A New Product Ideas Screening and Ranking by AHP-Fuzzy Hybrid Model & Approach

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Abstract. Introducing Cross-functional NPD Team into evaluations of product ideas can significantly improve the success rate of product development. Based on relevant research achievements of domestic and foreign scholars, this paper incorporates the evaluation results of product ideas at the two levels of R&D Department and Steering Committee into the comprehensive evaluation, screening and ranking of product development projects by AHP-Fuzzy Hybrid Model and Approach for avoiding the risks to the greatest extent that the valuable resources are wasted on the low profit projects while the high value projects are shelved.

Keywords: Cross-functional NPD Team, AHP-Fuzzy Hybrid Model, synthetic evaluation, screening, ranking.

1. Introduction

Product innovation helps maintain the vitality and competitiveness of an existing product portfolio and sustains a company's lasting competitive advantage. However, research statistics show that the majority of new products fail to reach the market, with a failure rate of 25% to 45%. The following numbers of projects declining curve (Figure 1) outlines the characteristics of product innovation [1].

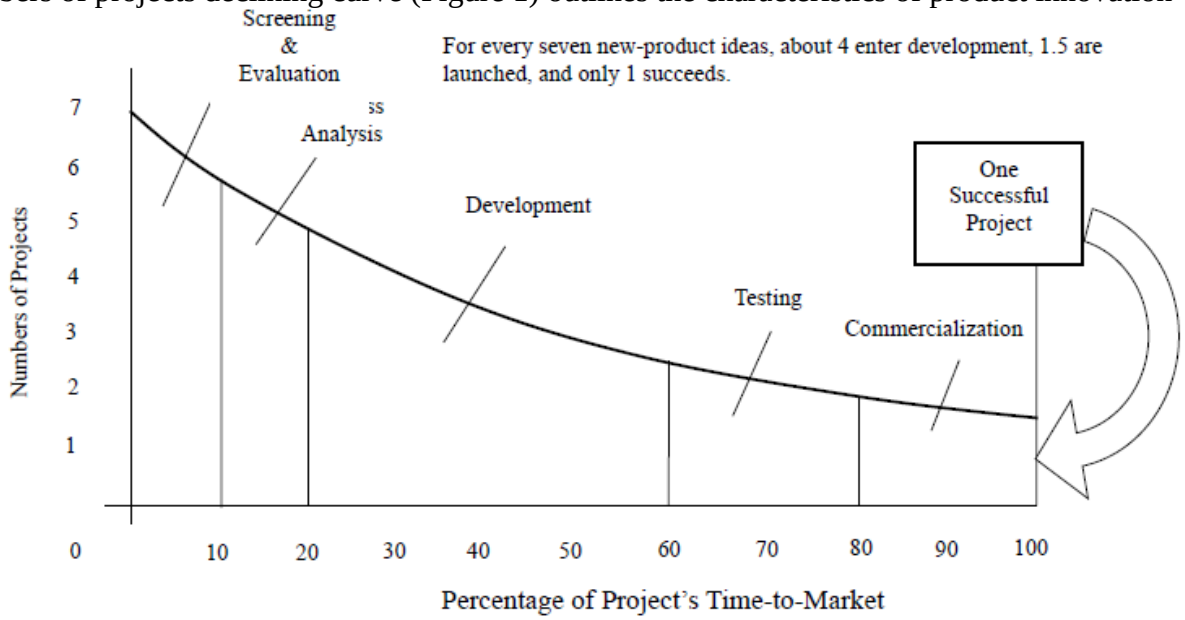

Figure 1. The Attrition Rate of New-Product Projects

It can be seen from the decline curve of product innovations that new product development decision-making needs a new-product funnel rather than a tunnel. Robert G. Cooper's new product development Stage-Gate System (SGS) (Figure 2) provides a way to improve the quality of product development by setting up a gate or Go/Kill decision point before each development stage. At each stage of new product development, a Go/Kill decision point is required to screen and prioritize new product development ideas so as to solve the difficult decision-making problems of how to "choose the right project" and how to "do project right" in the decision-making of the new product development process [2].

