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Establishment of the Modified Fuzzy VIKOR Method that Combines with the Modified Fuzzy DANP for Application to Improvement Plan Selection of Dental Light

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Keywords: dental light, technical/functional matrix, modified fuzzy DANP, modified fuzzy VIKOR

ABSTRACT

First of all, the paper collects the dental light-related technical patents, and then establishes technical/function matrix of dental light. Through word segmentation system, the paper defines the normalized numerical values of the important technical words in each technical fields of the dental light-related technical patents. The paper uses 3 main technical fields in the 1st-layer technical fields of dental light to form 3 technical improvement plans with technical interdependence. Through the steps of the modified fuzzy DANP, the related weight matrix is calculated. The modified fuzzy DEMATEL is applied to calculation. The paper substitutes the previously calculated interdependent prioritized weight W_C^D of the modified fuzzy DANP into equations S_i and R_i of the modified fuzzy VIKOR method, and calculates other related equations of the modified the modified fuzzy VIKOR method. Finally, the paper calculates the comprehensive index Q_i, and then decides and selects the most prioritized optional plan.

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INTRODUCTION

Dental light is used to illuminate a patient's mouth cavity, and is a lighting device during dental surgery, diagnosis and treatment. Regarding dental light, the patent developed by Rose et al. (2005) mentioned that a dental light structure consists of a support holder, a lamp head, and a light module that is attached to the cavity inside the lampshade. Thomas et al. (2018) invented a dental light for irradiating the treatment area of a patient in treatment process.

Decision Making Trial and Evaluation Laboratory (DEMATEL) is an effective method for collecting group knowledge to form a structural model. Wu et al. (2007) suggested using fuzzy DEMATEL method to evaluate the competency of global managers. Tuzkaya et al. (2008) proposed using fuzzy analytic network process (ANP) to select the most prioritized transportation mode. Ayag et al. (2009) used fuzzy ANP method to evaluate the optional design plans in the environment of new product development. Uygun et al. (2016) used fuzzy DANP (DEMATEL-based ANP) method to evaluate green supply-chain management (GSCM) in order to find out plans for the fuzzy and complicated multi-attribute problems in fuzzy environments. Vinodh et al. (2016), with the purpose to improve the effectiveness of concept selection, combined fuzzy DEMATEL with fuzzy ANP. Within agility standards, fuzzy DEMATEL produces interdependence relationship and the strength of interdependence, where fuzzy concept was used for evaluating and considering the uncertainty existing between agility factors.

In reality and in some cases there is ambiguity in the things evaluated, so it is difficult for decision makers to make accurate judgments. As fuzzy VIKOR method stresses ranking of optional plans in fuzzy environments, and determining compromising plans for issues with conflicting standards. Chang (2014) used VIKOR method that was based on fuzzy set theory to provide hospitals with a reasonable and systematic evaluation of service quality, and used the theory of fuzzy triangular membership function to solve the uncertain, subjective and ambiguous problems of hospital service quality. Since different patients had different preferences for hospital service quality, fuzzy VIKOR method was used in fuzzy environments to rank the hospital service qualities. Rezaei, et al. (2013) proposed using fuzzy ANP method and fuzzy VIKOR that were both based on fuzzy set theory. Through fuzzy VIKOR, suitable suppliers can be selected, and uncertain human judgment can be transformed into meaningful results. Opricovic (2011) used fuzzy VIKOR method to study the development of reservoir system, and took a numerical example to illustrate its application to water resources planning.

None of the above literature is like this paper that uses product technology to obtain decision-making steps with the modified fuzzy DANP combined with the modified fuzzy VIKOR to calculate the priority order of 3 technical improvement plans for selection of dental light.

ESTABLISHMENT PROCEDURE OF PATENTED TECHNICAL/ FUNCTIONAL MATRIX OF DENTAL LIGHT

The paper develops a technical/functional matrix of dental light that is established based on its own engineering knowledge and search of patents. First of all, the paper defines the 1st-layer technical fields of dental light. The 1st-layer technical fields are: (1) overall holder structural technology of dental light, (2) lampshade structural technology of dental light (3) lamp control technology of dental light. After that, the 1st- and 2nd-layer technical/functional matrices are preliminarily established.

After the 1st-layer technical fields of dental light are defined above, the paper starts to combine a lot of relevant patents having improved cosine similarities, and being searched through important patent vocabularies and International Patent Classification (IPC). From the large number of relevant patents being searched, the paper adds in word segmentation system of patent semantic analysis to conduct analysis of the patents' key technical words, part/component words and functional words, and calculate the normalized numerical values of different keywords (Lin et al., 2017). The patents with highly correlated techniques and functions are categorized under this technical word group and functional word group, and matched with synonym concept to establish word groups of important technical words and part/component words in each 1st-layer technical field of the dental light-related patents.

After that, these word groups are used to make comparison using the modified cosine similarity, and manual classification is used to define the 2nd-layer technical field and functional field of each 1st-layer technical field, and establish the 1st-layer and 2nd-layer technical/ functional matrices. The 1st-layer and 2nd-layer technical/ functional matrices of the dental light patents in Chinese and English, as well as the 1st-layer and 2nd-layer technical fields and functional fields of the dental light-related patents are briefly explained as follows.

The 2nd-layer technologies under the 1st layer's "overall holder structural technology" are divided into two kinds: (1) support holder structural technology (2) structural technology near lamp handle.

The 2nd-layer technologies under the 1st layer's "lampshade structural technology" are divided into two kinds: (1) light source arrangement technology (2) light source heat dissipation technology.

The 2nd-layer technologies under the 1st-layer's "lamp control technology" are divided into two kinds: (1) light source irradiation range technology (2) light source brightness technology.

The functions of dental light patents are divided into 7 kinds: (1) Improve ease of use (2) Improve shadows and dazzling light (3) Improve light uniformity and brightness, (4) Improve heat dissipation (5) Reduce eye fatigue (6) Reduce costs and extend service life (7) Adjust lighting range.

Using the word segmentation system of patent semantic analysis mentioned above, the paper obtains the key technical words of each technical layer, as shown in Table 1.

