中國機械工程學刊第三十九卷第三期第 255~266 頁(民國一百零七年)
Journal of the Chinese Society of Mechanical Engineers, Vol.39, No.3, pp 255~266 (2018)

Priority Order Design Plans of LED Reading Light Using Modified Analytic Network Process Method

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Keywords: Analytic Network Process, normalized value, reading light, weights, design..

ABSTRACT

This article proposed a modified ANP (MANP) approach that analyzes the technical words corresponding to the techniques proposed in various technical documents and patents to determine the appearance rates and normalized numerical values of these words. The gaps between the normalized numerical values of different technical words were used to determine the relative importance scales for the technical words. The innovative equations for calculating the weight values are also proposed. LED reading light (LED-RL) were adopted as the target for design improvement. Relevant technical patents concerning three technical categories of overall structural design, heat dissipation, and main body of the LED were collected. Then, the technical categories of LED-RL were used to form three preliminary technical design plans (i,e. Plans A, B, and C). Each plan consisted of two technical categories among three technical categories. Each plan was then processed using the seven steps proposed by the MANP approach to determine the priority weights of the three technical design plans. The technical design plan with highest priority weight was then chosen as the ideal innovative technical design plan.

INTRODUCTION

Zhuang (2010) proposed a technical patent for manufacturing a portable reading lamp. The reading lamp comprises a base with a hollow chamber, a light source placed within the chamber, a switch to activate/deactivate the light source, and a light guide plate. The plate contains an incidence surface for the light source. Fredricks (2011) proposed a light-emitting diode (LED) lamp equipped with an optical lens beneath the lamp. The lens can be rotated to change the scattering angle, consequently producing different illumination areas. Tai (2003) proposed a lamp with a grooved base. A highly reflective metal coating is applied to the inside of the groove. Light is reflected by the groove and condensed by a lens. Subsequently, the condensing angle can be changed by altering the radius of the groove or the focal point of the light source. In recent years, LED applications have increased the operating temperature of LEDs, creating a heat dissipation problem that has gained considerable attention. McGlen et al. (2004) categorized the favorable heat management of LED into two parts. The first part entails designing a suitable integrated circuit architecture to reduce heat flux. The second part entails directing heat to a cooling system to achieve heat dissipation. Solutions to heat dissipation are generally related to the two parts. Jang et al. (2012) discussed the cooling effects of radial heatsinks and the optimization of relevant weights. The researchers compared plate-shaped and pin-shaped heat dissipation fins and found that pin-shaped fins had lower heat resistance than plate-shaped fins and that the former weighed significantly less than the latter. Culham and Muzychka. (2001) adopted the method of entropy generation minimization to test the height, quantity, thickness, and velocity parameters of plate-shaped heat dissipation fins. The various sets of data and diagrams collected from the tests were examined identify an optimal design.

The decision levels in conventional analytic hierarchy processes (AHP) are generally linear. That is, each hierarchy (i.e., level) is independent of and unassociated with one another. Different from AHPs, which presume that the hierarchical structure of the decision mode is independent, the analytic network process (ANP) includes a feedback mechanism in the hierarchical structure of the decision mode to explain the relationships between the various hierarchical

Paper Received January, 2018. Revised April, 2018. Accepted May, 2018. Author for Correspondence: Zone-ching Lin.

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criteria. Thus, AHPs are a specific type of ANP model. Satty and Takizawa (1986) introduced non-linear network structure in 1986, and Satty (1996) introduced the ANP in 1996. The ANP is a multi-objective decision-making method commonly applied in the economic, social, and management sciences. It primarily facilitates decision-makers in understanding ambiguous problems or problems with multiple evaluation assessment factors and in processing complex decision-making problems (Partovi and Jachuck 2006). The ANP includes a feedback mechanism in the hierarchical structure of the decision mode to explain and process the associations between the various hierarchies. Specifically, it analyzes the associations within a hierarchy or between different hierarchies to obtain a priority weight of the various alternative plans. This priority weight is then used to select the ideal solution from a set of solutions.Liang et al. (2013) adopted an ANP to determine the ideal thermal waste recycling solution for internal combustion engines.

ANPs are often applied in economics, social science, and management science. In this article, a modified ANP (MANP) approach was applied to the field of construction, which is relatively new to the domain. The present study proposed a modified ANP (MANP) approach that analyzes the technical words corresponding to the functions proposed in various technical documents and patents to determine the appearance rates and normalized numerical values of these words. The gaps between the normalized numerical values of different technical words were used to determine the relative importance of the words and equations were subsequently proposed to calculate relevant weights. LED reading light (LED-RL) were adopted as the target for design improvement. First, relevant technical patents concerning overall structural design, heat dissipation, and main body of the LED were collected. Then, the technical categories of LED-RL were selected using keywords contained in the patents. These patents were used to form three preliminary plans (i.e., Plans A, B, and C). Each plan consisted of two techniques used to improve the structural design, heat dissipation, and main body of the LED. By modifying the ANP using the seven steps proposed by the MANP approach, the priority weights of three technical design plans were obtained. The technical design plan with highest priority weight was then chosen as the ideal innovative technical design plan.

ANALYTIC NETWORK PROCESS

Satty et al. (1986) adopted a matrix calculation method to determine the dependent associations between the criteria for ANP.

In the traditional ANP approach, it has seven-steps procedure and the relative importance weights are generally established through a questionnaire survey or expert interviews. Directly administering a questionnaire survey and inviting respondents to allocate weights subjectively defeats the goal of objective weight allocation. Subjectivity negatively influences the objectivity and reliability of the evaluation results. After relevant weights were set through a questionnaire survey or expert interviews, the data were analyzed using the aforementioned seven-step procedure to calculate the priority weight of each plan and identify the preferred plan. Few ANP-related studies have analyzed LED reading light (LED-RL) patents. In the present study, the proposed modified ANP (MANP) approach was adopted to analyze LED-RL patents to identify the preferred design plan.

