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Application of the Modified DANP Method Combined with the Modified TOPSIS Method to Selection of Improvement Plans for LED Track Lighting

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Keywords: LED track lighting, product function, modified DANP, TOPSIS

ABSTRACT

From the analysis of track lighting patents, the paper develops the concept of obtaining the normalized numerical values of functional word groups in each functional field, and then combines this concept with the modified DEMATEL-based Analytical Network Process (DANP) method and the modified Techniques for Order Preference by Similarity to an Ideal Solution (TOPSIS) method for application to track lighting in order to determine the priority of the functional improvement plans of different LED track lightings. Through exploration of the related literature on LED track lighting products as well as analysis of different patents, this paper has sorted out three product functional improvement plans for LED track lighting products. Then the paper divides the criteria for product functions into seven functional areas. This paper substitutes the W_{pij} of W_P and W_C^D obtained by using the modified DANP method into the related equations of the modified TOPSIS method, and uses the modified TOPSIS method to calculate the priority of various functional improvement plans so as to select the most prioritized functional improvement plan.

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INTRODUCTION

LED track lighting is a type of lighting product that uses LED as the light source and is fixed on a track, along which individual lights can slide to different spots, and illuminates at different angles within multiple ranges. It is commonly fixed to the wall or ceiling, etc.

LED track lighting is generally for commercial use. As mentioned in a traditional Chinese patent No. TW201109568(2011), track lighting system is commonly used in many places, such as retail stores, residences and museums. Since track lighting system provides flexibility, track lighting fixtures can be reconfigured to meet the lighting requirements of a space, without requiring any skilled craftsman or any additional special equipment to adjust the existing lighting fixtures or install additional lights. The lighting fixtures in track lighting system can also be easily changed or reconfigured to adapt to different changing styles and keep up with technological advancements.

Decision Making and Trial Evaluation Laboratory (DEMATEL) is a method developed by the Battelle Memorial Institute of Geneva, Switzerland from 1972 to 1976 for the Science and Human Affairs program. Tzeng et als. (2007) mentioned that the main functions and characteristics of DEMATEL 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) mentioned in their studies that in the analytic network process (ANP) calculation method, when processing the steps of regularizing a super matrix, it was assumed that every cluster had the same weight.

Although this method of regularizing a super matrix is simpler, the fact that different clusters should have different degrees of influence was ignored, implying that different clusters should have different weights. Therefore, a new decision-making method with multiple criteria mixed was proposed, and called the DANP method. After practical application of DANP method, it was found that this traditional method was more suitable and closer to the reality. Sugiyanto and Rochimah (2013) used DANP to calculate the weight of software quality in order to further understand the mutual influencing relationship among different factors of software quality. Wu (2005) proposed applying DANP to evaluation of knowledge management strategies.

The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method, first proposed by Hwang (1981), was a kind of useful Multiple Attribute Decision-Making (MADM) technique mainly for solving problems. Yang (2007) proposed an evaluation research and verified that analytical network process (ANP) could also cause a rank reversal problem, and suggested combining ANP with TOPSIS for evaluation to solve the problem caused by ANP. Huan (2006) used the TOPSIS method together with the ANP method for selection of the existing commercial off-the-shelf (COTS) products, conducted an empirical research on real cases, and proved the effectiveness and feasibility of the evaluation procedure proposed by him. Adil (2013) combined DEMATEL with TOPSIS to solve the selection problem of SWOT strategies. By using the TOPSIS algorithm, he overcame the problem of computational overload and increased the practicability and applicability of this method.

THREE FUNCTIONAL IMPROVEMENT PLANS AND FUNCTIONAL CRITERIA FOR LED TRACK LIGHTING

Through review of the related literature and various patents of LED track lighting products, this studied case, and through the term and word segmentation system, the criteria for seven product functions of LED track lighting-related patents are screened out, and they are: (a) Increase structural stability; (b) Improve assembly convenience; (c) Increase heat dissipation; (d) Reduce costs, extend lifespan and save energy; (e) Increase light intensity and luminous range; (f) Adjust light source angle and color tone; and (g) Light source control. After that, based on the searched patents about LED track lighting, the functional word and part/component word groups of various functional criteria are established as shown in Table 1. (Chiang, 2018)

This paper uses the three functional improvement plans of the expanded view of "LED track lighting" mode, including plan A "Increase overall stability and convenience + improve lighting efficiency", plan B "Increase heat dissipation and lifespan + improve lighting efficiency", as well as plan C "Increase overall stability and convenience + increase heat dissipation and lifespan". Each plan contains two or three functional improvements so as to make the three plans interdependent.

Table 1. Functional word and part/component word groups of various functional criteria of LED track lighting (Chiang, 2018)

Functional criterion	Functional word group
Increase structural stability	Support, stability, safety, reliability, anti-loosening, connection, ... etc.
Improve assembly convenience	Quick installation, lighter weight, convenience, flexibility, work efficiency, ... etc.
Increase heat dissipation	Heat dissipation area, heat dissipation efficiency, heat dissipation effect, convection, temperature lowering, cooling, ... etc.
Reduce costs, extend lifespan and save energy	Cost reduction, service life, shading, flattening, energy saving, charging, ... etc.
Increase light intensity and luminous range	Light brightness, shading, light transmittance, irradiation range, concentration, ... etc.
Adjust light source angle and color tone	Illumination angle, refraction, uniformity, surface structure, light source efficiency, light emission, light source dispersion, light scattering, ... etc.
Light source control	Control, environmental protection, energy saving, regulation, ... etc.

