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# A study method of risk evaluation for children's toys

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China is an important toy production and export country in the world. The injury incidents caused by Children's toys have become increasingly prominent, and the recall of toys also led to a large number of economic losses. Therefore, in this paper, the fuzzy comprehensive evaluation method is proposed for the children's toys risk evaluation. Firstly, the ETA method is used to determine the index and establish the index system of risk evaluation for children's toys. To determine the index weight, AHP method is adopted to calculate the weight of each index. Then make the fuzzy comprehensive evaluation model for the risk evaluation of children's toys. Finally, the feasibility and effectiveness of method were illustrated by an example. Result shows that it provides a new perspective and tool for the risk evaluation of children's toys.

Key words: ETA, Risk evaluation, Children's toys, Fuzzy comprehensive evaluation

## INTRODUCTION

With the development of China's economy and the improvement of people's living standards, more and more children want to have their own toys, and parents are willing to spend money for their children to buy all kinds of toys with little security concerns.

China is an important toy production and export country in the world. Every year, the toy industry offers an annual product income in excess of 80 billion RMB and invests almost 6 billion dollars in the export of Chinese products [1]. Toys made in China occupy a substantial part of the international market, for example, 65% of imported toys in America and 80% of those in Australia originate from China [2]. However, the fact that toys made in China make up a large proportion in terms of recall times and recalled products indicates that toys made in China pose a threat in respect of potential safety hazards [3]. Table 1 shows the amount and the proportion of toy injury cases during the period from January to July 2014. In this duration, the product injury surveillance system of China cited 246 injury cases relating to toys from 11 different cities, accounting for 45.06% of the total amount of injury cases pertaining to children's toys and supplies injury cases.

Currently, the risk evaluation for children's toys is still far from satisfactory, therefore the majority of countries worldwide continue merely using the quality inspection according to national standards, such as the Chinese Safety for Toys criteria (GB 6675-86) and the American Safety for Toys (ASTM-F963), required by the American Society for Testing and Materials [4]. A product which is tested according to these regulations, however, does not necessarily entail having zero risk, and cannot explicitly display this safety grading. In the view of the injury model, a simple and effective model of children's toys risk evaluation is put forward based on the method of Fuzzy-AHP. The evaluation conclusions obtained through the model and calculation are advantageous in identifying hidden dangers, thus reducing potential hazards, and ultimately preventing accidents.

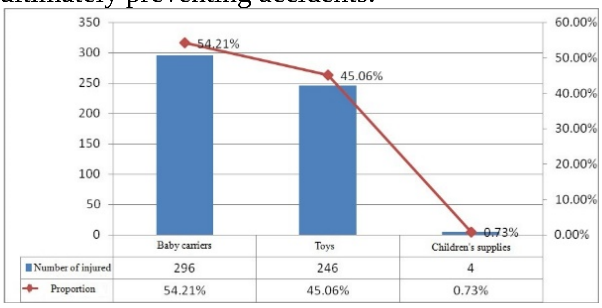


**Fig. 1**. The amount and proportion of children's toys and supplies injury cases

## BUILDING THE INDEX SYSTEM

There are some qualitative factors necessary in the process of evaluating toys, which involve definite intension and indefinite extension, two methods which are difficult to be described in numerical form. The evaluation of these factors depends on the experience. However, if factors without measurement are impossible to be given a valuation, it would make gathering the basic data an impossible task. In this eventuality further research would not be feasible.

Some common factors have been identified in the manufacture of toys which can lead to the occurrence of potential injuries, however, the relationship between them is complex. A single-factor evaluation merely gives one factor's degree of

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safety from a different perspective, and is ineffective in pinpointing potential problems owing to a toy's complex manufacturing system and the fact that the influence of factors leading to injuries is so diverse. Therefore a method which can determine the weights of factors and which can carry out a comprehensive evaluation is of paramount importance.

