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Developing an ANP-QFD Approach for Balers' Appearance Design: A Case Study

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Abstract: *The appearance of products plays a crucial role in determining consumers' preferences and purchase intentions. However, there is sparse literature focusing on the modelling design or related approaches for agriculture machines. To address the issue, this article proposed an innovative design model integrating the Analytic Network Process (ANP) and Quality Function Deployment (QFD) to improve the appearance of a baler, coordinating customer requirements and engineering technical requirements in the design process. First, three customer requirements (CRs) and eight design requirements (DRs) were identified via several qualitative research methods, including literature review, market research and user interviews. Second, the integrated ANP-QFD model was employed to obtain the weights of DRs considering the inner relationship among them and was then compared with the results derived from a single QFD model. Finally, the theoretical findings in the present study were applied to the appearance design of a baler. The researcher then conducted a specific analysis on the aspects of shape, colour, material, and surface decoration. It can be derived that an integrated ANP-QFD model can overcome the shortcomings of the single QFD method and clarify the weight of demand indicators, providing valuable insights for different stakeholders with regard to balers' appearance design.*

Keywords: *Appearance design; Baler; ANP; QFD; Product development*

1. Introduction

A baler is a piece of farm machinery used to compress grass or straw crops, such as hay, cotton, flax straw, salt marsh hay or silage, etc. The employment of balers has been widely popular in agriculture and animal husbandry fields due to several merits, for example, ease of operation, high flexibility, low cost in transportation and storage, and low need for human labour. As a technical report demonstrated, straws will experience a huge change after being processed by balers. To be more specific, its density will increase by 10 times, storage space will reduce by 90%, and transportation costs will reduce by 70% [1]. In recent years, Chinese governmental authorities have launched a series of policies to address the air pollution and environmental deterioration issues caused by the incorrect disposal of straws. Hence, it is of high significance to concentrate on the development and design of new balers.

At present, the research on the baler mainly focuses on solving technical problems such as cutting, picking and baling in the working process. For instance, Liu et al. (2023) proposed an improvement design scheme for a stem-leaf vegetable baler, providing an optimal solution for various parameters, such as winding position, feeding amount, and baling speed [2]. Zhu et al. (2022) designed an automatic baling device for cotton stalks, and conducted an experiment that simulates the process of cotton stalk pretreatment, compression, and baling [3]. Shang et al. (2021) designed a corn stalk baler with an intelligent control system and remote monitoring function for field tests [4]. The results showed that the baler feeding success rate and baling counting accuracy were both as high as 98%. Guerrieri et al. (2019) tested the performance and technical parameters of the HD 1270 baler from the manufacturer "Cicoria Square Bales" based on a series of comparative experiments [5]. Most scholars strive to refine the technical parameters and functions of balers. However, there is sparse literature focusing on balers' appearance design. In effect, balers' appearance plays an essential role in determining enterprises' benefits and profits. The main reason is that a machine's appearance is associated with many costs in the production, processing, usage and maintenance process. On the other hand, appearances have a direct

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impact on customers' first impressions of a product, thereby determining customers' preferences and purchase intention of the product.

Based on the above illustration, this paper attempts to propose an integrated ANP-QFD model and applied it in a case study of baler appearance design. The innovative model can effectively clarify CRs and DRs of the baler appearance design, providing novel insights and guidance for design practices in related areas.

2. Literature Review

2.1. The Review of Baler

Nowadays, balers are widely applied in crop harvesting, integrating the process of picking, transmission, compression, and bundling. In the early stage, the baler was invented to compress and tie pastures. With the advancement of technology, various balers were developed to improve production efficiency and scope, including steam pressure balers, rope balers and hydraulic balers. Today, balers can pack and tie a variety of crops other than pastures, such as flax, peanut vines, alfalfa, etc. Around 1970, China began to study the technology, performance and technology of the imported balers.

The workflow of the baler mainly includes picking and feeding, screw conveying, compression moulding, and automatic strapping. Generally speaking, the core components of a baler are composed of five parts, including a picker, feeding system, baling chamber, wrapping film and unloading system. The external structure of a baler includes traction brackets, front guards, side doors, bottom guards, top supports, rotating rollers, bottom brackets, compression chamber guards, etc. The visual centre of the device contains several facets. The first one is the side door and top guard that wraps the main drive structure. The second one is the side guard and back guard that wraps the compression chamber. Thereby, the extraction of styling elements will concentrate on these modules.