COMBINING PRODUCT TECHNOLOGY WITH THE MODIFIED FUZZY DANP AND THE MODIFIED FUZZY VIKOR DECISION MAKING PROCEDURE FOR SELECTION OF PRIORITIZED IMPROVEMENT PLAN OF DENTAL LIGHT

According to the decision making steps with the modified fuzzy DANP combined with the modified fuzzy VIKOR, the paper selects a prioritized improvement plan among the 3 improvement plans of dental light. The paper performs the aforesaid mutual combination of the 1st-layer technologies of dental light or develops 3 interdependent improvement plans, with plan A being "overall holder structural technology + lamp control technology", plan B being "lampshade structural technology + lamp control technology", and plan C being "overall holder structural technology + lampshade structural technology".

Table 1 Word groups of technical words and part/component words in the 1st-layer technical field and the 2nd-layer technical field of the dental light-related patents

1st-layer technology	2nd-layer technology	Word group of technical words and part/component words
Overall holder structural technology of dental light	Support holder structural technology	Sleeve, install, mouth cavity light, LED, structure, lamp, holder, adjust, melt, shell, handle, hinge, connect, base, connecting arm, fix ... etc.
	Structural technology near lamp handle	LED, light source, handle, lens, dental light, shell, install, structure, connect, revolving axis, support member, light stand, lamp head, fixing block, positioning ... etc.
Lampshade structural technology of dental light	Light source arrangement technology	LED, light source, lens, reflector, illuminate, control, lamp, irradiate, angle, dazzling light, shadow, positioning, illumination, filter, adjust ... etc.
	Light source heat dissipation technology	LED, light source, lens, shell, radiator, heat dissipation, lampshade, radiation fin, thermally conductive shell, condenser lens, service life, circuit board, structure, switch ... etc.
Lamp control technology of dental light	Light source irradiation range technology	LED, light source, lamp, control, structure, handle, install, reflector, electromagnet, beam, light stand, radiator, outer shell, heat dissipation, shadow, illuminate ... etc.
	Light source brightness technology	Light source, lamp, illuminate, LED, install, lens, control, structure, adjust, switch, brightness, radiation fin, light spot, operate, outer shell, instrument ... etc.

The paper firstly follows the steps of the modified fuzzy ANP decision-making procedure to calculate the related weight matrix, and applies the modified fuzzy DEMATEL for calculation. The normalized direct/indirect matrix of the modified fuzzy DEMATEL is substituted into the modified fuzzy ANP, obtaining a result of the modified fuzzy DANP, and calculating the interdependent prioritized weight W_C^D of the modified fuzzy DANP. Besides, the matrix table of importance scale value of each fuzzied product technology criterion of fuzzy ANP in plans A, B, C as well as the transposed matrix $(\mathrm{W}_C^{\mathrm{D}})^{\mathrm{T}}$ of the fuzzied $\mathrm{W}_C^{\mathrm{D}}$ are further applied for calculation of the distance ratio of each optional plan of the modified fuzzy VIKOR to ideal solution and non-ideal solution. Finally, the most prioritized optional plan is determined and selected. The paper's innovative establishment of decision-making steps by combining the modified fuzzy DANP with the modified fuzzy VIKOR is explained as follows.

Below explains the stepwise calculation of the result of a prioritized improvement plan from the 3 improvement plans.

The following [Step 1] to [Step 12] are the steps of modified fuzzy DANP. [Step 1] to [Step3] are the steps of fuzzy ANP , [Step 4] to [Step 9] are the steps of modified fuzzy DEMATEL, and [Step 10] to [Step 12] are the steps of modified fuzzy DEMATEL combining the fuzzy ANP to form the modified DANP. The steps from [Step 13] to [Step 18] are the steps of modified fuzzy VIKOR.

[Step 1] Achieve pairwise comparison result among different product technology criteria.

First of all, for the technical word group of each technical criterion, the paper calculates the normalized numerical value of each technical criterion. The paper takes the 2nd-layer technologies of the established technical/functional matrix of dental light as the technical criteria mentioned below, as shown in Table 2. In Table 2, the equation for calculation of normalized numerical value is expressed as equation (1). From the result of normalized numerical value of each technology criterion obtained in Table 2, the normalized numerical value of each technology criterion is divided by the total normalized numerical value, obtaining the specific weight of normalized numerical value of each technology criterion. Using the fuzzy theory's triangular membership function and α-cut concept, the relative importance scale is calculated. Using the obtained fuzzy importance scale, a pairwise comparison matrix is established for each product technology criterion.

$$\text{Normalized numerical value} = \frac{\begin{array}{c}\text{No. of occurrence times of}\\ \text{important technical keywords}\end{array}}{\begin{array}{c}\text{No. of words in the full texts of}\\ \text{the related patent groups}\end{array}} \tag{1}$$

For example: When comparison of relative importance is made between criterion b. structure near lamp handle and criterion a. support holder structure, the specific weight of normalized numerical value of criterion b. structure near lamp handle is 16.11%, and the specific weight of normalized numerical value of criterion a. support holder structure is 13.87%.

The difference in specific weight of normalized numerical value between these two criteria is 2.24%. For the difference in specific weight of normalized numerical value,1.3% is taken as an interval to calculate the relative importance scale. As shown in Figure 1, the triangular membership function $\mu_A(x)$ is at the range of 0~2.6%, and the triangular membership function $\mu_B(x)$ is at the range of 1.3~3.9%. Therefore, the fuzzy triangular zone is in the range of 1.3~3.9%. For pairwise comparison of the specific weight of normalized numerical value among other product technology criteria, 1.3% is taken as an interval to calculate the relative importance scale. For the importance scale, 1 is of equal importance, 3 is slightly important, 5 is important, 7 is quite important, 9 is absolutely important.