According to the statistics on toy recall reports provided by the Consumer Product Safety Commission (CPSC) and Rapid Alert System for non-food Consumer Products (RAPEX), five types of injury models are summarized: physical wounds, chemical wounds, burns and scald wounds, those caused by suffocation and so on, and the causes are analyzed based on the theory of Event Tree Analysis (ETA). ETA is commonly used to identify the consequences which result from the occurrence of a potentially hazardous event. The system was first applied in risk assessment for the nuclear industry, but nowadays it is also used in other industries. Figure 2 shows the causes analysis of the process of physical wounds. The specific injury forms of physical wounding include compression, crash and impact, stab wounds and cut wounds, friction and so on, and the causes leading to these injuries are classified into unqualified materials, sharp pointed edges, invalid fixing devices and so on.

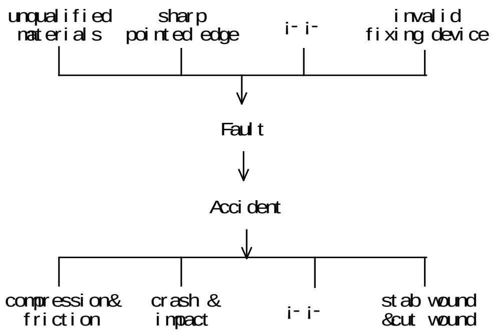


**Fig. 2**. The cause analysis of the process of mechanical wound based on ETA

Based upon the analysis outlined above and related literature [5], four types of toy injury causes which are used as evaluation factors for children's toys, are categorized as follows:

(a) Physical properties, including a toy's physical index, structure, strength, etc.;

(b) Flammable properties, including the material's flammability, combustibility, burning rate and so on;

(c) Chemical properties, including the content of harmful heavy metals used in the manufacturing process along with other toxic and harmful substances;

(d) Electrical properties, including overheating of batteries, explosion and burning caused by batteries, leakage of battery liquid and dangers imposed by congestion of the cell.

**Table 1**. Index system of risk evaluation for children's toys

| Assessment object | Primary Index | Grade Two Index |
|---|---|---|
| Risk Evaluation for Children's Toys U | Physical properties U1 | Structural stability |
| | | Product material |
| | | Parts Fastener |
| | | Component strength |
| | | Gap and opening |
| | | Surface roughness, sharp edges, sharp tips |
| | | Ejection kinetic energy |
| | | Folding mechanism clearance and its reliability |
| | Flammable properties U2 | Flame retardant properties of non metallic materials |
| | | Flame retardant properties of textile materials |
| | | Shell protection defect |
| | | Parts installation problem |
| | | Component structure and dimensions |
| | | Battery overcharging / overdischarging |
| | Chemical properties U3 | Content and concentration of toxic and harmful substances |
| | | Volatile and odor of toxic and harmful substances |
| | | Shell tightness and sealing property |
| | | Parts installation problem |
| | | Component structure and dimensions |
| | | Creepage distance and clearance |
| | | Moisture resistance |
| | | Double insulation structure |

## DETERMINING THE INDEX WEIGHT

The Fuzzy Analytic Hierarchy Process entails a combination of Analytic hierarchy process (AHP) and Fuzzy mathematics [6,7]. It is one of the most effective approaches used to address uncertainty and ambiguity from a subjective perception and involves the experience of humans in its decision-making process. F-AHP combines the advantages of both the AHP and fuzzy comprehensive evaluation method, in a fuzzy environment, to consider numerous factors, and thus uses fuzzy membership theory to adequately quantify the qualitative indicators [8,9]. The Fuzzy-AHP method is useful in providing an attribution as to which indicators significantly affect the results, the degree of membership, it confirms the factors' weight, and then carries out a comprehensive evaluation through the fuzzy transformation principle [10,11]. The traditional AHP uses a two-two and more judgment matrix which is called the 1-9 scale method. This method entails using integers from 1 to 9 to represent the comparison of results of different aspects' relative importance degree, displayed in Table 2.

