Design of Car Child Safety Seat Based on Analytic Hierarchy Process

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Abstract

This paper analyzes the existing problems of car children's safety seats at present, looks for the space of product design innovation, and designs products that meet the needs of private car owners and meet the trend of the times from the angle of shape and function. Through the analysis of the characteristics of common brands of child safety seats in the market, the design elements are found and the measures layer of product design is constructed; By searching the existing literature on car child safety seats and questionnaire survey, the characteristic index of products is obtained, and the design criterion layer is constructed Analytic hierarchy process (AHP) is applied to calculate the weights of indexes at different levels and sort them to determine the design opportunities of products. Through an example of car child safety seat design, it is proved that AHP can quickly obtain the demand points of product upgrading and innovation, determine the design opportunities of products, help designers to improve product design efficiency, and promote the healthy development of car child safety seat industry.

Keywords

Car child safety seat; Analytic hierarchy process; Innovative design; Children's ride safety

Introduction

With the rapid development of the car industry and the opening of the "two-child policy", the public has paid more attention to the safety of children riding cars, and the market of children's safety seats in China has increased year by year. The National Highway Traffic Safety Administration (NHTSA) obtained relevant data through a dummy collision simulation experiment and found that when a vehicle has a traffic accident, children using child safety seats will greatly reduce the death rate in the accident (Wang & Huang, 2020). Child safety seat is an important tool to ensure the safety of children. In real life, there are still private car owners who will not take the initiative to

install child safety seat, mainly because the existing child seat is inconvenient to install and disassemble; The use of child seats is limited to cars, and the frequency of use is low; The price is higher than that of ordinary seats (Marziyeh Moradi, Narges Khanjini, Amir Reza Nabipour, 2019). Compared with China, the research on child safety seat in foreign countries is earlier, and the research enterprises of the child safety seat in China are still in the growth period (Liao Haiyong, Zhang Tian, Liu Shefang, 2020), and many design methods and concepts have not been fully cited, so the products are positioned to obtain a larger market by lowering the cost, which makes the car child industry fall into the vicious competition and affects the iterative upgrading of products. Therefore, this paper adopts AHP to analyze the innovative design process of child safety seats, find the design elements that can be improved, determine the design opportunities of products, and help designers to design and develop child safety seats better.

Brief Introduction of Analytic Hierarchy Process

Concept of Analytic Hierarchy Process

Analytic hierarchy process (AHP) is a multi-factor decision analysis method put forward by Thomas L. Saaty (1971), an American logistics scientist, which combines qualitative and quantitative analysis. The main method is to divide the decision into progressive levels, list the constituent factors in different levels, build a judgment matrix by comparing the importance of every two, and calculate the synthetic weight of each plan to the overall goal, thus determining the importance of each plan, which can help the decision-makers to make decisions quickly and accurately under the complex structure of judgment factors.

Basic Principles and Steps of Analytic Hierarchy Process

The practical application of the Analytic Hierarchy Process is divided into four steps: First, build a progressive structure model, including target layer, criterion layer, and measure layer. Second, construct all judgment matrixes at all levels. Thirdly, rank order and consistency check, by calculating the judgment matrix, we can get the weight of each level factor to the upper-level goal. Fourthly, rank and consistency check, calculate the composite weight value of each factor in the measure layer to the importance of the total target in the target layer and determine the design opportunity.

Acquisition of innovative design elements of products

Analysis of the Present Situation of the Car Child Safety Seat Market

By analyzing the characteristics of car child safety seat products at home and abroad, it can be

known that the related industrial structure abroad is perfect, the design innovation is high, and the products are more humanized and intelligent. However, domestic car child safety seat products still have some problems, such as difficult disassembly, inconvenient storage, low comfort, and lack of innovation, as shown in Table 1.