Table 2 Normalized numerical values and specific weights of patents' key technical words of each technical criterion

Technology criterion	Normalized numerical value of each product technology criterion	Specific weight of normalized numerical value
a. Support holder structure	0.026096	13.87%
b. Structure near lamp handle	0.030309	16.11%
c. Light source arrangement	0.036008	19.14%
d. Light source heat dissipation	0.031789	16.90%
e. Light source irradiation range	0.036373	19.33%
f. Light source brightness	0.027579	14.66%
Total	0.188154	100.00%

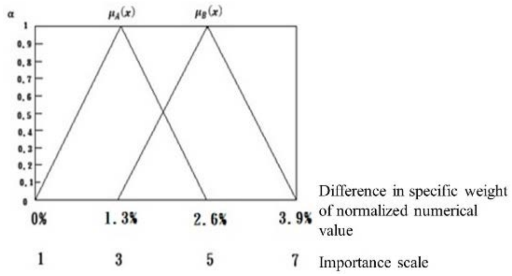

Figure 1 Fuzzy zone of the difference in specific weight of normalized numerical value at 1.3~2.6%

Substitute these 2 triangular membership functions into equation (2), obtaining: (Wan et al., 2006)

$$\mu_A(x) = \begin{cases} 0 & for \quad x < 0 \\ \frac{x-0}{1.3-0} & for \ 0 \le x < 1.3 \\ 1 & for \quad x = 1.3 \\ \frac{2.6-x}{2.6-1.3} & for \ 1.3 < x \le 2.6 \\ 0 & for \quad x > 2.6 \end{cases}$$

$$\mu_B(x) = \begin{cases} 0 & for \ x < 1.3 \\ \frac{x-1.3}{2.6-1.3} & for \ 1.3 \le x < 2.6 \\ 1 & for \ x = 2.6 \\ \frac{3.9-x}{3.9-2.6} & for \ 2.6 < x \le 3.9 \\ 0 & for \ x > 3.9 \end{cases} \qquad (2)$$

Substitute 2.24%, being between 1.3% and 2.6%, into the above equations, obtaining:

$$\mu_A = \frac{2.6-2.24}{2.6-1.3} = \frac{0.36}{1.3} = 0.28$$

$$\mu_B = \frac{2.24-1.3}{2.6-1.3} = \frac{0.94}{1.3} = 0.72$$

Since $\mu_A(x) = 0.28$, which is a value smaller than 0.5, 0 is taken. For $\mu_B(x) = 0.71$, which is a value greater than 0.5, so 1 is taken. As shown in Figure 1, 5 is thus taken as the corresponding importance scale of $\mu_B(x)$, implying that the relative importance of criterion b. structure near lamp handle to criterion a. support holder structure is 5, indicating that it is "important". Conversely, the relative importance of criterion a. support holder structure to criterion b. structure near lamp handle is 1/5, indicating that it is "unimportant". The diagonal values of the pairwise comparison of different most important technical words are all 1, indicating that during mutual comparison technical words, they are agreed to be of equal importance. As to the calculation method of importance scale during comparison of relative importance of different product technology criteria, the above calculation method can be used. The pairwise comparison matrix of different product technology criteria in the table of relative importance scales is shown in Table 3.

Table 3 Pairwise comparison matrix of different product technology criteria

	a	b	c	d	e	f	Geometric mean value	Weight
a	1	1/5	1/9	1/5	1/9	1/3	0.23410	0.02451
b	5	1	1/5	1/3	1/5	3	0.76472	0.08007
c	9	5	1	5	1	7	3.41099	0.35713
d	5	3	1/5	1	1/5	5	1.20094	0.12574
e	9	5	1	5	1	9	3.55689	0.37421
f	3	1/3	1/7	1/5	1/9	1	0.38337	0.04014

After that, the paper proposes a calculation method of the weight of pairwise comparison matrix. First of all, find the geometric mean value, which is expressed as equation (3):

$$Y_i = \sqrt[n]{x_{i1} \cdot x_{i2} \cdot \ldots \ldots \cdot x_{in}} \tag{3}$$

In this equation, Y_i = geometric mean value; x_i = comparative value of relative importance scale; and $i = a, b, c, d, e, f$. Therefore, the innovative weight equation of the paper is expressed as equation (4):

$$\text{Weight } w_{1i} = \frac{Y_i}{\sum_{i=1}^{n} Y_i}, \ i = a, b, c, d, e, f \tag{4}$$

Y_a = Geometric mean of support holder structure; Y_b = Geometric mean of structure near lamp handle; Y_c= Geometric mean of light source arrangement …… For example:

$$W_{1a} = \frac{Y_a}{\sum_{i=1}^{n} Y_i} = \frac{0.23410}{9.55101} = 0.02451$$

For other weights, they can be obtained using the above calculation method. All the calculated weights would form a weight matrix W_1, as shown below.

$$W_1 = \begin{bmatrix} W_{1a} \\ W_{1b} \\ W_{1c} \\ W_{1d} \\ W_{1e} \\ W_{1f} \end{bmatrix} = \begin{bmatrix} 0.02451 \\ 0.08007 \\ 0.35713 \\ 0.12574 \\ 0.37241 \\ 0.04014 \end{bmatrix}$$

[Step2] Compare the relative importance between each product technology criterion and each plan.

For example, the two improvement technologies of “overall holder structural technology + lamp control technology” in plan A cover these technologies: criterion a. support holder structure; criterion b. structure near lamp handle; criterion e. light source irradiation range; and criterion f. light source brightness. Since other technologies do not belong to the technologies in this plan, the specific weights of other normalized numerical values are not considered. The paper proposes adding up the specific weights of normalized numerical values of all the technical word groups covered in plan A, and calculating the ratio of specific weight of normalized numerical value of each product technology criterion in plan A. By doing so, the paper’s innovative equation of specific weight of normalized numerical value of each product technology criterion in plan A can be obtained, and is expressed as equation (5) and equation (6):

For example, in plan A,

$$n_A = n_a + n_b + n_e + n_f \tag{5}$$

and $n_{a1} = \frac{n_a}{n_A}$, $n_{a2} = \frac{n_b}{n_A}$, $n_{a3} = \frac{n_c}{n_A}$, $n_{a4} = \frac{n_d}{n_A}$, $n_{a5} = \frac{n_e}{n_A}$,

$$n_{a6} = \frac{n_f}{n_A} \tag{6}$$

In these equations, n_A = Sum of specific weights of normalized numerical values

$n_{a.b.e.f.}$= Specific weight of the original normalized numerical value of each product technology evaluation criterion

n_{a1} = Calculated specific weight of normalized numerical value of criterion a. support holder structure in plan A.

n_{a2} = Calculated specific weight of normalized numerical value of criterion b. structure near lamp handle in plan A.

n_{a3} = Calculated specific weight of normalized numerical value of criterion c. light source arrangement in plan A.

n_{a4} = Calculated specific weight of normalized numerical value of criterion d. light source heat dissipation in plan A.

n_{a5} = Calculated specific weight of normalized numerical value of criterion e. light source irradiation range in plan A.

