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Research Article

Fuzzy Comprehensive Evaluation Model of Trapezoidal Fuzzy AHP Empowerment used in the Evaluation of Barrier-Free Packing for Children's Food

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Abstract: Children as a kind of weak consumers, the status of their food security are the focus of society and media. In order to study the condition of the barrier-free packing of children's food, combining with children's psychological and physiological characteristics and on the basis of relevant laws and regulations of food and food packing safety, this study uses the screening index of Principal Component Analysis (PCA) to build a set of accessible pre-warning index system for barrier-free packing of children's food and then uses the trapezoidal fuzzy Analytic Hierarchy Process (AHP) to weigh the two-leveled index in the system and establishes the pre-warning model for children's food packing by means of the fuzzy comprehensive evaluation, finally analyzes the relative importance of each index for influencing children's food barrier-free packing based on certain cases and provides some corresponding suggestions to improve the level of barrier-free packaging for children's food.

Keywords: Barrier-free, children's food, packing, pre-warning

INTRODUCTION

"Barrier-free" concept comes from the Civil Rights Movement in American in the 1950s, barrier-free design derives from the conception of normalization principle raised by the Danes in the 1950s (Huang, 2009), which was mainly for the handicapped and only applies in buildings and public facilities construction and a few other areas. As people constantly improve the level of consuming demand, "barrier-free" concept began to enter the field of packing design in the 1990s and "barrier-free packing design" gradually attracted people's attention. "barrier-free packing design" is a new design concept that combines barrier-free design with the proposing, designing and manufacturing products, added by other procedures of marketing, transportation, storage, usage and recycling which are closely related with product packing (Bai, 2011). In order to improve existed shortcomings of the traditional packing, it is a more scientific, convenient, safe, low-carbon, environmental protection designing method. Currently, in some developed countries like the United States, France, Britain and other countries, although they are required to design the packing to follow the related barrier-free principle and the designed packing is suitable for all of the people to use as much as possible, there is still no systematic and comprehensive specialized theoretical system.

In China, the study on barrier-free packaging design is still in its initial stage and its concept has been mentioned in small amounts of the books about general design and barrier-free facilities, but there is no detailed and in-depth research and few related research papers, only fewer can be found (Han and Liang, 2012; Liu and Li, 2011) that mainly explain the concept of barrier-free packing design or simply explore the factors of barrier packaging design used by some certain goods, there is no higher theoretical level and no feasible designing and pre-warning methods, moreover, barrier-free packing design specifically for children is fewer and fewer. This study will build a set of pre-warning index systems and models for children's food packing according to the relevant laws and regulations for food packaging safety and psychological and physiological characteristics of children, then display the relative importance of the indexes for influencing barrier-free packing of children's food based on the cases analysis, provide some suggestions to improve the level of barrier-free packaging for children's food.

METHODOLOGY

Establishing pre-warning mechanism for barrier-free packing of children's food:

Constructing pre-warning system: To build a scientific and reasonable pre-warning index system for children's food is the most important issue for evaluating barrier-free packing for children's food. Bases on the relevant laws and regulations like Food Safety Law, Food Packaging Law of the People's Republic of China and Certification Management Approach for food Packaging Product and on the principles of science, safety, appropriateness, comprehensiveness and hierarchy combining the