Table 1. Similar products at home and abroad

Domestic children's car safety seat		Foreign children's car safety seats	
Product Brand	Product Features	Product Brand	Product Features
Goodbaby	For the whole age coverage of 0-6 years old, children's body curve design is emphasized, and the back protection is better. Five-point fixing, GBES material instantaneous energy absorption, and multi-gear angle adjustment create a comfortable and safe riding environment.	BRITAX (UK)	Rotate the base at 360 degrees for easy holding of children. A cradle-type holding cabin is convenient for sleeping children. ISOFIX system reduces the displacement caused by inertia and reduces the probability of dangerous situations.
Baby first	Emphasis should be placed on protecting children's vulnerable spine and cervical vertebrae, supporting their backs in reverse, and reducing the harm of inertia to children's upper body. The all-side wrapped cockpit provides closer protection against side impact.	STM (Germany)	The appearance is mainly based on cartoon characters, which makes children feel more intimate with products. A double airflow air circulation system ensures that children are dry and comfortable on the back and buttocks of the seat.
Welldon	The innovative hidden five-point buckle can be removed and hidden when children grow older and don't need it. A special rubber wing module is used to effectively absorb side-impact force. The reinforcing steel bar framework is injected integrally, which is safer and more stable.	GRACO (USA)	Support forward and backward ISOFIX installation, add a connecting belt, and stress is more uniform and stable. Can be disassembled into an independent height increasing pad to meet the sitting height requirements of children of different ages. The hook and loop and hidden buckle can be disassembled and assembled quickly.

Aibei	This safety seat pays more attention to the design that gives the baby more freedom, and the anti-skid and anti-strangling shoulder pad avoid the baby's injury caused by sliding. The outer layer of cloth cover is easy to disassemble and fold.	CHICCO (Italy)	The skeleton is made by the tight injection molding process, which makes the material density higher and more stable. U-shaped pillow design provides flank protection. The breathable fabric is tailored to fit the natural curvature of the seat, and the hip pressure can be released evenly.
Joie	The enhanced side impact energy absorbing device adds an airbag for children, and the stable triangular structure fixing mode ensures the stability of the seat. The integrally molded injection-molded steel skeleton can effectively resist shock, flame, and impact.	KIDDY (Germany)	The basket-type safety seat can realize a seamless connection with the baby carriage, and can be used as a safety seat in cars, and can be carried out by lifting it to the baby carriage when getting off the bus. The three-point safety belt is fixed for easy installation.
Beibei kaxi	This product is a folding safety seat, which is easy to install, disassemble and wash, convenient to store in the trunk, and saves space. Bright fabric colors and printed patterns give children a colorful activity space.	AFRICA (Japan)	The three-stage design of sleeping and lying in the chair should deal with children's different sitting modes, follow the abdominal breathing needs of young children and ensure the sleeping environment. Full-cover visual awning reduces the damage caused by sunlight to the baby.

Acquisition of Innovative Design Elements of Products

From the market environment and related scholars' research, we can find out the development trend of car child safety seats in recent years and thus obtain innovative design elements of products.

Firstly, lightweight products. In many traffic accidents, children don't take safety seats, which

causes unnecessary casualties. Many private car owners are reluctant to take the initiative to install car children's safety seats. One of the reasons is that the existing safety seats are bulky and heavy, which makes it inconvenient for car owners to take them (Grace Lee, Caitlin N. Pope, Ann Nwosu, et al., 2019). Lightweight design can improve the reluctance of private car owners to take the initiative to install child safety seats and reduce the casualties of children in accidents.

Secondly, enhance the aesthetics. The aesthetic design of safety seats is an important factor in product market competition. However, nowadays, the design of children's safety seats often determines the appearance design of products based on the aesthetics of adults, ignoring children's psychological needs and physiological behaviors.

Third, increase the applicable places. Many design manufacturers limit the design and positioning of child safety seats to cars, but the frequency of children traveling in private cars is low, and most of the time, child safety seats are idle. The possibility of space application of products can be increased by combinable design, which can effectively solve the problem that safety seats are idle for a long time.

Fourth, voice interaction. In the process of driving, children will be noisy when sitting alone in the back row. Car owners can comfort children by playing animation or children's stories through voice interaction, which can well solve the problem that children are bored or noisy when sitting alone in the back row (Guo & Yan, 2020).

