

# RESEARCH ON PRODUCT DESIGN STRATEGY BASED ON “DIVERGENCE-CONVERGENCE”

Peng Lu (Department of Industrial Design, Xi'an Academy of Fine Arts University, Xian, China; Department of Industrial Design, National Cheng Kung University, Tainan, Taiwan)  
 Shih-Wen Hsiao (Department of Industrial Design, National Cheng Kung University, Tainan, Taiwan)

Email: 417884366@qq.com

**Abstract**—Innovation is the core driving force of design. The purpose of this study is to propose a creative design strategy based on "divergence-convergence", which aims to optimize the design behavior of designers or design teams in the product development phase. The proposed design strategy integrates the objectives tree method, function analysis method, finite structure method and morphological chart method in the design problem of desert tree-planting vehicle. Finally, the best solution is selected by fuzzy comprehensive evaluation. The results show that the proposed "divergence-convergence" design strategy provides a new design approach for designers, which is suitable for innovative design projects with high generality.

**Keywords**—design strategy; objectives tree method; function analysis method; finite structure method; morphological chart method; fuzzy comprehensive evaluation

## I. INTRODUCTION

The development of new products is a complex problem involving strategy, management, research and development, production, market, decision-making, science and technology, patent invention and market innovation, etc [1]. Because of the high competition and unstable market environment, the life cycle of products becomes shorter. Therefore, the development of new products should not only guarantee the quality and speed of production, but also improve the innovative value of products. Good design strategy helps to improve product competitiveness and creativity in the new product development phase. However, despite the widespread acceptance of this view, 40% of enterprises still adopt informal product development and design strategies [2]. A design strategy is a master plan and specific design behavior developed by a designer or team for a design project, including the techniques and methods used in each phase. Generally speaking, the design strategy is convergent, but it will be divergent and convergent at different stages of the design process [3]. Specifically, product design is regarded as a problem-solving activity, and “divergence” can expand

the search scope of solutions, so as to find more creative design ideas and new design needs [4]; On this basis, convergence is not only to find suitable sub-solutions, but also to evaluate the optimal design scheme from a large number of alternatives [5].

In this paper, an innovative desert tree planting vehicle is used as a design case to verify the effectiveness of the proposed design strategy. In the divergent stage, objectives tree method, functional analysis and finite structure method are used. In the transforming stage, specific design elements are implemented by morphological analysis. In the convergent stage, the optimal design scheme is obtained by fuzzy comprehensive evaluation.

## II. THEORETICAL BACKGROUND

### A. Determine the Product Design Goals

Desert tree planting vehicle is an innovative design project proposed in this paper. Its design objective is relatively vague and belongs to a design project of higher generality level. In the early stage of innovative product development and design, through market research, product analysis and customer consultation, the list of the main design objectives of the product you want to develop can be drawn up, and then all objectives can be distinguished according to the hierarchy, and subordinate objectives can be separated from the main target hierarchy, so as to better understand the relationship between subordinate levels, that is, the objectives tree method [3].

Defining the design goal is a key step in the design. Only by thoroughly understanding the design objectives, can we design a product that really meets the needs of the market. At the beginning of the design, designers usually can not grasp a very clear and complete set of design objectives, reasonable use of objectives tree method can clearly present all the design objectives, through the way of charts can show the relationship between different goals. Thus a clearer representation of the master-slave relationship between the design objectives. The concrete operation steps are as follows:

- Listing the design objectives through discussion, consultation and research drawing the secondary function block diagram.
- Grouping the objectives according to the high and low levels draw the boundary of the system.
- Drawing the target tree, showing the relationship between the objectives.

### B. Widening the System Boundary of Product Function

The function analysis method regards the function of the target product as a “black box” and transforms a certain “input” into the “output” of the target [3]. As shown in Fig.1. Therefore, the whole function of the product should be embodied in the black box as far as possible and its functional system boundary should be constantly broadened. Some scholars have applied the method of function analysis to the design of automatic packing machine [6] and fire engine [7]. It can be seen that this method is more suitable for the product design of flow water operation system, such as the equipment that packs the bulk carpet into bundles; It is also suitable for the design of household appliances, such as washing machine design, the input is dirty clothes, the output is clean clothes, the black box function is “loose stain - separating stain - removing moisture”, In order to widen the boundary of the system, the function of drying clothes and levelling clothes can be added to the function of black box.



