Comprehensive Assessment of Explosion Risk of Glass Shower Enclosures Based on Dempster-Shafer (D-S) Evidence Theory

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Abstract. In recent years, an increasing number of consumers have bought glass shower enclosures for their homes as their living standards continue to rise. However, despite the convenience the product has to offer, incidents of exploding glass shower enclosures have been arousing wider concerns among the public. This paper is intended to conduct a comprehensive assessment on the explosion risk of glass shower enclosure products based on the Dempster-Shafer (D-S) evidence theory by establishing a glass shower enclosure explosion risk system, so as to provide a reference for reducing the safety risk of glass shower enclosure products.

Keywords: Dempster-Shafer (D-S) Evidence Theory, Glass Shower Enclosure, Explosion

1. Introduction

People have been seeking to improve the quality of domestic life as their living standards continue to rise. Glass shower enclosure products for domestic use are among the list of articles of daily use to serve their growing appetite for quality life. Although glass shower enclosures have been widely used to improve significantly the quality of life, incidents of exploding glass shower enclosures have become prominent. The statistics from public opinion show that in 2019 there were 15 incidents of exploding glass of shower enclosures that aroused public concern, 12 of which caused personal injuries; and 12 were reported with 9 causing personal injuries in 2018.

At present, many scholars have studied a lot on the quality safety risk of consumer goods. For example, Lu-yao Lin, et al. have proposed a combined approach of injury scenarios and 3D matrix integration for the assessment on the risk of consumer goods by comparing the practices of oversight of quality safety of consumer goods in the United States, the EU countries, and China [1]. Wei Cao, et al. have made suggestions on how to make the risk assessment system intelligent based on the hazard severity rating and the analysis on Bayesian weighted moving average model [2]. Xia Liu, et al. have conducted comprehensive research on the chemical hazards of toys for children from perspectives of standards, production process of toymakers, and market surveillance, among others [3]. This paper is intended to conduct a comprehensive assessment on glass shower enclosure products based on the Dempster-Shafer (D-S) evidence theory. The D-S evidence theory has been widely applied across an
array of disciplines. For example, Hong-fu Mi, Jin-bao Wan, et al. have studied fire risk with the D-S evidence theory [4-5]; Qian Song has studied risk management of metro construction with the D-S evidence theory [6]; and Shui-quan Lin has proposed a fault diagnosis method based on a combination of back-propagation (BP) neural network and D-S evidence theory [7]. Since the analytical calculation of uncertainty based on the D-S evidence theory accords, to a great extent, with people's intuitive understanding of uncertainty of an incident, the D-S evidence theory has been widely used for uncertainty analysis across an array of disciplines.

This paper is intended to take a closer look at the glass shower enclosure industry and manufacturers, identify the causes for explosion of glass shower enclosure products, establish an indicator system concerned, and conduct a comprehensive assessment on the explosion risk, in an attempt to provide a reference basis for interested parties of such products.

2. Establishment of Comprehensive Assessment System for Explosion Risk of Glass Shower Enclosure Products

2.1. Basic Principle

1) Full process

The indicators that may have an impact on the explosion of glass shower enclosure products involve not only the products themselves but also have close relationship with the installation and use of the products.

2) Core indicator

In order to improve the feasibility of the comprehensive assessment, a targeted indicator should be selected, that is, a core indicator related to the explosion of glass shower enclosures should be identified.

2.2. Comprehensive Assessment System for Explosion Risk of Glass Shower Enclosure Products

To establish an assessment indicator system, investigations and surveys on the core issues that may affect the explosion of the product should be conducted in the glass shower enclosure industry and manufacturers. Based on the investigation and survey results, this paper establishes an indicator system, as shown in Table 1, from three aspects: product, installation, and use.

Table 1. Comprehensive Assessment System for Explosion Risk of Glass Shower Enclosure Products

| Primary Indicator | Secondary Indicator | Description of Indicator |
|-------------------|---------------------|--------------------------|
| C1: Product       | C11: Brand          | For different brands in the industry, quality control comes in varying levels. |
|                   | C12: Raw glass sheets | Raw glass sheets are untreated (e.g. non-tempered) products, which present a possible shattering hazard due to brittleness of the material itself. |
|                   | C13: Tempering      | Tempering is an established process, which has been widely used by large glass manufacturers. However, to save the cost, small glassworks may use one tempering furnace to produce tempered glass of different thicknesses. The furnace switches over among different thicknesses, posing a higher risk of explosion to the first batch of glass processed in the furnace. As such, the unstable production process results in inconsistent quality of products. |
| C2: Installation  | C21: Logistics      | Shower enclosures are customized products in China, which involve a number of stages including measurement, production, shipping, and installation. A shower enclosure can turn into a finished product |
only when it is delivered to a customer's home from a semi-finished product shipped from the factory. Logistics and transportation during this process will become one of the factors that may cause spontaneous explosion. Therefore, even those shower enclosures which are not believed to explode spontaneously before installation may explode due to stress from improper installation.