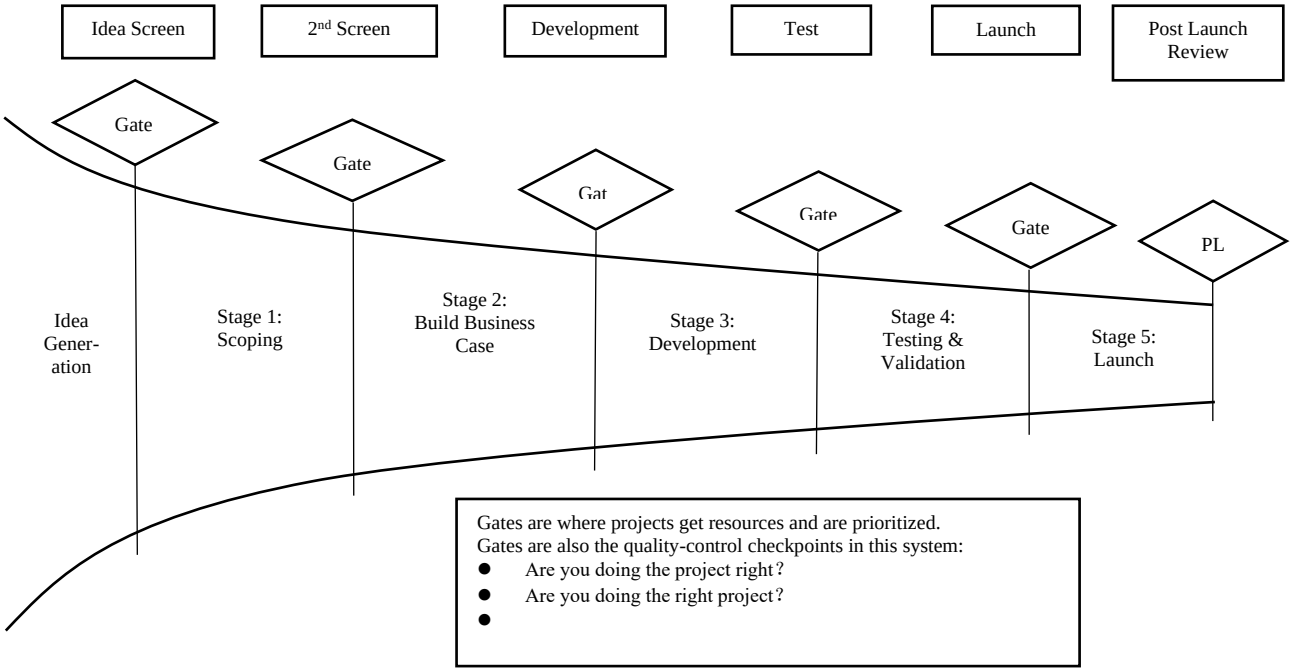

Figure 2. Stage-Gate System(SGS)

Figure 3 shows the screening model for product development ideas at Gate 1. It's a rapid, primary evaluation and screening process. Projects that pass the screening process will move on to the first stage (preliminary investigation or scoping phase) for re-screening of ideas at Gate 2 with the goal of reducing the number of ideas.

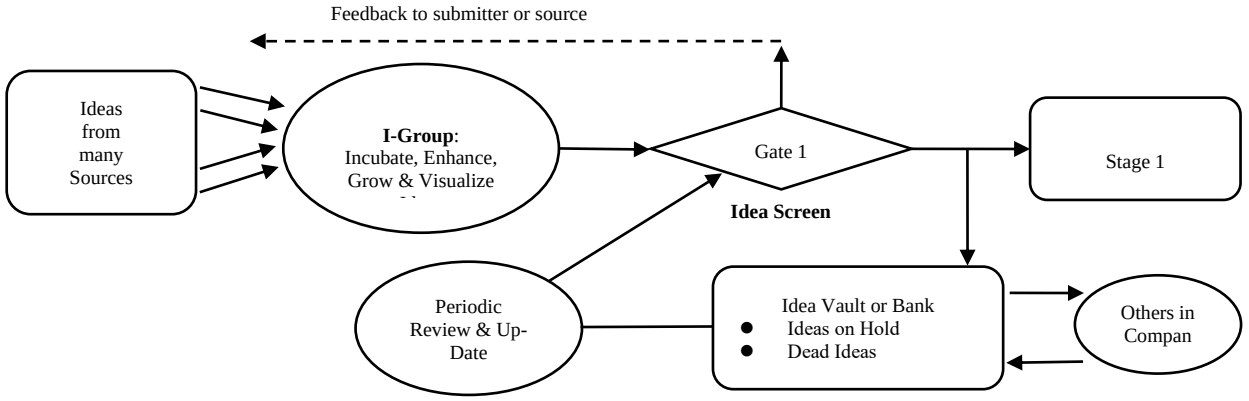

Figure 3. New Idea Management System - Systematic Idea Acquisition and Screening Process

The second screening process for Gate 2 is essentially the same as the screening process for the Gate 1. It's done in conjunction with the new information obtained in the first stage, incorporating other "should meet" factors that affect the success of the product development (e.g., standards, technology, laws, regulations, etc.) and quick, easy financial calculations (e.g., payback period, etc.) into the evaluation of the Gate 2.

2. Literature Review

2.1. A review of partial foreign product innovation management methods, models and evaluation approaches

C. Merle Crawford applies the theories, methods and tools of marketing to all stages of product development from idea generation to PLR[3].

Shapiro A F, Koissi M C. research findings: the fuzzy logic correction of AHP is still a fruitful exploration field in the future [4].

Zhe Huang, Cherifi Ahmed and Gardoni Mickael came up with an idea screening model based on the combination of EcaTRIZ, hierarchical analysis (AHP) and SWOT analysis (SWOT)[5].

J. Gyani, A. Ahmed, M.A. Haq research found that AHP is the best choice method and model for the CSS in decision-making[6].