n_{a6} = Calculated specific weight of normalized numerical value of criterion f. light source brightness in plan A.

n_A = 13.87%+16.11%+19.33%+14.66%=63.97%

$n_{a1} = \frac{13.87}{63.97}$ = 21.68%

Similarly in plan B：

$n_B = n_c + n_d + n_e + n_f$, $n_{b1} = \frac{n_a}{n_B}$, $n_{b2} = \frac{n_b}{n_B}$,

$n_{b3} = \frac{n_c}{n_B}$, $n_{b4} = \frac{n_d}{n_B}$, $n_{b5} = \frac{n_e}{n_B}$……

Similarly in plan C：

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

$n_{c3} = \frac{n_c}{n_C}$, $n_{c4} = \frac{n_d}{n_C}$, $n_{c5} = \frac{n_e}{n_C}$……

The ratio of specific weight of normalized numerical value of each product technology criterion in each plan for judgment of importance is shown in Table 4.

Table 4 Ratio of specific weight of normalized numerical value of each product technology criterion in each plan for judgment of importance

	a	b	c	d	e	f
Plan A	21.68%	25.18%	0.00%	0.00%	30.22%	22.91%
Plan B	0.00%	0.00%	27.33%	24.13%	27.61%	20.93%
Plan C	21.01%	24.40%	28.99%	25.59%	0.00%	0.00%

Through the fuzzy theory’s triangular membership function and α-cut concept, the relative importance scale value of each product technology criterion to each plan is calculated, establishing a table of comparison of the relative importance scale values of different product technology criteria to different plans. As observed from Table 4, for the ratio of specific weight of normalized numerical value, 8.5% is taken as an interval to make the result of importance scale values of different product technology criteria in different plans become more uniform. Perform operation of fuzzy numerical value, so as to calculate the relative importance scale, and establish a table of the relative importance scale values of different product technology criteria to different plans, as shown in Table 5.

Table 5 Importance scale values of different fuzzied product technology criteria in plans A, B and C

	a	b	c	d	e	f	Weight
A	7	7	1	1	9	7	0.35545
B	1	1	7	7	7	5	0.32228
C	5	7	7	7	1	1	0.32228

The calculation method of weight in Table 5 is expressed as equation (3) and equation (4).

For example: The eigen vector value w_{2aA} of criterion a. support holder structure to plan A is expressed as equation (7) and equation (8) as follows:

$$w_{2aA} = \frac{w_{aA}}{W} \qquad (7)$$

where, $\boldsymbol{W} = \boldsymbol{w_{aA}} + \boldsymbol{w_{aB}} + \boldsymbol{w_{aC}}$ (8)

W = Sum of relative importance scale values of criterion a. support holder structure to plans A, B and C

w_{aA} = Relative importance scale value of criterion a. support holder structure to plan A. From Table 5, we can obtain: w_{aA} =7

w_{aB} = Relative importance scale value of criterion a. support holder structure to plan B. From Table 5, we can obtain: w_{bB} =1

w_{aC} = Relative importance scale value of criterion a. support holder structure to plan C. From Table 5, we can obtain: w_{aC} =5

Therefore:

$$W = w_{aA} + w_{aB} + w_{aC} = 13, \quad w_{2aA} = \frac{7}{13} = 0.538$$

According to the above calculation method, an eigen vector is obtained:

$$\text{Eigen vector } w_{2aA} = \begin{bmatrix} w_{2aA} \\ w_{2aB} \\ w_{2aC} \end{bmatrix} = \begin{array}{c|c} & w_{2a} \\ \hline A & 0.538 \\ B & 0.077 \\ C & 0.385 \end{array}$$

For the eigen vectors of the remaining product technology evaluation criteria, this method can be used for calculation. Calculate the eigen vectors w_2 of all the product technology evaluation criteria to form a weight matrix W_2.

$$W_2 = \begin{array}{c|cccccc} & w_{2a} & w_{2b} & w_{2c} & w_{2d} & w_{2e} & w_{2f} \\ \hline A & 0.538 & 0.467 & 0.067 & 0.067 & 0.529 & 0.538 \\ B & 0.077 & 0.067 & 0.467 & 0.467 & 0.412 & 0.385 \\ C & 0.385 & 0.467 & 0.467 & 0.467 & 0.059 & 0.077 \end{array}$$

[Step 3] Make pairwise comparison of internal interdependence relationship among different product technology criteria.

The paper takes the technical word group of each technology criterion for analysis. Observe the important technical words in the technical word group of a certain technology criterion, and then compare the important technical words of other criteria's technical word groups with the important technical words previously found. If the occurrence of some important technical words is relatively frequent, combination with engineering knowledge can be performed to judge which technology criteria would be relevant to that certain criterion, as shown in Figure 2.

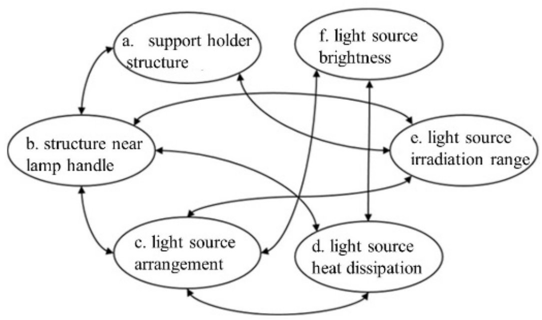

Figure 2 Internal interdependence among various technology criteria of dental light

As seen from Figure 2, the technical criteria having internal interdependence relationship with criterion a. support holder structure are criterion b. structure near lamp handle, and criterion e. light source irradiation range. Using equation (1), the normalized numerical values of criteria a, b and e are calculated. After that, calculate the sum of the normalized numerical values of the technology criteria with relevance, and find the specific weights of their normalized numerical values, with the results shown in Table 6. Take an appropriate specific weight of normalized numerical value as a scale interval. Through the fuzzy theory's triangular membership function and α-cut concept, the relative importance scale is calculated. Furthermore, a pairwise comparison table of internal interdependence relationship among different product technology criteria is established, as shown in Table 7. Through equation (3) and equation (4), the weights are calculated.