C22: Installation
The distance from a hole on a shower enclosure to the edge of its panel, edging and size of the hole, the distance between holes, and uneven stress on contact surface between glass and hardware can all lead to spontaneous explosion of glass of the shower enclosure.

C3: Maintenance
C31: Use by consumers
The habit of consumers to use their glass shower enclosures, e.g. leaving them in a hot or cold environment all of a sudden, may increase the possibility of explosion.

C32: Maintenance by consumers
For installation of a glass shower enclosure, tracks and other types of hardware are necessary. Maintenance of hardware plays an important role in reducing the stress between the hardware and the glass.

2.3. Determination of Weight of Indicators
2.3.1 Building Hierarchical Structure Model
According to Table 1, a hierarchical structure model as shown in Figure 1.

![Figure 1. Hierarchical Model for Comprehensive Assessment of Explosion Risk of Glass Shower Enclosure Products](image)

2.3.2 Analytic Hierarchy Process (AHP)
In this paper, satty's 1-9 scale method is used to measure the weight between the two indexes. The relative weight of each indicator is calculated as shown in Table 2.

| index   | Weight | index   | Weight |
|---------|--------|---------|--------|
| C1      | 0.6442 | C14     | 0.0870 |
| C2      | 0.2706 | C21     | 0.1667 |
| C3      | 0.0852 | C22     | 0.8333 |
| C11     | 0.1037 | C31     | 0.8    |
| C12     | 0.3013 | C32     | 0.2    |
3. Comprehensive Assessment on Safety Risk of Glass Shower Enclosures Based on Dempster-Shafer (D-S) Evidence Theory

3.1. Dempster-Shafer (D-S) Evidence Theory

Dempster-Shafer (D-S) evidence theory is a reasoning method, which was first proposed by Dempster in 1967 and then developed and improved by his student Shafer. The expression of the uncertainty information by the D-S evidence theory accords with people's expression of an uncertainty incident. In addition, this approach has distinct advantages when it comes to the combination of uncertainty evidence [5].

In the D-S evidence theory, reasoning is built on a non-empty set Θ, which is composed of a mutually exclusive and exhaustive collection of elements. Let Θ be a frame of discernment, and the power set consisting of all propositions is denoted by \(2^\Theta\). Let \(m\) be a basic probability assignment (BPA) function, which should satisfy \(m:2^\Theta \rightarrow [0,1]\), then \(m\) is called the belief function on the frame of discernment \(\Theta\). \(m\) should satisfy \(\sum_{\Theta} m(A)= 1\), then \(m\) is called a BPA or mass function of the frame of discernment \(\Theta\). The degree of support of the mass function for Proposition \(A\) in the frame of discernment \(\Theta\) is expressed as \(m(A)\) [8].

The assessment on the explosion risk of glass shower enclosures is an uncertainty issue, which is represented by the D-S evidence theory as a probability issue to allow a reasonable interpretation of the risk uncertainty.

3.2. D-S Evidence Theory's Rule of Combination

(1) Combination rule for two items of evidence

After the BPA is obtained, two items of evidence are pooled using the Dempster's rule of combination in the D-S evidence theory, primarily the orthogonal sum of the two is computed.