2.2. A review of partial domestic product innovation management methods, models and evaluation approaches

Zhu Keyu's research concluded that[7]: (1) There are many problems in the basic mathematical logic of Fuzzy AHP method: 1) the results are not credible; 2) There is no effective method to test the consistency of fuzzy judgments; 3) There is no recognized method to rank the fuzzy weight - the fuzzy judgment result of fuzzy AHP. (2) Fuzzy AHP is a false proposition and a mathematical proof is given. (3) The triangular Fuzzy AHP method proposed by Laarhoven & Pedrycs still has invalid solutions. (4) The triangular Fuzzy AHP degree analysis method proposed by Chang has obvious errors and leads to unreliable results.

2.3. A review of partial domestic and foreign research on key factors affecting the success of new product development

The screening and identification of evaluation factors benefit to reduce the risk of decision-making errors in the evaluating and screening of new ideas, so that enterprises can start from focusing on the key factors in the management activities of new product development [8-12].

3. Research Methodology

3.1. Selection of methods for evaluating and screening new product development ideas

New idea screening includes the following two steps: determining screening criteria and screening methods. By referring to the main existing decision-making methods and models, it can be seen that the analytic hierarchy process (AHP) takes the research object as a system and makes decisions according to the decomposition, comparative judgment and comprehensive thinking mode, which is a more appropriate method to evaluate and screen the product development ideas of manufacturing industry.

In this paper, Robert G. Cooper's "5 categories and 12 research-based scorecards for assessing the use of bold innovation" are used as key elements for "1st Level (R&D Sector)"evaluation, screening, and prioritization of product development departments[13]; the six critical success factors of "pioneering companies" product innovation strategy by Fang Wei and Sun Shu-dong - " Team Communication Skills, Soft Support from Company Top Management, Innovative Cultural Atmosphere, Project Team Building Up, Pre-development Proficiency, Product Launch Proficiency" as key factors for the "2nd Level " evaluation of the Steering Committee, and the qualitative indicators of "Excellent, Very Good, Good, Fair, Poor" are incorporated into the "2nd Level" ideas evaluation. The selected ideas will be finally evaluated, screened and ranked through the comprehensive evaluation of the AHP-Fuzzy Hybrid Model in order for the Steering Committee to decide and approve the ideas to be entered to "Gate 2 - Build Business Case" [14].

The Four-level AHP-Fuzzy Hybrid Model is given in Figure 4:

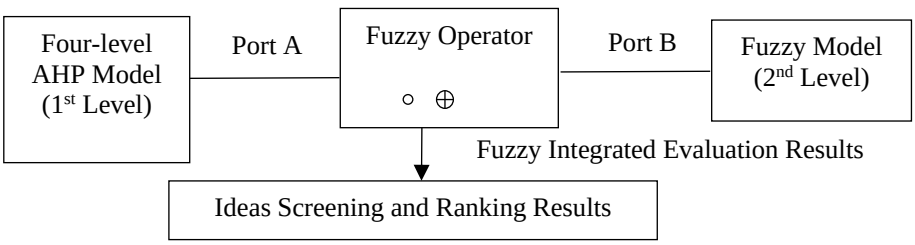

Figure 4. Four-level AHP-Fuzzy Hybrid Model

Refer to Figure 5 for the Four-level AHP Model (1st Level):