Table 6 Normalized numerical values and specific weights of criterion a, criterion b and criterion e

Technology criterion	Normalized numerical value of each product technology criterion	Specific weight of normalized numerical value
a. support holder structure	0.026096033	28.13%
b. structure near lamp handle	0.030308586	32.67%
e. light source irradiation range	0.036373484	39.20%

Table 7 Relative importance scale values and weights of criterion a, criterion b and criterion e

Criterion a	**a**	**b**	**e**	Geometric mean	Weight
a	1	1/5	1/9	0.281	0.155
b	5	1	1/5	1.000	0.552
e	9	5	1	0.530	0.93

Taking criterion a. support stand structure for explanation, the key technical words of support stand structure have internal interdependence relationship with criterion b. structure near lamp handle and criterion e. light source irradiation range. And the rest of the key technical words have no internal interdependence relationship. Since there is no important relationship among the key technical word of these several criteria, the weight is 0. After calculation, the weights can be obtained in Table 7: w_{3aa} =0.155, w_{3ab} =0.552, and w_{3ae} =0.293. Therefore, the weight matrix formed by criterion a. support stand structure is w_{3a} = (0.155, 0.552, 0, 0, 0.293, 0). The weight matrices (w_{3b}, w_{3c}, w_{3d}, w_{3e}, w_{3f}, w_{3g}) of internal interdependence relationship among different product technology evaluation criteria are all calculated using the above method. Then, all the weight matrices are used for form a matrix W_3. Hence, W_3 = (w_{3a}, w_{3b}, w_{3c}, w_{3d}, w_{3e}, w_{3f}, w_{3g}).

$$W_3 = \begin{bmatrix} 0.155 & 0.552 & 0 & 0 & 0.293 & 0 \\ 0.029 & 0.076 & 0.388 & 0.119 & 0.388 & 0 \\ 0 & 0.063 & 0.381 & 0.117 & 0.408 & 0.031 \\ 0 & 0.108 & 0.650 & 0.203 & 0 & 0.040 \\ 0.037 & 0.110 & 0.427 & 0 & 0.427 & 0 \\ 0 & 0 & 0.735 & 0207 & 0 & 0.058 \end{bmatrix}$$

[Step 4] Define product technology criteria and judge the mutual impact relationship to each other.

To establish the degree of mutual impact among different product technology criteria, the paper uses the method of collating the technical words of patents. First of all, the technical words and part/component words possessed by each technical field and their normalized numerical values are calculated, further finding out the total number of occurrence times of a technical field's technical words and part/component words repeatedly occurring or having the same definitions in another field as well as the sum of their normalized numerical values. Then, divide the sum of normalized numerical values of another technical field's technical words and part/component words repeatedly occurring or having the same definitions in the main technical field by the total normalized numerical value of the main technical field's technical words and part/component words, obtaining the ratio of the normalized numerical value defined by the paper, which is expressed as equation (9).

$$\frac{\text{Sum of normalized numerical values of another technical field's technical words and part/component/element words repeatedly occurring or having the same definitions in the main technical field}}{\text{Total normalized numerical value of the main technical field's technical words and part/component/element words}} = \text{Ratio of normalized numerical value of technology} \quad (9)$$

According to the ratio of normalized numerical values, the degree of pairwise impact among the 6 product technology criteria is used to determine the degree of impact among different product technology criteria. The patent technical words of criterion b. structure near lamp handle repeatedly occurring or having the same definitions in criterion a. support holder structure are LED, handle, install, mouth cavity light, holder ... etc., having a ratio of normalized numerical value at 21.16% in criterion a, as shown in Table 8.

Table 8 Ratio of the normalized numerical values of criterion b's technical words in criterion a

Occurred technical word	Normalized numerical value
LED	0.002423
handle	0.001533
install	0.000816
mouth cavity light	0.000542
holder	0.000204
⋮	⋮
Account for 21.16%	

Following the above example, calculate the ratios of normalized numerical values among other product technology criteria, and form a matrix of ratio of normalized numerical values among 6 product technology criteria, with its calculation results shown in Table 9.

Table 9 Matrix of ratio of normalized numerical values among 6 product technology criteria of dental light

	a.	**b.**	**c.**	**d.**	**e.**	**f.**
a.	100%	19.71%	23.68%	15.47%	31.46%	9.21%
b.	21.16%	100%	41.97%	42.61%	38.53%	17.26%
c.	19.38%	47.65%	100%	58.39%	52.98%	54.91%
d.	13.27%	33.49%	44.21%	100%	16.85%	25.67%
e.	26.37%	31.23%	46.67%	20.31%	100%	19.57%
f.	7.14%	13.36%	32.77%	38.52%	13.40%	100%

[Step 5] Establish a direct relation matrix Z.

First of all, determine that the relationship of the degree of mutual impact among product technology criteria is at the value of 0~4, with 0 indicating “no impact”, 1 indicating “low impact”, 2 indicating “medium impact”, 3 indicating “high impact”, and 4 indicating “extremely high impact”. According to the total normalized numerical value of the patent technical words among different criteria, the ratio of normalized numerical values of the patent technical words repeatedly occurring or having the same definitions in the criteria is reviewed in terms of physical meaning and range of intervals. Through the fuzzy set’s attached triangular membership function, the ratio value of normalized numerical values is judged to be located at the fuzzy zone where the 2 triangles intersect. Adopting α-cut concept, if the membership function $\alpha \geqq 0.5$, it belongs to 1; and if the membership function $\alpha < 0.5$, it belongs to 0. With this result, the degree of relative importance among the criteria is evaluated and determined. After that, a direct relation matrix *Z* is established. As seen from the matrix of ratios of normalized numerical values among 6 product technology criteria in Table 9 and as observed from the overall ratios of normalized numerical values of different technology criteria, 13% is taken as a fuzzy interval to make the overall relationship results of the degree of mutual impact at 0~4 of the ratios of normalized numerical values among different product technology criteria become more uniform.

As to comparison of other relative importance scales, the calculation method aforesaid can be used to obtain the result. The ratio of product technology criteria to their normalized numerical values is 100%, so that the degree of mutual impact is 0, indicating “no impact”. Finally, a direct relation matrix *Z* can be established, as shown below.

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

[Step 6] Establish a normalized direct relation matrix.