Fig. 1. Function “Black Box”.

Therefore, in the initial stage of the design strategy, the function analysis method can be combined with the objective tree analysis method, so as to widen the system boundary of the product as much as possible and play the role of divergent thinking on the basis of defining the design objective. The specific steps are as follows:

- Based on "input" and "output" to define the "black box" of the overall function, broaden the boundaries of the system as far as possible.
- Decompose the overall function into a series of necessary secondary functions.
- Drawing the secondary function block diagram.
- Draw the boundary of the system.
- Find the appropriate elements to realize the correlation between the secondary functions.

### C. Getting More Product Modeling

“function determining form” or “form following function” is the basic principle of product modeling design. The products with the same main function will produce different shapes due to the difference of their

secondary functions. For example, the main function of the roller is to smooth the asphalt pavement, and the secondary function unit can be decomposed into wheels, engines and cockpits. The layout of the three units can be divided into one layer, two layers or three layers. On the premise of satisfying the main functions, the difference in spatial layout will result in a variety of modeling schemes. On the basis of defining product design objectives and functional system boundaries, the finite structure method can limit the secondary functions of products to a certain number, and change the configuration and spatial layout to obtain more possibilities of modeling [8]. Therefore, in the transformation stage of design strategy, the abstract design concepts can be further concretized through the rational thinking of shape through the finite structure analysis method (FSM).

The operation steps of FSM are as follows:

- Identify the main functions of the target product.
- The main function is the combination of several secondary functions, and it is limited to a certain number.
- The basic structure of the limited secondary functions is expanded in three variables.
- While developing the diversification of forms, the main functions that conform to the original design objectives of products are also considered.
- Choose the best feasible scheme

### D. Establishing Morphological Charts of Target Products

The conceptual design produced in the divergence stage is not concrete enough. On the basis of the spatial layout analysis of the design concept, the conceptual design can be transformed into reality by using the morphological chart method. The morphological chart method, which was proposed by Swiss astronomer Fritz Zwicky in 1948 [9], is also called shape synthesis method, morphological matrix method or chessboard method. It has been widely used in various fields, such as design engineering [10], manufacturing engineering [11], industrial engineering [12] and ergonomics [13]. Morphological chart method is a systematic method to analyze all possible forms of product. Its characteristic is that it can deal with the details of the problem objectively, grasp the problem more accurately and make a comprehensive analysis [14]. The purpose of the transformation phase is to further implement the conceptual design, and the morphological analysis method generates a solution matrix on the basis of the functional and structural analysis. Then the concept of design can be transformed into a more creative and more specific design scheme by re-composition, and finally presented more intuitively in the form of a graph.

Specific steps are as follows:

- List the functional characteristics after the product has been disassembled.
- According to the functions and features, list the methods that can be efficacious.
- Make a form for the possible secondary solutions.
- Combine the options and choose the optimal solution.

E. Fuzzy Comprehensive Evaluation

Because the same thing has many attributes and is influenced by many factors, in the process of evaluating things, it is necessary to comprehensively consider and evaluate many related factors, that is, comprehensive evaluation. If fuzzy factors are involved in the process of evaluation, it is called fuzzy comprehensive evaluation [15]. Some scholars have applied fuzzy comprehensive evaluation method to the design of old shopping cart [16] and mechanical products [17], and proved that fuzzy comprehensive evaluation is an objective and effective decision-making method. In the stage of convergence, fuzzy comprehensive evaluation is adopted to make decision-making, which avoids the defect of designers judging multiple design schemes only on the basis of individual experience and aesthetic intuition, and ensures that the whole design strategy is more scientific.

Fuzzy comprehensive evaluation includes five steps: establishing factor set, establishing weight set, establishing evaluation set, single factor fuzzy evaluation and fuzzy comprehensive evaluation [18]. The following are listed:

- 1) Establish factor set: Factor set is a common set of factors that affect the object of evaluation, which is usually expressed by  $U$ .