The criteria for the product functions corresponding to plan A's "Increase overall stability and convenience + improve lighting efficiency" are: (a) Increase structural stability; (b) Improve assembly convenience; (e) Increase light intensity and luminous range; (f) Adjust light source ngle and color tone; and (g) Light source control. The criteria for the product functions corresponding to plan B's "Increase heat dissipation and lifespan + improve lighting efficiency" are: (c)Increase heat dissipation, (d) Reduce costs, extend life and save energy, (e) Increase lighting intensity and luminous range, (f) Adjust light source angle and color tone, and (g) Light source control. The criteria for the product functions corresponding to plan C's "Increase overall stability and convenience + increase heat dissipation and lifespan" are: (a) Increase structural stability; (b) Improve assembly convenience; (c) Increase heat dissipation; (d) Reduce costs, extend life and save energy.

PRIORITIZED DESIGN PLAN FOR SELECTION OF LED TRACK LIGHTING BY COMBING PRODUCT FUNCTIONS WITH THE MODIFIED DANP METHOD AND THE MODIFIED TOPSIS METHOD

Through the abovementioned criteria for seven product functions, the paper calculates the modified ANP of the LED track lighting, and then uses the three interdepending product function improvement plans as the modified ANP solutions for making a priority order for selection. Each plan contains two or three functions. After that, matrix calculation is carried out for the total relationship influence matrix T of the modified DEMATEL as well as the internally depending pairwise comparison matrix W_3 of the modified ANP, so as to form the W_3^D weight of the newly modified DANP. Then, the paper calculates the decision matrix W_P of each plan according to the steps of the modified DANP method, substitutes each $[W_3^D]_i$ of W_3^D and W_{pij} into the related equation of the modified TOPSIS method, and uses the modified TOPSIS method to calculate the priority order of various plan, and select the most prioritized plan.

Steps and Process of Combining Product Functions with the Modified ANP for Selection of LED Track Lighting

The paper evaluates and calculates the relative importance as well as the internal interdependence among functional words according to the operating steps of the modified ANP. The steps of the analysis process are shown below.

【Step 1】Find the paired comparison results of the criteria for various product functions.

First of all, a comparison of relative importance is made among the various most important functional words, and the equation for calculating the normalized numerical values is expressed as Equation (1). Table 2 shows the normalized numerical values and ratios of the patents' key functional words for judging the importance scales of the criteria for various product functions.

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

The intervals between various importance scales are shown in Table 3. Therefore, for example, in table 2 the ratio of normalized numerical value of criterion a is 7.54%, and the ratio of normalized numerical value of criterion b is 13.58%, so the difference in between is: 13.58% - 7.54% = 6.04%. As a result, the importance scale of criterion b is 5, and that of criterion a is 1/5 in table 4.

The calculation of relative importance scale value is obtained by using this calculation method. From Table 2 and Table 3, the pairwise comparison matrix of the criteria for various product functions, as shown in Table 4, can be further obtained.

Table 2. Normalized numerical values and ratios of the patents' key functional words for judging the importance scales of the criteria for various product functions

Criterion for each product function	Normalized numerical value of criterion for functional word group of each product function	Ratio of normalized numerical value
a. Increase structural stability	0.0121	7.54%
b. Improve assembly convenience	0.0217	13.58%
c. Increase heat dissipation	0.0276	17.24%
d. Reduce costs, extend lifespan and save energy	0.0178	11.15%
e. Increase light intensity and luminous range	0.0301	18.80%
f. Adjust light source angle and color tone	0.0227	14.19%
g. Light source control	0.0280	17.51%
Total	0.1599	100.00%

Table 3. Relationship between the difference in ratio of normalized numerical value and importance scale of each criterion

Difference in ratio	Importance scale
Below 0.3%	1
0.3%~3.7%	3
3.7%~6.7%	5
6.7%~9.8%	7
Above 9.8%	9

Table 4. Pairwise comparison matrix of the criteria for various product functions

	a	b	c	d	e	f	g	Weight
a	1	1/5	1/7	1/3	1/9	1/9	1/3	0.022
b	5	1	1/3	3	1/5	1/5	3	0.088
c	7	3	1	5	1/3	1/9	3	0.135
d	3	1/3	1/5	1	1/7	1/9	1/5	0.033
e	9	5	3	7	1	9	9	0.473
f	5	3	1/3	3	1/9	1	7	0.135
g	9	3	1	5	1/9	1/7	1	0.114

After that, this paper proposes a method to calculate the weight of the pairwise comparison matrix. First of all, the geometric mean is obtained, and its equation is expressed as Equation (2). Then, the paper adds up the geometric mean calculated by all the criteria for product function evaluation, and divides the geometric mean of the criterion for calculation and evaluation of product function by the sum of geometric means in order to obtain the weight of the criterion for product function evaluation. Therefore, this paper develops a weight equation, which is expressed as Equation (3). Other weights can be obtained by the above calculation method, and all the calculated weights can form a weight matrix W_1. As for the investigation results of paired comparisons, the C.R. values defined by Saaty have to be calculated so as to check whether they are consistent.

$$\boldsymbol{Y_i} = \sqrt[n]{x_{i1} \cdot x_{i2} \cdot \ldots\ldots x_{in}} \tag{2}$$

where $\boldsymbol{Y_i}$ = geometric mean; x_i = comparison value of relative importance scale; and i = a, b, c, d, e, f, g.

$$\textbf{Weight } \boldsymbol{W_{1i}} = \frac{Y_i}{\sum_{i=1} Y_i} \quad \text{i=a、i=a、b、c、d、e、f、g}$$

The calculated W_1 is shown as follows:

$$w_1 = \begin{bmatrix} 0.022 \\ 0.088 \\ 0.135 \\ 0.033 \\ 0.473 \\ 0.135 \\ 0.114 \end{bmatrix}$$

【Step 2】Compare the relative importance of the criteria for various product functions to various plans.