**Table 2.** Scale method

| Scale | Meaning |
|---|---|
| 1 | Factor $A_i$ and factor $A_j$, are the same importance |
| 3 | Factor $A_i$ is slightly more important than factor $A_j$ |
| 5 | Factor $A_i$ is obviously more important than factor $A_j$ |
| 7 | Factor $A_i$ is significantly more important than factor $A_j$ |
| 9 | Factor $A_i$ is extremely more important than factor $A_j$ |
| 2,4, 6,8 | The mid-value of these two adjacent judgment values |
| Reciprocal | Compare $A_i$ to $A_j$, get $a_{ij}$, so compare $A_i$ to $A_j$ get $a_{ij}=1/a_i$ |

Although each discrete number shown in the table is clear, this Scale method does not reflect the ambiguity of human judgment. Owing to this shortcoming, the Dutch mathematician Van Laarhoven, used triangular fuzzy number taken from the branch of fuzzy mathematics to carry out the transition from traditional AHP to Fuzzy-AHP. Its basic concept is to use triangular fuzzy number to replace traditional AHP's 1-9 scale and uses this to show the result of the comparison. According to this method, a fuzzy judgment matrix can be obtained from the triangular fuzzy number. A hierarchical analysis of the fuzzy environment can then be achieved. Figure 3 shows the basic steps of Fuzzy Hierarchical Analysis.

The basic steps of Fuzzy-AHP are described below

1. One must find the basic influential factors in the problems which are being studied.
2. Analyse the relation and interrelation between aspects to create an orderly hierarchical structure.
3. Make a comparison between different aspects of factors on the same level, to build a judgment matrix.
4. Based on the judgment matrix, a calculation can be made relating to weight problems, for example comparative factors' corresponding standards, and then carry out a consistency examination.
5. Calculate the weight of every level's relative total system and place in hierarchical order.

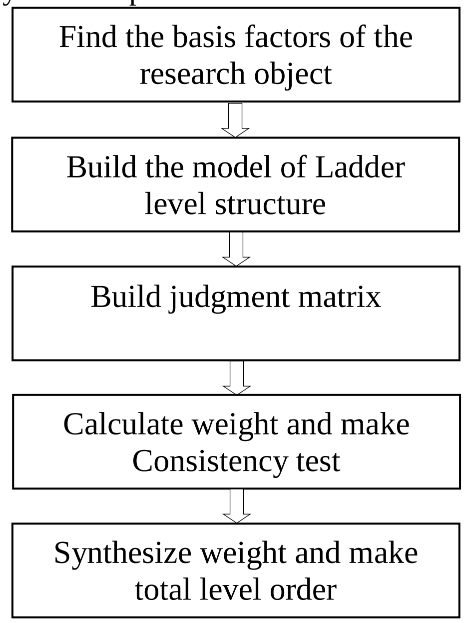


**Figure 3.** Basic steps of Fuzzy Hierarchical Analysis

To calculate the evaluation factors' weight, the process based on AHP is shown as follows [12]:

(a) Compare each pair of factors with the method of 1-9 scale method and form judgment matrix A, where $a_{ij}$ indicates the relative importance degree of factor i compared with factor j. In the Fuzzy-AHP, building the judgment matrix is a crucial step. To obtain the judgment elements of the upper layer in the judgment matrix, to evaluate the relative importance degree among every set of related elements is very important, the form is shown below:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \quad (1)$$

Or A= $[a_{ij}]$, i, j=1,2.…n

(b) Calculate the products $M_i$ of the elements in the same line of judgment matrix A;

(c) Calculate $W_i$, then the root of $M_i$, obtaining the weight $W_i^0$, and then form the weight set:

$$W = \begin{bmatrix} W_1^0 & W_2^0 & \cdots & W_n^0 \end{bmatrix}^T \quad (2)$$

where $W_i^0 = \frac{W_i}{\sum_{j=1}^{n} W_j}$ (3)

(d) Calculate the maximum feature root λ of the judgment matrix A, where

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i^0} \quad (4)$$

(e) Check the consistency of judgment matrix A.