That is,  $U = \{u_1, u_2, \dots, u_m\}$ ,  $u_i (i = 1, 2, \dots, m)$  represents the influencing factors.

- 2) Establish weight set: In order to reflect the importance of each factor, each factor  $u_i$  is given a corresponding weight  $a_i (i = 1, 2, \dots, m)$ . The set  $A = (a_1, a_2, \dots, a_m)$  composed of each weight is called the factor weight set, in which  $a_i$  should be satisfied (1).

$$\sum_{i=1}^n a_i = 1, a_i \geq 0, (i = 1, 2, 3, \dots, n) \quad (1)$$

- 3) Establish evaluation set: The evaluation set is a set of all kinds of evaluation results that the judge may make on the object of judgment. It is usually expressed by  $V$ , that is  $V = \{V_1, V_2, \dots, V_n\}$ , and  $V_i (i = 1, 2, \dots, n)$  represents all kinds of possible total judgement results. The purpose of fuzzy comprehensive evaluation is to obtain the best

evaluation result from the evaluation set on the basis of comprehensive consideration of all the influencing factors.

- 4) Single factor fuzzy evaluation: A single factor fuzzy evaluation system evaluates single factors to determine the membership of an evaluation object to an evaluation set. The evaluation object is evaluated as the No.  $i$  factor  $u_i$  in the factor set, and the membership of No.  $j$  factor  $V_j$  in the evaluation set is  $r_{ij}$ , so the evaluation result of No.  $i$  factor  $u_i$  can be expressed as:

$$R_i = \frac{r_{i1}}{V_1} + \frac{r_{i2}}{V_2} + \dots + \frac{r_{in}}{V_n} \quad (2)$$

Where  $R_i$  is called single factor evaluation set. As a fuzzy subset, it can be expressed as  $R_i = (r_{i1}, r_{i2}, \dots, r_{in})$ . Similarly, the single factor evaluation set for each factor is as follows:

$$\begin{aligned} R_1 &= (r_{11}, r_{12}, \dots, r_{1n}) \\ R_2 &= (r_{21}, r_{22}, \dots, r_{2n}) \\ &\dots \\ R_m &= (r_{m1}, r_{m2}, \dots, r_{mn}) \end{aligned} \quad (3)$$

The memberships of each single factor evaluation set constitute a fuzzy matrix, As shown in (4)

$$R = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_i \\ \vdots \\ R_n \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1j} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2j} & \dots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i1} & r_{i2} & \dots & r_{ij} & \dots & r_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \dots & r_{nj} & \dots & r_{nm} \end{bmatrix} \quad (4)$$

- 5) fuzzy comprehensive evaluation: Single factor evaluation only reflects the influence of one factor on the object of evaluation. If the influence of all factors can be considered, the correct evaluation result can be obtained, so the fuzzy comprehensive evaluation set  $B$  can be expressed as shown in (5).

$$B = A \bullet R = [b_1, b_2, \dots, b_j, \dots, b_m] \quad (5)$$

In the above formula, the symbol “ $\bullet$ ” represents fuzzy composition.  $b_j$  is called the fuzzy comprehensive evaluation index, which is referred to as the evaluation index for short. In this study, we will use the composition  $M(\wedge, \vee)$  to work out evaluation result, the models are as follows:

$$b_j = \bigvee_{i=1}^m (a_i \wedge r_{ij}), j = 1, 2, \dots, n \quad (6)$$

Where “ $\vee$ ” and “ $\wedge$ ” represent big-choosing or small-choosing, respectively.

### III. CASE DESIGN

The design outline of this study is to design an innovative desert tree planting vehicle. Firstly, the target product is determined, the relevant data are collected and classified, and the discussion is carried out in the way of focus group. In the proposed design strategy, the objectives tree method is used in the divergence stage to identify the design objectives of the product, and then the potential "black box" function of the desert tree planting vehicle is analyzed. The finite structure method is used to analyze the spatial layout of the desert tree planting vehicle. In the transforming stage, the solution space can be generated by means of morphological chart method. On the one hand, the concept of design generated in the divergent phase can be specified, and on the other hand, the search range of the design scheme can be further expanded. In the convergent stage, the fuzzy comprehensive evaluation method is used to evaluate all the alternative design schemes, and finally the optimal design scheme is determined. The specific design process is shown in Fig. 2.