For example, in plan A, the criteria for the key functional words included in the two functional improvements of "Increase overall stability and convenience + improve lighting efficiency" are: (a) Increase structural stability; (b) Improve assembly convenience; (e) Increase light intensity and luminous range; (f) Adjust light source angle and color tone; and (g) Light source control. Since other functions do not belong to this plan, the normalized numerical values of other product function criteria are not considered. The paper proposes summing up the normalized numerical values of all the key functional words groups of the product function criteria included in plan A, and recalculating the ratios of normalized numerical values of the key functional words of the related criteria for various product functions in plan A. Based on this, the paper can further develop equations for calculating the ratios of normalized numerical values of the key functional words of the criteria for various product functions in each plan, and the equations are expressed as Equation (3) and Equation (4):

e.g. In plan A, $n_A = n_a + n_b + n_e + n_f + n_g$ (3)

$$n_{a1} = \frac{n_a}{n_A}, \; n_{a2} = \frac{n_b}{n_A}, \; n_{a3} = \frac{n_c}{n_A}$$
$$n_{a4} = \frac{n_d}{n_A}, \; n_{a5} = \frac{n_e}{n_A}, \; n_{a6} = \frac{n_f}{n_A}, \; n_{a7} = \frac{n_g}{n_A} \tag{4}$$

where n_a to n_g are the ratios of the normalized numerical values of criterion a to criterion g shown in Table 2.n_A denotes the ratios n_a, n_b, n_e, n_f and n_g of the normalized numerical values corresponding to the new criteria a, b, e, f and g in plan A.

Table 5. Ratios of normalized numerical values for judging the importance of various product function criteria to each plan

Ratios of normalized numerical values for judging the importance of various product function criteria to each plan								
		a	b	c	d	e	f	g
plan	A	10.53%	18.96%	0.00%	0.00%	26.52%	19.81%	24.46%
	B	0.00%	0.00%	21.85%	14.13%	23.83%	17.99%	22.20%
	C	15.23%	27.43%	34.82%	22.52%	0.00%	0.00%	0.00%

Table 5 shows the results obtained by using the abovementioned calculation equation of the ratio of normalized numerical value. Table 5 shows the ratios of normalized numerical values of the functional word groups, as appeared in plans A, B and C, of the criteria for product function evaluation. Since the difference between the ratios of normalized numerical values in Table 5 is not great, an interval of 9% is found between the differences in ratio of normalized numerical value, and is taken to determine the relative importance scale, as shown in Table 6 below. Furthermore, the pairwise comparison matrix of the criteria for various product functions to various solutions can be calculated, as shown in Table 7.

Table 6. Relationship between the difference in ratio of normalized numerical value and importance scales of the criteria for various product functions to plan A, B and C

Difference in ratio	Importance scale
0~10%	1
10~18%	3
18~27%	5
27~34%	7
Above 34%	9

Table 7. Pairwise comparison matrix of the criteria for various product functions to various plans

	a	b	c	d	e	f	g	Weight
A	3	5	1	1	5	5	5	0.353
B	1	1	5	3	5	3	5	0.328
C	3	7	9	5	1	1	1	0.320

The calculation method of weight in Table 7 is shown in Equation (1) and Equation (2). The paper normalizes the values in each column, and then divides the sum of normalized elements in each column by the number of elements in each column. Then the paper calculates the eigenvectors W_2 of all criteria for product function evaluation to form a weight matrix.

e.g. $W_{2aA} = \frac{W_{aA}}{W}$ (5)

$W = W_{aA} + W_{aB} + W_{Ac}$ (6)

As acquired from Table 7,

$W_{aA}=3$，$W_{aB}=1$，$W_{aC}=3$，$W2_{aA} = = \frac{3}{3+1+3} = 0.429$

Similarly, W_{2aB} and W_{2aC} can be calculated, and W_2 can be further obtained.

The value of W_2 is shown below.

$$W_2 = \begin{matrix} & W_{2a} & W_{2b} & W_{2c} & W_{2d} & W_{2e} & W_{2f} & W_{2g} \\ A & 0.429 & 0.385 & 0.067 & 0.111 & 0.455 & 0.556 & 0.455 \\ B & 0.143 & 0.077 & 0.333 & 0.333 & 0.455 & 0.333 & 0.455 \\ C & 0.429 & 0.538 & 0.6 & 0.556 & 0.091 & 0.111 & 0.091 \end{matrix}$$

【Step 3】Establish a pairwise comparisons matrix of the internally interdepending criteria for various product functions.

Next, ANP has to consider the internal interdependent relationship among various criteria for product function evaluation. Therefore, the paper uses the keywords searched from the patented functional word search system as well as the normalized numerical value group of the important functional words that appear in the criteria for this product function. And based on patent analysis and engineering knowledge for a certain product function criterion, there may be several patent documents with interdepending product function criteria and their related product function criteria. from these several related patent documents, the paper calculates the criterion for each product function and the functional words that would have interdepending product function criteria, and then calculates the difference in ratio of normalized value of each product function criterion of this patent. The equation of normalized numerical value for the total number of words in the full text of the patent with the criteria for each important functional word and the related product functions is expressed as Equation (7). Furthermore, using the difference in ratio of normalized numerical value, the paper sets the importance scale value so as to find the weight of the actual influence of each product function criterion to the solution. This importance scale value is represented by the value matrix W_3. Table 8 shows the ratios of normalized numerical values of the internally interdepending criteria under Criterion a. Increase structural stability.

$$\text{Normalized numerical value} = \frac{\text{Appearance frequency of related words of important functional words}}{\text{Total number of words in the full texts of the patents of various related criteria}} \quad (7)$$

When the relative importance of criterion a. Increase structural stability is compared with that of criterion d. Reduce costs, extend lifespan and save energy and criterion f. Adjust light source angel and color tone, the ratio of normalized numerical value of criterion a. Increase structural stability is 26.53%, and the ratio of normalized numerical value of criterion f. Adjust light source angle and color tone is 50.51%

Table 8. Ratios of normalized numerical values of various internally interdepending criteria under criterion a. Increase structural stability

Criterion for each product function	Normalized numerical value of criterion for functional word group of each product function	Ratio of normalized numerical value
a. Increase structural stability	0.265	26.53%
b. Improve assembly convenience	0.224	22.45%
d. Reduce costs, extend lifespan and save energy	0.005	0.51%
f. Adjust light source angle and color tone	0.505	50.51%

$$50.51\% - 26.53\% = 23.98\%$$

The difference ratio of normalized numerical value between criterion a. Increase structural stability and criterion f. Adjust light source angle and color tone is 23.98%. Therefore, after comparison of importance scale, criterion a is 1/5, and criterion f is 5. The intervals between various importance scales are shown in Table 9.