Fifth, easy storage. When many car owners collect and store the car safety seats, they will have the problem that the seats cannot be folded and are not easy to store in the trunk, thus affecting the car owners' goodwill towards the products.

Product Characteristic Index Analysis

Safety

Safety is one of the important considerations in the design and production of children's products. Children's bones are more vulnerable to collision accidents than adults. As an important safety restraint system for children, car child safety seats play an important role in children's safety protection (Fan & Wang, 2020). Through the statistics of the relevant crash test results, the influencing factors of the anti-collision performance of the child safety seat are analyzed, to improve the safety restraint performance of the child safety seat by optimizing the design of the product functional structure, which plays an important role in ensuring the safety of children riding.

Emotional

Today's rapid development of production technology can meet the functional needs of children's products, but people still need more emotional design concepts to be integrated into product design for higher-level aesthetic and experience needs of products. The goal of emotional design is to take people as the center and take people's emotions as the design focus. Under the trend that modern parents pay more and more attention to the influence of products on children's psychological feelings, designers need to pay more attention to the interactive relationship between users and products, fully understand children's psychological feelings, and establish emotional ties between children and products, so that children can get a better product experience.

Availability

Children's control ability and cognitive ability are weaker than those of adults, so the use of children's products should be simplified and the operation should be simple and clear. Children's patience is limited, and complicated operation steps will reduce children's expectations of use, and even bring children a sense of rejection. In the innovative design of children's products, children's use psychology should be fully considered to make the products available (Wang, 2018).

Intelligent

Intelligentization is the trend of product design in the future. At present, most children's products are close to foreign products in shape, and today's technology is not fully utilized to realize product intellectualization. Through the study of children's psychology and physiology, we can understand children's psychological and emotional needs, and apply artificial intelligence technology to children's products, so that products can take care of children's emotions in simple human-computer interaction.

Modularization

Children's growth is a constantly changing process. Children's products have a short life cycle and diversified needs. Modular design methods can avoid the problem that children's products are idle after a certain number of years of use (Luo, 2014). At the same time, modular design can meet the needs of children's products for easy disassembly and storage, and expand the possibility of using products in different places.

Determine the Direction of Innovative Design with Analytic Hierarchy Process

Establish a Progressive Hierarchy Model

The ultimate goal of this paper is to realize the design innovation of car child safety seats. To achieve this goal, comprehensive elements involving multiple levels, multiple factors, and multiple indicators should be considered. As far as car child safety seats are concerned, combined with the current research trend of related attributes of child safety seats, five children's product characteristic indicators, namely safety, humanization, usability, intelligence, and modularization, are mainly considered as the influencing factors in the criterion layer. From the market situation and related literature analysis, five elements of the innovative design of products are obtained, which constitute the measure layer. Finally, a progressive hierarchical structure model is constructed, as shown in Figure 1.