MODIFIED ANALYTIC NETWORK PROCESS

The key technical innovations achieved for the method of modified ANP (MANP) in the present study are discussed in this section. An innovative method was adopted for Step1 of the aforementioned ANP. This method was a pairwise comparison of key technical words extracted from the criteria proposed in various LED-RL patents. The LED-RL patents were analyzed using a term and word segmentation system (Lin et al. 2012). Subsequently, seven evaluation criteria and their key technical words were identified. These words were then categorized into technical words, functional words, and part/component words and the number of times these words appeared in the patents was converted into normalized numerical values. An importance scale was adopted with a larger gap of normalized numerical values when a broader range of normalized numerical values was compared. By comparison, an importance scale was used with a smaller normalized numerical values when a narrower range of normalized numerical values was compared. For example, 5% or 10% can be used to allocate an important scale of ratio of normalized numerical values. The importance scales converted from the normalized numerical values were then incorporated into a novel geometric mean equation and a weight equation to calculate their values of geometric means and weights. Next, a new method to calculate the weights of pairwise comparison matrices was developed, in which the values geometric means were first determined before calculating the innovation weights of the evaluation criteria. These weights were to identify the appearance rate of the most important technical words in various technical projects. Regarding the relative importance between the various criteria and plans, they were compared in Step 2. All key weights should be obtained before performing evaluation analysis. Conventionally, a value of one to nine is allocated to a weight depending on its level of importance (Table 1).

Table 1 Descriptions of the Importance Value (1 to 9)

Pairwise Comparison of A and B										
	Absolutely	Very unimportant	Unimportant	Slightly unimportant		Slightly important	important		Absolutely important	
A	1/9	1/7	1/5	1/3	1	3	5	7	9	B

The term and word segmentation system (2012) was adopted in the present study to calculate the normalized values. This system is a semi-automatic method to normalize the number of technical word, functional word, and part/component word clusters contained in LED-RL patents. Therefore, the normalized value is defined as the total number of the words in a specific patent divided by the appearance rate of a key technical word, functional word, or part/component word generated from the term and word segmentation system. Normalized numerical values can be determined using the following equation:

$$\text{Normalized value}=\frac{\text{apperance rate of key technical word}}{\text{total number of patent words}} \quad (1)$$

The normalized numerical values of the key technical words were compared. An importance scale was allocated with a larger gap of normalized numerical values when a broader range of normalized numerical values was compared. By comparison, an importance scale was allocated with a smaller gap of normalized numerical values when a narrower range of normalized numerical values was compared. Subsequently, the importance scale was increased by an additional unit if the numbers exceeded the original range. Finally, the priority weights of the various plans were calculated. The advantages of the proposed MANP are that it is able to prioritize the technologies in LED-RL product for improvement by analyzing the appearance rate and normalized numerical values of keywords contained in patents and determine whether the improvement of specific technologies meets consumer demands.

Identifying Key Technical Word Groups from Patents to Establish Evaluation Criteria

LED-RL patents were analyzed to identify the key technical words concerning the three important technical categories of LED-RL products, specifically, overall structural design, heat dissipation, and main body of the LED. The technical words were then placed in descending order according to their normalized numerical values. The importance of the word is directly proportional to the size of its normalized numerical values. The words with high normalized numerical values in the three word groups were adopted as the evaluation criteria and the key technical words. The technical and functional words of 65 patents and technical engineering documents were processed using the proposed calculation procedure to obtain technical and functional analysis results. According to the results, fin structure, convenience structure, support style, reading light (RL) weight, reading light (RL) material, LED light source, and reflector design were defined as Criterions a to g, respectively.

The evaluation criteria and the technical words contained in each criterion are as follows:

Criterion a. fin structure: heat dissipation fin, heat dissipation module, heat sink…

Criterion b. convenience structure: rotary shaft, adjustment, rotation, convenience…

Criterion c. support style: support structure, support component/part…

Criterion d. RL weight: weight

Criterion e. RL material: heat dissipation material

Criterion f. LED light source: light emitting device, light emitting component/part, light source…

Criterion g. reflector design: reflector and lampshade, optical lampshade…

Establishing the Three MANP Innovative Plans and the Hierarchical Structure Diagram

The three may be improved techniques for LED-RL in this study were overall structural design, heat dissipation, and main body of the LED. Three improvement plans were developed for the said techniques, with each plan containing a combination of two techniques.

Plan A: heat dissipation + overall structural design

Plan B: overall structural design + main body of the LED

Plan C: heat dissipation + main body of the LED

Among the three plans, Plans A and B both evaluated overall structural design, Plans A and C both assessed heat dissipation, and Plans A and C gauged for main body of the LED. The three plans were thus correlated, enabling that MANP be used to calculate the final priority weight (WANP). The ideal design improvement plan can be determined based on the WANP values of each plan.

An analysis of the normalized numerical values of the key technical words in each criterion revealed the key technical words for the various criteria. Subsequently, the content of the seven criteria was substituted with the key technical words. That is, the content of Criterion a was substituted with heat dissipation fin, that of Criterion b was substituted with rotary shaft, that of Criterion c was substituted with support structure, that of Criterion d was substituted with weight, that of Criterion e was substituted with heat dissipation material, that of Criterion f was substituted with light source, and that of Criterion g was substituted with reflector and lampshade. These key technical words of criteria were then used to calculate the normalized numerical values.