2.2. ANP

ANP is a decision-making tool that adapts to the non-independent hierarchical structure, which is developed based on AHP [6]. Similar to AHP, ANP can transform individual qualitative judgment into quantitative analysis, but it considers more internal relationships between decision elements at different levels. The main steps in the ANP application process include: (1) establishing AHP elements (2) constructing an AHP super-matrix (3) performing pairwise comparisons (4) judging the results [7]. At present, ANP is used as an evaluation method in different disciplines such as product improvement [7], supply chain management [8], quality evaluation [9] and service innovation [10].

2.3. QFD

QFD, also known as the affinity graph method or tree graph method, is a systematic decision-making tool based on customer requirements. It was proposed by a Japanese scholar called Akao in 1967. The core construct of QFD is to build a house of quality [11]. In the conceptual design stage, the house of quality in the QFD method can transform customer requirements into technical and technological requirements for product production. In the field of design, QFD can provide guidance based on user requirements, so that the product's shape, function and other characteristics are more easily recognized and accepted by customers. In recent years, many researchers have applied the QFD method to product development processes in different fields, such as business management [12], product modelling design [13], and user experience optimization [14].

2.4. The Integrated ANP-QFD Model

QFD can convert users' requirements for products into technical requirements in actual production. However, the evaluation of design elements is accurate and objective. To overcome this drawback, we integrated an ANP approach into the present study. As discussed above, ANP can establish a super-matrix and conducts a series of correlation analysis to calculate the weight of decision elements. Therefore, the innovative model of the integrated ANP-QFD can make up for the defects of the single QFD method, and make the calculation results of the importance of the elements more accurate and objective. Figure 1 shows the difference between the single QFD model and the integrated ANP-QFD model. It can be seen that the innovation model not only considers the external correlation between DRs and CRs, but

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also takes into account their respective internal interactions when calculating the weights of decision elements [7] [10].

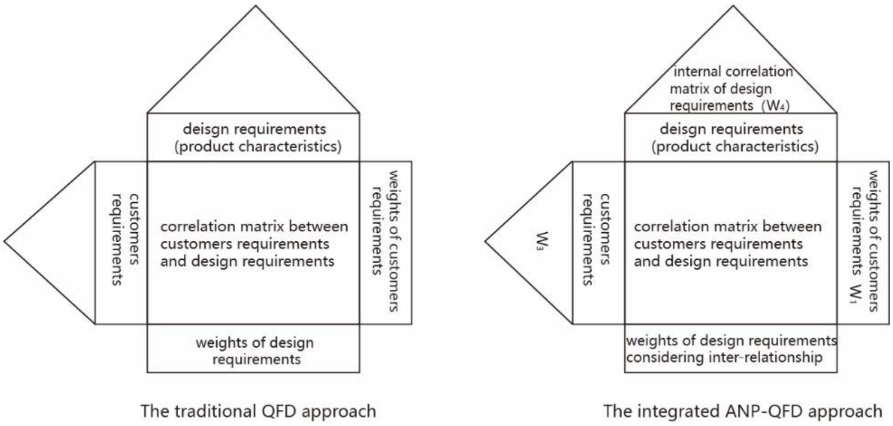

Figure 1: The traditional QFD model and the integrated ANP-QFD model (Adapted from Liu et al. (2021) [7]).

3. Methodology

The innovation model proposed in this paper includes the following 8 steps, which were adapted from previous literature [7] [8].

Step 1: Identified CRs and design requirements. Select research objects and obtain them through qualitative research methods such as market surveys, interviews, and literature research.

Step 2: Make a pairwise comparison for each CRs and identify the feature vector W_1, that is, the relative weights of user requirements.

Step 3: Make a pairwise comparison for DRs with respect to each CRs, and identify the feature vector W_2, that is, the correlation matrix between the user requirement and the design requirement.

Step 4: Make a pairwise comparison for CRs with respect to each CRs, and identify the feature vector W_3, that is, the internal correlation matrix of user requirements.

Step 5: Make a pairwise comparison for DRs with respect to each DRs, and establish the eigenvector W_4, that is, the internal correlation degree matrix of the design requirement.

Step 6: Calculate the interdependent priorities of CRs based on the Formula (1) "$W_C = W_3*W_1$".