Table 9. Relationship between the difference in ratio of normalized numerical value and importance scales of various criteria

Difference in ratio	Importance scale
0~10%	1
10~18%	3
18~27%	5
27~34%	7
Above 34%	9

The weights in Table 10 are calculated using Equation (2) and Equation (3). After calculation of the weights of the various internally interdepending criteria for product function evaluation, the weights of various criteria for product function evaluation have to be grouped as a weight matrix of various criteria for product function evaluation, and the values of those criteria without internal interdependent relationship for product function evaluation are 0. When explaining this by criterion a. Increase structural stability, the key functional words having internal interdependent relationship with “increase structural stability” are criterion b. Improve assembly convenience, criterion d. Reduce costs, extend lifespan and save energy, and criterion f. Adjust light source angle and color tone. The rest of the criteria have key functional words without internal interdependent relationship and are unrelated to criterion a. Increase structural stability, so their weights are 0.

After calculation, the weights can be obtained: $W_{3aa} = 0.179$, $W_{3ab} = 0.157$, $W_{3ad} = 0.050$, and $W_{3af} = 0.614$, and they are shown in Table 10. Therefore, the weight matrix formed by criterion a. Increase structural stability is $W_{3a} = (0.179, 0.157, 0, 0.05, 0, 0.614, 0)$.

Table 10. Pairwise comparison matrix of the various internally interdepending criteria under criterion a. Increase structural stability

Criterion a	a	b	d	f	Weight
a	1	1	5	1/5	0.179
b	1	1	3	1/5	0.157
d	1/5	1/3	1	1/9	0.050
f	5	5	9	1	0.614

The weight matrices of the rest of the criteria with internal interdependent relationship for product function evaluation, (W_{3b}、W_{3c}、W_{3d}、W_{3e}、W_{3f}、W_{3g}), are calculated using the abovementioned method. All the weight matrices are grouped as matrix W_3. Therefore, W_3= (W_{3b}、W_{3c}、W_{3d}、W_{3e}、W_{3f}、W_{3g}).

$$W_3 = \begin{bmatrix} 0.179 & 0.157 & 0 & 0.05 & 0 & 0.614 & 0 \\ 0.061 & 0.422 & 0.057 & 0.057 & 0 & 0.402 & 0 \\ 0.054 & 0.535 & 0.051 & 0.153 & 0 & 0.208 & 0 \\ 0.097 & 0.102 & 0.102 & 0.443 & 0.214 & 0.042 & 0 \\ 0 & 0.066 & 0.087 & 0.07 & 0.598 & 0.18 & 0 \\ 0.060 & 0.180 & 0.06 & 0.06 & 0.06 & 0.579 & 0 \\ 0 & 0.071 & 0.071 & 0.067 & 0.183 & 0 & 0.608 \end{bmatrix}$$

【Step 4】Make pairwise comparison of internal interdependent relationship among various plans.

A comparison of relative importance is made for the various criteria with internal interdependent relationship. As to the judging method of the ratio of relative importance scale of various internally interdepending criteria as well as the calculation method of each weight in the plan-to-plan weight matrix W_4, which is similar to the calculation method of Step 3’s criteria-to-criteria matrix W_3. The acquired W_{4a}, W_{4b}, W_{4c}, W_{4d}, W_{4e}, W_{4f} and W_{4g} are shown as follows:

$$W_{4a} = \begin{bmatrix} 0.677 & 0.538 & 0.714 \\ 0.097 & 0.077 & 0.048 \\ 0.226 & 0.385 & 0.238 \end{bmatrix} \quad W_{4b} = \begin{bmatrix} 0.692 & 0.714 & 0.600 \\ 0.231 & 0.238 & 0.333 \\ 0.077 & 0.048 & 0.067 \end{bmatrix}$$

$$W_{4c} = \begin{bmatrix} 0.231 & 0.231 & 0.231 \\ 0.692 & 0.692 & 0.692 \\ 0.077 & 0.077 & 0.077 \end{bmatrix} \quad W_{4d} = \begin{bmatrix} 0.158 & 0.149 & 0.273 \\ 0.789 & 0.745 & 0.636 \\ 0.053 & 0.106 & 0.091 \end{bmatrix}$$

$$W_{4e} = \begin{bmatrix} 0.763 & 0.789 & 0.692 \\ 0.153 & 0.158 & 0.231 \\ 0.085 & 0.053 & 0.077 \end{bmatrix} \quad W_{4f} = \begin{bmatrix} 0.797 & 0.840 & 0.692 \\ 0.114 & 0.120 & 0.231 \\ 0.089 & 0.040 & 0.077 \end{bmatrix}$$

$$W_{4g} = \begin{bmatrix} 0.677 & 0.714 & 0.385 \\ 0.226 & 0.238 & 0.385 \\ 0.097 & 0.048 & 0.077 \end{bmatrix}$$

Application of the Modified DEMATEL Method to the Calculation Process of LED Track Lighting

【Step 1】Define the criteria for product functions and judge the mutual influence on each other.