The aforementioned key technical words were used to create an MANP hierarchical diagram for LED-RLs, as shown in Fig. 1. Details of Fig. 1 are as follows:

(1) Evaluation criteria: Criteria a to g

(2) Plan A: heat dissipation + overall structural design; Plan B: overall structural design + main body of the LED; Plan C: heat dissipation + main body of the LED

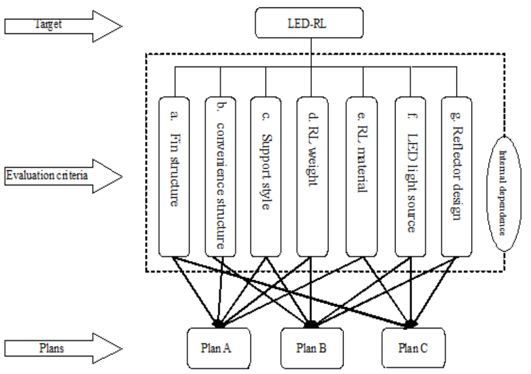

Fig. 1 MANP Hierarchical Diagram for the Selection of LED-RL Plans

Determining the Relative Importance Scales and Weights of the Various MANP Pairwise Comparison Matrices

Descriptions of the seven-step MANP are as follows:

Step 1. Pairwise comparison of the various key technical words

A relative importance comparison was first performed on the various key technical words to determine the normalized numerical value equation (Equation (1)). The normalized numerical values of the most important technical words, specifically heat dissipation fin, rotary shaft, and support structure, were compared using the data tabulated in Table 2. A 5% distance between normalized numerical values was adopted to determine the relative importance scale and establish the pairwise comparison matrix. Then, a numerical analysis was performed to calculate the weights of the pairwise comparison matrix.

Table 2 The Normalized numerical values of key technical words of criteria a, b, and c

Key technical word group	Patent appearance rate	Normalized value
criterion a. Heat dissipation fin	423	20.7%
criterion b. Rotary shaft	312	15.3%
criterion c. Support structure	493	24.2%

According to Table 2, a relative importance comparison between Criteria a and b produced a normalized numerical value of 20.7% and15.3% for Criteria a and b, respectively. The distance between the two criteria was 5.4%. Thus, the distance 5% between the two numerical values was used as the unit relative importance scale. A value exceeding 5% but less than 10% indicated an importance scale in addition to the scale. Thus, the rela69tive importance scale between Criteria a and b was two importance scales because a normalized numerical value of 5.4% was larger than 5%. Therefore, when the relative importance of Criterion b is 1, that of Criterion a would be 5 because it was indicated in Table 1 that two important scales was 5. Alternatively, when the relative importance of Criteria a is 1, that of Criterion b would be 1/5 following the Table 1 (Table 3). All relative importance scales are determined using the aforementioned method.

Table 3 Relative importance scale, value of geometric mean, and weight of criteria a, b, and c

	A	B	C	values of geometric mean	weight
A	1	5	1/3	1.182	0.296
B	1/5	1	1/5	0.342	0.086
C	3	5	1	2.466	0.618
Total values of geometric mean				3.99	

Next, a method to calculate the weights of pairwise comparison matrices was developed. First, the values of geometric mean were determined using Equation (2).

$$Y_i = \sqrt[n]{x_{i1} \cdot x_{i2} \cdot \ldots\ldots x_{in}} \qquad (2)$$

where Y_i represents the value of geometric mean,

x_i represents the comparison value between relative importance scales, and i represents the criteria of a, b, and c.

The sum of the values of geometric mean of the criteria was determined, and the value of geometric mean of each individual criterion was divided by the sum of the values of geometric mean to determine the weights of each criterion. The innovative weight equation can be expressed as follows.

$$\text{Weight } w_{1i} = \frac{Y_i}{\sum_{i=1} Y_i} \qquad i = \text{a、b、c} \tag{3}$$

where, Y_a represents the value of geometric mean of heat dissipation fin of criterion a, Y_b represents the value of geometric mean of rotary shaft of criterion b, Y_c represents the value of geometric mean of support structure of criterion c.

The weights of rotary shaft of criterion b and support structure of criterion c were calculated using the aforementioned method. The weights of the three key technical words were collated to form a weight matrix (W_1).

Step 2. Comparison of the relative importance of criteria and plans

To determine the relative importance between the criteria and plans, the following procedure was adopted: first, the normalized numerical values of the key technical words of criteria related in the three techniques of heat dissipation, overall structure design and main body of the LED for each plan were summed. Then, the normalized numerical value ratios of key technical words in each plan were determined. The size of the normalized numerical value ratio was used to determine the relative importance scale and weight. The normalized numerical values of key technical words of seven criteria are tabulated in Table 4.

For example, Plan A included two improvement techniques, namely heat dissipation and overall structural design, in which they contained five key technical words of five criteria, namely the key technical words of criterion a to criterion e. Light source of criterion f and reflector and lampshade of criterion g were key technical words of the “main body of the LED” technique. Therefore, they were excluded from Plan A. All the normalized numerical values in Plan A were summed to recalculate the normalized numerical value ratio of key technical words in Plan A. The aforementioned process was used to develop an innovative equation for calculating the normalized numerical value ratio of the key technical words in each plan, as shown in Equation (4) and Equation (5).

Table 4 Normalized numerical values of key technical words of seven criteria

Key technical word group	Appearance rate in patent context	Normalized numerical values
criterion a. Heat dissipation fin	423	20.7%
criterion b.Rotary shaft	312	15.3%
criterion c.Support structure	493	24.2%
criterion d.Weight	23	1.1%
criterion e. Heat dissipation material	31	1.5%
criterion f.Light source	351	17.2%
criterion g. Reflector and lampshade	406	20%
Total	2039	

For example of Plan A:

$$n_A = n_a + n_b + n_c + n_d + n_e \tag{4}$$

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

$$n_{a5} = \frac{n_e}{n_A} \tag{5}$$

where n_A represents the sum of the normalized numerical values, $n_{a.b.c.d.e}$ represent the original normalized numerical value of key technical word of each criterion, n_{a1} represents the normalized numerical value ratio of heat dissipation fin of criterion a in Plan A, n_{a2} represents the normalized numerical value ratio of rotary shaft of criterion b in Plan A, n_{a3} represents the normalized numerical value ratio of support structure of criterion c in Plan A, n_{a4} represents the normalized numerical value ratio of weight of criterion d in Plan A, n_{a5} represents the normalized numerical value ratio of heat dissipation material of criterion e in Plan A.