From the obtained matrix *Z* and based on equation (10), find the greatest total value S in columns, and the value is 17. Divide matrix “*Z*” by 17, obtaining a normalized direct relation matrix “*X*”, as shown below equation (11).

$$S = \left(\max_{1\le i\le n} \sum_{j=1}^{n} Z_{ij} \text{ , } \max_{1\le j\le n} \sum_{i=1}^{n} Z_{ij} \right) = 1+4+0+4+4+4 = 17 \tag{10}$$

$$X = \frac{Z}{S} = \frac{1}{17} \begin{bmatrix} 0&2&2&1&2&1 \\ 2&0&3&3&3&1 \\ 1&4&0&4&4&4 \\ 1&3&3&0&1&2 \\ 2&2&4&2&0&2 \\ 1&1&3&3&1&0 \end{bmatrix} \tag{11}$$

A normalized direct relation matrix is obtained.

$$X = \begin{bmatrix} 0 & 0.118 & 0.118 & 0.059 & 0.118 & 0.059 \\ 0.118 & 0 & 0.176 & 0.176 & 0.176 & 0.059 \\ 0.059 & 0.235 & 0 & 0.235 & 0.235 & 0.235 \\ 0.059 & 0.176 & 0.176 & 0 & 0.059 & 0.118 \\ 0.118 & 0.118 & 0.235 & 0.118 & 0 & 0.118 \\ 0.059 & 0.059 & 0.176 & 0.118 & 0.059 & 0 \end{bmatrix}$$

[Step 7] Establish a direct/indirect matrix.

The calculation of direct/indirect matrix *T* is shown as follows:

$$T = X(I-X)^{-1} \tag{12}$$

where I denotes the unit matrix, and X denotes the normalized direct relation matrix.

$$T = \begin{bmatrix} 1.122 & 0.312 & 0.348 & 0.280 & 0.299 & 0.235 \\ 0.279 & 1.303 & 0.502 & 0.471 & 0.427 & 0.317 \\ 0.289 & 0.588 & 1.473 & 0.627 & 0.553 & 0.537 \\ 0.205 & 0.411 & 0.451 & 1.284 & 0.298 & 0.328 \\ 0.279 & 0.412 & 0.550 & 0.435 & 1.282 & 0.372 \\ 0.186 & 0.296 & 0.422 & 0.407 & 0.268 & 1.207 \end{bmatrix}$$

[Step 8] Calculate the centrality and causality.

For the value of direct/indirect matrix *T*, calculate the total value D in rows and the total value R in columns according to equation (13) and equation (14), and calculate the D+R value and D-R value, with their results shown in Table 12.

D_i denotes the total value in rows;

$$D_i = \sum_{j=1}^{n} t_{ij} (I = 1, 2, \dots, n) \tag{13}$$

R_j denotes the total value in columns;

$$R_j = \sum_{i=1}^{n} t_{ij} (j = 1, 2, \dots, n) \tag{14}$$

Table 10 Total value D in rows, total value R in columns, D+R value and D-R value of 6 criteria of dental light

	Total value D in rows	Total value R in columns	D+R	D-R
a	1.598	1.362	2.959	0.236
b	2.300	2.322	4.622	(0.022)
c	3.069	2.747	5.816	0.322
d	1.977	2.504	4.480	(0.527)
e	2.329	2.128	4.457	0.201
f	1.786	1.996	3.782	(0.210)

[Step 9] Draw a causal diagram

After that, according to the causal diagram established in Step 8, draw the 6 criteria on the coordinate axes based on (D+R, D-R). Through the average value of centrality (D+R), draw a vertical axis to divide the causal diagram into four quadrants.The contants of the 4 quadrants of causal diagram shown in figure 3.

Subsequently, according to the causal diagram established in Table 10, draw the 6 criteria on the coordinate axes based on (D+R, D-R). Through the average value 4.353 of centrality (D+R), draw a vertical axis to divide the causal diagram into four quadrants (as shown in Figure 4), with the existence criteria of each quadrant shown as follows:

As known in Figure 4, when the 6 product technology criteria of dental light are to be discussed, the technologies of criterion c. light source arrangement and criterion e. light source irradiation range existing in the 1st quadrant are core technologies. Criterion a. support holder structure exists in the 2nd quadrant. Criterion f. light source brightness exists in the 3rd quadrant. Criterion b. structure near lamp handle and criterion d. light source heat dissipation existing in the 4th quadrant are the product function criteria that can be easily affected by other criteria.

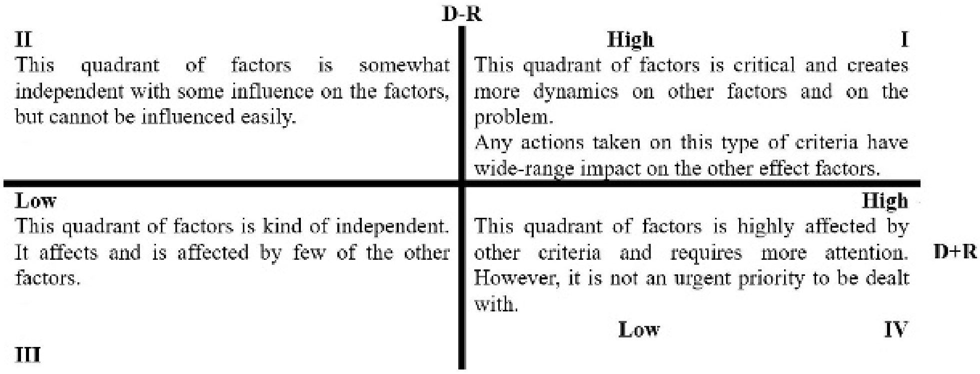

Figure 3 Contents of the 4 quadrants of causal diagram

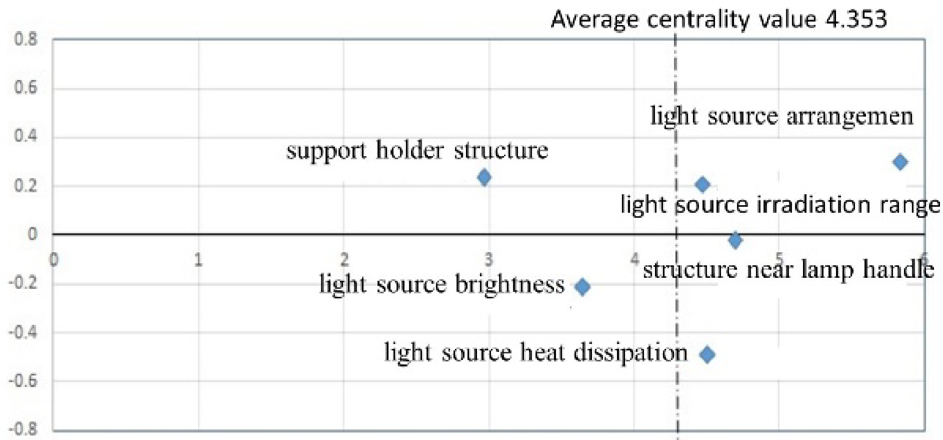

Figure 4 Causal diagram of 6 product technology criteria of dental light

[Step 10] Normalize the direct/indirect matrix T_C.

