Safety analysis and forecast of new energy vehicle fire accident

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Abstract: In recent years, due to the aggravation of air pollution and the exhaustion of coal and oil resources, new energy vehicles have achieved rapid development. However, new energy vehicles have many hidden dangers. Spontaneous combustion, explosion and other accidents often occur all over the world, which restrict the development of new energy vehicles. In this paper, the fault tree analysis method is used to qualitatively analyse the new energy vehicle, the accident diagram is obtained, the importance of each basic event is analysed, and the fuzzy decision method is used to predict the fire accident of new energy vehicle.

1. Introduction
After more than 20 years of rapid development, China's new energy vehicles have been completed from the initial research and development to production to the final market sales.[1] With the shortage of traditional energy and the problem of environmental pollution is becoming increasingly urgent, the world has already turned its attention to new energy, new energy vehicles have attracted wide attention, especially in recent years, the number of new energy vehicles has increased rapidly.[2] However, new energy vehicles have many hidden dangers, spontaneous combustion, explosion and other accidents often occur all over the world. Some time ago, Tesla cars had spontaneous combustion. This is not the first time that Tesla cars have caught fire. From 2013 to 2014, there were 6 fire accidents of Tesla new energy vehicles. [3] So this article is based on the above situation, dangerous and harmful factors of new energy vehicles identification, analysis, assessment and prediction of new energy vehicles the danger of fire accident.

2. Fire accident analysis of new energy vehicles

2.1. Fire accident cause statistics
New energy vehicles refer to all other energy vehicles in addition to the traditional petroleum and coal energy vehicles. However, fire accidents of new energy vehicles have always occurred. As can be seen from Table 1, most of the fire causes of the 8 accidents are related to spontaneous combustion. According to the data in Table 1, we can draw the corresponding line chart 1, and we can clearly see the change of the number of fire accidents from month to month.

| Time   | Place   | Brand     | Vehicle type | Dynamic type | Cause of the fire                  | number |
|--------|---------|-----------|--------------|--------------|------------------------------------|--------|
| 2018.1 | Chongqing| Tesla     | Passenger car| Pure electric| No charge, no collision and fire    | 1      |
| 2018.5 | Anhui   | Other     | Passenger car| Pure electric| Charge combustion                  | 1      |
| 2018.5 | Other   | Wild horses| Passenger car| Pure electric| Charge combustion                  | 1      |
Figure 1. Monthly distribution of new energy vehicle accidents from January to June 2018.

As can be seen from the figure 1, there were no new energy vehicle fire accidents in February, March and April in the first half of 2018, but there were 7 fire accidents after May. This indicates that accidents are more likely to occur in summer, and temperature is also a major factor.

2.2. Fault tree analysis

Fault tree is a kind of safety system analysis method which uses logical deduction method to gradually find out the cause of accident from the result, and at the same time, safety countermeasures can be found to prevent and reduce the occurrence of accident.[4] Fault tree analysis is generally divided into the following steps, as shown in Figure 2:

(a) Basic event determination
According to the analysis of new energy vehicle fire accidents, 8 intermediate events and 13 basic events that may cause new energy vehicle fire and explosion are determined.[5] Events are shown in Table 2.

(b) Draw the accident tree, as shown in Figure 3.

Table 2. Fire causes of new energy vehicles

| Serial number | The event                          | Serial number | The event                                      |
|---------------|-----------------------------------|---------------|-----------------------------------------------|
| $T$           | New energy vehicles caught fire   | $X_3$         | Short circuit between positive and negative poles |
| $A_1$         | Charging a fire                   | $X_4$         | Charging time is too long                      |
| $A_2$         | Collision of fire                 | $X_5$         | The collision of the car produced sparks       |
| $A_3$         | Flooding is on fire               | $X_6$         | Cars gain considerable momentum at high speeds |
| $A_4$         | Fire in the stop state            | $X_7$         | The battery pack has been squeezed out of shape |
| $B_1$         | The cell difference is larger     | $X_8$         | The cooling system stops working and heat accumulates locally |
| $B_2$         | Battery rupture short circuit     | $X_9$         | The radiant heat of the ground is absorbed by the battery pack |
| $B_3$         | Short circuit in the internal cell| $X_{10}$      | Battery box seal is not up to standard         |
| $C$           | Rain-corroded parts               | $X_{11}$      | The vehicle is soaked too long                 |
| $X_1$         | Battery substandard               | $X_{12}$      | Water pressure compresses the battery pack seals |
| $X_2$         | BMS monitoring failure            | $X_{13}$      | A lightning strike                             |
(c) Determine the structure function
Structure function of accident tree
With the gate accident tree structure function:

$$\emptyset(X) = x_1, x_2, \ldots, x_n = \prod_{i=1}^{n} x_i$$  \hspace{1cm} (1)

Or gate accident tree structure function:

$$\emptyset(X) = 1 - (1 - x_1)(1 - x_2) \ldots (1 - x_n) = 1 - \prod_{i=1}^{n} (1 - x_i)$$  \hspace{1cm} (2)