The data in Table 4 can be used to make the following inferences in Plan A:

n_A =20.7+15.3+24.2+1.1+1.5=62.8

$$\therefore \quad n_{a1} = \frac{20.7}{62.8} = 33\%$$

Similarly, for Plan B:

$$n_B = n_b + n_c + n_d + n_f + n_g$$

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

Also, for Plan C:

$$n_C = n_a + n_e + n_f + n_g, \quad n_{c1} = \frac{n_a}{n_C}, \quad n_{c2} = \frac{n_e}{n_C}, \quad n_{c3} = \frac{n_f}{n_C},$$

$n_{c4} = \dfrac{n_g}{n_C}$

Table 5 Normalized numerical values ratios of key technical words of seven criteria in Plans A, B, C

criterion / Plan	a	b	c	d	e	f	g
A	33%	24.6%	38.5%	1.75%	2.4%	0	0
B	0	19.6%	31%	1.4%	0	22%	26%
C	35%	0	0	0	2.5%	29%	33.5%

Table 5 shows the normalized numerical values ratios of key technical words of seven criteria in the three plans. The distance of 10% between the normalized numerical value ratios in Table 5 was allocated an importance scale because of their larger differences among the normalized numerical ratio. The sizes of the normalized numerical value ratios were compared to determine the relative importance scale for the pairwise comparison matrix. In Plan A, the normalized numerical value ratio for criterion c was the highest. Therefore, its importance scale was 9, followed by criterion a (importance scale: 7) and criterion b (importance scale: 5). The normalized numerical value ratios of criterion d and criterion e were similar and before 10%, thus an importance scale of 3 was assigned. The importance scales of the various criteria and weight in each plan are tabled in Table 6.

Table 6 Importance scales of the seven criteria and weight in each plan

Criterion / Plan	a	b	c	d	e	f	g	weight
A	7	5	9	3	3	1	1	0.06734
B	1	5	9	3	1	5	7	0.14173
C	9	1	1	1	3	5	7	0.07383

The weights in Table 6 were calculated using Equation (2) and Equation (3). Then, the average of normalized columns proposed by Saaty (1982) was adopted to calculate the eigenvectors.

For example, the eigenvector of criterion a in Plan A was , which was calculated using Equation (6) and Equation(7)

$$w_{2aA} = \frac{w_{aA}}{w} \tag{6}$$

$$w = w_{aA} + w_{aB} + w_{aC} \tag{7}$$

where, w represents the sum of the relative importance scale of criterion a in the three plans, w_{aA} represents the relative importance scale of criterion a in Plan A (w_{aA}= 7 obtained from Table 6), w_{aB} represents the relative importance scale of criterion a in Plan B (w_{aB} = 1 obtained from Table 6), (w_{aC} represents the relative importance scale of criterion a in Plan C ((w_{aC}= 9 obtained from Table (6).

Therefore, $w = w_{aA} + w_{aB} + w_{aC} = 17$ and $w_{2aA} = \frac{7}{17} = 0.411$

The eigenvectors of all the criteria (W_2) in three plans were calculated to create a weight matrix (W_2).

W_2=

$$\begin{array}{c} \\ A \\ B \\ C \end{array}\begin{array}{c} \begin{matrix} w_{2a} & w_{2b} & w_{2c} & w_{2d} & w_{2e} & w_{2f} & w_{2g} \end{matrix} \\ \begin{bmatrix} w_{2aA} & w_{2bA} & w_{2cA} & w_{2dA} & w_{2eA} & w_{2fA} & w_{2gA} \\ w_{2aB} & w_{2bB} & w_{2cB} & w_{2dB} & w_{2eB} & w_{2fB} & w_{2gB} \\ w_{2aC} & w_{2bC} & w_{2cC} & w_{2dC} & w_{2eC} & w_{2fC} & w_{2gC} \end{bmatrix} \end{array}$$

Step3. Pairwise comparison of criteria internal dependence

In this step of the ANP, the internal dependence between the seven criteria was determined. A retrieval procedure was performed to collect various keywords from patents. These keywords were compared with the various criteria to calculate their normalized numerical values. If the key technical word were observed in the patent, the dependence between the technical words and the criteria were calculated using this method. Three patents were selected as examples for the key technical words of criteria a, e, and f. The normalized numerical value was determined by dividing the total number of words of the three patents by the appearance rate of key technical words Equation (8).

Normalized numerical value

$$= \frac{\text{appearancerate of the key technical word}}{\text{total number of words in three patents}} \tag{8}$$

Table 7 Key technical words of relevant patents and their normalized numerical values

Key technical word	Key Technical words in the patents	Normalized numerical value
Criterion a: heat dissipation fin	116	65.2%
Criterion e: heat dissipation material	15	6.8%
Criterion f: light source	50	28%

Table 7 shows that differences between normalized numerical values of key technical words were relatively large. Therefore, a relative importance scale was adopted when the difference of normalized numerical values was 15%. A difference of normalized numerical values exceeding 15% but less than 30% indicated an importance scale in addition to. Prior to comparing relative importance scales, the differences between the normalized numerical values of key technical words of criterion a and those of criteria e and f were determined. The procedures are explained in the following section.

The results of Table 7 show that the difference between the normalized numerical values of criterion a (65.2%) and criterion e (6.8%) was 58.4%. Therefore, the difference between the relative importance scale of the two criteria was 4 units and a maximum relative importance scale of 9 was selected. By comparison, the difference the normalized numerical values of criterion a (65.2%) and criterion f (28%) was 37.2% and the difference between the relative importance scale of the two criteria was 3 units. Therefore, a maximum relative importance scale of 7 was selected (as shown in Table 8). Following the abovementioned procedure, the relative importance scales for criterion b and criterion c with the other criteria were calculated (as shown in Table 8).