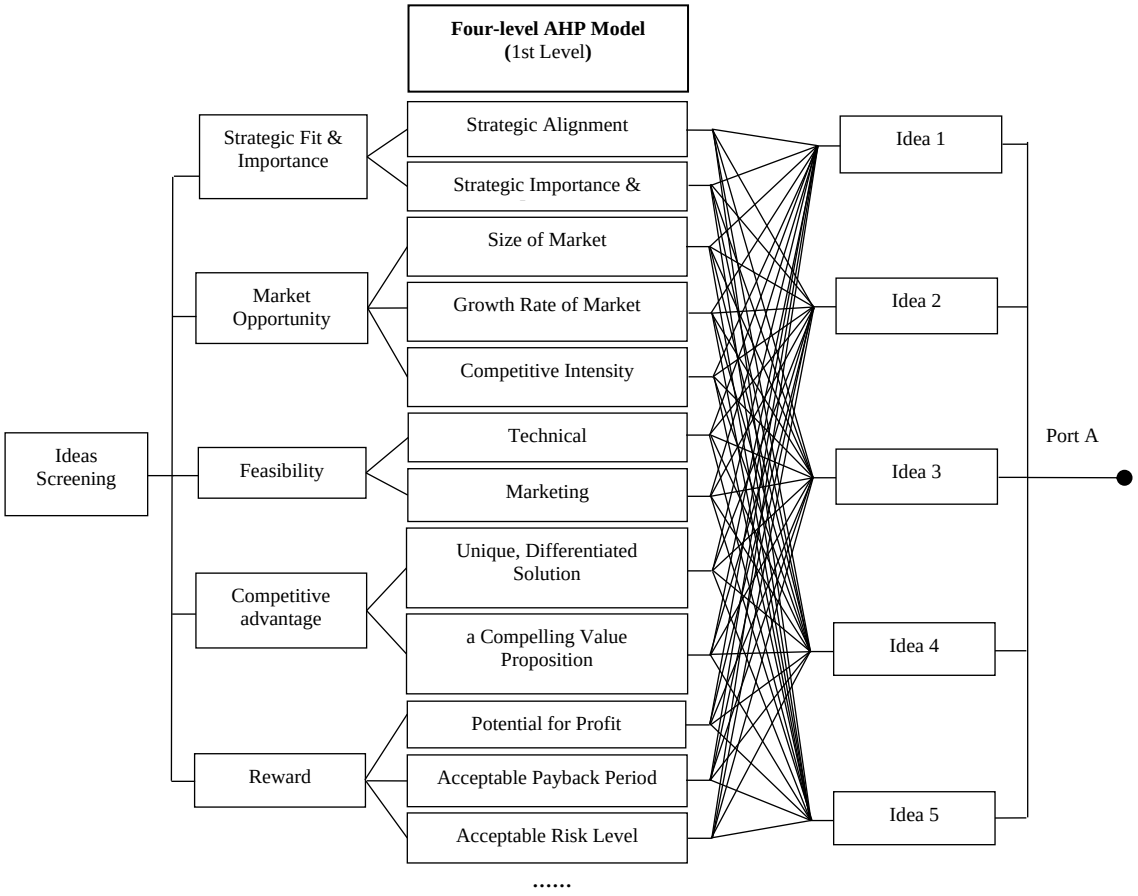

Figure 5. Four-level AHP Model (1st Level)

Refer to Figure 6 for the Fuzzy Model (2nd Level):

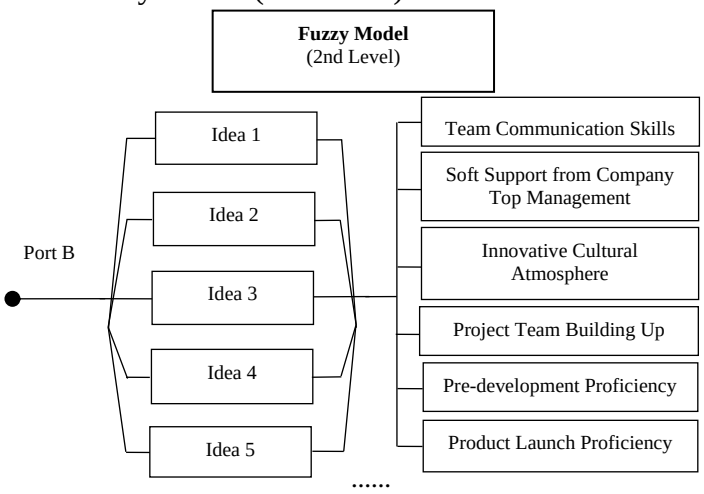

Figure 6. Fuzzy Model (2nd Level)

3.2. Idea evaluating, screening, ranking process

3.2.1 The weight vector of idea's comprehensive evaluation of AHP-Fuzzy Hybrid Model is calculated according to the following formula.

$$S_i = W_i \circ R_i \tag{1}$$

Where,

S_1: Idea's comprehensive evaluation weight vector$[S_1, S_2, S_3, S_4, S_5 \cdots S_i]$;

W_1: Weight vector matrix of the Four-level AHP Model (1st Level)$[W_1, W_2, W_3, W_4, W_5 \cdots W_i]$;

R_1: Normalized 5-scale indicators transformed fuzzy matrix of the Fuzzy Model (2nd Level).

$$R_i = \begin{array}{c} \\ Idea\ 1 \\ Idea\ 2 \\ Idea\ 3 \\ \vdots \\ Idea\ i \end{array} \begin{array}{c} \begin{array}{cccccccc} R_1 & R_2 & R_3 & R_4 & R_5 & R_6 & \cdots & R_j \end{array} \\ \begin{bmatrix} R_{11} & R_{12} & R_{13} & R_{14} & R_{15} & R_{16} \cdots R_{1j} \\ R_{21} & R_{22} & R_{23} & R_{24} & R_{25} & R_{26} \cdots R_{2j} \\ R_{31} & R_{32} & R_{33} & R_{34} & R_{35} & R_{36} \cdots R_{3j} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \cdots \vdots \\ R_{i1} & R_{i2} & R_{i3} & R_{i4} & R_{i5} & R_{i6} \cdots R_{ij} \end{bmatrix} \end{array} \tag{2}$$

$\circ$: Fuzzy operator

3.2.2 The following formula is used to calculate the comprehensive score for each idea proposed to be entered into Gate 2 - Build Business Case:

$$T_i = \frac{\sum_{i=1}^{n} V_i \times S_i}{\sum_{i=1}^{n} S_i} \tag{3}$$

$$V_i = \begin{array}{c} \\ Idea\ 1 \\ Idea\ 2 \\ Idea\ 3 \\ \vdots \\ Idea\ i \end{array} \begin{array}{c} \begin{array}{cccccccc} V_1 & V_2 & V_3 & V_4 & V_5 & V_6 & \cdots & V_j \end{array} \\ \begin{bmatrix} V_{11} & V_{12} & V_{13} & V_{14} & V_{15} & V_{16} \cdots V_{1j} \\ V_{21} & V_{22} & V_{23} & V_{24} & V_{25} & V_{26} \cdots V_{2j} \\ V_{31} & V_{32} & V_{33} & V_{34} & V_{35} & V_{36} \cdots V_{3j} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \cdots \vdots \\ V_{i1} & V_{i2} & V_{i3} & V_{i4} & V_{i5} & V_{i6} \cdots V_{ij} \end{bmatrix} \end{array} \tag{4}$$

3.2.3 The ideas are ranked from the highest to the lowest with the comprehensive score of $T_1, T_2, T_3, T_4, T_5 \cdots T_i$ obtained, higher comprehensive score characterizing higher priority.