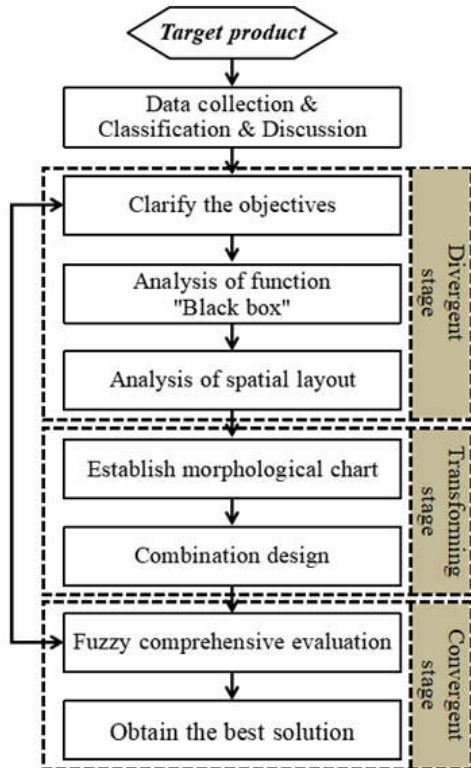


Fig. 2. Research flow chart.

#### A. Divergent stage of the design strategy

Firstly, the design goal of desert tree planting vehicle is defined. Through the objectives tree method, the design objectives of the desert tree planting vehicle can be comprehensively considered, and the hierarchical relationship between the design objectives can be clarified. Finally, three main design objectives are determined, including high efficiency, good operability and high safety. The detailed objectives tree method frame diagram is shown in Fig. 3, where top-down is "how" and bottom-up is "why". In order to facilitate the evaluation of convergent stage, all design objectives are divided into two levels. The first level includes efficiency, operability and safety. The second level includes large storage capacity, rapid planting speed, easy replacement of saplings, reasonable body structure, not easy to mistake, sand prevention and good heat insulation. Based on the analysis of objectives tree method, the function system of the desert tree planting vehicle is further analyzed. The function "black box" of the desert tree planting vehicle is transformed into "open box" by using the function analysis method. According to the different boundaries of the required functional systems, the functional systems of the desert tree growers can be divided into three types, including simple, traditional and complicated. The detailed description is shown in Fig. 4. Then, FSM is used to analyze the shape of desert tree planting vehicle, which can ensure the idealization of its shape. Specifically, its main function system is divided into five sub-function units, which are driving unit, power unit, storage unit, work unit and brace unit, and expressed in different colors. Finally, four design concepts are developed, as shown in Fig. 5. The similarities and differences between the four design concepts are as follows:

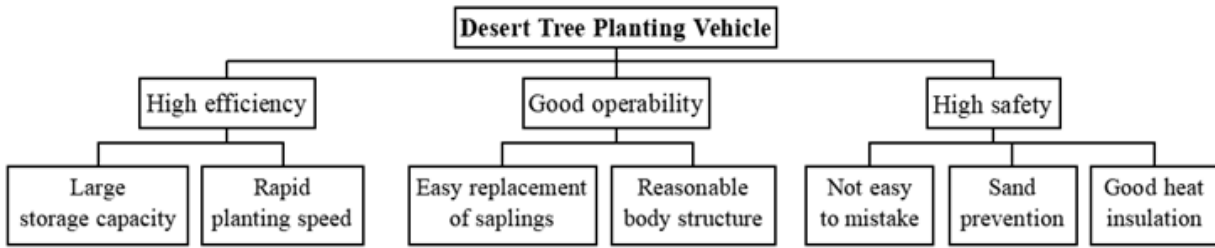


Fig. 3. Objectives tree analysis.