Table 8 The Relative importance scales and weights of criteria a, e and f

Criterion	a	e	f	weight
a	1	9	7	0.772
e	1/9	1	1/5	0.054
f	1/7	5	1	0.173

The weights tabulated in Table 8 were calculated using Equation (2) and Equation (3). Once the internal dependence weights of the various criteria were determined, they were arranged into a weight matrix. Criteria without internal dependence were allocated a value of 0. The criteria that were dependent on heat dissipation fin of criterion a were heat dissipation material of criterion e and light source of criterion f. Those that were not dependent on criterion a were criteria b, c, d and g. Those criteria were allocated a weight of 0. Subsequently, the weights calculated by using Equation (2) and Equation (3). for the three dependent criteria were $\boldsymbol{w_{3aa}}$= 0.772**,** $\boldsymbol{w_{3ae}}$=0.054, $\boldsymbol{w_{3af}}$=0.173 (as shown in Table 8). Thus, the weight matrix for criterion a was $\boldsymbol{w_{3a}}$ =(0.772 , 0 , 0 , 0 , 0.055 , 0.173 , 0). The internal dependence weight matrices of the order criteria $\boldsymbol{w_{3b}}$, $\boldsymbol{w_{3c}}$, $\boldsymbol{w_{3d}}$, $\boldsymbol{w_{3e}}$, $\boldsymbol{w_{3f}}$**,** and $\boldsymbol{w_{3g}}$ were calculated using the aforementioned method. The matrices of all the criteria were then arranged into a single matrix ($\mathbf{W_3}$). Therefore, $\mathbf{W_3}$= [$\boldsymbol{w_{3b}}$ $\boldsymbol{w_{3c}}$, $\boldsymbol{w_{3d}}$, $\boldsymbol{w_{3e}}$, $\boldsymbol{w_{3f}}$, and $\boldsymbol{w_{3g}}$].

Step 4. Pairwise comparison of the internal dependence of the plans

The methods for calculating the relative importance scale concerning the internal dependence of the various plans and the various plans and the various weights in the W_4 weight matrix are discussed in this section.

The key technical words in each plan are as follows:

Plan A: The key technical words of relative criteria corresponding to the “heat dissipation” and “overall structural design” techniques were heat dissipation fin of criterion a, rotary shaft of criterion b, support structure of criterion c, weight of criterion d, and heat dissipation material of criterion e.

Plan B: The key technical words of relative criteria corresponding to the “overall structural design” and “main body of the LED” techniques were rotary shaft of criterion b, support structure of criterion c, weight of criterion d, light source of criterion f, and reflector and lampshade of criterion g.

Plan C: The key technical words of relative criteria corresponding to the ”heat dissipation” and “main body of the LED” techniques were heat dissipation fin of criterion a, heat dissipation material of criterion e, light source of criterion f and reflector and lampshade of criterion g.

The relative importance scale of criterion a in each plan was compared. The key technical words of the internal dependence criteria that were dependent on criterion a were heat dissipation material of criterion e and light source of criterion f. Based on the two techniques in each plan, the original normalized numerical values of heat dissipation fin of criterion a and key technical words of its dependent criteria were summed to form a new normalized numerical value. Such as in Plan A, heat dissipation material of criterion e exhibited an internal dependence with heat dissipation fin of criterion a. By comparison, light source of criterion f was not a technical word of either technique in Plan A. Thus, the normalized numerical values of heat dissipation fin of criterion a and heat dissipation material of criterion e in Table 4 were summed (i.e.., 20.7%+1.5%=22.2%), where 22.2% was the new normalized numerical value to determine the relative importance scale of Plan A. The new normalized numerical value for criterion a in Plan B and Plan C were calculated using the same method applied in Plan A (as shown in Table 9). The new normalized numerical value for key technical words of the other criteria in the three plans was calculated using the same as above mentioned method to calculate that for key technical word of criterion a (as shown in Table 9).

A difference 10% of new normalized numerical value was allocated a relative importance scale to form a pairwise comparison matrix of the internal dependence of the plans. Comparison of the relative importance scale of criterion a in Plans A and B can be calculated as follows:

Table 9 New normalized numerical value for key technical word of criterion a in Plans A, B, and Plan C

Plan	new normalized numerical value

A	22.2%
B	17.2%
C	39.4%

The difference of new normalized numerical value between Plan A and Plan B according Table 9 was as follows:

22.2%-17.2%=5%

From Table 9, it also was found that the difference of new normalized numerical value between Plan A and Plan C was as follows:

22.2%-39.4%=-17.4%

Therefore, the 5% difference in new normalized numerical value between Plans A and B constituted a single importance scale, thus it had a relative importance scale of 3, whereas the -17.4% difference in new normalized numerical value between Plans A and C constituted three inverted importance scales, thus it had a relative importance scale of 1/5. The relative importance scales of criterion a in Plans A, B, and C are tabulated in Table 10. The other relative importance scales in Table 10 are obtained using the same method.

Table 10 Relative importance scales of criterion a in plans A, B, and C

Criterion a	A	B	C
A	1	3	1/5
B	1/3	1	1/7
C	5	7	1

The relative importance scales for internal dependence of the plans were used to calculate the eigenvectors for the three plans and obtained the weight matrices w_{4a}, w_{4b}, w_{4c}, w_{4d}, w_{4e}, w_{4f}, and w_{4g}, producing $\mathbf{W}_4=[w_{4a}\ w_{4b}\ w_{4c}\ w_{4d}\ w_{4e}\ w_{4f}\ w_{4g}]$.The calculation procedure is discussed as follows.

For example, the considering criterion a, w_{aA} was calculated by summing the relative importance scales of criterion a in Plans A, B, and C: From Table 10,

$w_{aA}=w_{aAA}+w_{aAB}+w_{aAC}=1+1/3+5=6.33$.