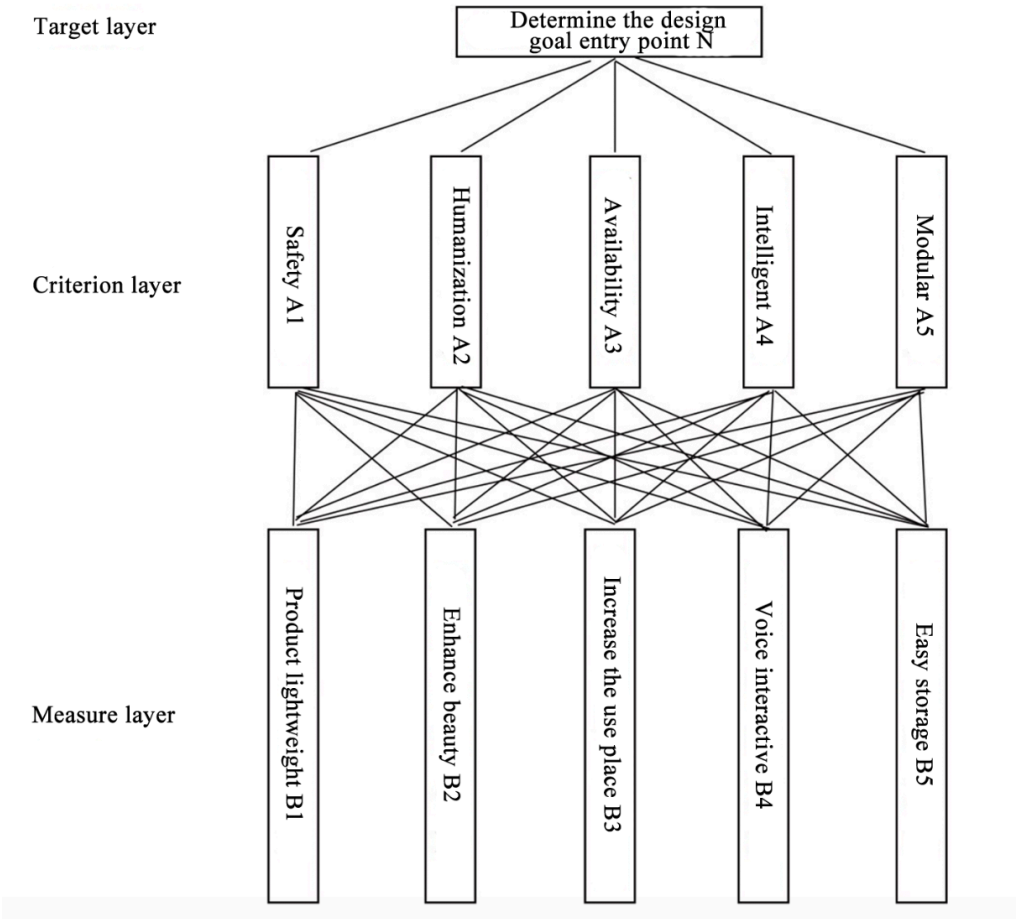


Figure 1. Progressive hierarchy model

Build Judgment Matrix at All Levels

For n judgment elements, the judgment matrix $A = (a_{ij})_{n\times n}$, refer to the numbers 1-9 and they're reciprocal as scales to define, see Table 2.

Table 2. Definition of Judgment Matrix Scale

Scale	Meaning
1	i and j have the same importance compared with each other
3	Compared with i and j, the former is slightly more important than the latter
5	Compared with i and j, the former is more important than the latter
7	Compared with i and j, the former is more important than the latter
9	Compared with i and j, the former is extremely important than the latter
2,4,6,8	Said the intermediate value of the adjacent judgment
reciprocal	If the ratio of the importance of factor i to factor j is a_{ij}, the ratio of factor j to factor i is satisfied $a_{ij}=1/a_{ij}$

To make the design scheme of car child safety seat more rational and evaluated, this study selected 5 safety seat designers, 3 business managers, and 40 private car owners with children in their families to compare the evaluation indexes, and obtained the judgment matrix as follows:

$$N=\begin{pmatrix} 1 & 3 & 1/4 & 1 & 1/2 \\ 1/3 & 1 & 1/3 & 1/4 & 1/2 \\ 4 & 3 & 1 & 2 & 3 \\ 1 & 4 & 1/2 & 1 & 1/2 \\ 2 & 2 & 1/3 & 2 & 1 \end{pmatrix}$$

$$A_1=\begin{pmatrix} 1 & 2 & 1/4 & 2 & 1 \\ 1/2 & 1 & 1/5 & 1 & 1/4 \\ 4 & 5 & 1 & 4 & 2 \\ 1/2 & 1 & 3 & 1 & 1/3 \\ 1 & 4 & 1/2 & 3 & 1 \end{pmatrix}$$

$$A_2=\begin{pmatrix} 1 & 3 & 1/4 & 1 & 1/2 \\ 1/3 & 1 & 1/4 & 1 & 1/2 \\ 4 & 4 & 1 & 4 & 2 \\ 1 & 1 & 1/4 & 1 & 1/2 \\ 2 & 2 & 2 & 2 & 1 \end{pmatrix}$$