Table 1: Pre-warning index system of barrier-free packing for children's food

Primary indexes	Secondary indexes	Evaluation set					Combination weights	Sort of weights
		Green	Blue	Yellow	Orange	Red		
Barrier-free safety A_1 (0.332)	Barrier-free material B_{11} (0.440)	0.1	0.2	0.4	0.2	0.1	0.146	1
	Barrier-free structure and shape B_{12} (0.363)	0.2	0.4	0.1	0.2	0.1	0.121	3
	Barrier-free function B_{13} (0.197)	0.3	0.5	0.2	0.0	0.0	0.065	8
Barrier-free usage A_2 (0.287)	Barrier-free opening B_{21} (0.331)	0.1	0.4	0.4	0.1	0.0	0.095	5
	Barrier-free carrying B_{22} (0.318)	0.2	0.3	0.1	0.2	0.2	0.091	6
	Barrier-free eating B_{23} (0.351)	0.3	0.4	0.1	0.1	0.1	0.101	4
Barrier-free communication A_3 (0.193)	Conveying property B_{31} (0.348)	0.1	0.4	0.3	0.1	0.1	0.067	7
	Promotion property B_{32} (0.652)	0.0	0.3	0.2	0.4	0.1	0.126	2
Barrier-free intelligence A_4 (0.188)	Experience and interaction Property B_{41} (0.237)	0.2	0.4	0.3	0.0	0.1	0.045	11
	Combination and creativity Property B_{42} (0.199)	0.2	0.4	0.2	0.1	0.1	0.037	12
	Guide and education property B_{43} (0.256)	0.1	0.5	0.2	0.2	0.0	0.048	10
	Development of intellectual Property B_{43} (0.308)	0.2	0.3	0.2	0.2	0.1	0.058	9

opinions of experts, this study uses the Principal Component Analysis (PCA) to screen important ones among the numerous factors, establishes the pre-warning index system for barrier-free packing of children's food including 4 primary indexes of barrier-free safety (A_1), the barrier-free usage (A_2), barrier-free communication (A_3), barrier-free intelligence (A_4), namely a set of evaluation factors equals $A = \{A_1, A_2, A_3, A_4\}$, $A_1 = \{B_{11}, B_{12}, B_{13}\}$, $A_2 = \{B_{21}, B_{22}, B_{23}\}$, $A_3 = \{B_{31}, B_{32}\}$. $A_4 = \{B_{41}, B_{42}, B_{43}, B_{44}\}$, Table 1 as followed.

Setting evaluation set: Based on the actual research situation, five grades of "green", "blue", "yellow", "orange" and "red" are to be set for warning level of children's food packaging and be assigned and we get $V = \{v_1, v_2, v_3, v_4, v_5\} = \{95, 95, 75, 65, 55\} = \{$green, blue, yellow, orange, red$\}$.

Using the trapezoidal fuzzy AHP to determine the weight of the index system: Steps for weight.

Structure of trapezoidal fuzzy judgment matrix: Using the paired comparison method and hierarchy analytic method of the trapezoidal fuzzy to determine the scale and construct the fuzzy judgment matrix in the same layer index belonging to the upper one (Liu and Wang, 2002).

Consistency check: While checking the consistency of matrix, first we need to calculate the gravity center of each trapezoid fuzzy number $A = (a, b, c, d)$ with the formula:

$$c(A) = \frac{(d^2 + cd + c^2) - (b^2 + ab + a^2)}{3(c + d - a - b)}$$

so the fuzzy judgment matrix can be transformed into an ordinary judgment matrix (referred as the core matrix) and then use the method of the bibliography (Jiang, 1987) to check the consistency of the core matrix. If the consistency ratio is $CR \leq 0.1$, then the original trapezoidal fuzzy judgment matrix passes the testing, so the matrix can be used to find the fuzzy weight of the index, if $CR > 0.1$, then it does not pass, we need to let the experts to re-score, thereby adjust the value of the trapezoidal fuzzy judgment matrix.

The calculation of fuzzy weight:

Step 1: According to the experts' scoring, obtains the fuzzy judgment matrix r_{ij} $(i, j \in N)$ by using the formula of:

$$r_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij}) = \frac{1}{L} \otimes (r_{ij}^{(1)} \oplus r_{ij}^{(2)} \oplus r_{ij}^{(3)} \oplus r_{ij}^{(4)})$$
$$= (\frac{1}{L}\sum_{k=1}^{L} a_{ij}^{(k)}, \frac{1}{L}\sum_{k=1}^{L} b_{ij}^{(k)}, \frac{1}{L}\sum_{k=1}^{L} c_{ij}^{(k)}, \frac{1}{L}\sum_{k=1}^{L} d_{ij}^{(k)}).$$