Calculate consistency index CI and consistency rate CR. A number of experts note the importance of n indicators on the same layer by using the Delphi method, then establish the judgment matrix, and finally check the consistency. If CR is less than 0.1, the judgment matrix A meets the requirements of the consistency and the weight set W can be adopted. Otherwise, the judgment matrix A can be adjusted. The CI and CR are described as follows:

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (5)$$

and, $$CR = \frac{CI}{RI} \qquad (6)$$

where, RI is the mean random consistency index shown in Table 3.

**Table 3.** The values of RI

| n | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| RI | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 |
| N | 6 | 7 | 8 | 9 | 10 |
| RI | 1.26 | 1.36 | 1.41 | 1.46 | 1.49 |

## FUZZY COMPREHENSIVE ASSESSMENT METHOD

The fuzzy comprehensive evaluation method [13] is a kind of comprehensive evaluation method for complex systems with multiple levels and multiple factors, based on fuzzy mathematics and applied the principle of fuzzy relation synthesis to quantify the unclear boundary factors. Because the assessment is concerned with many factors, the multi-level fuzzy evaluation method was used in this paper. Based on the fuzzy mathematics theory [9], fuzzy comprehensive evaluation for children’s toys was carried out.

### *Evaluation factors*

According to the index system of emergency capability assessment, determine the evaluation factors set: $U = \{U_1, U_2, \ldots, U_4\}$ , $U_1 = \{U_{11}, U_{12}, U_{13}, \ldots, U_{18}\}$ , $U_2 = \{U_{21}, U_{22}, U_{23}, \ldots, U_{26}\}$, $U_3 = \{U_{31}, U_{32}, U_{33}\}$,$U_4 = \{U_{41}, U_{42}, \ldots, U_{46}\}$

### *Comment sets*

Comment set is a set of evaluation results of the evaluation object. According to the fuzzy characteristic of children’s toys risk evaluation index, 5 grades of reviews (i.e., excellent, good, moderate, qualified and unqualified) were used as the evaluation sets to evaluate emergency capability assessment of port coal storage base, marked $V = \{v_1, v_2, v_3, v_4, v_5\}$. In order to more directly reflect the evaluation results, assign the 5 comment sets a value from 0-1, shown in table 4.

**Table 4**. The score of each level

| Level | Value |
|---|---|
| Excellent | 100-80 |
| Good | 80-60 |
| Moderate | 60-40 |
| Qualified | 40-20 |
| Unqualified | 20-0 |

### *Degree of membership*

Because the risk is difficult to be quantified, the fuzzy statistical method was used to determine the degree of membership. The expert graded the indicators according to the given set of V, and then registered the statistics of the frequency of each target. The membership degree of index uij is a ratio between the frequency and the total number of experts.

$$r_{ijl} = {n_{ijl}}/{N} \qquad (7)$$

By determining the membership degree, the fuzzy evaluation matrix is obtained.

$$R_i = \begin{bmatrix} r_{i11} & \cdots & r_{i15} \\ \vdots & \ddots & \vdots \\ r_{im1} & \cdots & r_{im5} \end{bmatrix} \qquad (8)$$

### *Assessment of Primary Index*

According to the weight matrix $\omega_i$and evaluation matrix $R_i$, carry on the grade two index and primary index evaluation calculation.

$$R = B_i = \omega_i R_i = \begin{bmatrix} \omega_1 R_1 \\ \omega_2 R_2 \\ \omega_3 R_3 \\ \cdots \quad \cdots \\ \omega_4 R_4 \end{bmatrix} \qquad (9)$$

### *Fuzzy comprehensive assessment*

After each evaluation index of the index layer is evaluated, the evaluation matrix C is obtained by fuzzy comprehensive evaluation of the criteria layer index $U_i$.

$$C = W^T R = [c_1, c_2, c_3, c_4, c_5] \qquad (10)$$

The comprehensive evaluation matrix C is characterized by the form of membership degree, but the result is not very intuitive. So select the median value of the value of the critical value of the evaluation grade,$D = (90,70,50,30,10)$, as the rank weighted vector of the evaluation set:

$$E = CD^T \qquad (11)$$

According to the E value, determine the risk level of children’s toys. This method has been widely used in the field of environmental quality [14-15], for example building [16] and petrochemicals [17] and receives satisfactory feedback, although it is seldom used in toy risk evaluation.