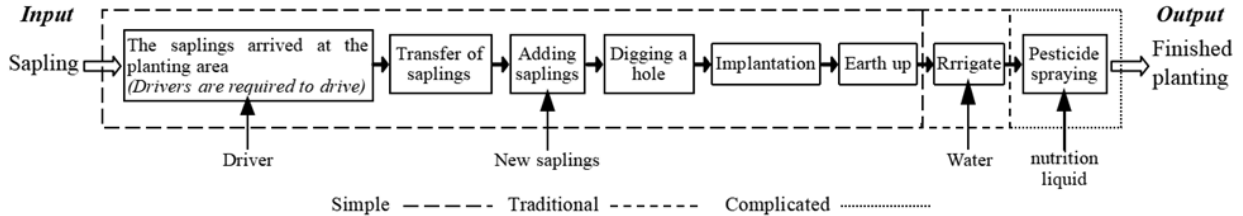


Fig. 4. The function analysis of desert planting vehicle.

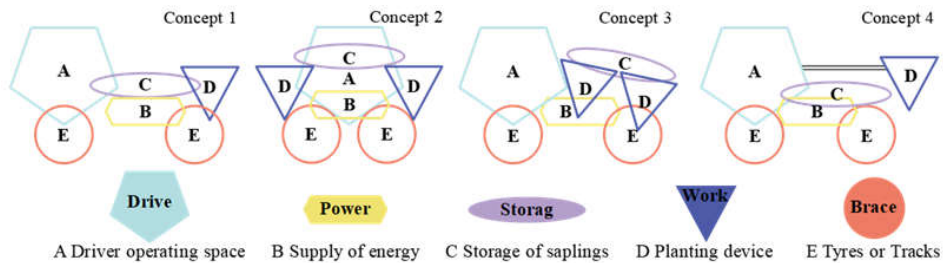


Fig. 5. Spatial layout analysis of desert planting cart.

- The storage unit C and the working unit D of Design Concept 2 and Design Concept 3 are integrated.
- Storage unit C and work unit D of design concept 1 and 4 are independent of each other.
- Design Concept 2 has a working unit D on both sides of the car body, which can improve the planting efficiency to a certain extent.
- Design Concept 3 has two working units D, which can increase the number of saplings carried.
- Unit D of Design Concept 4 is suspended external, thus having a larger storage unit C.

TABLE II. Morphological Chart for Idea 1

	Type 1	Type 2	Type 3	Type 3	Type 5
Drive	D1	D2	D3	D4	D5
Power	P1	P2	P3	P4	
Storag	S1	S2			
Work	W1	W2	W3	W4	W5
Brace	Z1	Z2	Z3		

TABLE I. Morphological Chart of Desert Planting

Sub-function	Type 1	Type 2	Type 3	Type 4	Type 5
Drive (D)					
Power (P)	Fuel oil	Solar energy	Electric energy	Hybrid energy	
Storage (S)	Separate existence	All-in-one			
Work (W)					
Brace (B)					

TABLE III. Morphological Chart For Idea 2

	Type 1	Type 2	Type 3	Type 3	Type 5
Drive	D1	D2	D3	D4	D5
Power	P1	P2	P3	P4	
Storag	S1	S2			
Work	W1	W2	W3	W4	W5
Brace	Z1	Z2	Z3		

B. Transforming stage of the design strategy

In the transforming stage, the design concepts generated in the divergence stage are further concretized. Firstly, the main functions of desert tree planting vehicle are dismantled into five secondary functions, and then morphological charts are established according to the way each secondary function can achieve, as shown in Table I. Theoretically, more than 600 conceptual design schemes can be produced. According to the objectives tree analysis, the function "black box" analysis and the divergent thinking on the spatial layout of the desert tree planting vehicle, three alternatives were developed. The detailed expression is shown in Tables II-IV. The detailed design of the rendering effect is shown in fig. 6.