$$A_3=\begin{pmatrix} 1 & 4 & 1/3 & 2 & 3 \\ 1/4 & 1 & 1/4 & 3 & 2 \\ 3 & 4 & 1 & 4 & 3 \\ 1/2 & 1/3 & 1/4 & 1 & 1/2 \\ 1/3 & 1/2 & 1/3 & 2 & 1 \end{pmatrix}$$

$$A_4=\begin{pmatrix} 1 & 2 & 3 & 1/2 & 2 \\ 3 & 1 & 2 & 1/2 & 3 \\ 1/3 & 1/2 & 1 & 1/4 & 1/3 \\ 2 & 2 & 4 & 1 & 2 \\ 1/2 & 1/3 & 1/3 & 1/2 & 1 \end{pmatrix}$$

$$A_5=\begin{pmatrix} 1 & 3 & 2 & 1 & 2 \\ 1/3 & 1 & 3 & 1 & 3 \\ 1/2 & 1/3 & 1 & 1/4 & 1 \\ 1 & 1 & 4 & 1 & 2 \\ 1/2 & 1/3 & 1 & 1/2 & 1 \end{pmatrix}$$

Hierarchical Single Sorting and Consistency Test

Through the above judgment matrix, the weight value of each index is the maximum eigenvalue of the judgment matrix λ_{max}, the eigenvector corresponding to max. The weight value of the judgment matrix is calculated by the geometric average method, and the comprehensive weight of each design factor index of the car child safety seat is obtained.

$$N = (0.1413 \quad 0.0731 \quad 0.4044 \quad 0.1719 \quad 0.2092)^T$$

$$A_1 = (0.1613 \quad 0.0771 \quad 0.4452 \quad 0.0854 \quad 0.2309)^T$$

$$A_2 = (0.1714 \quad 0.0875 \quad 0.4562 \quad 0.0949 \quad 0.1899)^T$$

$$A_3 = (0.2467 \quad 0.1337 \quad 0.4397 \quad 0.0750 \quad 0.1040)^T$$

$$A_4 = (0.2511 \quad 0.1903 \quad 0.0746 \quad 0.3510 \quad 0.1330)^T$$

$$A_5 = (0.2965 \quad 0.2247 \quad 0.0955 \quad 0.2734 \quad 0.1098)^T$$

After the judgment matrix is determined, the consistency test must be carried out to avoid the influence of subjective factors of the judges. Calculate the consistency index CI:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

In which: λ_{max} is the maximum eigenvalue of the judgment matrix. When calculating the judgment matrix, to determine whether the judgment matrix passes the consistency, the consistency index RI (in Table 3) is introduced to calculate whether the consistency ratio CR passes. The formula for calculating the consistency ratio CR is:

$$CR = \frac{CI}{RI}$$

If CR<0.1, it is considered that the judgment matrix passes the consistency test; otherwise, it is necessary to adjust the judgment matrix until it passes the consistency test.

Through calculation, the consistency test results of all judgment matrixes (in Table 4) are less than 0.1, which shows that all judgment matrixes have passed the consistency test.

Table 3. Average random consistency index

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.12	1.24	1.36	1.41	1.46

Table 4. Consistency ratio CR

	N	B1	B2	B3	B4	B5
CR	0.077	0.0212	0.0348	0.0959	0.0606	0.065

General Ranking of Levels and Determination of Design Innovation Opportunities

Calculate the composite weight of each layer element to the target layer, and the results are shown in Table 5.

Table 5. Composite Weight Results

project	B1	B2	B3	B4	B5
weight	0.2403	0.1511	0.3069	0.1669	0.1344

According to the total weight value of each innovative design element, it can be known that the relative order of innovative design elements of car child safety seat is: B3 to increase the use place; B1 product lightweight; B4 can interact with voice; B2 to enhance aesthetics; B5 is easy to store.

