Weight Calculation Method for Consumer Goods Risk Assessment Indexes Based on Analytic Hierarchy Process

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Abstract. This Paper, by comprehensively analyzing the factors influencing consumer goods safety risk assessment and following the principles of completeness, maneuverability, rationality and comparability, constructs a consumer goods safety risk assessment index system covering human-product-environment, and proposes the weight calculation method for consumer goods safety risk assessment index system based on Analytic Hierarchy Process (AHP), laying the foundation for the related work of consumer goods safety risk assessment.

1. Introduction
In recent years, serious incidents concerning the quality and safety of consumer goods have occurred frequently, such as the "A&W wood floor with over standard formaldehyde" incident in 2012, the "toxic school uniform with cancer genic substance" incident in 2013, the "tap with over standard lead" incident in 2014, the "exploded mobile power" incident in 2015, the "quality issue of Samsung mobile phones" incident in 2016, the "baby powder containing cancer genic substance of Johnson & Johnson " incident in 2017, and the "toxic crystal mud" incident in 2018, which have seriously affected consumers' health and property, and attracted much attention from all walks of life. How to evaluate, prevent and reduce the safety risk of consumer goods has become a major issue to be addressed.

At present, risk assessment is an important method to ensure the safety of consumer goods over the world, and also one of the major bases for the recall management work by governments and enterprises. There are two major risk assessment methods: quantitative assessment and qualitative assessment [1]. Quantitative risk assessment method can accurately judge the safety risk level of consumer goods; one of its research difficulties lies in how to determine the weight of consumer goods safety risk assessment indexes. The quality and safety of consumer goods are influenced by numerous factors with complex relationships therein. The Analytic Hierarchy Process (AHP) can solve these problems very well, and therefore has been successful applied in the fields of construction engineering, ship engineering, scheme optimization, water quality evaluation and risk management [2-7]. This Paper constructs the consumer goods safety risk assessment index system by analyzing the factors influencing the safety risk of consumer goods, and determines the weight of each assessment index with AHP.
2. Construction of Consumer Goods Safety Risk Assessment Index System

2.1. Principles for index system construction

Construction of a scientific and rational consumer goods safety risk assessment index system is the precondition to develop safety risk assessment for consumer goods. The principles [8-10] for the construction are as follows:

2.1.1. Completeness: the assessment index system should cover the factors of various dimensions influencing the consumer goods safety risk assessment as far as possible.

2.1.2. Maneuverability: the assessment index must be quantitative if possible, to perform an intuitive comparison based on values.

2.1.3. Rationality: the assessment index must have clear boundary and reasonable content, to clearly express the contents to be compared.

2.1.4. Comparability: the same assessment index must be comparable among different consumer goods.

2.2. Consumer goods safety risk assessment index system

The quality and safety incidents of consumer goods are usually caused jointly by "human-product-environment". This Paper constructs the framework of consumer goods safety risk assessment index system [1] from consumers, consumer goods and service environment according to the aforesaid construction principles. The details are as shown in Figure 1.

2.2.1. Consumer. Consumers are one of the important factors influencing the consumer goods safety risk assessment. Consumers of different ages, genders, health and educational backgrounds have different cognitions about products and control capabilities for the service environment, so different quality and safety accidents may be caused for consumers when using the same product. For example, children under three may swallow small parts of toys to lead to suffocation when playing toy products; the aged may overcharge the electric blanket and cause fire due to deterioration of the memory.

2.2.2. Consumer goods. The risk factor of consumer goods includes inherent risk and design risk. The inherent risk refers to the necessary attribute of products to realize certain functions, such as the

Figure 1. Consumer Goods Safety Risk Assessment Index System.
necessary bullet ejection function of projectile toy guns, the required sound alarming function of ambulance toys. The design attribute means some additional attributes of products after production, packaging, transportation and other series links in the process of changing the products from concept model to practical products, such as the application of inferior raw materials for furniture products for saving costs to lead to over standard hazardous chemicals, like formaldehyde.