Step 2: Use the following formula: (1) to calculate the fuzzy appraisal value of each index:

$$I(v_i) = (\sum_{j=1}^{n} a_{ij}, \sum_{j=1}^{n} b_{ij}, \sum_{j=1}^{n} c_{ij}, \sum_{j=1}^{n} d_{ij}) \otimes$$
$$(\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij})$$
$$= (\frac{\sum_{j=1}^{n} a_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}}, \frac{\sum_{j=1}^{n} b_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}}, \frac{\sum_{j=1}^{n} c_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}}, \frac{\sum_{j=1}^{n} d_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}}), (i, j \in N) \quad (1)$$

Step 3: Use the formula:

$$I(\bar{v_i}) = \frac{a_i + b_i + c_i + d_i}{4}, i \in N \quad (2)$$

Liu and Wang (2002) to calculate the expectation value of the fuzzy evaluation of each index and use the formula:

$$w_i = \frac{\bar{I(v_i)}}{\sum_{i=1}^{n} \bar{I(v_i)}}, i \in N \quad (3)$$

To normally process the calculation results of the above, then we can get the weight of each index.

Calculating the results of comprehensive evaluation: Calculate the results of comprehensive evaluation by using the formula:

$$y = \sum_{i=1}^{n} w_i x_i \quad (4)$$

Here y is the comprehensive evaluation value of the system and the evaluation index of x_i corresponds to the weight of:

$$w_i \ (\sum_{i=1}^{n} w_i = 1)$$

The implementation of fuzzy comprehensive evaluation: According to the evaluation experts (n persons) on the levels of indexes, we obtain the membership grade of the single factor (n_1/n, n_2/n, n_3/n, n_4/n, n_5/n), where n_1, n_2, n_3, n_4, n_5 is respectively rated as the grade number ($n = \sum_{i=1}^{5} n_i$) of v_1, v_2, v_3, v_4, v_5, so that we can obtain the evaluation and decision matrix R_i (i = 1, 2, 3, 4, 5) of a single factor in each subset of A_i (i = 1, 2, 3, 4, 5), then use the multileveled comprehensive evaluation method (Chen *et al*., 2010) to calculate the evaluation and decision matrix of each subset and finally obtain the evaluation results of children's food barrier-free packing.

Examples of application: This study takes a kind of children's dairy food as an example to pre-warn the barrier-free condition of its packing.

Determining the weight of every index: We take four secondary indicators-experience and interaction property (B_{41}), combination and creativity property (B_{42}), guide and education property (B_{43}), the development of intellectual property (B_{44}) of the primary index of barrier-free intelligence (A_4) as an example to illustrate the determination of weights.

Structuring trapezoidal fuzzy judgment matrix: According to the trapezoidal fuzzy judgment matrix given by the invited 3 experts, we use the weighted average number to get comprehensive fuzzy judgment matrix as followed:

$$\bar{r}_{A_4-B} = \begin{pmatrix} (1,1,1,1) & (2.5,3,4,4.5) & (3,3.5,4.5,5) & (5.5,6,7,7.5) \\ (0.2222,0.25,0.3333,0.4) & (1,1,1,1) & (2,2.5,3.5,4) & (3.5,4,5,5.5) \\ (0.2,0.2222,0.2857,0.3333) & (0.25,0.2857,0.4,0.5) & (1,1,1,1) & (1,1.5,2.5,3) \\ (0.1333,0.1429,0.1667,0.1818) & (0.1818,0.2,0.25,0.2857) & (0.3333,0.4,0.6667,1) & (1,1,1,1) \end{pmatrix}$$

Consistency check: We calculate the kernel matrix of the above matrix:

$$\bar{r}_{A_4-B} = \begin{pmatrix} 1 & 3 & 4.5 & 6 \\ 0.3278 & 1 & 3.5 & 4 \\ 0.2185 & 0.3154 & 1 & 2 \\ 0.1701 & 0.2547 & 0.5521 & 1 \end{pmatrix}$$

by using the formula of trapezoid's gravity center.

Then use the summation method (Jiang, 1987) to calculate the maximum eigenvalue λ_{max} = 4.2002 and the consistency index $CI = (\lambda_{max}\text{-}n) / (n\text{-}1) = 0.0667$ of the matrix ($\bar{r}\ A_4\text{-}B$), so as to obtain the consistency ratio $CR = CI/RI = 0.0742<0.1$, wherein RI = 0.9 (which can be checked by the numerical list of random consistency index RI), so the trapezoidal fuzzy judgment matrix can pass the consistency check.