4. Evaluating, screening and ranking of product development ideas (an example)

4.1. Constructing a Four-level AHP Model (1st Level)

Refer to Figure 7 for the Four-level AHP Model (1st Level):

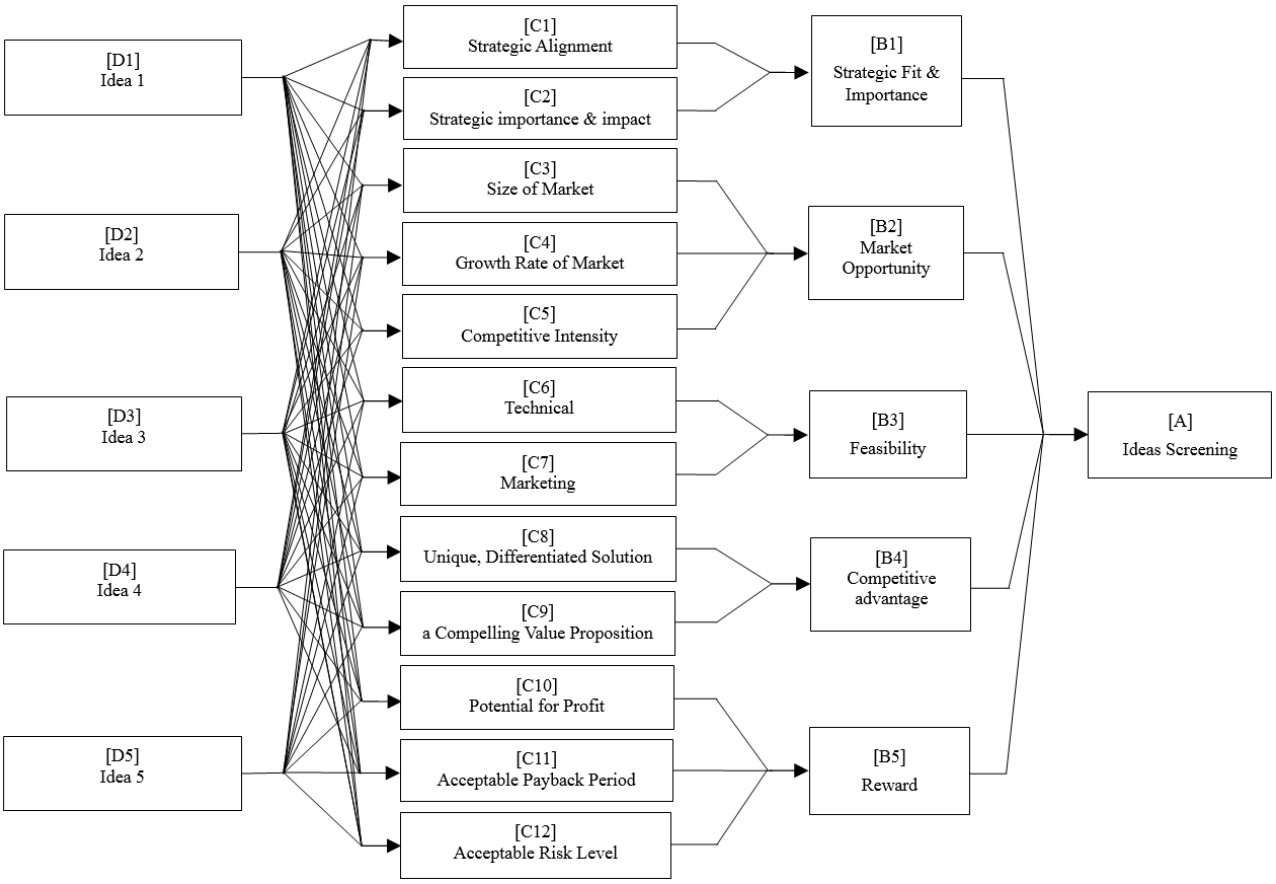

Figure 7. Four-level AHP Model (1st Level)

4.2. Assigning attribute weights to the Four-level AHP Model (1st Level)

In this paper, the subjective assignment method is used to assign the attribute weights.