TABLE IV. Morphological Chart for Idea 3

	Type 1	Type 2	Type 3	Type 3	Type 5
Drive	D1	D2	D3	D4	D5
Power	P1	P2	P3	P4	
Storag	S1	S2			
Work	W1	W2	W3	W4	W5
Brace	Z1	Z2	Z3		



Fig. 6. The alternative solutions of desert planting vehicle

C. Convergent stage of the design strategy

The convergent stage is the final stage of the design strategy proposed in this paper. In this stage, fuzzy comprehensive evaluation is used to select the best design scheme among the three alternatives.

Establish factor set: The evaluation items for level 1 are efficiency, operability, and safety, so the factor set of level 1 can be expressed as:

$$U = \{Efficiency(u_{11}), Operability(u_{12}), Safety(u_{13})\}$$

The evaluation items of level 2 are storage capacity, planting speed, the degree of difficulty of the replacement of saplings, the rationality of car body structure, the inclusiveness of operation errors, the sand prevention performance and heat-shielding performance. Therefore, the factor set of level 2 can be expressed as follows:

$$U = \{Storage\ capacity(u_{21}), Planting\ speed(u_{22}), Degree\ of\ difficulty\ of\ replacement(u_{23}), Rationality\ of\ structure(u_{24}), Inclusiveness\ of\ operation\ errors(u_{25}), Sand\ prevention\ performance(u_{26}), Heat\ -\ shielding\ performance(u_{27})\}$$

Establish weight set: The weight of level 1 was determined by expert questionnaire survey. There were 12 subjects, including agricultural machinery designers and industrial design teachers in colleges. After calculating the questionnaire data, the weight set of level 1 can be expressed as follows:

$$A = \frac{a_{11}}{u_{11}} + \frac{a_{12}}{u_{12}} + \frac{a_{13}}{u_{13}} = \frac{0.34}{Efficiency} + \frac{0.32}{Operability} + \frac{0.34}{Safety} = (0.34, 0.32, 0.34)$$

The weights of level 2 are divided into three groups, which are also obtained by questionnaire. The

questionnaire was made by Likert Five-Point Scale. Five grades of the scale included "Very unsuitable (0)", "Unsuitable (0.25)", "Ordinary (0.5)", "Suitable (0.75)" and "Very suitable (1)". A total of 50 valid questionnaires were collected. The subjects included designers, university teachers and students. After calculating the questionnaire data, the three sets of weights of level 2 can be expressed as follows:

$$A_{11} = \frac{a_{21}}{u_{21}} + \frac{a_{22}}{u_{22}} = \frac{0.54}{\text{Storage Capacity}} + \frac{0.46}{\text{Planting speed}} = (0.54, 0.46)$$

$$A_{12} = \frac{a_{23}}{u_{23}} + \frac{a_{24}}{u_{24}} = \frac{0.49}{\text{Degree of difficulty of replacement}} + \frac{0.51}{\text{Rationality of structure}} = (0.49, 0.51)$$

$$A_{13} = \frac{a_{25}}{u_{25}} + \frac{a_{26}}{u_{26}} + \frac{a_{27}}{u_{27}} = \frac{0.31}{\text{Inclusiveness of difficulty of replacement}} + \frac{0.36}{\text{Sand prevention performance}} + \frac{0.33}{\text{Heat-shielding performance}} = (0.31, 0.36, 0.33)$$

*Establish evaluation set: The evaluation set is divided into five levels, which can be expressed as*

$$V = \{0 \text{ Very unsuitable}, 0.25 \text{ Unsuitable}, 0.5 \text{ Ordinary}, 0.75 \text{ Suitable}, 1 \text{ Very suitable}\}$$

*Single factor fuzzy evaluation: In this stage, the evaluation items of level 2 are used as factor sets to evaluate the three alternative design schemes. According to the evaluation set, expert evaluation questionnaire is designed. A total of 20 participants are tested. The data after statistical analysis are shown in Table V.*

Therefore, the single factor evaluation set can be expressed as

$$R_1 = [0.54 \ 0.46] \circ \begin{bmatrix} 0.19 & 0.59 & 0.31 \\ 0.16 & 0.19 & 0.56 \end{bmatrix} = [0.18 \ 0.41 \ 0.43]$$