Calculating the fuzzy weight: The fuzzy evaluation value of each index calculated by the formula (1) as flowed:

$$I(v_1) = (0.244 + 0.268 + 0.275 + 0.237)$$

$$I(v_2) = (0.481 + 0.289 + 0.359 + 0.241)$$

$$I(v_3) = (0.223 + 0.323 + 0.225 + 0.184)$$

$$I(v_4) = (0.191 + 0.232 + 0.313 + 0.226)$$

Then we calculate the fuzzy evaluation expectation for each index through the formula (2), which is:

$$\bar{I(v_1)} = (0.244 + 0.268 + 0.275 + 0.237) / 4 = 0.256$$

$$\bar{I(v_2)} = (0.481 + 0.289 + 0.359 + 0.241) / 4 = 0.343$$

$$\bar{I(v_3)} = (0.223 + 0.323 + 0.225 + 0.184) / 4 = 0.239$$

$$\bar{I}(v_4) = (0.191 + 0.232 + 0.313 + 0.226)/4 = 0.241$$

And then, we can obtain the weight of each index by the formula (3):

$$w_1 = 0.256/(0.256 + 0.343 + 0.239 + 0.241) = 0.237$$

$$w_2 = 0.199,\ w_3 = 0.256,\ w_4 = 0.308$$

And then get the weight vector:

$$W_{B_4} = (0.237, 0.199, 0.256, 0.308)$$

On the same logic, we can get:

$$W_{B_1} = (0.440, 0.363, 0.197)$$

$$W_{B_2} = (0.331, 0.318, 0.351)$$

$$W_{B_3} = (0.348, 0.652)$$

$$W_A = (0.332, 0.287, 0.193, 0.188)$$

Which are the numerical values in brackets of Table 1.

Calculating the results of comprehensive evaluation: Calculate the results of comprehensive evaluation of each index by using the formula (4), which are shown in Table 1.

The implementation of fuzzy comprehensive evaluation: In order to pre-warn barrier-free packing of this kind of children's dairy food, at first we must organize the relevant experts to grade each evaluation factors in the corresponding evaluation column of the pre-programmed evaluation checklist. For reasons of space, we will list the normalized results voted by the experts in Table 1 because of limited room. So the weight vector of barrier-free intelligence is:

$$W_{A_1} = W_{B_1} \cdot R_1$$

$$= (0.237, 0.199, 0.256, 0.308)\begin{pmatrix} 0.2 & 0.4 & 0.3 & 0 & 0.1 \\ 0.2 & 0.4 & 0.2 & 0.1 & 0.1 \\ 0.1 & 0.5 & 0.2 & 0.2 & 0 \\ 0.2 & 0.3 & 0.2 & 0.2 & 0.1 \end{pmatrix}$$

$$= (0.2, 0.3, 0.237, 0.2, 0.1)$$

After normalizing, we can get the comprehensive evaluation $\bar{W}_{A_4}$ = (0.193, 0.289, 0.229, 0.193, 0.096) for barrier-free intelligence. Similarly, we can obtain the normalization results of the factor weight of the barrier-free safety, barrier-free usage and barrier-free communication, which are:

$$\bar{W}_{A_1} = (0.158, 0.287, 0.317, 0.158, 0.079)$$

$$\bar{W}_{A_2} = (0.217, 0.254, 0.240, 0.145, 0.145)$$

$$\bar{W}_{A_3} = (0.080, 0.279, 0.240, 0.321, 0.080)$$

To get the comprehensive evaluation of the barrier-free packaging for this children's dairy food is:

$$W = W_A \cdot R = W_A \cdot (\bar{W}_{A_1}, \bar{W}_{A_2}, \bar{W}_{A_3}, \bar{W}_{A_4}, \bar{W}_{A_5})^T$$

$$= (0.322, 0.287, 0.193, 0.188)\begin{pmatrix} 0.193 & 0.289 & 0.229 & 0.193 & 0.096 \\ 0.217 & 0.254 & 0.240 & 0.145 & 0.145 \\ 0.080 & 0.279 & 0.240 & 0.321 & 0.080 \\ 0.158 & 0.287 & 0.317 & 0.158 & 0.079 \end{pmatrix}$$

$$= (0.217, 0.289, 0.240, 0.193, 0.145)$$

Normalizing to get $\bar{W} = (0.2, 0.267, 0.221, 0.178, 0.134)$.