4.3. Constructing pairwise comparison matrix for the Four-level AHP Model (1st Level)

4.3.1 Criteria Level - Sub-criteria Level pairwise comparison matrix:

$$[B1]=\begin{pmatrix}1 & 1\\ 1 & 1\end{pmatrix};\quad [B2]=\begin{pmatrix}1 & 1 & 1/2\\ 1 & 1 & 1/3\\ 2 & 3 & 1\end{pmatrix};\quad [B3]=\begin{pmatrix}1 & 1/2\\ 2 & 1\end{pmatrix};\quad [B4]=\begin{pmatrix}1 & 1\\ 1 & 1\end{pmatrix};[B5]=\begin{pmatrix}1 & 1/3 & 1/5\\ 3 & 1 & 1/3\\ 5 & 3 & 1\end{pmatrix}$$

4.3.2 Sub-criteria Level – Ideas Level pairwise comparison matrix:

$$[C1]=\begin{pmatrix}1 & 1/4 & 1 & 1/2 & 1/3\\ 4 & 1 & 3 & 3 & 1\\ 1 & 1/3 & 1 & 1/2 & 1/5\\ 2 & 1/3 & 2 & 1 & 1\\ 3 & 1 & 5 & 1 & 1\end{pmatrix};\quad [C2]=\begin{pmatrix}1 & 1/2 & 1/3 & 1/2 & 1/5\\ 2 & 1 & 1/2 & 1/4 & 1/3\\ 3 & 2 & 1 & 1 & 1/2\\ 2 & 4 & 1 & 1 & 1\\ 5 & 3 & 2 & 1 & 1\end{pmatrix};\quad [C3]=\begin{pmatrix}1 & 1 & 1/2 & 4 & 1\\ 1 & 1 & 1/4 & 1 & 1/3\\ 2 & 4 & 1 & 3 & 2\\ 1/4 & 1 & 1/3 & 1 & 1/4\\ 1 & 3 & 1/2 & 4 & 1\end{pmatrix};\quad [C4]=\begin{pmatrix}1 & 1 & 1/3 & 2 & 1\\ 1 & 1 & 1/4 & 1 & 1/2\\ 3 & 4 & 1 & 1 & 2\\ 1/2 & 1 & 1 & 1 & 1/2\\ 1 & 2 & 1/2 & 2 & 1\end{pmatrix};$$

$$[C5]=\begin{pmatrix}1 & 1 & 1/2 & 1/4 & 1/2\\ 1 & 1 & 2 & 1/2 & 1/4\\ 2 & 1/2 & 1 & 1/3 & 1/3\\ 4 & 2 & 3 & 1 & 1\\ 2 & 4 & 3 & 1 & 1\end{pmatrix};\quad [C6]=\begin{pmatrix}1 & 1 & 1/4 & 1/2 & 1\\ 1 & 1 & 1/2 & 1 & 1/4\\ 4 & 2 & 1 & 2 & 1\\ 2 & 1 & 1/2 & 1 & 1/2\\ 1 & 4 & 1 & 2 & 1\end{pmatrix};\quad [C7]=\begin{pmatrix}1 & 1 & 1/2 & 1/3 & 1\\ 1 & 1 & 2 & 1/2 & 1\\ 2 & 1/2 & 1 & 1 & 1/2\\ 3 & 2 & 1 & 1 & 3\\ 1 & 1 & 2 & 1/3 & 1\end{pmatrix};\quad [C8]=\begin{pmatrix}1 & 2 & 1/2 & 1 & 1\\ 1/2 & 1 & 1/5 & 1/3 & 1\\ 2 & 5 & 1 & 2 & 2\\ 1 & 3 & 1/2 & 1 & 1/3\\ 1 & 1 & 1/2 & 3 & 1\end{pmatrix};$$

$$[C9]=\begin{pmatrix} 1 & 2 & 1 & 1/3 & 1 \\ 1/2 & 1 & 1/3 & 1/4 & 1/2 \\ 1 & 3 & 1 & 1/2 & 1 \\ 3 & 4 & 2 & 1 & 1/2 \\ 1 & 2 & 1 & 2 & 1 \end{pmatrix}; \quad [C10]=\begin{pmatrix} 1 & 4 & 1 & 2 & 1 \\ 1/4 & 1 & 1/2 & 1/3 & 1/2 \\ 1 & 2 & 1 & 1 & 1/4 \\ 1/2 & 3 & 1 & 1 & 1/3 \\ 1 & 2 & 4 & 3 & 1 \end{pmatrix}; \quad [C11]=\begin{pmatrix} 1 & 1 & 1/2 & 1/4 & 1 \\ 1 & 1 & 2 & 1 & 1/2 \\ 2 & 1/2 & 1 & 1/2 & 1/3 \\ 4 & 1 & 2 & 1 & 1 \\ 1 & 2 & 3 & 1 & 1 \end{pmatrix}; \quad [C12]=\begin{pmatrix} 1 & 1/2 & 2 & 1/2 & 1 \\ 2 & 1 & 3 & 2 & 1/2 \\ 1/2 & 1/3 & 1 & 1/3 & 1/2 \\ 2 & 1/2 & 3 & 1 & 1 \\ 1 & 2 & 2 & 1 & 1 \end{pmatrix}$$

4.3.3 Goal Level - Criterion Level pairwise comparison matrix:

$$[A]=\begin{pmatrix} 1 & 1 & 2 & 1/3 & 1/5 \\ 1 & 1 & 2 & 1/2 & 1/2 \\ 1/2 & 1/2 & 1 & 1/3 & 1/3 \\ 3 & 2 & 3 & 1 & 1/4 \\ 5 & 2 & 3 & 4 & 1 \end{pmatrix}$$

4.3.4 Ranking the ideas based on the Four-level AHP Model (1st Level), the pairwise comparison matrix consistency ratio check:

In this paper, the sum method is used to normalize the pairwise comparison matrix.