Step 7: Calculate the interdependent priorities of DRs by utilizing Formula (2) "$W_A = W_4*W_2$".

Step 8: Determine the overall priorities of DRs by employing Formula (3) "$W_{ANP}=W_A*W_C$".

4. A Case Study: the Appearance Design of a Baler based on ANP-QFD Model

4.1. Identify CRs and DRs of balers' appearance design

Table 1: Customer requirements and design requirements.

Customer requirements	Design requirements
CR1 Practical value	DR1 High flexibility
CR2 Aesthetic value	DR2 Low cost
CR3 Innovation value	DR3 Safety
	DR4 Simplicity and elegance
	DR5 Visual Attraction
	D6 Corporate Image Recognition
	DR7 Sustainable Materials and Craftsmanship
	DR8 Modularization

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To begin with, the researcher searched relevant literature and picture with the keywords "agricultural machinery", "agricultural equipment", "balers" and "appearance design" to gain valuable materials. These materials were analyzed to generate themes for the subsequent user interview. During the interview, the researcher selected 8 experts with relevant knowledge backgrounds, including 3 designers, 3 design teachers, 1 PhD in design, and an engineer in agricultural machinery enterprises for the in-depth interview. After that, the researcher recorded the interview data set and analyzed them based on the thematic analysis method. Finally, a series of CRs and DRs of Balers appearance design were identified, see Table 1.

A detailed description of each CR and DR is demonstrated as follows:

CR1 practical Value: it concerns the function and usefulness of a product, which can be illustrated from several facets: safety, reliability, easy operation and maintenance, conformation to ergonomics, etc. Practical value is associated with the profits and costs generated by a product.

CR2 aesthetic value: it can be reflected in the external attractiveness of a product. Generally, a beautiful product can make customers feel pleasure. Hence, this type of value can directly affect people's preferences towards a product and contribute to increasing sales.

CR3 innovation Value: it refers to innovative design thinking and concepts of a product, which can make customers a sense of technology and modernity.

DR1 high flexibility: In terms of baler appearance design, part of the casing of the machine should be easily disassembled and assembled in time to ensure that some components can operate normally during the working process. At the same time, the shell should not be too heavy to reduce activity resistance. It is because the compression chamber part of the device rotates considerably when unloading the bale.

DR2 low cost: designers should consider minimizing the total cost during the production process. It contains material procurement cost, mould opening cost, production process cost, surface decoration cost, maintenance cost, etc.

DR3 safety: The machine is safe and reliable during the operation or maintenance process, and the risk of accidents should be low.

DR4 simplicity and elegance: The appearance of the machine is simple and regular, with the volume and modernity of large-scale agricultural equipment.

DR5 Visual Attraction: The appearance of the machine has a strong visual impact, which can stand out among similar products. Hence, this attribute can increase customers' acceptance of a product.

DR6 Corporate Image Recognition: Products should reflect corporate characteristics and cultural genes in terms of colour, shape, surface treatment process and logo design, which help to enhance corporate image and influences.

DR7 Sustainable Materials and Craftsmanship: Designers should consider applying environmentally friendly materials and craftsmanship during the product manufacturing process, reflecting the concept of green design and sustainable design.

DR8 Modularization: A product formed by standardized components will be updated quickly, as most components can be flexibly reused between different similar models.

4.2. Calculate the Weights of CRs and DRs

The researchers then carried out a questionnaire survey to obtain respondents' assessments of CRs and DRs of baler appearance design. The questionnaire contains 5 parts: the first one is used to obtain the demographic characteristics of the respondents (such as age, gender, occupation, etc.), and the results of the remaining 4 parts were associated with the feature vectors W_1, W_2, W_3 and W_4, respectively. A nine-scale Likert Table was used for pairwise comparison in this study, and the scale was depicted in Table 2. The researchers distributed questionnaires on an online platform and finally collected 71 valid questionnaires. The results of the questionnaire survey were calculated, and the evaluation results of all the respondents were compared with each other as the mean value, and a correlation matrix was constructed. The SPSSAU software was used for data analysis and consistency tests, and to calculate the relative weights of CRs and DRs.

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Table 2: The scale of pairwise comparison.

