m\text{,}\ j = 1,2,\ldots,n \quad (16)$$

In matrix $\bar{X}$, the equation for its normalized numerical $\bar{X}_{ij}$ is expressed as equation (17) below:

$$\bar{X}_{ij} = \frac{x_{ij}^*}{\sum_{i=0}^{m} x_{ij}^*} \quad ;\quad i = 0,1,\ldots,m \quad (17)$$

Example: In criterion a with j = 1, the sum of various plans $\sum_{i=0}^{m} x_{i1}^* = 9 + 5 + 1 + 9 = 24$. For criterion a, when j = 1, the normalized numerical value is $\bar{X}_{i1} = \frac{x_{i1}^*}{24}$; i = 0, 1, ..., m. Thus, $\bar{X}01 = \frac{9}{24} = 0.375$ 、 $\bar{X}_{11} = \frac{5}{24} = 0.208$ 、 $\bar{X}_{21} = \frac{1}{24} = 0.042$ 、 $\bar{X}_{31} = \frac{9}{24} = 0.375$. After calculation in this way, the normalized matrix $\bar{X}$ of various columns can be obtained as follows:

$$\bar{X}=\begin{array}{c} i=0 \\ i=1 \\ i=2 \\ i=3 \end{array}\begin{bmatrix} 0.375 & 0.409 & 0.389 & 0.318 & 0.318 & 0.318 \\ 0.208 & 0.045 & 0.056 & 0.318 & 0.318 & 0.318 \\ 0.042 & 0.136 & 0.167 & 0.318 & 0.318 & 0.318 \\ 0.375 & 0.409 & 0.389 & 0.045 & 0.045 & 0.045 \end{bmatrix}$$

【Step 12】Fuzzy normalized $\bar{X}_{ij}$ decision matrix

First of all, take an appropriate value as a range of normalized values for calculation of fuzzy numerical values. It can be seen from the normalized matrix $\bar{X}_{ij}$ that the interval of 9% can make the distribution in the matrix after fuzzification to be relatively even.

Example: The normalized numerical value of plan A with i = 1 to that of criterion a with j = 1 is 20.8%. Its triangular membership function $\mu_A(\chi)$ is within the range of 4%~22%, and the triangular membership function $\mu_B(\chi)$ is within the range of 13%~31%. Therefore, the fuzzy triangular area is within the range of 13%~22%. Make a calculation of these two triangular membership functions.

20.8% is within the range of 13%~22%. Substitute it into the equation, obtaining:

$$\mu_A(\chi)=\frac{22-20.8}{22-13}=0.133 \quad ; \quad \mu_B(\chi)=\frac{20.8-13}{22-13}=0.867$$

Since $\mu_A(\chi)=0.133$, which is smaller than 0.5, 0 is taken as its value. Since $\mu_B(\chi)=0.867$, which is greater than 0.5, 1 is taken as its value. Therefore, the corresponding level of importance 5 of $\mu_B(\chi)$ is taken, implying that the level of importance of criterion a. Enhancement of convenience and stability of operation to plan A is 5. After fuzzification of other normalized numerical values of $\bar{X}_{ij}$, all values are calculated using the same calculation method above. Furthermore, the following $\tilde{x}_{ij}$ matrix after fuzzification of the normalized matrix $\bar{X}_{ij}$ can be obtained, and the calculation result is as follows:

$$\tilde{x}_{ij}=\begin{bmatrix} 7 & 9 & 9 & 7 & 7 & 7 \\ 5 & 1 & 1 & 7 & 7 & 7 \\ 1 & 3 & 5 & 7 & 7 & 7 \\ 7 & 9 & 9 & 1 & 1 & 1 \end{bmatrix}$$

【Step 13】Establishment of a weight-normalized decision matrix for each plan

The equation for the weight normalized value of each attribute is $\hat{x}_{ij}=\tilde{x}_{ij}\cdot W_j$, in which $\sum_{j=1}^{n} W_j=1$, with W_j being equivalent to W_C^D matrix in FUZZY DANP. But this paper applies the FUZZY DANP method, so W_j is further modified. The modified FUZZY DANP method is then used to obtain the internal interdependent prioritized wight value W_C^D, which is substituted into W_j. Since $W_C^D = W_3^D \cdot W_1$, the equation of the modified weight-normalized decision matrix $\hat{x}$ is expressed as follows:

$$\hat{x}=\begin{bmatrix} \hat{x}_{01} & \cdots & \hat{x}_{0j} & \cdots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix} ; \ i=0,1,\ldots,m \text{ , } j=1,2,\ldots,n \qquad (18)$$

And $\hat{x}_{ij}=\tilde{X}_{ij}\cdot W_C^D \quad ; \quad i=0,1,\ldots,m \text{ , } j=1,2,\ldots,n \qquad (19)$

Substitute the $\tilde{x}_{ij}$ obtained from calculation in Step 12 as well as the above W_C^D into equation (19), and the following calculation result of $\hat{x}_{ij}$ can be obtained:

$$\hat{x}_{ij}=\tilde{X}_{ij}\cdot W_C^D=\begin{bmatrix} 7 & 9 & 9 & 7 & 7 & 7 \\ 5 & 1 & 1 & 7 & 7 & 7 \\ 1 & 3 & 5 & 7 & 7 & 7 \\ 7 & 9 & 9 & 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} 0.297 \\ 0.264 \\ 0.315 \\ 0.257 \\ 0.225 \\ 0.233 \end{bmatrix}$$

$$=\begin{bmatrix} 2.079 & 2.374 & 2.831 & 1.798 & 1.576 & 1.632 \\ 1.485 & 0.264 & 0.315 & 1.798 & 1.576 & 1.632 \\ 0.297 & 0.791 & 1.573 & 1.798 & 1.576 & 1.632 \\ 2.079 & 2.374 & 2.831 & 0.257 & 0.225 & 0.233 \end{bmatrix} ; \ i=0,1,\ldots,m \text{ , } j=1,2,\ldots,n$$