Table 11. Ratio of normalized numerical values of patented functional words of criterion b. Improve assembly convenience, that are repeated or have the same definitions in criteria a. Increase structural stability

Functional word	Normalized numerical value
Installation	0.00202
Lighting	0.00183
Connection	0.00168
Spring	0.00063
Rotation	0.00059
Accounting for 56.70% of ratio of the normalized numerical value	

Table 12. The Matrix of the ratios of normalized numerical values among the seven product functions of LED track light

criterion	a	b	c	d	e	f	g
a	100%	43.14%	10.73%	52.88%	19.25%	41.91%	28.07%
b	56.70%	100%	49.04%	73.74%	45.34%	53.37%	65.69%
c	25.48%	33.61%	100%	54.92%	39.48%	45.49%	37.03%
d	38.89%	40.65%	51.12%	100%	40.10%	59.34%	32.91%
e	22.09%	31.56%	45.45%	36.31%	100%	27.96%	27.80%
f	48.34%	58.73%	48.60%	67.13%	41.12%	100%	36.43%
g	9.90%	13.78%	7.25%	30.41%	29.62%	17.10%	100%

To set the degree of mutual influence among the criteria for various product functions, the paper adopts a method of using patents’ functional words.

An explanation is made in this example: In Table 11, the patented functional words of criterion b. Improve assembly convenience, that are repeated or have the same definitions in criteria a. Increase structural stability, are installation, lighting, connection, spring and rotation, and they account for 56.70% of ratio of the normalized numerical value.

Table 12 shows the matrix of the ratio of normalized numerical values among the seven product functions of LED track light.

【Step 2】Establish a direct relation matrix.

After analysis, in order to show the relative importance scales among the criteria for various product functions, the paper takes below 10% as 0 to indicate "no influence", 10%~19% as 1 to indicate "small influence", 19%~ 32% as 2 to indicate "medium influence", 32%~ 49% as 3 to indicate "big influence", and above 49% as 4 to indicate "extremely big influence".

Furthermore, from the matrix of the ratios of normalized numerical values among the criteria for various product functions, as shown in Table 12, the paper subsequently establishes a direct relation matrix Z, which is expressed as equation (8), where a_{ij} denotes the degree of influence of criterion i on criterion j, as shown below.

$$\text{Direct relation matrix Z} = \begin{bmatrix} 0 & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & 0 & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & 0 \end{bmatrix} \quad (8)$$

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

【Step 3】Establish a normalized direct relation matrix.

Next, the paper normalizes the direct relation matrix obtained in Step 2, and based on equation (9), finds the largest column sum (S) of the matrix Z, which is 23. Then, divide the matrix Z by 23, achieving a normalized direct relation matrix X, as shown below.

$$S = \left(\max_{1 \le i \le n} \sum_{j=1}^{n} z_{ij} , \max_{1 \le j \le n} \sum_{i=1}^{n} z_{ij} \right) = 4 + 0 + 4 + 4 + 3 + 4 + 4 = 23 \quad (9)$$

$$X = \frac{Z}{S} = \frac{1}{23} \begin{bmatrix} 0 & 3 & 1 & 4 & 2 & 3 & 2 \\ 4 & 0 & 4 & 4 & 3 & 4 & 4 \\ 2 & 3 & 0 & 4 & 3 & 3 & 3 \\ 3 & 3 & 4 & 0 & 3 & 4 & 3 \\ 2 & 2 & 3 & 3 & 0 & 2 & 2 \\ 3 & 4 & 3 & 4 & 3 & 0 & 3 \\ 0 & 1 & 0 & 2 & 2 & 1 & 0 \end{bmatrix} \quad (10)$$

【Step 4】Establish a total influence matrix

The total influence matrix is $T = X(1 - X)^{-1}$, where 1 denotes the unit matrix, and X denotes the normalized direct relation matrix. After calculation of the matrix, Normalized direct relation matrix X =

$$\begin{bmatrix} 0 & 0.130 & 0.043 & 0.174 & 0.087 & 0.130 & 0.087 \\ 0.174 & 0 & 0.174 & 0.174 & 0.130 & 0.174 & 0.174 \\ 0.087 & 0.130 & 0 & 0.174 & 0.130 & 0.130 & 0.130 \\ 0.130 & 0.130 & 0.174 & 0 & 0.130 & 0.174 & 0.130 \\ 0.087 & 0.087 & 0.130 & 0.130 & 0 & 0.087 & 0.087 \\ 0.130 & 0.174 & 0.130 & 0.174 & 0.130 & 0 & 0.130 \\ 0 & 0.043 & 0 & 0.087 & 0.087 & 0.043 & 0 \end{bmatrix}$$

the total influence matrix T of LED track lighting is obtained, and the results are shown as follows:

Total influence matrix T =

$$\begin{bmatrix} 0.233 & 0.374 & 0.296 & 0.474 & 0.338 & 0.392 & 0.353 \\ 0.470 & 0.362 & 0.495 & 0.606 & 0.478 & 0.533 & 0.532 \\ 0.342 & 0.409 & 0.286 & 0.520 & 0.412 & 0.428 & 0.428 \\ 0.403 & 0.441 & 0.461 & 0.410 & 0.441 & 0.493 & 0.458 \\ 0.289 & 0.316 & 0.344 & 0.413 & 0.237 & 0.331 & 0.330 \\ 0.408 & 0.476 & 0.432 & 0.561 & 0.443 & 0.349 & 0.462 \\ 0.098 & 0.146 & 0.110 & 0.209 & 0.186 & 0.153 & 0.112 \end{bmatrix}$$

Selection Process with Priority Order of LED Track Lighting by Combining Product Functions with the Modified DANP Method

The paper uses the modified DEMATEL method to calculate the total relation influence matrix T of LED track lighting, and the internally interdepending pairwise comparison matrix W_3 in the modified ANP. Through the calculation steps of matrix, the following matrix can be obtained:

【Step 1】Normalize the total influence matrix T.