After normalization, the matrix is [0.18 0.40 0.42].

$$R_2 = [0.49 \ 0.51] \circ \begin{bmatrix} 0.28 & 0.38 & 0.22 \\ 0.19 & 0.31 & 0.19 \end{bmatrix} = [0.23 \ 0.34 \ 0.20]$$

After normalization, the matrix is [0.30 0.44 0.26].

$$R_3 = [0.31 \ 0.36 \ 0.33] \circ \begin{bmatrix} 0.19 & 0.28 & 0.28 \\ 0.41 & 0.25 & 0.28 \\ 0.25 & 0.22 & 0.28 \end{bmatrix} = [0.29 \ 0.25 \ 0.28]$$

After normalization, the matrix is [0.35 0.31 0.34].

Finally, the single factor evaluation matrix  $R$  of the desert tree planter is obtained as follows.

$$R = \begin{bmatrix} 0.18 & 0.40 & 0.42 \\ 0.30 & 0.44 & 0.26 \\ 0.35 & 0.31 & 0.34 \end{bmatrix}$$

*fuzzy comprehensive evaluation:* Calculated using (5), the results are as follows:

$$B = A \circ R = [0.34 \ 0.32 \ 0.34] \circ \begin{bmatrix} 0.18 & 0.40 & 0.42 \\ 0.30 & 0.44 & 0.26 \\ 0.35 & 0.31 & 0.34 \end{bmatrix} = [0.28 \ 0.38 \ 0.34]$$

The above vector shows that the priority is Idea 2, Idea 3 and Idea 1, so Idea 2 is the best design scheme in this study. Detailed design instructions are as follows:

Because of the harsh environment and low efficiency of traditional artificial planting, it is necessary to design a desert tree planting vehicle. The design features of this case are as follows:

- a) There is a device for storing sapling alone, so that sufficient quantities of saplings can be carried.
- b) Those saplings in the storage device can be automatically transferred to the working unit, thereby improving the planting speed.

TABLE V. Results of Questionnaire Statistics

The factor set of level 2	Code	Weight	The evaluation of alternatives		
			Idea 1	Idea 2	Idea 3
Storage capacity	W11	0.54	0.19	0.59	0.31
Planting speed	W12	0.46	0.16	0.19	0.56
Degree of difficulty of replacement	W21	0.49	0.28	0.38	0.22
Rationality of structure	W22	0.51	0.19	0.31	0.19
Inclusiveness of operation errors	W31	0.31	0.19	0.28	0.28
Sand prevention performance	W32	0.36	0.41	0.25	0.28
Heat-shielding performance	W33	0.33	0.25	0.22	0.28

- c) The working unit has the functions of turning over, planting, soil cultivation and irrigation, so the system operation process can improve the planting efficiency and ensure the survival rate of saplings.

- d) The overall concise shape can defend against wind and sand, and shorten the manufacturing process, thus reducing the manufacturing cost.

#### IV. DISCUSSION AND CONCLUSIONS

In this paper, a design strategy based on "divergence-convergence" is proposed for the development of new products, which is divided into three stages, including divergent stage, transforming stage and convergent stage. Each stage uses different design methods to achieve the purpose of this stage. The divergent stage integrates the objectives tree method, the functional analysis method and the finite structure method to diverge the thinking, so as to expand the search scope of the design scheme; In the transforming stage, the design concept is further concretized by morphological chart method; In the convergent stage, the fuzzy comprehensive evaluation method is used to select the best design scheme among the three design schemes.

The design strategy proposed in this paper is suitable for the development of innovative products. Generally, the characteristics of innovative products are that their design outlines are more general, and there are not too many restrictive factors. Therefore, the use of the "divergence-convergence" design strategy mentioned in this paper can improve the creativity of products to a certain extent. This paper takes desert tree planting vehicle as a case study. From this study, it can be found that the functional analysis method is used to analyze the target product. On the one hand, the function "black box" of the target product can be transformed into "white box", on the other hand, the main function of the product can be disassembled into several secondary functional units, so as to facilitate the later shape design; The application of finite structure method is beneficial to the development of shaping and ensures rational shaping thinking. On this basis, combining with the morphological chart method, the efficiency of the shape design can be further improved; the factor set of fuzzy comprehensive evaluation is derived from the result of objectives tree method, which makes the evaluation result more rigorous and ensures that the selected design scheme meets the original design goal. In summary, the design strategy proposed in this paper can be used as a reference for designers or design teams in developing innovative products. The design strategy of "divergence-transformation-convergence" is conducive to improving the creativity and competitiveness of products, shortening the development cycle of products and reducing the development cost of new products.