By analyzing the possible accidents of new energy vehicles, the logical relationship between the causes of accidents is determined. The accident tree of new energy vehicles is shown in the figure. The minimum cut set of the accident tree of new energy vehicles is analyzed by Boolean algebra method, and the structure function is as follows:

\[
T = A_1 + A_2 + A_3 + A_4 = X_1 + B_1 + X_7 + B_2 + X_5 + X_6 + X_9 + B_3 + X_{13} \\
= X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_9 + X_{10} + C + X_{13} \\
= X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_9 + X_{10} + X_{11} + X_{12} + X_{13}
\]

(d) Calculation of minimum cut set
The method of finding the minimum cut set
The simplest and more common method is Boolean algebra method. Starting from the top event and working down, all logic gates are expanded into basic events. Finally, the logical sum of the logical products of several basic events is obtained, and each logical product is a minimum cut set.

By analyzing the 11 basic events of the accident tree, 9 minimum cut sets can be obtained, as shown in Table 5. Therefore, there are many ways that may lead to the accident of new energy vehicles, and the system risk is high.

| The serial number | The minimum cut set                     | The serial number | The minimum cut set |
|-------------------|----------------------------------------|-------------------|---------------------|
| 1                 | \( \{X_1\} \)                           | 6                 | \( \{X_9\} \)       |
| 2                 | \( \{X_2, X_3, X_4\} \)                | 7                 | \( \{X_{10}\} \)    |
3. Importance analysis

After the minimum cut set of the accident tree is obtained, the structural importance of each basic event is determined as follows:

\[ I_{\Phi(i)} = \sum_{X_j \in k_j} \frac{1}{n_j-1} \]

where \( I_{\Phi(i)} \) is the structural importance of the \( i \)th basic event; \( k_j \) is the minimum total number of cut sets; \( n_j \) is the total number of all basic events in \( k_j \) where the \( i \)th basic event is located.

The structural importance coefficient of basic events is determined by the structural importance formula of the minimum cut set, and the order of structural importance of each basic event is obtained:

\[ I_{\Phi(1)} = I_{\Phi(5)} = I_{\Phi(8)} = I_{\Phi(9)} = I_{\Phi(10)} = I_{\Phi(13)} > I_{\Phi(6)} = I_{\Phi(7)} = I_{\Phi(11)} = I_{\Phi(12)} > I_{\Phi(2)} = I_{\Phi(3)} = I_{\Phi(4)} \]

As it turns out, \( X_{1} \), \( X_{5} \), \( X_{8} \), \( X_{9} \), \( X_{10} \), \( X_{13} \), Six basic events are of the greatest importance, which are substandard battery, spark generated by vehicle collision friction, local heat accumulation when the cooling system stops working, large amount of heat absorbed by the battery pack due to the influence of ambient temperature on ground radiation, sealing of the battery box failing to meet waterproof requirements, and lightning strike.

Therefore, the relevant departments to strengthen supervision of quality control, the driver should be alert when driving to prevent automobile collisions, regularly check the cooling system as much as possible, vehicles parked in a cool and ventilated place, manufacturer shall pay the relevant taxes in accordance with the production of battery box, the thunderstorm weather don’t parked the car under the tree and don't open the power supply, etc.[6]

3. Safety prediction of new energy vehicle accidents based on fuzzy decision method

Fuzzy decision method is to quantify the fuzzy safety information with the method of fuzzy mathematics, so that we can evaluate and make decisions on many factors. Fuzzy safety information is a qualitative term related to safety, such as high probability, low probability and low probability or catastrophic, dangerous, critical, etc. Fuzzy decisions can be used to measure risk with a concrete real number.[7]

(a) Setting up Factor Set

Factor set: the various factors that can influence the system security of the required decision are constituted as a set of elements, which is represented by \( U \), namely:

\[ U = \{u_1, u_2, \ldots, u_n\} \]  

Among them: \( u_i \) (i=1,2,\ldots,n) Represents each influencing factor

Factors affecting the safety of new energy vehicles generally include: \( u_1 \) — The car caught fire while charging; \( u_2 \) — Car crash fire; \( u_3 \) — The car soaked in water and caught fire; \( u_4 \) — Affected to be ignited. These 4 factors can constitute the risk factor set, namely: \( U = \{u_1, u_2, u_3, u_4\} \)

(b) Setting up a weight set

Since each factor in factor set \( U \) has different influence degrees on system security, in order to express the influence degrees of different factors, Each factor needs to be given corresponding weights, and the set composed of each weight is called the weight species set \( A \), namely:

\[ A = \{a_1, a_2, \ldots, a_n\} \]  

Among them, each weight should satisfy: \( \sum_{i=1}^{n} a_i = 1 \) (\( a_i \geq 0 \))

The weight set of new energy vehicle fire accident is determined as: \( A = (0.5,0.2,0.2,0.1) \)

(c) Setting up a judgment set
The judgment set refers to that the factor set receives the judgment of the evaluator, and then the comments of each evaluator on the factor set are treated as elements to form a set, which is represented by $V$, namely:

$$V = \{v_1, v_2, \ldots, v_n\}$$ (6)