Normalized direct/indirect matrix,

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

$$= \begin{bmatrix} t_{11}^1 & \cdots & t_{1j}^1 & \cdots & t_{1m}^1 \\ \vdots & & \vdots & & \vdots \\ t_{i1}^1 & \cdots & t_{ij}^1 & \cdots & t_{im}^1 \\ \vdots & & \vdots & & \vdots \\ t_{m1}^1 & \cdots & t_{mj}^1 & \cdots & t_{mm}^1 \end{bmatrix} \quad (15)$$

d_λ denotes the normalized value, being the total value in rows of this criterion.

According to the equation of normalized direct/indirect matrix T_c, calculate the total value of each item in the rows of matrix T, and divide it by the value of each item in each column, obtaining:

$$T_c = \begin{bmatrix} 0.432 & 0.120 & 0.134 & 0.108 & 0.115 & 0.090 \\ 0.085 & 0.395 & 0.152 & 0.143 & 0.130 & 0.096 \\ 0.071 & 0.145 & 0.362 & 0.154 & 0.136 & 0.132 \\ 0.069 & 0.138 & 0.152 & 0.431 & 0.100 & 0.110 \\ 0.084 & 0.124 & 0.165 & 0.131 & 0.385 & 0.112 \\ 0.067 & 0.106 & 0.151 & 0.146 & 0.096 & 0.433 \end{bmatrix}$$

[Step 11] Transpose the normalized matrix, and multiply it by the weight matrix.

For the pairwise comparison matrix W_3 obtained in Step 3, the transposed normalized direct/indirect matrix T_c is multiplied by the pairwise comparison matrix W_3, obtaining a new matrix W_3^D, and the calculation process is as follows:

$$T_c^T \times W_3 = W_3^D \tag{16}$$

$$W_3^D=\begin{bmatrix} 0.073 & 0.266 & 0.190 & 0.046 & 0.224 & 0.009 \\ 0.035 & 0.134 & 0.429 & 0.114 & 0.301 & 0.016 \\ 0.031 & 0.143 & 0.477 & 0.123 & 0.316 & 0.026 \\ 0.026 & 0.141 & 0.558 & 0.153 & 0.206 & 0.030 \\ 0.036 & 0.135 & 0.402 & 0.072 & 0.304 & 0.014 \\ 0.021 & 0.089 & 0.532 & 0.141 & 0.165 & 0.034 \end{bmatrix}$$

[Step 12] Calculate the internally interdependent prioritized weight W_C^D after adding in fuzzy DEMATEL.

Multiply the W_3^D obtained in the previous step by the W_1, achieving a new internally interdependent prioritized weight W_C^D.

$$W_3^D \times W_1 = W_C^D \tag{17}$$

$$W_C^D = \begin{bmatrix} 0.181 \\ 0.292 \\ 0.317 \\ 0.308 \\ 0.278 \\ 0.278 \end{bmatrix}$$

The steps from [Step 13] to [Step 18] below are the steps of the modified fuzzy VIKOR decision making steps.

[Step 13] Establish a matrix of different criteria to different plans.

Use the fuzzy triangular membership function and α-cut concept to calculate the relative importance scale, obtaining the importance scale value of each fuzzied product technology criterion in plans A, B and C, as shown in Table 5. After that, using Table 5, a matrix of a table of criterion-plan relationship is established in Table 5, and the matrix is expressed as f_{ij}, as shown in Table 11.

Table 11 Establishment of a table of criterion-plan relationship

	Criterion 1	Criterion 2	...	Criterion n
Plan 1	f_{11}	f_{12}	...	f_{1n}
Plan 2	f_{21}	f_{22}	...	f_{2n}
⋮	...	...	...	...
Plan m	f_{m1}	f_{m2}	...	f_{mn}

[Step 14] Normalize the matrix f_{ij}.

Normalize the matrix f_{ij} of the fuzzied product technology criteria to different plans to reduce occurrence of error. The normalized matrix is y_{ij}.

$$y_{ij} = f_{ij} \Big/ \sqrt{\sum_{j=1}^{n} {f_{ij}}^2} \quad , i = 1,2,\dots,m \; ; \; j = 1,2,\dots,n \tag{18}$$

$$y_{ij} = \begin{bmatrix} 0.462 & 0.462 & 0.066 & 0.066 & 0.593 & 0.462 \\ 0.076 & 0.076 & 0.531 & 0.531 & 0.531 & 0.379 \\ 0.379 & 0.531 & 0.531 & 0.531 & 0.076 & 0.076 \end{bmatrix}$$

[Step 15] Fuzzy the matrix y_{ij}.

After that, take an appropriate difference in y_{ij} value as an interval to fuzzy the matrix. As observed from the numerical values in matrix y_{ij}, for the difference in y_{ij} value, 15% is taken as an interval to make the results of relative importance scale values in the fuzzied matrix k_{ij} become more uniform.

Matrix y_{ij} can be fuzzied to become matrix k_{ij}, as shown below.

$$[k_{ij}] = \begin{bmatrix} 7 & 7 & 1 & 1 & 9 & 7 \\ 3 & 3 & 9 & 9 & 9 & 7 \\ 7 & 9 & 9 & 9 & 3 & 3 \end{bmatrix}$$

[Step 16] Determine the ideal solution and non-ideal solution.