Given two items of evidence \(E_1\) and \(E_2\) in the frame of discernment \(\Theta\), their corresponding BPA functions are \(m_1\) and \(m_2\), and focal elements are \(A_i\) and \(B_j\), respectively. Given that: \(K=\sum_{A \subseteq \Theta - \emptyset} m(A)m_j(B_j)\). Then the D-S combination rule is represented by:

\[
m(A) = \begin{cases} 
\sum_{B \subseteq \Theta - \emptyset} m(A)m(B) & A \neq \emptyset \\
1-K & A = \emptyset 
\end{cases}
\]

(1)

(2) Combination rule for multiple items of evidence

Given \(m_1, m_2, \ldots, m_n\) are n BPAs in the same frame of discernment \(\Theta\), and the focal elements are \(A_i(i=1,2,\ldots,N)\), then the D-S combination rule is represented by:

\[
m(A) = \begin{cases} 
\sum_{A \subseteq \Theta - \emptyset} m(A) & A \neq \emptyset \\
1-K & A = \emptyset 
\end{cases}
\]

(3)

(4)

In addition, considering that each item of evidence is of importance to decision-making at varying degrees, this paper resorts to Yager's basic idea of improving the D-S evidence theory's rule of combination, i.e. introducing the discounting rate to differentiate the evidence's degrees of importance. In general, the discounting rate is valued between 0.9 and 1.
3.3 Comprehensive Assessment of Safety Risk of Glass Shower Enclosures Based on Dempster-Shafer (D-S) Evidence Theory

Based on the hierarchical structure model as built above, the weight of each indicator is obtained through AHP. On this basis, the frame of discernment $\Theta$ in the D-S evidence theory is constructed and the weight of each indicator is converted using the discounting rate. Recursive combination of evidence is conducted based on the frame of discernment to obtain the mass value of the combined assessment indicators and make comprehensive assessment on the risk of the product.

4. Empirical Research

In this paper, glass shower enclosures of a certain model under a certain brand are chosen for empirical research.

4.1 Determination of Weight Set

Based on the weight of indicators as determined above, the weight of each indicator in overall ranking is as follows:

$$w_{c1} = \{0.1037, 0.3013, 0.508, 0.087\}$$
$$w_{c2} = \{0.1667, 0.8333\}$$
$$w_{c3} = \{0.08, 0.2\}$$

4.2 Assessment Process Based on D-S Evidence Reasoning

The explosion risk of glass shower enclosures is divided into five levels of assessment scale: very high, high, medium, low, and very low, which are expressed as $\Theta, \Theta, \Theta, \Theta, \Theta$, respectively, and the frame of discernment is expressed as $\Theta = \{\Theta, \Theta, \Theta, \Theta, \Theta\}$. 10 technical specialists from the glass shower enclosure industry and manufacturers and raw glass sheet manufacturers are invited to take part in the assessment on the explosion risk of the glass shower enclosure product. The risk assessment result of secondary indicators, as shown in Table 6, is obtained from the specialists.

| Secondary Indicator | Risk Assessment Result |
|---------------------|------------------------|
|                     | Very High | High | Medium | Low | Very Low |
| C11: Brand          | 0.2        | 0.3  | 0.3    | 0.2 | 0        |
| C12: Raw glass sheets | 0.1        | 0.22 | 0.5    | 0.18| 0        |
| C13: Tempering      | 0.15       | 0.3  | 0.25   | 0.2 | 0.1      |
| C14: Product design | 0.05       | 0.3  | 0.25   | 0.3 | 0.1      |
| C21: Logistics      | 0.2        | 0.2  | 0.3    | 0.25| 0.05     |
| C22: Installation   | 0.1        | 0.35 | 0.25   | 0.2 | 0.1      |
| C31: Use by consumers | 0.05      | 0.2  | 0.35   | 0.2 | 0.2      |
| C32: Maintenance by consumers | 0.1 | 0.2 | 0.25 | 0.25 | 0.2 |

In this paper, the discounting rate (a) is valued 0.9. Based on weight distribution, it can be known that C13, C22, and C31 are key indicators, and the discounting rate of the non-key indicators C11, C12, C13, and C14 in primary indicator C1 is 0.1837, 0.5338, 0.9000, and 0.1541, respectively. Based on the results shown in Table 7, the matrix of mass function of C1 is as follows:

$$M(c1) = \begin{bmatrix}
0.0367 & 0.0551 & 0.0551 & 0.0367 & 0.0000 & 0.8163 \\
0.0534 & 0.1174 & 0.2669 & 0.0961 & 0.0000 & 0.4662 \\
0.1350 & 0.2700 & 0.2250 & 0.1800 & 0.0900 & 0.1000 \\
0.0077 & 0.0462 & 0.0385 & 0.0462 & 0.0154 & 0.8459
\end{bmatrix}$$