#### ACKNOWLEDGMENT

The authors are grateful to the reviewers for their helpful comments.

#### REFERENCES

- [1] K.J. Chaturvedi, and Y.S. Rajan, "New product development: Challenges of globalisation," *International Journal of Technology Management*, vol. 19, pp. 788-805, July 2000.
- [2] A. Griffin, "A research on new product development practices: updating trends and benchmarking best practices," *Journal of Product Innovation Management*, vol. 14, pp. 429-458, June 1997.
- [3] N. Cross, *Engineering Design Methods*, 3rd ed., vol. 4, New York: John Wiley & Sons, 1994, pp. 182-195, 62-66, 78-81.
- [4] G. Goldschmidt, "Capturing indeterminism: representation in the design problem space," *Design Studies*, vol. 18, pp. 441-445, April 1997.
- [5] S.W. Hsiao, and J.R. Chou, "A creativity-based design process for innovative product design," *International Journal of Industrial Ergonomics*, vol. 34, pp. 421-443, May 2004.
- [6] F. Wang, Z.W. Wang, "Design of automatic packaging machine for PVC gusset plate based on functional analysis," *Packaging engineering*, pp. 208-213, September 2017.
- [7] Li, and Z.W. Cheng, "Design of a minitype firefighting truck based on function analysis," *Manufacturing Automation*, vol. 40, pp. 88-91, February 2018.
- [8] S.W. Hsiao, "Application research of integrating FSM, STM and DFA in faucet design," *Journal of the Chinese Institute of Industrial Engineers*, vol. 13, pp. 225-235, May 1996.
- [9] F. Zwicky, "Morphological astronomy," *The Observatory*, vol. 68, pp. 121-143, May 1948.
- [10] M. Belaziz, A Bouras, and J.M. Brun, "Morphological analysis for product design," *Computer Aided Design*, vol. 32, pp. 377-388, May 2000.
- [11] S.J. Luo, Y.T. Fu, and P. Korvenmaa, "A preliminary study of perceptual matching for the evaluation of beverage bottle design," *International Journal of Industrial Ergonomics*, vol. 42, pp. 219-232, February 2012.
- [12] C.C. Chang, J.C. Wu, "The underlying factors dominating categorical perception of product form of mobile phones," *International Journal of Industrial Ergonomics*, vol. 39, pp. 667-680, May 2009.
- [13] M.C. Chuang, and Y.C. Ma, "Expressing the expected product images in product design of micro-electronic products," *International Journal of Industrial Ergonomics*, vol. 27, pp. 233-245, April 2001.
- [14] S.C. Chen, H.A. Yen, and C.S. Hsieh, *Product form design theory and methods*, China: Tianjin University Press, 1994, pp. 52-54.
- [15] Q.M. Tian, "The result analysis of fuzzy comprehensive evaluation," *Journal of Dalian Fisheries College*, vol. 5, pp. 61-65, September 1990.



- [16] D.M. Yang, J.N. Zhang, and X.Y. Xu, "Design of elderly shopping cart based on fuzzy comprehensive evaluation method," *Journal of Machine Design*, vol. Ee, pp. 117-120, september 2016.
- [17] K.D. Liu, Q. Zhao, and S.L. Zhou, "Fuzzy comprehensive evaluation for conceptual design of mechanic product based on new membership conversion," *Journal of mechanical engineering*, vol. 45, pp. 162-166, December 2009.
- [18] [18] S.L. Chuen, *Application of fuzzy mathematics*. Scientific & Technical Publishing Co., Ltd., Taipei, 2001, pp. 143-168.