Design Practice of Car Child Safety Seat

According to the analysis results of innovative design elements of car child safety seat, combined with product design theory, combining research conclusions with design practice, a smart car child safety seat is designed for children aged 1-6 years. The safety seat is light in shape and easy to store, has the aesthetic feeling of modern design, can be assembled and adjusted to adapt to different use places, and at the same time, increases the auxiliary function of voice interaction.

Place of Use of Car Child Safety Seat

The main use places of car children's safety seats are divided into three situations: car use, outdoor use, and indoor use. In-car use focuses on the safety and comfort of children, mainly considering the stability of seat installation, the permeability of skin-sticking materials, and the package structure against collision and impact (Pollock Lindsay J, Barczyk Amanda N, Piper Karen, et al., 2019). When switching from in-car use to out-of-car use, it is necessary to fully consider the convenience of seat removal and the influence of weight and volume on the difficulty of carrying, and try to make it light and convenient to take (Binbing Huang, Shucaixu, Zhizheng Zhu, Xing Liu, Guoying Ma, 2019). Outdoor use should focus on the influence of the outdoor environment on children's comfort, and achieve the effects of sun protection, insect prevention, and shock absorption. When the safety seat is used indoors, it is often used as a crib. The sleeping posture and health of children

should be taken into account to realize the smooth transition from the seat to the bed.

Functional Requirements and Application of Intelligent Technology

By consulting the data, the safety function requirements of car child safety seats are obtained. Firstly, the restraint system requires that the seat should be equipped with at least one belt connected with the hook in the car so that the seat can be safely fixed on the seat. There are different installation directions for children with different weights. Children with less than 10KG weight should use back seats, children with 10KG-18KG weight should use forward seats, and children with more than 18KG weight should use children's booster pads and fasten their safety belts. Collision protection system requires that children must be in a protected state, the locking mechanism of the buckle cannot break or bounce off, and the displacement distance of children's head cannot be larger than 300 mm when the simulated object is subjected to forward throwing motion and impact force within a specified range (Reza Razaghi, Hasan Biglari, Mojtaba Hasani, et al., 2019). When designing the structural function of the safety seat, the forward and backward installation requirements of the seat and the anti-collision structure are fully considered, and the intelligent auxiliary function of voice interaction is provided on the premise of ensuring children's riding safety. When parents drive, children's songs can be played by voice control and the seat angle can be adjusted to meet children's dynamic physiological and emotional needs.

Design Scheme and Display of Child Safety Seat in Smart Car

The final design features are as follows.

First, use it in the car during driving to ensure the safety of children, as shown in fig. 2A. In this use state, it can ensure that the child is in a protected state when the car collides or rolls over during the ride. Parents can play children's songs through voice interaction function or adjust the angle of the safety seat to appease children sitting alone in the back row, and give children a comfortable and safe riding environment.

Second, matching cart chassis can be used in combination to realize the change of use from inside to outside, as shown in Figure 2B. In this use state, the sleeping child can be directly taken out of the car together with the safety seat, and the safety seat can be pushed away after being installed on the card base. On the one hand, it increases the possibility of using the safety seat, on the other hand, it improves the experience of parents.

Third, the modular design method is adopted to facilitate storage and use. The design style pays attention to simplicity and practicality, and the user can realize the conversion of usage mode by

simple disassembly and combination. When not in use, it can be quickly stored by folding, which is convenient for storage.



Figure 2. Car child safety seat solution

Conclusion

Through market research, literature collection and experts' and users' opinions, the hierarchical index of car children's safety seats is determined. Analytic Hierarchy Process (AHP) is applied to provide a quantitative decision-making basis for innovative design elements of car children's safety seats. And the conclusion of innovative design elements of car child safety seat is obtained, and it is transformed into a superior product whose modeling function meets the user needs and caters to the emotional needs of users. This design not only pays attention to ensuring the safety of children riding on the bus, but also can be used in combination with the supporting cart base to increase the possibility of using places, and at the same time increase the intelligent auxiliary function of voice interaction, to ensure the parents' care for children during driving and provide a comfortable and safe environment for children to grow up to the greatest extent.

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