2.2.3. Service environment. The service environment of consumer goods is generally divided into normal service environment and abnormal service environment. The normal service environment refers to the applicable environment specified in the product manual, and the abnormal service environment means the environment beyond the requirements of the product manual.

3. Weight Calculation Method Based on Analytic Hierarchy Process

AHP is a concise and practical weight and decision hierarchical parsing approach combining qualitative and quantitative analysis that is proposed on the basis of network system theory and multi-objective comprehensive evaluation method. It quantifies the decision-making process [3] based on less quantitative information by deeply analyzing the essence of complex decision-making issues, influencing factors and their internal relations, and determines the importance of various elements on the same level in relative to elements of the last level by pairwise comparison, to finally obtain the weight of indexes.

3.1. Establishing index hierarchy

AHP divides indexes into different levels, including generally objective level, criterion level and scheme level. The objective level mainly refers to the intended objective of issues; the criterion level usually refers to the relevant criterions affecting the realization of objectives; it can also be sub-divided into sub-criterion level as needed; the scheme level means the scheme in relation to the realization of objectives. The details are as shown in Figure 2.

![Figure 2. Index Hierarchy.](image)

3.2. Constructing judgment matrix

It is difficult to determine the importance of each index directly in multi-attribute evaluation, in particular to the situation with multiple evaluation indexes. AHP requires judging the relative importance of each index at each level, and scaling the judgment with numerical values to form a judge matrix.

It is assumed that factor A consists of n indexes which are expressed as: $A_1, A_2, ..., A_n$; the importance of lower level factor $A_i$ and $A_j$ (i, j = 1, 2, ..., n) is compared in pairwise by discussion by
evaluators on meetings or Delphi method, and the ratio scale of 1-9 is given according to its relative importance. The detailed meaning of ratio scale is as shown in Table 1.

### Table 1. Meaning of Ratio Scale.

| Scale value | Relative importance of two factors          |
|-------------|---------------------------------------------|
| 1           | Equally important                           |
| 3           | Slightly more important                     |
| 5           | Apparently more important                   |
| 7           | Greatly more important                      |
| 9           | Absolutely more important                   |
| 2,4,6,8     | The median value of adjacent judgments above |

Note: If \( A_{ij} \) is obtained by comparing \( A_j \) with \( A_i \), \( A_{ij} = \frac{1}{A_{ij}} \) is obtained by comparing \( A_j \) and \( A_i \).

Thus, the judgment matrix \( A = (A_{ij})_{n \times n} \) can be obtained, as shown in Table 2:

### Table 2. Elements of Judgment Matrix A.

| \( A_{ij} \) | \( A_1 \) | \( A_2 \) | ...... | \( A_n \) |
|-------------|----------|----------|-------|----------|
| \( A_1 \)   | 1        | \( A_{12} \) | ...... | \( A_{1n} \) |
| \( A_2 \)   | \( A_{21} \) | 1        | ...... | \( A_{2n} \) |
| ......      | ......    | ......    | ...... | ......    |
| \( A_n \)   | \( A_{n1} \) | \( A_{n2} \) | ...... | 1        |

### 3.3. Determining index weight

The key to determine the weight of index system by AHP lies in how to calculate the maximum eigenvalue \( \lambda_{max} \) of judgment matrix and its corresponding eigenvector. The maximum eigenvalue and its eigenvector are usually calculated by three methods, such as sum and product method, power method and square root method. This Paper introduces the sum and product method in detail, with the specific steps as follows:

1. Normalize each column of the judgment matrix.
   \[
   \overline{A}_{ij} = \frac{A_{ij}}{\sum_{k=1}^{n} A_{kj}}, \text{ i,j=1,2, ...,n} \tag{1}
   \]

2. Add the judgment matrix with normalized columns by lines.
   \[
   \overline{W}_i = \sum_{j=1}^{n} \overline{A}_{ij}, \text{ i,j=1,2, ...,n} \tag{2}
   \]

3. Normalize the vector \( \overline{W} = [\overline{W}_1, \overline{W}_2, ..., \overline{W}_n]^T \), \( W_i = \frac{\overline{W}_i}{\sum_{j=1}^{n} \overline{W}_j} \), \( i=1, 2, ..., n \), and obtain the eigenvector \( W = [W_1, W_2, ..., W_n]^T \).