For the total influence matrix T obtained above, the paper calculates each column sum based on equation (11), and divides each column sum by each criterion in each column to obtain a normalized total influence matrix Tc as follows:

$$\mathbf{T} = \begin{bmatrix} 0 & \cdots & t_{lm} \\ \vdots & & \vdots \\ t_{i1} & \cdots & t_{im} \\ \vdots & & \vdots \\ t_{n1} & \cdots & t_{nm} \end{bmatrix}$$

d_i is the normalized value, also the column sum of this criterion

$$\mathbf{T_c} = \begin{bmatrix} t_{11}/d_1 & \cdots & t_{1m}/d_1 \\ \vdots & & \vdots \\ t_{m1}/d_m & \cdots & t_{mm}/d_m \end{bmatrix} \quad (11)$$

$$\mathbf{T_c}=\begin{bmatrix} 0.095 & 0.152 & 0.120 & 0.193 & 0.137 & 0.159 & 0.144 \\ 0.095 & 0.152 & 0.142 & 0.174 & 0.137 & 0.153 & 0.153 \\ 0.121 & 0.145 & 0.101 & 0.184 & 0.146 & 0.152 & 0.152 \\ 0.130 & 0.142 & 0.148 & 0.132 & 0.142 & 0.159 & 0.148 \\ 0.128 & 0.140 & 0.152 & 0.183 & 0.105 & 0.147 & 0.146 \\ 0.128 & 0.152 & 0.138 & 0.179 & 0.142 & 0.111 & 0.148 \\ 0.128 & 0.144 & 0.109 & 0.206 & 0.183 & 0.151 & 0.110 \end{bmatrix}$$

【Step 2】Transpose the normalized matrix Tc, and multiply it by the weight matrix.

In the process of applying the modified ANP to selection of LED track lighting, a pairwise comparison matrix W_3 is obtained in Step 3. With the characteristic of weight shift in ANP method, the paper transposes the normalized total influence matrix T_c to be T_c^T, and lets the transposed TcT multiply by the pairwise comparison matrix W_3 to acquire a new matrix W_3^D, and the calculation result is shown as follows:

$$T_c^T \times W_3 = W_3^D \tag{12}$$

$$\text{TcT}\times\text{W3}=\begin{bmatrix} 0.179 & 0.157 & 0 & 0.05 & 0 & 0.614 & 0 \\ 0.061 & 0.422 & 0.057 & 0.057 & 0 & 0.402 & 0 \\ 0.054 & 0.535 & 0.051 & 0.153 & 0 & 0.208 & 0 \\ 0.097 & 0.102 & 0.102 & 0.443 & 0.214 & 0.042 & 0 \\ 0 & 0.066 & 0.087 & 0.07 & 0.598 & 0.18 & 0 \\ 0.060 & 0.180 & 0.06 & 0.06 & 0.06 & 0.579 & 0 \\ 0 & 0.071 & 0.071 & 0.067 & 0.183 & 0 & 0.608 \end{bmatrix}=W_3^D$$

【Step 3】Calculate the matrix W_C^D after adding in DEMATEL.

First of all, let the W_3^D obtained in the previous step multiply by W_1 to obtain a new internally interdepending prioritized weight W_C^D , and the calculation results are as follows

$$W_3^D \times W_1 = W_C^D \tag{13}$$

:

$$\begin{bmatrix} 0.052 & 0.189 & 0.053 & 0.112 & 0.130 & 0.242 & 0.059 \\ 0.064 & 0.207 & 0.059 & 0.127 & 0.150 & 0.284 & 0.088 \\ 0.058 & 0.191 & 0.058 & 0.121 & 0.151 & 0.265 & 0.066 \\ 0.079 & 0.275 & 0.074 & 0.144 & 0.186 & 0.369 & 0.125 \\ 0.063 & 0.217 & 0.060 & 0.128 & 0.135 & 0.227 & 0.111 \\ 0.068 & 0.227 & 0.063 & 0.137 & 0.156 & 0.288 & 0.0.92 \\ 0.067 & 0.228 & 0.061 & 0.131 & 0.148 & 0.300 & 0.067 \end{bmatrix}\times\begin{bmatrix} 0.022 \\ 0.088 \\ 0.135 \\ 0.033 \\ 0.473 \\ 0.135 \\ 0.114 \end{bmatrix}=\begin{bmatrix} 0.130 \\ 0.151 \\ 0.145 \\ 0.193 \\ 0.147 \\ 0.158 \\ 0.152 \end{bmatrix}=W_C^D$$

Selection Process with Priority Order of LED Track Lighting by Combining Product Functions with the Modified DANP Method and the Modified TOPSIS Method

Using the modified DANP method, the paper calculates the internally interdepending prioritized weight W_C^D as well as the decision matrix W_{pij} for various plans, substitutes them into the related equations of the modified TOPSIS method, and uses the modified TOPSIS method to calculate the priority order of various plans, and select the most prioritized plan.

【Step 1】Find the decision matrix W_p of various solutions to criteria.

Since $W_P = [W_{pa}\ W_{pb} \cdots\ W_{pg}]$

$$= [W_4][W_2] = [W_{4a} W_{4b} W_{4c} W_{4d} W_{4e} W_{4f} W_{4g}]\begin{bmatrix} W_{2a} \\ W_{2b} \\ W_{2c} \\ W_{2d} \\ W_{2e} \\ W_{2f} \\ W_{2g} \end{bmatrix} \tag{14}$$

Therefore, after multiplying the W_{4a} value by the W_{2a} value, the product is W_{pa}.