Scale	Description
1	One matrix is similarly important as the other
3	One matrix is slightly more important than the other
5	One matrix is moderately more important than the other
7	One matrix is considerably more important than the other
9	One matrix is dramatically more important than the other
2,4,6,8	Mediating degrees between these mentioned above
The inverse of a scale	Reverse comparison (if the importance of one is 5 compared to the other, the inverse scale is 1/5)
0	One matrix has no relation with the other

According to the data analysis results, the feature vectors W_1, W_2, W_3, and W_4 can be calculated respectively, as shown in Table 3-7.

Table 3: Relative weights of each CR (W_1).

W_1	CR1	CR2	CR3	Weight
CR1	1	2	4	0.544
CR2	1/2	1	4	0.346
CR3	1/4	1/4	1	0.110

Table 4: Relative weights of DRs with respect to each CR (W_2).

W_2	CR1	CR2	CR3
DR1	0.268	0.050	0.083
DR2	0.262	0.045	0.061
DR3	0.210	0.039	0.050
DR4	0.062	0.255	0.081
DR5	0.056	0.314	0.068
DR6	0.044	0.164	0.073
DR7	0.035	0.076	0.288
DR8	0.063	0.057	0.296

Table 5: Relative weights of CRs with respect to each CR (W_3).

W_3	CR1	CR2	CR3
CR1	0.677	0.149	0.143
CR2	0.131	0.690	0.143
CR3	0.192	0.161	0.714

Table 6: The relative weight of DRs with respect to the DR1 "high flexibility" (W_4-DR1).

W_4-CR1	DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8	Weight
DR1	1	0	0	4	0	0	0	3	0.623
DR2	0	0	0	0	0	0	0	0	0.000
DR3	0	0	0	0	0	0	0	0	0.000
DR4	1/4	0	0	1	0	0	0	1/2	0.137
DR5	0	0	0	0	0	0	0	0	0.000
DR6	0	0	0	0	0	0	0	0	0.000
DR7	0	0	0	0	0	0	0	0	0.000
DR8	1/3	0	0	2	0	0	0	1	0.240

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Table 7: Relative weights of DRs with respect to each DR (W_4).

W_4	DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8
DR1	0.623	0.116	0.333	0.000	0.000	0.000	0.000	0.261
DR2	0.000	0.550	0.000	0.000	0.000	0.000	0.000	0.106
DR3	0.000	0.000	0.667	0.000	0.000	0.000	0.000	0.000
DR4	0.137	0.224	0.000	0.667	0.301	0.119	0.000	0.000
DR5	0.000	0.000	0.000	0.333	0.484	0.243	0.000	0.000
DR6	0.000	0.000	0.000	0.000	0.143	0.528	0.000	0.000
DR7	0.000	0.000	0.000	0.000	0.072	0.110	0.750	0.000
DR8	0.240	0.110	0.000	0.000	0.000	0.000	0.250	0.633

In addition, all pairwise comparison results passed the consistency test (CI value less than 0.1), indicating that the analysis results are reasonable and reliable. According to formulas 1 and 2, W_C and W_A can be calculated as

$$W_C=\begin{bmatrix}0.435\\0.326\\0.239\end{bmatrix}$$

$$W_A=\begin{bmatrix}0.284 & 0.064 & 0.153\\0.151 & 0.031 & 0.065\\0.140 & 0.026 & 0.034\\0.159 & 0.301 & 0.108\\0.058 & 0.277 & 0.077\\0.031 & 0.131 & 0.048\\0.035 & 0.098 & 0.229\\0.142 & 0.072 & 0.286\end{bmatrix}$$

Finally, W_{ANP} is calculated according to formula 3, which is the overall priority of DRs considering the internal influence relationship. The weights of the CRs are: CR1 practical value (0.544), CR2 aesthetic value (0.346), CR3 innovation value (0.110). The weights of the DRs are as follows: DR4 simplicity and elegance (0.193), DR1 high flexibility (0.181), DR8 modular (0.153), DR5 visual impact (0.134), DR7 sustainable materials and processes (0.102), DR2 high safety factor (0.091), DR3 low cost (0.078), DR6 corporate image recognition (0.068).

$$W_{ANP}=\begin{bmatrix}0.181\\0.091\\0.078\\0.193\\0.134\\0.068\\0.102\\0.153\end{bmatrix}=\begin{bmatrix}DR1\\DR2\\DR3\\DR4\\DR5\\DR6\\DR7\\DR8\end{bmatrix}$$

4.3. The Validation Design

To better appreciate the advantages of the integrated ANP-QFD model, the researcher conducted another survey to calculate the weights of CRs and DRs by using a single QFD method. The researcher distributed the questionnaire to the same respondents and collect the results to ensure the validity of the results. The QFD method is used to first establish a correlation matrix to describe the strength of the correlation between DRs and CRs, where 0, 1, 3, and 5 represent "irrelevant", "weakly relevant", "moderately relevant" and "strongly relevant" respectively.