4.4. Summary of path weights and node weights for the Four-level AHP Model (1st Level) (Table 1):

Table. 1. Path Weights and Node Weights of the Four-level AHP Model (1st Level)

Paths	Weights	Paths	Path weighting	Node weighting	Idea 1	Idea 2	Idea 3	Idea 4	Idea 5
［A］-［B1］	**0.1145**	［B1］-［C1］	**0.5000**	**0.0573**	0.0875	0.3479	0.0857	0.1825	0.2964
		［B1］-［C2］	**0.5000**	**0.0573**	0.0786	0.1058	0.2119	0.2676	0.3361
［A］-［B2］	**0.4286**	［B2］-［C3］	**0.5485**	**0.2351**	0.2020	0.1074	0.3670	0.0816	0.2420
		［B2］-［C4］	**0.2106**	**0.0903**	0.1178	0.1718	0.3546	0.1510	0.2048
		［B2］-［C5］	**0.2409**	**0.1032**	0.1027	0.1343	0.1161	0.3199	0.3270
［A］-［B3］	**0.1462**	［B3］-［C6］	**0.3333**	**0.0487**	0.1285	0.1193	0.3097	0.1549	0.2875
		［B3］-［C7］	**0.6667**	**0.0975**	0.1286	0.1853	0.1775	0.3340	0.1747
［A］-［B4］	**0.0831**	［B4］-［C8］	**0.5000**	**0.0416**	0.1715	0.0963	0.3597	0.1632	0.2094
		［B4］-［C9］	**0.5000**	**0.0416**	0.0818	0.1928	0.3080	0.2496	0.1679
［A］-［B5］	**0.2276**	［B5］-［C10］	**0.1062**	**0.0242**	0.2661	0.0849	0.1568	0.1522	0.3400
		［B5］-［C11］	**0.2605**	**0.0593**	0.1359	0.1851	0.1302	0.2778	0.2710
		［B5］-［C12］	**0.6333**	**0.1441**	0.1609	0.2700	0.0877	0.2305	0.2508
Four-level AHP Model (1st Level) Weight Vector W_i					**0.1452**	**0.1684**	**0.2316**	**0.2023**	**0.2525**

4.5. Construction of membership function and Fuzzy value transformation matrix based on Fuzzy Model (2nd Level) key factors evaluation criteria

It is assumed that a comprehensive evaluation and prioritization of the 5 ideas to be proposed for approval and development.

The conclusions of the fuzzy evaluation of the Fuzzy Model (2nd Level) are given in Table 2.

Table. 2. Conclusions of the fuzzy evaluation of the Fuzzy Model (2nd Level)

Factors / Idea	Team communication skills	Soft Support from Top Management	Innovative Cultural Atmosphere	Project Team Building Up	Pre-development Proficiency	Product Launch Proficiency
Idea 1	Very Good	Excellent	Very Good	Good	Good	Excellent
Idea 2	Excellent	Very Good	Excellent	Very Good	Excellent	Good
Idea3	Very Good	Good	Good	Excellent	Very Good	Excellent
Idea 4	Good	Excellent	Excellent	Very Good	Good	Very Good
Idea 5	Excellent	Very Good	Good	Excellent	Excellent	Good

4.5.1 Construction of the Fuzzy Model (2nd Level) evaluation matrix

The following 1-5 point scale is adopted in this paper (Table 3).

Table. 3. 1-5 Point Scale

Qualitative Indicators	5-point Scale
Excellent	5
Very Good	4
Good	3
Fair	2
Poor	1

According to Chen & Hwang (1992) research results that approved by Springer Science and Business Media, membership function expression (5) and qualitative indicator conversion value per 1-5 point scale (Table 4) of the ideas evaluation conclusion generated by the Steering Committee are detailed as follows:

$$\mu_{M1}(x)=\begin{cases}1, & x=0\\ (0.3-x)/0.3, & 0\le x\le 0.3\end{cases}$$

$$\mu_{M2}(x)=\begin{cases}(x-0)/0.25, & 0\le x\le 0.3\\ (0.5-x)/0.25, & 0.25\le x\le 0.5\end{cases}$$

$$\mu_{M3}(x)=\begin{cases}(x-0.3)/0.2, & 0.3\le x\le 0.5\\ (0.7-x)/0.2, & 0.5\le x\le 0.7\end{cases} \quad (5)$$

$$\mu_{M4}(x)=\begin{cases}(x-0.5)/0.25, & 0.5\le x\le 0.75\\ (1.0-x)/0.25, & 0.75\le x\le 1.0\end{cases}$$

$$\mu_{M5}(x)=\begin{cases}(x-0.7)/0.3, & 0.7\le x\le 1.0\\ 1, & x=1\end{cases}$$