The first combination is conducted based on formula 2 with the calculation result as follows:
\[ K = \sum_{A \cap B \neq \emptyset} m(A) m(B) = 0.0714 \]

\[ m(\theta) = 0.0675, m(\theta) = 0.1379, m(\theta) = 0.2781, m(\theta) = 0.1067, m(\theta) = 0 \]

Similarly, the second combination of the D-S evidence theory is conducted with the calculation result as follows:

\[ m(\theta) = 0.1192, m(\theta) = 0.2708, m(\theta) = 0.3059, m(\theta) = 0.1736, m(\theta) = 0.0618 \]

The third recursive combination of the D-S evidence theory is conducted to obtain the assessment matrix of primary indicator C1 for explosion of glass shower enclosures as follows:

\[ D(\theta) = \begin{bmatrix} 0.1149 & 0.2748 & 0.3067 & 0.1775 & 0.0609 \end{bmatrix} \]

Following the steps mentioned above, the assessment matrix corresponding to primary indicator set is obtained as follows:

\[ D(\theta) = \begin{bmatrix} 0.1149 & 0.2748 & 0.3067 & 0.1775 & 0.0609 \\ 0.0923 & 0.3128 & 0.2313 & 0.1834 & 0.0846 \\ 0.0453 & 0.1805 & 0.3174 & 0.1843 & 0.1805 \end{bmatrix} \]

### 4.3. Calculation of Comprehensive Assessment Value

Based on the weight of primary indicator, the discounting rate of C1, C2, and C3 is 0.9, 0.3781, and 0.1190, respectively. Therefore, the matrix system of mass function for the explosion risk of glass shower enclosures is expressed as:

\[ M(C) = \begin{bmatrix} 0.1034 & 0.2473 & 0.2760 & 0.1597 & 0.0548 & 0.1587 \\ 0.0357 & 0.1211 & 0.0895 & 0.0710 & 0.0335 & 0.6492 \\ 0.0054 & 0.0215 & 0.0378 & 0.0219 & 0.0215 & 0.8919 \end{bmatrix} \]

Similarly, based on Dempster's recursive combination algorithm, recursive combination is conducted twice to obtain the final calculation result of combination as follows:

\[ m_c(\theta^1) = 0.0960, m_c(\theta^2) = 0.2690, m_c(\theta^3) = 0.2869, m_c(\theta^4) = 0.1633, m_c(\theta^5) = 0.0573 \]

The results mentioned above show that the degree of belief is 9.6% for this model of glass shower enclosures whose explosion risk rated "very high", 26.9% for that rated "high", 16.33% for that rated "low", and 5.73% for that rated "very low". Based on the maximum membership principle, the explosion risk of the product is rated "medium".

### 5. Conclusion

Risk assessment of products is an uncertainty issue that involves a wide range of factors. The risk of products is not just originated from the products themselves. Based on the investigations and surveys conducted in the glass shower enclosure industry and manufacturers and in-depth discussions among the experts, this paper establishes an indicator system for explosion of glass shower enclosures, and conducts a comprehensive assessment on the explosion risk of glass shower enclosures with examples through combination and calculation of uncertainty based on the D-S evidence theory.

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### References

[1] LIN Lu-yao et al. Integration of 3D risk matrix with injury scenarios for assessing consumer product risks[J]. Journal of Safety Science and Technology, 2014, 10(04): 178-184.

[2] CAO We et al. Application of Risk Assessment in Inspection and Supervision of Imported
Industrial Products[J]. Journal of inspection and quarantine, 2018, 28(06): 39-42

[3] Xia Liu, Hongqi Luo. Risk Analysis of Chemical Hazard for Children's Toys[C]. The sixth annual meeting of Risk Analysis Committee of China Association for disaster prevention

[4] MI Hongpu et al. Research on the framework of fire risk assessment based on evidence theory[J]. Fire science and technology, 2018, 037(011): 1579-1582.

[5] Wan Jian Bao et al. Research on the framework of fire risk assessment based on evidence theory[J]. Industrial Buildings, 2010(S1): 94-99.

[6] Songqian. Risk management of subway construction based on D-S evidence theory - In the case of Qingdao Metro line 13[D]. Qingdao University of Technology

[7] Li Shuiquan. Research on fault diagnosis of rolling bearing in petrochemical unit based on BP neural network and D-S evidence theory [D]. South China University of Technology.

[8] Yang Siling et al. Safety risk assessment of prefabricated building construction based on entropy weight of structure and modified evidence theory[J]. Safety and environmental engineering, 2019(6).