4. Calculate the maximum eigenvalue \( \lambda_{max} \) of the judgment matrix.
   \[
   \lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} = \frac{\sum_{i=1}^{n} (W_i \cdot (AW)_i)}{n} \tag{3}
   \]

### 3.4. Consistency inspection

Errors may exist when pairwise comparing the importance of various indexes, to fail to meet the consistency requirement. In order to ensure the rationality of determining weight by AHP, it is necessary to inspect the consistency of judgment matrix.
Calculate the consistency index CI.

\[ CI = \frac{\lambda_{\text{max}} - n}{n-1} \]  

(4)

Look up Table 3 below to get the average random one-time index RI, which is the arithmetic average after repeatedly calculating the random judgment matrix characteristic value for many times (> 500 times).

**Table 3. RI after Repeated Calculation for 1,000 Times.**

| N  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI | 0.00| 0.00| 0.52| 0.89| 1.12| 1.26| 1.36| 1.41| 1.46| 1.49| 1.52| 1.54|

Calculating consistency ratio CR.

\[ CR = \frac{CI}{RI} \]  

(5)

When CR < 0.1, it is generally considered that the consistency of judgment matrix A is acceptable, otherwise, the A needs to be adjusted until a satisfactory consistency is reached.

Repeat the calculation in sections 3.2-3.4 to determine the weight of indexes at other levels.

4. Examples

4.1. Case background
According to the statistics of 100 quality and safety incidents of consumer goods in 2018, 53 were caused by human factors, 45 were caused by product itself, and 22 were caused by improper service environment. In consideration of the data of the 100 quality and safety incidents and experts' experience, the decision matrix at the criterion level and sub-criterion level of the consumer goods safety risk assessment index system is constructed, as shown in Table 4-7.

**Table 4. Judgment Matrix at Criterion Level.**

| Criterion level | B₁ | B₂ | B₃ |
|-----------------|----|----|----|
| B₁              | 1  | 4  | 6  |
| B₂              | 0.25 | 1 | 3  |
| B₃              | 0.1667 | 0.3333 | 1  |

**Table 5. Judgment Matrix at Sub-criterion Level B₁.**

| Sub-criterion Level B₁ | C₁   | C₂   | C₃   | C₄   |
|------------------------|------|------|------|------|
| C₁                     | 1    | 4    | 5    | 3    |
| C₂                     | 0.25 | 1    | 0.3333 | 0.2 |
| C₃                     | 0.2  | 3    | 1    | 0.5  |
| C₄                     | 0.3333 | 5 | 2    | 1    |

**Table 6. Judgment Matrix at Sub-criterion Level B₂.**

| Sub-criterion Level B₂ | C₅ | C₆ |
|------------------------|----|----|
| C₅                     | 1  | 0.2|
| C₆                     | 5  | 1  |

**Table 7. Judgment Matrix at Sub-criterion Level B₃.**

| Sub-criterion Level B₃ | C₇ | C₈ |
|------------------------|----|----|
| C₇                     | 1  | 2  |
| C₈                     | 0.5 | 1  |
4.2. Weight calculation of indexes at different levels.

Calculate the weight of indexes at the criterion level and sub-criterion level of consumer goods safety risk assessment index according to Table 1-7, and taking the weight calculation process of consumers, consumer goods and service environment at the criterion level as an example, the specific algorithm is as follows by:

4.2.1. Normalizing columns of judgment matrix. Determine and construct the judgment matrix of consumer goods at criterion level according to the ratio scale of 1-9 in Table 1, compare the judgment matrix \( B = (b_{ij})_{3 \times 3} \) based on the relative importance, and normalize each column of the judgment matrix to obtain.