【Step 14】Calculation of the optimality function Si

According to equation (20), calculate the optimality function value S_i of plan i. When i = 0, S_0 is the maximum value.

$$S_i=\sum_{j=1}^{n}\hat{x}_{ij} \quad ; \quad i=0,1,\ldots,m \qquad (20)$$

$\therefore S_0 = 2.079 + 2.374 + 2.831 + 1.798 + 1.5576 + 1.632 = 12.290$
$S_1 = 1.485 + 0.264 + 0.315 + 1.798 + 1.576 + 1.632 = 7.069$
$S_2 = 0.297 + 0.791 + 1.573 + 1.798 + 1.576 + 1.632 = 7.667$
$S_3 = 2.079 + 2.374 + 2.831 + 0.257 + 0.225 + 0.233 = 7.999$

【Step 15】Calculation of the relative weight values k_i for ranking of various plans, and achievement of the utility degree and final ranking plans

In the modified FUZZY ARAS method, the paper finally calculates the relative weight value k_i of each plan i for ranking, and performs ranking of various plans. As for S_0, it is the maximum value of S_i, and k_i has to be within (0, 1). The equation for calculation of k_i is expressed as equation (21):

$$k_i=\frac{S_i}{S_0} \quad ; \quad i=1,2,\ldots,m \qquad (21)$$

$$\therefore k_1=\frac{7.069}{12.290}=0.575 \ ; \ k_2=\frac{7.667}{12.290}=0.624 \ ; \ k_3=\frac{7.999}{12.290}=0.651 \ ;$$

The finally calculated maximum weight value k_i is used for ranking. The attribute with maximum value is taken as the most preferred plan to be selected. Therefore, $k3 > k2 > k1$.

After calculation by combining the modified FUZZY ARAS with the modified FUZZY DANP methods, the final weight values k_1, k_2 and k_3 of the three improvement plans are obtained, being 0.575, 0.624 and 0.651 respectively. Then it is known that the ranking of various plans is $k_3 > k_2 > k_1$. Here, the maximum final weight value is the value of ki, and its plan will be the most preferred one for selection. Therefore, $k3$ is the most preferred plan for selection. Since k_1 denotes plan A, k_2 denotes plan B, and k_3 denotes plan C, plan C is the most preferred plan for selection.

CONCLUSION

This paper develops the technical word groups of various technical words and component words in each technical field and functional field obtained from analysis of the patent literature, as well as the normalized numerical values of the functional word groups of various functional words and component words. The normalized numerical value is the ratio of appearance frequency of the key words of important technical words, functional words and component words in multiple pieces of patent literature through the term and word segmentation system to the total number of words in the full text of the related patent group. Then through analysis of patents, a technology/function matrix is obtained. This paper develops a method that combines the modified FUZZY DANP method with the modified FUZZY ARAS method for ranking of the prioritized improvement plans for different product function improvement plans of surgical light for selection. This is matched with the technology/function matrix of the product to select the relative technical fields that are optional for the prioritized improvement plans for product functions.

This paper applies product functions to surgical light, and combines the modified FUZZY DANP method with the modified FUZZY ARAS method to calculate the prioritized weight values of the improvement plans. Furthermore, the prioritized selection plan for improving the product functions of surgical light is plan C, "Enhancement of convenience of operation + Improvement of heat dissipation and service life", which contains these function criteria: a. Enhancement of convenience and stability of operation, b. Improvement of heat dissipation and air flow quality, and c. Reduction of costs and extension of service life.

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REFERENCES

Chang, Y. F. and Junzo, W. and Hiroaki, I., "A Fuzzy MCDM Approach to Building A Model of High Performance Project Team–A Case Study", ICIC International, pp. 7393–7404 (2012).

Liang, J.W., Cheng, C. C. and Wu, W. L., "Surgical light with function of fine-tuning of light intensity", Taiwan Patent No. TWI601905 (2017).

Lu, M. T. and Tzeng, G. H., and Tang L. L., "Environmental Strategic Orientations for Improving Green Innovation Performance in Fuzzy Environment - Using New Fuzzy Hybrid MCDM Model", International Journal of Fuzzy Systems, Vol. 15, No. 3, pp. 297-316 (2013).

Liang, J. W., "SURGICAL LAMP HANDLE ASSEMBLY WITH BUILT-IN VIDEO CAMERA", US Patent No. US6909465 (2005)

Liu, J.H., "Combining the patent-improved originality numerical values with the improved generality numerical values and new patent development rules for analysis of surgical light-related patents" , Master Thesis, National Taiwan University of Science and Technology (2021).

Ou Yang, Y. P., Shieh, H. M., Leu, J. D. and Tzeng, G. H., "A Novel Hybrid MCDM Model Combined with DEMATEL and ANP with Applications", International Journal of Operations Research, Vol. 5, No. 3, pp. 1-9 (2008)

Tzeng, G. H., Chiang, C. H., and Li, C. W., "Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on Factor Analysis and DEMATEL", Expert Systems with Applications, Vol. 32, No. 4, pp. 1028-1044 (2007).

Zavadskas, E. K., and Turskis, Z., "A new additive ratio assessment (ARAS) method in multicriteria decision-making", Technological and economic development of economy, Vol. 16, No. 2, pp. 159-172 (2010).