Besides, since $[W_{4a}] = \begin{bmatrix} W_{4aAA} & W_{4aAB} & W_{4aAC} \\ W_{4aBA} & W_{4aBB} & W_{4aBC} \\ W_{4aCA} & W_{4aCB} & W_{4aCC} \end{bmatrix}$, $[W_{2a}] = \begin{bmatrix} W_{2aA} \\ W_{2aB} \\ W_{2aC} \end{bmatrix}$,

it is achieved that $\begin{bmatrix} W_{4aAA} & W_{4aAB} & W_{4aAC} \\ W_{4aBA} & W_{4aBB} & W_{4aBC} \\ W_{4aCA} & W_{4aCB} & W_{4aCC} \end{bmatrix}\begin{bmatrix} W_{2aA} \\ W_{2aB} \\ W_{2aC} \end{bmatrix} = \begin{bmatrix} W_{paA} \\ W_{paB} \\ W_{paC} \end{bmatrix} = W_{pa}$ (15)

After multiplication of the above matrices, it is known that:

$$W_{4aAA}W_{2aA} + W_{4aAB}W_{2aB} + W_{4aAC}W_{2aC} = W_{paA}$$
$$W_{4aBA}W_{2aA} + W_{4aBB}W_{2aB} + W_{4aBC}W_{2aC} = W_{paB}$$
$$W_{4aCA}W_{2aA} + W_{4aCB}W_{2aB} + W_{4aCC}W_{2aC} = W_{paC}$$

Let us explain with an example. Substitute the $[W_{4a}]$ and $[W_{2a}]$ values calculated in the abovementioned example into equation (15) to obtain

$$[W_{4a}][W_{2a}] = \overset{W_{4a}}{\begin{matrix} \\ A \\ B \\ C \end{matrix}\begin{bmatrix} A & B & C \\ 0.667 & 0.538 & 0.714 \\ 0.097 & 0.077 & 0.048 \\ 0.226 & 0.385 & 0.238 \end{bmatrix}} \times \overset{W_{2a}}{\begin{bmatrix} 0.429 \\ 0.143 \\ 0.429 \end{bmatrix}} = \begin{bmatrix} 0.670 \\ 0.097 \\ 0.233 \end{bmatrix} = \begin{bmatrix} \boldsymbol{W_{paA}} \\ \boldsymbol{W_{paB}} \\ \boldsymbol{W_{paC}} \end{bmatrix}$$

Similarly, $W_{pb} = [W_{4b}] \times [W_{2b}]$

$$\therefore W_{pb} = \begin{bmatrix} W_{4bAA} & W_{4bAB} & W_{4bAC} \\ W_{4bBA} & W_{4bBB} & W_{4bBC} \\ W_{4bCA} & W_{4bCB} & W_{4bCC} \end{bmatrix}\begin{bmatrix} W_{2bA} \\ W_{2bB} \\ W_{2bC} \end{bmatrix} = \begin{bmatrix} W_{pbA} \\ W_{pbB} \\ W_{pbC} \end{bmatrix} = W_{pb}$$

Besides, the feature vectors of the remaining matrices, W_{pc}, W_{pd}, W_{pe}, W_{pf}, W_{pg} are obtained using this calculation method. Based on this principle, the weight vectors of W_{pa} , W_{pb}, W_{pc}, W_{pd} , W_{pe}, W_{pf} , W_{pg} can form a weight matrix $W_p = [W_{pij}]$, and the calculation results of W_p are as follows:

$$\mathbf{W_p} = \begin{matrix} \\ A \\ B \\ C \end{matrix}\begin{bmatrix} a & b & c & d & e & f & g \\ 0.674 & 0.644 & 0.231 & 0.219 & 0.769 & 0.80 & 0.682 \\ 0.073 & .286 & 0.692 & 0.689 & 0.163 & 0.129 & 0.246 \\ 0.254 & 0.069 & 0.077 & 0.092 & 0.070 & 0.071 & 0.073 \end{bmatrix} = [\mathbf{W_{pij}}]$$

【Step 2】Establish a normalized decision matrix.

In order to avoid occurrence of extreme values, the paper takes an action of normalizing the decision matrix since this can make the difference in scores among various plans under the same criterion be not too large. For this matrix, x_{ij} equivalent to the influence weights W_{Pij} with the plans of the modified ANP to various criteria. After normalizing the decision matrix W_P with plans to various criteria, a new normalized decision matrix ($R = [r_{ij}]$) can be obtained.

First of all, the paper finds the geometric mean. Through the above equation, the geometric mean with the plans for evaluating product functions or techniques to various criteria can be obtained, and substituted into the normalization equation, which is express as equation (16) below:

$$r_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{16}$$

Use all the calculated weights to form a normalized decision matrix $[r_{ij}]$

$$R=[r_{ij}]=\begin{bmatrix}0.931 & 0.910 & 0.315 & 0.3 & 0.974 & 0.983 & 0.936\\ 0.101 & 0.404 & 0.943 & 0.945 & 0.207 & 0.159 & 0.338\\ 0.351 & 0.097 & 0.105 & 0.126 & 0.089 & 0.087 & 0.1\end{bmatrix}$$

【Step 3】Establish a weight normalized decision matrix.

Multiply the internally interdepending prioritized weight matrix W_c^D by the normalization matrix $R=[r_{ij}]$ to acquire a weighted normalized decision matrix V_{ij}. Then, V_{ij} is a normalized score after multiplying by the criterion weight. Its weight matrix is the various criteria's internally interdepending prioritized weight matrix W_c^D using the modified DANP method. The calculated result of V_{ij} is shown as follows:

$$V_{ij}=W_c^D \times [r_{ij}] \tag{17}$$

$$V_{ij}=\begin{bmatrix}0.130\\0.151\\0.145\\0.193\\0.147\\0.158\\0.152\end{bmatrix}\times\begin{bmatrix}A & 0.931 & 0.910 & 0.315 & 0.3 & 0.974 & 0.983 & 0.936\\ B & 0.101 & 0.404 & 0.943 & 0.945 & 0.207 & 0.159 & 0.338\\ C & 0.351 & 0.097 & 0.105 & 0.126 & 0.089 & 0.087 & 0.1\end{bmatrix}$$

$$=\begin{bmatrix}0.121 & 0.137 & 0.046 & 0.058 & 0.143 & 0.155 & 0.142\\ 0.013 & 0.061 & 0.137 & 0.182 & 0.03 & 0.025 & 0.051\\ 0.046 & 0.015 & 0.015 & 0.024 & 0.013 & 0.014 & 0.015\end{bmatrix}$$