Therefore,

$w_{4aAA}=\frac{waAA}{waA}=\frac{1}{6.33}=0.158$, $w_{4aAB}=\frac{waAB}{waA}=\frac{\frac{1}{3}}{6.33}=0.0527$, and $w_{4aAC}=\frac{waAC}{waA}=\frac{5}{6.33}=0.789$,

where, w_{aAA} represents the relative importance scale of Plan A on itself (e.g. , in Table 10, $w_{aAA}=1$) , w_{aAB} represents the relative importance scale of Plan A on Plan B (e.g. , in Table 10, $w_{aAB}=1/3$), w_{aAC} represents the relative importance scale of Plan A on Plan C (e.g. , in Table 10, $w_{aAC}=5$), w_{4aAA} represents the eigenvector of Plan A on itself, w_{4aAB} represents the eigenvector of Plan A on Plan B, and w_{4Aac} represents the eigenvector of Plan A on Plan C.

Similarly, the w_{4aAA}, w_{4aAB} and w_{4Aac} values were obtained and incorporated into the matrix.

Let $w_{4a1}=\begin{array}{c}\\ A\\ B\\ C\end{array}\begin{array}{c}A\\ \begin{bmatrix}W_{4aAA}\\ W_{4aAB}\\ W_{4aAC}\end{bmatrix}\end{array}$, $w_{4a2}=\begin{array}{c}\\ A\\ B\\ C\end{array}\begin{array}{c}B\\ \begin{bmatrix}W_{4aBA}\\ W_{4aBB}\\ W_{4aBC}\end{bmatrix}\end{array}$,

$w_{4a3}=\begin{array}{c}\\ A\\ B\\ C\end{array}\begin{array}{c}C\\ \begin{bmatrix}W_{4aCA}\\ W_{4aCB}\\ W_{4aCC}\end{bmatrix}\end{array}$

Thus, the following numerical matrix (w_{4a}) was obtained:

$$w_{4a}=\begin{array}{c}\\ \\ A\\ B\\ C\end{array}\begin{array}{ccc}w_{4a1} & w_{4a2} & w_{4a3}\\ A & B & C\end{array}\hspace{-12em}\begin{array}{c}\\ \\ \begin{bmatrix}0.158 & 0.273 & 0.149\\ 0.052 & 0.091 & 0.106\\ 0.789 & 0.636 & 0.745\end{bmatrix}\end{array}$$

The matrices for w_{4b}, w_{4c}, w_{4d}, w_{4e}, w_{4f}, and w_{4g} were obtained using the aforementioned method. Therefore, $\mathbf{W}_4=[w_{4a}\ w_{4b}\ w_{4c}\ w_{4d}\ w_{4e}\ w_{4f}\ w_{4g}]$.

Step 5. Priority weights ($\mathbf{W}_c$) of the internal dependence key technical words of the various criteria

A new weight matrix ($\mathbf{W}_c$) was obtained by multiplying W_1 by W_3, which can be expressed as follows:

$$\mathbf{W}_c=\mathbf{W}_3\times\mathbf{W}_1 \tag{9}$$

Step 6 . Priority weight ($\mathbf{W}_p$) of the various alternative plans

where

$\mathbf{W}_P=\begin{bmatrix}w_{pa} & w_{pb} & \cdots & w_{pg}\end{bmatrix}$

$=[\mathbf{W}_4][\mathbf{W}_2]$

that is, $w_{pa}=w_{4a}\times w_{2a}$

In addition,

$$[w_{4a}]=\begin{bmatrix}w_{4aAA} & w_{4aAB} & w_{4aAC}\\ w_{4aBA} & w_{4aBB} & w_{4aBC}\\ w_{4aCA} & w_{4aCB} & w_{4aCC}\end{bmatrix}$$

and $[w_{2a}]=\begin{bmatrix}w_{2aA}\\ w_{2aB}\\ w_{2aC}\end{bmatrix}$.

Therefore, $\begin{bmatrix} w_{4aAA} & w_{4aAB} & w_{4aAC} \\ w_{4aBA} & w_{4aBB} & w_{4aBC} \\ w_{4aCA} & w_{4aCB} & w_{4aCC} \end{bmatrix} \begin{bmatrix} W_{2aA} \\ W_{2aB} \\ W_{2aC} \end{bmatrix} =$

$$\begin{bmatrix} w_{paA} \\ w_{paB} \\ w_{paC} \end{bmatrix} = w_{pa} \qquad (10)$$

By substituting $[w_{4a}]$ and $[w_{2a}]$ into Eq. (10), the following matrix was derived:

$$W_{pa} = \begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} W_{4a} \quad A \qquad B \qquad C \\ \begin{bmatrix} 0.158 & 0.273 & 0.149 \\ 0.052 & 0.091 & 0.106 \\ 0.789 & 0.636 & 0.745 \end{bmatrix} \end{array} \begin{array}{c} W_{2a} \\ \begin{bmatrix} 0.411 \\ 0.059 \\ 0.529 \end{bmatrix} \end{array}$$

$$W_{pa}$$

$$= \begin{array}{c} A \\ B \\ C \end{array} \begin{bmatrix} 0.16 \\ 0.083 \\ 0.756 \end{bmatrix}$$

Subsequently, the weight vector $w_{pa} = \begin{bmatrix} 0.716 \\ 0.106 \\ 0.178 \end{bmatrix}$ was obtained by combining the w_{paA} (0.71), w_{paB} (0.106), and w_{paC} (0.178) eigenvectors. Similarly, $w_{pb} = w_{4b} \times w_{2b}$.

The other eigenvectors, namely w_{pc}, w_{pd}, w_{pe}, w_{pf}, and w_{pg}, were calculated using the same method. Using the same principle, w_{pa}, w_{pb}, w_{pc}, w_{pd}, w_{pe}, w_{pf}, and w_{pg} weight vectors were combined to form $\mathbf{W_p}$, which is expressed as follows:

$$\mathbf{W_p} = [w_{pa} \quad w_{pb} \quad \cdots \quad w_{pg}]$$

$$= \begin{bmatrix} w_{paA} & w_{pbA} & \cdots & w_{pgA} \\ w_{paB} & w_{pbB} & \cdots & w_{pgB} \\ w_{paC} & w_{pbC} & \cdots & w_{pgC} \end{bmatrix} \qquad (11)$$

Step 7. Priority weights ($\mathbf{W_{ANP}}$) of the various alternative plans

Finally, the effects weights ($\mathbf{W_p}$) of the alternative plans and the internal dependence priority weights ($\mathbf{W_c}$) of the various criteria were analyzed to determine the priority weights of the alternative plans ($\mathbf{W_{ANP}}$), which is expressed as follows:

$$\mathbf{W_{ANP}} = \mathbf{W_p} \times \mathbf{W_c} = \begin{bmatrix} w_{ANPA} \\ w_{ANPB} \\ w_{ANPC} \end{bmatrix} \qquad (12)$$

The size of $\mathbf{W_{ANP}}$ was used to represent the priority of Plans A, B, and C. The plan with the largest priority weight was the preferred design plan.