Confirm the numerical values of the most ideal solution and the least ideal solution in each evaluation criterion. Of them, k_j^* denotes the positive ideal solution, implying to the greatest value among different criteria; and k_j^- denotes the negative ideal solution, implying to the smallest value among different criteria. The ideal solution and non-ideal solution can be obtained from equations (19) and (20).

$$k_j^* = \max_i \{k_{ij}, \dots, k_{mj}\} \quad , \quad j = 1,2,\dots,n \tag{19}$$

$$k_j^- = \min_i \{k_{ij}, \dots, k_{mj}\} \quad , \quad j = 1,2,\dots,n \tag{20}$$

Find the sets ${k_j}^*$ and ${k_j}^-$:

$${k_j}^* = \{ k_1^*, k_2^*, k_3^*, k_4^*, k_5^*, k_6^* \}$$
$$= \{ 7, 9, 9, 9, 9, 7 \}$$
$${k_j}^- = \{ k_1^-, k_2^-, k_3^-, k_4^-, k_5^-, k_6^- \}$$
$$= \{ 3, 3, 1, 1, 3, 3 \}$$

[Step 17] Calculate the distance ratio of each optional plan to ideal solution and non-ideal solution.

For this step, calculate the distance ratio of each optional plan to ideal solution and non-ideal solution. Of them, S_i denotes the distance ratio of a plan to ideal solution; R_i denotes the distance ratio of a plan to non-ideal solution. The paper uses fuzzy DANP method to obtain the relative weight ω_j, which denotes the relative weight among different evaluation criteria. Then, transpose matrix W_C^D derived by the paper using fuzzy DANP method to form $(W_C^D)^T$.

$$S_i = \sum_{j=1}^{n} \omega_j \left[\left(k_j^* - k_{ij}\right) / \left(k_j^* - k_j^-\right) \right] \tag{21}$$

$$R_i = \max_j \omega_j \left[\left(k_j^* - k_{ij}\right) / \left(k_j^* - k_j^-\right) \right] \tag{22}$$

$$\omega_j = (W_C^D)^T = [\omega_1, \omega_2, \omega_3, \omega_4, \omega_5, \omega_6]$$
$$= [\, 0.181, 0.292, 0.317, 0.308, 0.278, 0.278 \,]$$

After calculation, $[S]_i$ and $[R]_i$ are obtained as follows:

$$[S]_{i=1,2,3} = \begin{bmatrix} 0.669 \\ 0.473 \\ 0.556 \end{bmatrix} [R]_{i=1,2,3} = \begin{bmatrix} 0.317 \\ 0.292 \\ 0.278 \end{bmatrix}$$

[Step 18] Calculate the comprehensive index.

Calculate the comprehensive index Q_i, which is expressed as equation (23). The smaller the comprehensive index value, the more prioritized the optional plan. In the equation, v denotes the coefficient of decision-making mechanism. For the fuzzy VIKOR method, v is set to be 0.5, with:

$S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i R_i$

$$Q_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1-v)\left[\frac{R_i - R^*}{R^- - R^*}\right] \quad (23)$$

After calculation, $[Q]_i$ is obtained as follows:

$$[Q]_{i=1,2,3} = \begin{bmatrix} 1 \\ 0.179 \\ 0.211 \end{bmatrix}$$

After conducting mathematical calculation of the modified fuzzy VIKOR, the paper obtains 3 comprehensive indices for product technology improvement plans, namely 1, 0.179 and 0.211. The priority order of importance is plan B > plan C > plan A. When the comprehensive index value Q of a plan is closer to zero, it implies to a closer distance from the ideal solution, so it is the best optional plan, i.e. plan B, “lampshade structural technology + lamp control technology”, which is selected as the best product technology improvement plan for dental light. The reason for this can be explained by the causal diagram produced from the modified fuzzy DEMATEL. In plan B, there are criterion c. light source arrangement and plan e. light source irradiation range, which both lie on the 1st quadrant in the causal diagram. According to the description of each quadrant, the criteria in the1st quadrant have the broadest impact on other criteria. From a design perspective, plan B is the most prioritized technology improvement plan. As seen from the example of dental light, the use of fuzzy VIKOR method enables quantitative evaluation and presentation ways on the degree of mutual impact among product technology criteria, and provides designers with clear indices in judgment. Through the match of causal diagram and fuzzy VIKOR, the entire evaluation process is more accurate.

CONCLUSION

Through search of the dental light-related patents, the paper further establishes a technical/ functional matrix of dental light. Taking the technical fields of the technical/functional matrix as a basis for preliminary design, different technical fields of dental light are taken as the criteria of the modified fuzzy DANP. Among them, in the modified fuzzy VIKOR method that combines with the modified fuzzy DANP method, triangular membership function is used. Through the word segmentation system, the paper finds the technical words and part/component word groups of each technical field of dental light. After that, the 3 main technologies belonging to the 1st-layer technologies of the technical/functional matrix of dental light form 3 technology improvement plans with technological interdependence. After normalizing the direct/indirect matrix of the modified fuzzy DEMATEL, the paper substitutes it into the modified fuzzy ANP, obtaining the results of the modified fuzzy DANP. The paper calculates the interdependent prioritized weight W_C^D of the modified fuzzy DANP, and further applies it to calculation of the modified fuzzy VIKOR method’s distance ratio of each optional plan to ideal solution and non-ideal solution. Finally, the paper calculates the comprehensive index Q_i so as to decide and select the most prioritized optional plan. After mathematical calculation of the modified fuzzy VIKOR method of the modified fuzzy DANP method, 3 comprehensive indices of product technology improvement plans are obtained. The priority order of importance is plan B > plan C > plan A. Plan B, “lampshade structural technology + lamp control technology”, which is selected as the best product technology improvement plan being most suitable for dental light.

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建立結合修正式 FUZZY DANP 之修正式 FUZZY VIKOR 法並應用於牙科燈改善方案評選

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摘要

本研究首先收集牙科燈相關之技術專利，建立牙科燈之技術/功能矩陣，並透過斷詞斷字系統分別定義牙科燈相關專利之各技術領域的重要技術字常態化數值。本研究再將牙科燈的第一層技術領域的三項主要技術領域組成具有技術相依性的三個技術改善方案。透過修正式 FUZZY DANP 之步驟計算相關權值矩陣。其應用修正式 FUZZY DEMATEL 做計算。本研究將先前計算出修正式 FUZZY DANP 之相依優先權值W_C^D代入修正式 FUZZY VIKOR 法的S_i及R_i公式，並計算修正式 FUZZY VIKOR 的其他相關公式，最後再計算出綜合指標Q_i，決策評選出最優先選擇之方案。