Table. 4. Qualitative Indicator Conversion Value per 1-5 Point Scale

Qualitative Indicator	5-point Scale	Fuzzy Conversion Values
Excellent	5	0.895
Very Good	4	0.695
Good	3	0.495
Fair	2	0.295
Poor	1	0.115

4.5.2 Transformed fuzzy values on the 5-point scale for the evaluation result generated with the Fuzzy Model (2nd Level) are tabularized as the following (Table 5):

Table. 5. Transformed Fuzzy Values on a 5-point Scale for the Fuzzy Model (2nd Level)

Factors / Idea	Team communication skills	Soft Support from Top Management	Innovative Cultural Atmosphere	Project Team Building Up	Pre-development Proficiency	Product Launch Proficiency
Idea 1	0.695	0.895	0.695	0.495	0.495	0.895
Idea 2	Idea	0.695	0.895	0.695	0.895	0.495
Idea 3	0.695	0.495	0.495	0.895	0.695	0.895
Idea 4	0.495	0.895	0.895	0.695	0.495	0.695
Idea 5	0.895	0.695	0.495	0.895	0.895	0.495

4.5.3 Normalized 5-point scale conversion matrix of the evaluation result generated with the Fuzzy Model (2nd Level):

$$R_i = \begin{bmatrix} 0.1891 & 0.2435 & 0.2000 & 0.1347 & 0.1424 & 0.2576 \\ 0.2435 & 0.1891 & 0.2576 & 0.1891 & 0.2576 & 0.1424 \\ 0.1891 & 0.1347 & 0.1424 & 0.2435 & 0.2000 & 0.2576 \\ 0.1347 & 0.2435 & 0.2576 & 0.1891 & 0.1424 & 0.2000 \\ 0.2435 & 0.1891 & 0.1424 & 0.2435 & 0.2576 & 0.1424 \end{bmatrix}$$

4.5.4 Eigenvectors of fuzzy integrated evaluation matrix of the AHP-Fuzzy hybrid model:

$$S_i = W_i \circ R_i = [0.2010,\ 0.1954,\ 0.1935,\ 0.2075,\ 0.2042,\ 0.1975]$$

4.6. Comprehensive scoring and ranking of the ideas based on AHP Fuzzy hybrid model

4.6.1 Comprehensive scoring

Idea 1:

$$T_1 = \frac{4\times0.2010 + 5\times0.1954 + 4\times0.1935 + 3\times0.2075 + 3\times0.2042 + 5\times0.1975}{0.2010 + 0.1954 + 0.1935 + 0.2075 + 0.2042 + 0.1975} = 3.984$$

Idea 2:

$$T_2 = \frac{5\times0.2010 + 4\times0.1954 + 5\times0.1935 + 4\times0.2075 + 5\times0.2042 + 3\times0.1975}{0.2010 + 0.1954 + 0.1935 + 0.2075 + 0.2042 + 0.1975} = 4.335$$

Idea 3:

$$T_3 = \frac{4\times0.2010 + 3\times0.1954 + 3\times0.1935 + 5\times0.2075 + 4\times0.2042 + 5\times0.1975}{0.2010 + 0.1954 + 0.1935 + 0.2075 + 0.2042 + 0.1975} = 4.013$$

Idea 4:

$$T_4 = \frac{3\times0.2010 + 5\times0.1954 + 5\times0.1935 + 4\times0.2075 + 3\times0.2042 + 4\times0.1975}{0.2010 + 0.1954 + 0.1935 + 0.2075 + 0.2042 + 0.1975} = 3.986$$

Idea 5:

$$T_5 = \frac{5\times0.2010 + 4\times0.1954 + 3\times0.1935 + 5\times0.2075 + 5\times0.2042 + 3\times0.1975}{0.2010 + 0.1954 + 0.1935 + 0.2075 + 0.2042 + 0.1975} = 4.185$$

4.6.2 Prioritization of the ideas (from highest to lowest)

Idea 2 ＞ Idea 5 ＞ Idea 3 ＞ Idea 4 ＞ Idea 1

5. Conclusions

This paper incorporates the two-level product idea evaluation results from the R&D Department and Steering Committee into the comprehensive evaluation, screening, and ranking through the Four-level AHP Model (1st Level)-Fuzzy Model (2nd Level) hybrid model and approach. Although the model and approach are comprehensive, rigorous, and practical, it also features some limitations:

1) Whether building a hierarchical structure model or a pairwise comparison matrix, people's subjective judgments and choices demonstrate a greater impact on the evaluating, screening, ranking results, making the subjective components of the decision results still large.

2) The subjective weighting method cannot be separated from the assignment of experts. Therefore, some objective and non-objective reasons such as improper assignment of experts, deviation of subjective judgment from objective facts or deviation from changes in objective environment makes the evaluating, screening, ranking results unreliable.

3) For new idea development in the manufacturing industry or new product development without historical development data, the evaluating, screening and ranking relying on a multi-level hierarchy of subjective assignments still has the potential to "mis-Kill" and "mis-Go" product idea.

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