LED-RL INNOVATIVE DESIGN SELECTION OUT COMES USING THE MANP

The present study proposed a seven-step MANP to select the ideal design improvement plan for an innovative product. Numerous patents were collected and analyzed to determine the appearance rates and normalized numerical values of various technical words. The differences between normalized numerical values were analyzed to calculate the relative importance scales and weights of pairwise comparison matrices. The patents collected in the present study were those concerning LED-RLs. These patents were analyzed to calculate and explain the priority weights of three plans. Descriptions concerning the three plans and seven criteria in each step of the MANP are provided in the following section.

Step 1. The results of pairwise comparison of the various key technical words of the various criteria

In Step 1, the appearance rates and normalized numerical values of the various key technical words of the various criteria were calculated. The results are tabulated in Table 4. The difference of 5% in the normalized numerical values were used to determine the relative importance scales of the key technical words of the various criteria. The results of pairwise comparison matrix of the various key technical words of the various criteria and the relative importance scales and weights are tabulated in Table 11.

Table 11 The results of pairwise comparison matrix of the various key technical words of the various criteria and the relative importance scales and weights

	a	b	c	d	e	f	g	Weight
a	1	5	1/3	9	9	3	3	0.24379
b	1/5	1	1/5	9	9	1/3	1/3	0.07915
c	3	5	1	9	9	5	3	0.36569
d	1/9	1/9	1/9	1	1	1/9	1/9	0.01828
e	1/9	1/9	1/9	1	1	1/9	1/9	0.01828
f	1/3	3	1/5	9	9	1	1/3	0.11304
g	1/3	3	1/3	9	9	3	1	0.16176

The values along the diagonal line in the pairwise comparison matrix are 1 (as shown in Table 11), suggesting that the two criteria measured on the diagonal line were equally important. For example, row 1 shows that relative importance of criterion a and the seven criteria. Pairwise comparisons were conducted on all criteria combinations using the innovative equations proposed in the present study to calculate the weights of the criteria. Consequently, the weights of W_1 were calculated and obtained W_1= [0.24379, 0.07915, 0.36569, 0.01828, 0.01828, 0.11304, 0.16176].

Step 2. The results of comparison of the relative important of criteria and plans

In Step 2, Equation (4) and Equation (5) were proposed to calculate the normalized numerical value ratio of the seven criteria in each plan (as shown in Table 12). The difference of 10% in the normalized numerical value ratios were used to determine the relative importance scale of each criterion to each plan (as shown in Table 13). Subsequently, they were incorporated into Equation (2) and Equation (3) to calculate their weights (as shown in Table 13).

Table 12 Normalized numerical value ratio of the seven criteria in each plan

criterion / plan	a	b	c	d	e	f	g
A	33%	24.6%	38.5%	1.75%	2.4%	0	0
B	0	19.6%	31%	1.4%	0	22%	26%
C	35%	0	0	0	2.5%	29%	33.5%

Table 13 Relative importance scales of the seven criteria to each plan and weights

criterion / plan	a	b	c	d	e	f	g	Weights
A	7	5	9	3	3	1	1	0.06734
B	1	5	9	3	1	5	7	0.14173
C	9	1	1	1	3	5	7	0.07383

The aforementioned calculation method was used to determine the eigenvectors of the criteria on the various plans. The eigenvectors of criteria a, b, c, and g were w_{2a}, w_{2b}, w_{2c}, and w_{2g}. These

eigenvectors were combined to from the following matrix of $\mathbf{W_2}$:

$$\mathbf{W_2} = \begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{ccccccc} w_{2a} & w_{2b} & w_{2c} & w_{2d} & w_{2e} & w_{2f} & w_{2g} \end{array} \\ \begin{bmatrix} 0.411 & 0.455 & 0.474 & 0.429 & 0.429 & 0.091 & 0.067 \\ 0.059 & 0.455 & 0.474 & 0.429 & 0.143 & 0.455 & 0.467 \\ 0.529 & 0.091 & 0.053 & 0.143 & 0.429 & 0.455 & 0.467 \end{bmatrix} \end{array}$$

Step 3: The results of pairwise comparison of criteria internal dependence

In Step 3, a pairwise comparison was conducted to determine the internal dependence of the seven criteria and evaluate their mutual influence. The results of pairwise comparison of criteria internal dependence was shown as $\mathbf{W_3}$. The determination process for internal dependence is following the description in previous content of step 3 of MANP. The dependence between criteria was determined based on the content of the LED-RL patents and engineering knowledge. Then, the normalized numerical values of the key technical words of various criteria were calculated. The differences between the normalized numerical values were analyzed to determine the relative importance scale of dependent criteria and weights.

Finally, w_{3a}, w_{3b}, w_{3c}, w_{3d}, w_{3e}, w_{3f}, and w_{3g} were combined to create a weight matrix ($\mathbf{W_3}$).

Step 4: The results of pairwise comparison of the internal dependence of the plans

In Step 4, a pairwise comparison was conducted to determine the internal dependence of the three plans and evaluate their mutual influences. The relative weights of each alternative plan were compared with each criterion independently to from a weight matrix ($\mathbf{W_4}$). Using the determination process of $\mathbf{W_4}$ discussed in the previous description of step 4, the w_{4a} , w_{4b} , w_{4c} , w_{4d} , w_{4e} , w_{4f} and w_{4g} matrices were obtained.