## APPLICATION EXAMPLE

A kitchen model was taken as the application example in this article. The toy was assembled employing the models of water tank, cupboard and refrigerator, and some components can be dismantled. Prior to the recall date, the manufacturer has received 48 complaints, one of which is a serious accident in which a child became asphyxiated from swallowing a component and subsequently recovered following removal of the object.

*Calculate the index weights of evaluation factors*

According to the AHP method to calculate the weight of each layer index, taking U1—U4, 4 primary indices were taken as the criteria layer indices, as an example.

Employing the 1-9 scale method, the judgment matrix A was formed by some senior experts according to their experience.

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

After $M_i$, the products of the elements in the same line of judgment matrix A and $W_i$, then the root of $M_i$ were calculated, the weight $W_i^0$ was obtained and the weight set W was formed.

$$W=\begin{bmatrix}0.503 & 0.245 & 0.180 & 0.072\end{bmatrix}^T$$

It is known that the maximum feature root λ is 3.016, the consistency index CI is -0.328 and the consistency rate is -0.36 following the calculation. As CR was less than 0.1, the judgment matrix A meets the requirements and the weight set W is identified.

*Forming the membership matrix R*

Table 5 shows ten senior experts' evaluation levels for each evaluation factor, based on their experience.

**Table 5**. Experts' evaluation table

| | V1 | V2 | V3 | V4 | V5 |
|---|---|---|---|---|---|
| U1 | 0 | 1 | 3 | 5 | 1 |
| U2 | 1 | 4 | 3 | 2 | 0 |
| U3 | 2 | 5 | 2 | 1 | 0 |
| U4 | 5 | 4 | 1 | 0 | 0 |

The membership matrix R formed according to the data in Table 5 was processed using the method of normalization.

$$R=\begin{pmatrix}0 & 0.1 & 0.3 & 0.5 & 0.1\\ 0.1 & 0.4 & 0.3 & 0.2 & 0\\ 0.2 & 0.5 & 0.2 & 0.1 & 0\\ 0.5 & 0.4 & 0.1 & 0 & 0\end{pmatrix}$$

*Fuzzy comprehensive assessment*

Using fuzzy comprehensive evaluation to determine the risk level:

$$\mathrm{C}=\mathrm{W}^{\mathrm{T}}\mathrm{R}=$$
$$[0.0965 \quad 0.2671 \quad 0.2676 \quad 0.3185 \quad 0.0503]$$
$$E=CD^T=50.82$$

Therefore, the comprehensive evaluation of the kitchen toy was 50.84, between 60 and 40. The level is general, need to moderate.

CONCLUSIONS

1. In this article, only four evaluation factors were considered. However, as awareness of safety and environmental protection is raised, environment protection and biosafety will be considered as other important evaluation factors.

2. As the score of evaluation level, the degree of membership and the weight all depend considerably on the experts' experience; it is the senior experts who will be invited to participate in the practical operation.

3. According to the application example, it is explained how the model of children's toys risk evaluation based on Fuzzy-AHP is calculated and that the process is deemed simple enough to change the qualitative description into a quantitative analysis.

4. The weights of the evaluation factors based on the model are in accordance with conclusions from corresponding reports and the application example.

5. Collection of more extensive data, test of the accuracy of the evaluation theory and relevant improvements will be needed in further study through empirical research. The operating model needs continuous analysis and research to adapt to the changes and adjustments in the market, which will certainly promote the overall development and safety in the toy industry.

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