\[
B = \begin{bmatrix}
1 & 4 & 6 \\
0.25 & 1 & 3 \\
0.1667 & 0.3333 & 1
\end{bmatrix}
\]

Then:

\[
\tilde{B} = \begin{bmatrix}
0.7059 & 0.7500 & 0.6 \\
0.1765 & 0.1875 & 0.3 \\
0.1177 & 0.0625 & 0.1
\end{bmatrix}
\]

4.2.2. Add lines of the normalized judgment matrix. Add the normalized judgment matrix by lines to obtain the vector \( \tilde{W} = (\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_n)^T \) as follows:

\[
\tilde{W} = \begin{bmatrix}
2.0559 \\
0.6640 \\
0.2802
\end{bmatrix}
\]

4.2.3. Solving eigenvector. Normalize the vector \( \tilde{W} = (\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_n)^T \) to obtain the obtained eigenvector \( W = (w_1, w_2, ..., w_n)^T \), i.e. the weight vector of indexes at the criterion level:

\[
W = \begin{bmatrix}
0.6853 \\
0.2213 \\
0.0934
\end{bmatrix}
\]

Then:

\[
BW = \begin{bmatrix}
2.1309 \\
0.6728 \\
0.2814
\end{bmatrix}
\]

4.2.4. Solving maximum eigenvalue. Calculate the maximum eigenvalue \( \lambda_{max} \) of the judgment matrix, and the below can be obtained by \( BW \) and \( w_i \):

\[
\lambda_{max} = \sum_{i=1}^{n} \left( BW \right)_i = \frac{2.1309}{3 \times 0.6853} + \frac{0.6728}{3 \times 0.6853} + \frac{0.2814}{3 \times 0.0934} = 3.0542
\]

4.2.5. Consistency inspection. The consistency inspection index CI can be obtained based on the maximum eigenvalue of the judgment matrix:

\[
CI = \frac{\lambda_{max} - n}{n - 1} = \frac{3.0542 - 3}{3 - 1} = 0.0271
\]

Then the consistency index RI can be obtained according to Table 10, and the CR is calculated as follows:

\[
CR = \frac{CI}{RI} = \frac{0.0271}{0.52} = 0.0521 < 0.1
\]
Thus, it can be judged that the judgment matrix has satisfactory consistency, and moreover, the relative weight of the three indexes at the criterion level can be determined. Repeat the above process to calculate the weight of each index at the sub-criterion level, and finally determine the weight relationship among indexes, as shown in Table 8:

| Objective level | Criterion level | Sub-criterion level |
|-----------------|-----------------|---------------------|
| Consumer goods safety risk assessment index A | B₁ = 0.6853 | C₁=0.3687 |
| | | C₂=0.0481 |
| | | C₃=0.1043 |
| | | C₄=0.0369 |
| | B₂=0.2213 | C₅=0.1749 |
| | | C₆=0.1844 |
| | B₃=0.0934 | C₇=0.0156 |
| | | C₈=0.0778 |

4.3. Analysis of assessment results
The weight coefficient of safety risk assessment index of consumer goods is determined by AHP, and the weight of each index is basically consistent with the statistical data of quality and safety incidents in the cases. According to the calculation results, weight of consumers’ age index > weight of product design attribute > weight of product inherent attribute > weight of consumers' health > weight of abnormal service environment > weight of consumers’ gender > weight of consumers’ educational background > weight of normal service environment; the consumers’ age, product inherent attribute, product design attribute, and consumers’ health are important indexes influencing the consumer goods safety risk assessment results.

5. Summary
The scientific and rational weight of risk assessment index is the premise for consumer goods safety risk assessment. This Paper synthetically analyzes the factors influencing the consumer goods safety risk assessment from human-product-environment, constructs the consumer goods safety risk assessment index system, analyzes the relationship between indexes at the criterion-level, sub-criterion level and that at the objective level by AHP, and determines the weight of indexes at various levels. The weight calculation method for consumer goods safety risk assessment index based on AHP introduced in this Paper provides a kind of way to perform safety risk assessment for consumer goods, which is of certain reference significance.

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