The general comments on fire accidents of new energy vehicles are determined as high risk, large, average and small, that is, the evaluation set is:

$$V = \{v_1 \text{ (large)}, v_2 \text{ (larger)}, v_3 \text{ (general)}, v_4 \text{ (small)}\}$$

(d) Single factor fuzzy evaluation

First, an influence factor is evaluated to determine the importance of an evaluation object to the elements of the evaluation set. Then, the corresponding factors are evaluated separately. Finally, the evaluation set of each factor is formed into a matrix, which is the evaluation matrix:

$$R = \begin{pmatrix}
    r_{11} & \cdots & r_{1m} \\
    \vdots & \ddots & \vdots \\
    r_{n1} & \cdots & r_{nm}
\end{pmatrix}$$

The evaluation of various factors, after investigation, such as $u_1$—Evaluation of the likelihood of a fire occurring while charging a car, 50% said it's big, 30% said it was larger, 10% said it was average, 10% said it's small, The judgment set is as follows: $(0.5, 0.3, 0.1, 0.1)$

Similarly, a judgment set of the other three factors can be obtained, $u_2$—The evaluation set for a car crash fire is: $(0.3, 0.2, 0.2, 0.3)$

$u_3$—The judgment set for a car flooding fire is: $(0, 0.1, 0.4, 0.5)$

$u_4$—The critical set affected and ignited is: $(0.4, 0.4, 0.1, 0.1)$

The evaluation set of these four factors is composed of the evaluation matrix:

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

(e) Fuzzy comprehensive decision making

The fuzzy comprehensive decision is the decision matrix $R$, and then consider the importance of each factor, namely, is the weight set $A$, then the fuzzy comprehensive decision $B$ is:

$$B = AR$$ (8)

The fuzzy comprehensive decision-making model of fire risk of new energy vehicles is as follows:

$$B = (0.5, 0.2, 0.2, 0.1) \cdot \begin{pmatrix}
    0.5 & 0.3 & 0.1 & 0.1 \\
    0.3 & 0.2 & 0.2 & 0.3 \\
    0 & 0.1 & 0.4 & 0.5 \\
    0.4 & 0.4 & 0.1 & 0.1
\end{pmatrix}^T$$

$$= \begin{pmatrix}
    (0.5 \cap 0.5) \cup (0.2 \cap 0.3) \cup (0.2 \cap 0) \cup (0.1 \cap 0.4) \\
    (0.5 \cap 0.3) \cup (0.2 \cap 0.2) \cup (0.2 \cap 0.1) \cup (0.1 \cap 0.4) \\
    (0.5 \cap 0.1) \cup (0.2 \cap 0.2) \cup (0.2 \cap 0.4) \cup (0.2 \cap 0.5) \\
    (0.5 \cap 0.1) \cup (0.2 \cap 0.3) \cup (0.2 \cap 0.5) \cup (0.1 \cap 0.1)
\end{pmatrix}^T$$

$$= \begin{pmatrix}
    0.5 \cup 0.2 \cup 0 \cup 0.1 \\
    0.3 \cup 0.2 \cup 0.1 \cup 0.1 \\
    0.1 \cup 0.2 \cup 0.2 \cup 0.2 \\
    0.1 \cup 0.2 \cup 0.2 \cup 0.1
\end{pmatrix} \cdot \begin{pmatrix}
    0.5 \\
    0.3 \\
    0.2 \\
    0.2
\end{pmatrix} = (0.41, 0.25, 0.17, 0.17)$$

Due to the $0.5 + 0.3 + 0.2 + 0.2 = 1.2$. In order to find the percentage, the normalization process is performed, namely:

$$B' = \frac{1}{1.2} \begin{pmatrix}
    0.5 \\
    0.3 \\
    0.2 \\
    0.2
\end{pmatrix} = (0.41, 0.25, 0.17, 0.17)$$

It can be seen from the formula that the comprehensive decision of the four factors affecting the new energy vehicle fire is as follows: 41% people think such accidents are very dangerous, 25% people think relatively dangerous, 17% people think the danger is average, and 17% people think there is no danger.
4. Conclusion
Through the analysis and assessment of the risk and harmful factors of new energy vehicles and the prediction of the risk of fire accidents of new energy vehicles, the research contents of this paper are as follows:

(a) Through the statistics and analysis of the cause of new energy vehicle fire, the accident tree is used for analysis and evaluation, the minimum cut set of the accident and the structural importance of the basic event are found out, and the corresponding measures are proposed according to the impact degree. In other words, the quality supervision department should strengthen supervision, the driver should be vigilant when driving, the manufacturer should produce the battery box in accordance with the requirements, and do not park the car under a tree or turn on the power in thunderstorm weather, etc.

(b) The fire accident of new energy vehicle is predicted by fuzzy decision method. Focusing on the analysis of the four factors affecting car fire, the factor set and the judgment set are establish. First, a single factor is evaluated, and then the four factors are evaluated together. It can be seen that most people, that is, 66% of people think that new energy vehicle fire is a relatively dangerous accident.

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