【Step 4】 Determine the positive ideal solution V+ and the negative ideal solution V-

T0PSIS takes each solution's separation measures, which are each solution's distance from the positive ideal solution and that from the negative ideal solution, as the evaluation method. Either the positive ideal solution or the negative ideal solution is one of m pieces of evaluation criteria. The positive ideal solution V+ is a set composed of the best values of m pieces of evaluation criteria, whereas the negative ideal solution V- is a set composed of the worst values of m pieces of evaluation criteria.

$$V^{+}=[\max V_{ij} \mid j \in J]=\{v_1^+, v_2^+, \ldots, v_m^+\} \tag{18}$$
$$V^{-}=[\min V_{ij} \mid j \in J]=\{v_1^-, v_2^-, \ldots, v_m^-\} \tag{19}$$

Thus, the positive ideal solution V+ and the negative ideal solution V- can be acquired as follows:

V+=(0.121,0.137,0.137,0.182,0.143,0.155,0.142)
V-=(0.013,0.015,0.015,0.024,0.013,0.014,0.015)

【Step5】Calculate each solution's separation measures, D_i^+ and D_i^-.

Subsequently,the paper calculates each solution's separation measures. The distance from plan i to the positive ideal solution is expressed by the separation measure D_i^+, whereas the distance from plan i to the negative ideal solution is expressed by the separation measure D_i^-.

From $$D_i^+ = \sqrt{\sum_{j=1}^{m}(v_{ij}-v_j^+)^2},\ i=1,2,\ldots,n \tag{20}$$

$$D_i^- = \sqrt{\sum_{j=1}^{m}(v_{ij}-v_j^-)^2},\ i=1,2,\ldots,n \tag{21}$$

Therefore, the positive ideal separation measure and the negative ideal separation measure are obtained as Table 13.

Table 13. The positive ideal separation measure and the negative ideal separation measure

Separation measure / plan	D_i^+	D_i^-
i=l (A)	**0.154**	**0.286**
i=2 (B)	**0.236**	**0.209**
i=3 (C)	**0.337**	**0. 033**

【Step 6】Calculate the relative closeness ci of each plan and make a priority order of the plans for ranking.

TOPSIS ranks the feasible plans by calculating the index of "relative closeness". Through the index of relative closeness, the relative position of each plan from the positive and negative ideal solutions can be known. From the calculation equation of relative closeness ci:

$$c_i = \frac{D_i^-}{D_i^+ + D_i^-},\ I = 1, 2, \ldots, n \tag{22}$$

Hence, the relative closeness of each alternative plan is obtained as Table 14.

Table 14. The relative closeness of each alternative plan

Relative closeness / Plan	c_i
Plan **A**	**0.650**
Plan **B**	**0.470**
Plan **C**	**0. 088**

If the relative closeness ci calculated for a certain plan is great, it refers that this plan is closer to the positive ideal solution and farther from the negative ideal solution, also meaning that this plan is better. Finally, the relative closeness of each plan is calculated one by one. According to the extent of relative closeness of various plans, ranking of the plans can be done.

The three product function improvement plans obtained above are placed in a priority order as follows: (0.650, 0.470, 0.088), implying to the priority order of their importance being plan A > plan B > plan C. The plan with the greatest weight is just the most prioritized plan. That is to say, plan A "Increase overall stability and convenience + improve lighting efficiency" is selected as the most prioritized product function improvement plan for LED track lighting. In this paper's research on the product function improvement plan A "Increase overall stability and convenience + improve lighting efficiency", the prioritized weight of the various plans under the internal interdependent relationship obtained above can serve as an important reference for making future design and improvement studies and analysis of innovative products. After that, focusing on two related functions of plan A LED track lighting product, namely "Increase overall stability and convenience + improve lighting efficiency", it can consider prioritizing the innovative product function improvement plan in order to save the product developers' time required for developing products.

CONCLUSION

The traditional TOPSIS method has to rely heavily on experts' opinions, thus forming a disadvantage of being too subjective. Therefore, this paper develops the concept of calculating the normalized numerical values of each functional field's functional word groups that are obtained from patent analysis. Normalized numerical values are obtained based on the ratio of the frequency of appearance of important functional and part/component keywords acquired from multiple patented technical documents through the term and word segmentation system, to the total number of words in the full text of the highly relevant patent groups. The paper establishes combination of the modified TOPSIS method with the modified DANP method, so as to determine the priority order of different improvement plans. When the most prioritized function improvement plans obtained in this paper reflects some functions that meet the customers' needs, the plan can more accurately meet the needs of the market, resulting in reduction of unnecessary waste of time and materials.

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應用修正式 DANP 法結合修正式 TOPSIS 法於 LED 軌道燈改善方案評選

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摘要

本文發展出以軌道燈專利分析所得到的各功能領域的功能字群的常態化數值的觀念，結合修正式 DANP 法結合修正式 TOPSIS 方法，應用於軌道燈，以決定出不同 LED 軌道燈之功能改善方案之優先順序。本文經由 LED 軌道燈產品之相關文獻探討及各項專利分析，將 LED 軌道燈分為3個功能改善方案，7項功能領域。每一個功能改善方案各包含數個功能準則，本研究將修正式 DANP 法所得之 W_P 之 W_{pij} 及 W_C^D 代入修正式 TOPSIS 方法的相關公式，利用修正式 TOPSIS 法計算出各功能改善方案之優先次序，評選出最優先之功能改善方案。