The results obtained from the single QFD method and the integrated ANP-QFD method were compared, see Table 8 and Figure 2. According to the results derived from the single QFD method, although DR1 and DR4 are still in the top two, the ranking and weight of other DRs have changed greatly, especially for those DRs reflecting innovation value. At the same time, the weights of DR2, DR3, DR4, and DR5 are not distinguishable. According to the results derived from the integrated ANP-QFD method, DR8 is significantly more important because of its interaction with other design metrics, including DR1, DR2, and DR7. Therefore, the integrated ANP-QFD approach enables researchers to gain more subjective and valid results in terms of relative weights of CRs and DRs, as it considers the internal influential relationships among these factors.

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Table 8: Comparison of weight ranking obtained by the single QFD method and the integrated ANP-QFD method.

DRs	The traditional QFD method	The integrated ANP-QFD method
DR1	1	2
DR2	4	7
DR3	3	6
DR4	2	1
DR5	5	4
DR6	6	8
DR7	8	5
DR8	7	3

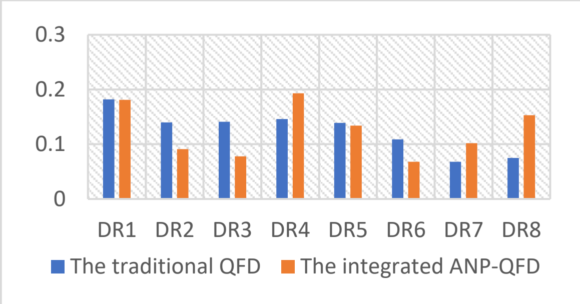

Figure 2: Comparison of weights obtained by single QFD method and ensemble ANP-QFD method.

5. The Design Practice of a Baler's Appearance

Based on the weights and rankings of CRs and DRs, the researcher proposed design strategies and schemes aiming to improve the original balers' appearance. As demonstrated in Figure 3, the overall cover of the baler is made of FRP material, the shape is a smooth curve shape, and the colour is grass green. When the machine unloads the bale, the back part needs to turn up and down, and the side cover and the top cover need to be disassembled frequently. Therefore, balers' appearance design should have the characteristics of lightweight and high flexibility (DR1). It is more suitable to use light-weight, high-strength and easy-to-form FRP. The material generally adopts the hand lay-up process, mainly using wet resin moulding. This type of moulding process is cost-effective and meets DR3 (low cost). In terms of shape, the large side guard is divided into three parts to make it easy for manual assembly. It maintains a streamlined style, making the overall shape appear simplicity and elegancy (DR4) and visually attractive (DR5). A warning sign is added beside the position that needs to be touched frequently, and this kind of design can attract workers' attention and ensure a safe operation (DR3) for the machine. At the same time, the divided shape is light, which can lower the risk of operation when disassembling. The shape can be divided into several sub-modules, and some can be applied and substituted for other series of products. This type of design can meet the DR8 (modularization). Moreover, the baler's colour is derived from the similar products in the company, as well as the logo of the company, because this design can form the serialized product characteristics and continuing corporate cultural gene (DR6). In addition, the designer placed a sticker that can present the model and company's name on the side panels. It is worth noting that DR7 is not reflected in this design. The main reason is that the design scheme is used for actual production.

Figure 3: Design scheme of a baler's appearance.

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6. Conclusion

This paper explores the application of an innovative approach integrating ANP-QFD in the appearance design of balers. The model combines the advantages of ANP and QFD theories, which can effectively determine the weights of CRs and DRs in product development. On the basis of theoretical findings, a design scheme for a round baler was proposed. This design scheme satisfies the user's needs for practical value, aesthetic value and innovative value in baler appearance design. Therefore, this research can directly hit the pain points of users, improve the efficiency of product innovation design, and provide new ideas for the application of relevant design theories and design practices. However, this approach is mostly used in the fields of supply chain management [8] and system development [10] and is less explored in design-related aspects. Therefore, future research is recommended to expand the application of this approach in interaction design and service design fields.

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