Pre-warning score: By the formula of $Z = \bar{W}.V^T$, we get the final score of barrier-free packaging for this children's dairy food is:

$$Z = (0.2, 0.267, 0.221, 0.178, 0.134) \cdot (95, 85, 75, 65, 55)^T$$
$$\approx 77.21$$

RESULT ANALYSIS

- Through these calculations, we can get the pre-warning results of barrier-free packaging for this children's dairy food that are "green" 20.0%, "blue" 26.7%, "yellow" 22.1%, "orange" 17.8%, "red" 18.7% by using the fuzzy comprehensive evaluation method. According to the maximum membership principle (Jiang, 1987), the evaluation rate of the barrier-free packaging for this children's dairy food for is the "blue" level with a comprehensive score of 77.21, the level of barrier-free design is very high, which basically match with the actual situation.
- From the calculation results in Table 1, it can be seen that in the primary level of impacting factors, the impacts of barrier-free safety and barrier-free usage on the accessibility level of children's food packaging are largest accounting for 33.2 and 28.7%, respectively; And the barrier-free materials, barrier-free eating, promotion property and the development of intellectual property have largest

influence on the corresponding primary factors accounting for 44.0, 35.1, 65.2 and 35.1%, respectively; In the secondary factors on the overall impact, barrier-free materials, promotion property, barrier-free structures and shapes and barrier-free eating account for 14.6, 12.6, 12.1 and 12.6% respectively. Therefore, we should especially strengthen several influential factors of the barrier-free design in barrier-free packaging design for children's food.

CONCLUSION

As the pre-warning mechanism of barrier-free packing for children's food is a multi-leveled and multi-attributed decision-making problem, based on the scientific, comprehensive and leveled principles and with the theoretical basis of relevant laws and regulations, combined with the experts' opinion, we employ the Principal Component Analysis (PAC) to screen the main index from many factors that affect barrier-free packing for children's food and establish a two-leveled pre-warning index system for children's food packaging. And then we propose a improved AHP method based on triangular fuzzy number to weight the all- leveled indicators of the established pre-warning index system for the barrier-free packing of children's food, which can effectively solve the shortcomings of the ordinary AHP when weighting and the obtained weights more reliable and persuasive and then we establish the pre-warning model of the barrier-free packing for children's food combining with the fuzzy comprehensive evaluation method, finally, taking the packaging of this children's dairy food as an example, we give the concrete solving process of the pre-warning model and analyze the relative importance of each index and also sort the importance of 12 indexes which influence the safety status of children's food packing to put forward the corresponding suggestions in order to improve the level of barrier-free packaging designing for children's food. The results of cases study basically match with the actual situation, which indicates the certain validity and feasibility of this pre-warning model.

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REFERENCES

Bai, L., 2011. In child food non-barrier packing design research [D]. Shanxi University, Shanxi.

Chen, Y.Z., G.Z. Liu and T. Liu, 2010. Comprehensive fuzzy evaluation for generalized product quality based on entropy weight. J. Northeastern Univ., Nat. Sci., 31(2): 241-244.

Han, J. and C. Liang, 2012. Thinking of multi sensory barrier-free packaging design dominated by visual [J]. Masterpiece appreciation, 9: 165-167.

Huang, Q., 2009. Barrier-free-universal Design [M]. Machinery Industry Press, Beijing.

Jiang, Q.Y., 1987. Mathematical Model [M]. Higher Education Publishing House, Beijing.

Liu, J.Q. and L. Wang, 2002. Trapezoidal fuzzy AHP and its application to optimal selection of satellite system schemes [J]. J. Harbin Inst. Technol., 34(3): 315-319.

Liu, C. and G.T. Li, 2011. Application of "barrier-free" design in packaging of personal care products [J]. Packag. Eng., 32(18): 117-120.