Then, it can obtain the weight matrix, $\mathbf{W_4}$=[w_{4a} w_{4b} w_{4c} w_{4d} w_{4e} w_{4f} w_{4g}].

Step 5: The result of priority weight (W_c) of the internal dependence key technical words of the various criteria

In Step 5, $\mathbf{W_c}$ was obtained by multiplying W_1 in Step 1 and W_3 in Step 3.
The results of $\mathbf{W_c}$ was as follows:

$$\mathbf{W_c} = \mathbf{W_3} \times \mathbf{W_1} = \begin{bmatrix} 0.209 \\ 0.286 \\ 0.272 \\ 0.198 \\ 0.221 \\ 0.131 \\ 0.315 \end{bmatrix}$$

Step 6: The results of effect weight ($\mathbf{W_p}$) of the various alternative plans

In Step 6, $\mathbf{W_p}$ was calculated using Wp= [$\mathbf{W_4}$][$\mathbf{W_2}$] following the proposed step 6 of MANP.

$\mathbf{W_p}$ to obtain the matrix values for $\mathbf{W_p}$ as follow:

$$\mathbf{W_p} = \begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{ccccccc} w_{pa} & w_{pb} & w_{pc} & w_{pd} & w_{pe} & w_{pf} & w_{pg} \end{array} \\ \begin{bmatrix} 0.16 & 0.474 & 0.166 & 0.113 & 0.467 & 0.059 & 0.057 \\ 0.083 & 0.474 & 0.776 & 0.824 & 0.067 & 0.173 & 0.94 \\ 0.756 & 0.052 & 0.059 & 0.063 & 0.467 & 0.769 & 0.151 \end{bmatrix} \end{array}$$

Step 7: The results of priority weight (W_{ANP}) of the various alternative plans

In Step 7, the effect weights of the various alternative plans ($\mathbf{W_p}$) and the priority weights of the various internal dependence criteria ($\mathbf{W_c}$) were multiplied to obtain the priority weights of the alternative plans ($\mathbf{W_{ANP}}$).

Thus, $\mathbf{W_{ANP}}=\mathbf{W_p} \times \mathbf{W_c} = \begin{bmatrix} w_{ANPA} \\ w_{ANPB} \\ w_{ANPC} \end{bmatrix}$

Then, the following results of $\mathbf{W_{ANP}}$ was obtained:

$$\mathbf{W_{ANP}}= \mathbf{W_p} \times \mathbf{W_c} = \begin{bmatrix} 0.365 \\ 0.82 \\ 0.447 \end{bmatrix} = \begin{bmatrix} w_{ANPA} \\ w_{ANPB} \\ w_{ANPC} \end{bmatrix}$$

Thus, the priority weights of Plans A, B, and C were 0.365, 0.82, and 0.447, respectively. It was found that the priority weight order of the plans was Plan B>Plan C>Plan A. The plan with highest priority weight was the first selection plan. That is, Plan B was selected to be the preferred improvement plan for LED-RL designs. The method of calculating priority weights based on dependence proposed can serve as a valuable reference for future analysis on improving innovative product designs. Researchers can also first consider to innovatively improve two techniques of overall structure design and main body of the LED of plan B, thereby reducing the time required to develop product.

CONCLUSION

Developing new products is an immense undertaking for enterprises or research and development teams. Not only can new product development take numerous months to several years to complete, it also requires immense material and human resource commitments, which is especially strenuous for small and medium enterprises with no guarantee of return. The present study aimed to develop an effective tool to reduce the selection time during the initial stages of product development. An MANP-based-decision-making and selection tool were developed using the appearance rates and normalized numerical values of specific technical words contained in patents. This method can be used to identify priority design improvement plans that are consistent with real market conditions.

The MANP proposed in the present study is based on the appearance rates and normalized numerical values and normalized numerical values ratios of specific technical words in patent. The difference of the normalized numerical values and normalized numerical value ratios of technical words were used to allocate relative importance scales and build innovative equations for calculating weights. Pairwise comparison matrices and weight matrices were developed by comparing the various relative importance scales. A seven-step procedure of MANP was introduced to gradually and systematically calculate the priority values and selection results of various plans. Three plans were presented in the study. The priority weights of the three plans were analyzed using the MANP. Results indicated that the priority order for the plans was Plan B>Plan C>Plan A. Rather, the plan with the highest priority weight was the ideal improvement plan. Plan B comprised two improvement techniques, namely overall structural design and main body of the LED. It was evaluated to be the preferred design improvement plan for LED-RL products. The proposed MANP helps researchers formulate conceptual plans. It also facilitates researchers in analyzing the priority weights of product designs and determining the priority order of various design improvement plans, thereby reducing the time required to develop products.

ACKNOWLEDGMENT

The authors would like to thank the support from Ministry of Science and Technology, Taiwan (MOST 105-2221-E-011-001).

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採用修正式分析網路程序法應用於 LED 閱讀燈創新設計方案優先次序評估

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摘要

本研究提出了一種修正式 ANP（MANP）方法，其分析與各種技術文獻和專利中提出的技術相對應的技術詞彙，以確定這些詞語的出現率和歸一化數值。使用不同技術詞的歸一化數值之間的差距來確定技術詞的相對重要性等級。還提出了用於計算權重值的創新方程式。採用 LED 閱讀燈（LED-RL）作為設計改進的目標。收集了涉及 LED 閱讀燈整體結構設計，散熱和主體三大技術類別的相關技術專利。然後，使用 LED-RL 的技術類別形成三個初步技術設計方案（即方案 A，B 和 C）。每個方案包含三個技術類別中的兩個技術類別。然後使用 MANP 方法提出的七個步驟處理每個方案，以確定三個技術設計計劃的優先權重。然後選擇最高優先權重的技術設計方案作為理想的創新技術設計方案。