Fire Risk of Electric Bicycle Based on Fuzzy Bayesian Network

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Abstract. Frequent fire incidents on electric bicycles; have brought great harm to consumers' personal and property safety. This article sort and analyze the data, combine the collected accident reports of electric bicycles. Due to the incompleteness of the data, this article use Bayesian Network to construct the Bayesian network topology model of electric bicycles fire risk, use fuzzy set theory to solve Fuzzy computing the language discussed by experts. Finally, the fuzzy Bayesian theory is used to calculate the example, and the fire risk of the electric bicycle in the example is low. This method provides a reference for the accident investigation and analysis of electric bicycles.

Keywords: Bayesian Network, Triangular Fuzzy Number, Electric Bicycle, Risk

1. Introduction
Electric bicycles use batteries as auxiliary power sources. It is an important means of transportation for people to travel. At present, there are about 250 million electric bicycles in China. In recent years, the safety of electric bicycles has attracted great attention from relevant departments, industries, enterprises and consumers. The hazards are mainly reflected in traffic safety and fire accidents. According to the statistics of the Emergency Management Department, there are 7 major fires caused by electric bicycles, which are in the fire accident statistics in 2019. The proportion of fires caused by electric vehicles in urban and rural houses is relatively large, posing a great threat to people's life and property safety.

Fire accidents caused by electric bicycles have attracted great attention from relevant departments. In April 2019, the new mandatory national standard GB 17761-2018 "Safety Technical Specifications for Electric Bicycles" was officially implemented. The State Administration of Market Supervision, the Ministry of Industry and Information Technology, and the Ministry of Public Security and other three departments jointly triggered the "Opinions on Strengthening the Implementation of National Standards for Electric Bicycles." The opinion proposed to strengthen electric bicycle production management, sales supervision, registration management and so on. The State Administration of Market Supervision proposed to strengthen the management of compulsory product certification (CCC) for electric bicycles.
In view of the fire risks caused by electric bicycles, some scholars have analyzed their causes in conjunction with fire investigations. Rao Qiufei pointed out that inferior products are flowing into the market, battery and charger failures are the main reasons for electric bicycles. He analyzes the difficulties in investigating electric bicycle fires [1]. Feng Changxi analyzed overcharge performance of the lithium-ion battery and electric short circuit among the reasons for the electric bicycle fire [2]. Chu Futao pointed out that the unbalanced battery capacity of the battery of electric bicycles, the non-flammable battery casing, and the irregular battery wiring are the main reasons for the fire [3]. Yuan Linyan analyzed the quality problems of electric bicycles in China, combined with the results of China's supervision and random inspection and national standards [4]. At the same time, some scholars have studied the fire hazards of electric bicycles through experiments. For example, Han Zizhong has studied the heat release rate, flame spread, smoke temperature and spread through physical fire tests [5].

It can be seen from the above introduction that the supervision of new electric bicycle products is more comprehensive. However, there are relatively few quantitative studies on the fire risk of existing 250 million electric bicycles. In this paper, a Bayesian network is used to construct a topological model of electric bicycle fire risk, so as to provide a reference for related departments and researchers.

2 Survey Data Analysis

Based on the collected 119 electric bicycle fire incidents in 2019, statistics and analysis are made on the state and time of the fired train vehicles, as shown in Figure 1-2.

**Fig 1** Statistics of vehicle status when an electric bicycle is on fire

- Fire while charging: 88, 74%
- Fire while driving: 14, 12%
- Fire when standing: 16, 13%
- Unknown state of fire: 26, 22%

**Fig 2** Statistics of vehicle status when an electric bicycle catches fire

- 0:00-7:00: 63, 53%
- 7:00-12:00: 16, 13%
- 12:00-19:00: 14, 12%
- 19:00-24:00: 10, 8%

The results show that:

1. 88 accidents occurred while the electric bicycle was being charged. This reflects that the fire accident has a great relationship with the charger and battery.
2. 63 incidents occurred in the early morning, when most batteries were in an overcharge.
3. The vehicle spontaneously ignites during driving, which is related to the battery and wiring settings.
(4) Irregular charging behavior is also one of the potential safety hazards.
(5) It can be seen from the investigation of some fire accidents that non-original batteries and chargers, and unmatched chargers are also important safety risks.

Electric bicycles are durable consumer goods. The sources of risk include batteries, chargers, wiring arrangements, and so on. The product's useful life, charging conditions, and riding environment also have a certain impact on the risk sources. For example, bad road conditions may cause loose components in the battery, charger, and wiring settings during cycling.

3 Bayesian Network Model Construction

3.1 Bayesian Network
Bayesian Network (BN) constructs a directed graph to express the relationship between variables in an accident, making the expression and reasoning of uncertain relationships between node variables more intuitive and clear [6-8].

Suppose there are n variables, \( X_1, X_2, X_3, \ldots, X_n \), the joint distribution \( P \) with n variables is \( P(X_1, X_2, X_3, \ldots, X_n) \), \( P \) can be expressed as:

\[
P(X_1, X_2, X_3, \ldots, X_n) = \prod_{i=1}^{n} P(X_i | X_1, X_2, X_3, \ldots, X_{i-1})
\]  

(1)

Assume for any \( X_i, \pi(X_i) \in \{X_1, X_2, X_3, \ldots, X_{i-1}\} \), under given conditions \( \pi(X_i) \), the other variables are independent of each other, in \( X_i \) and \( \{X_1, X_2, X_3, \ldots, X_{i-1}\} \), equation 1 can be changed to:

\[
P(X_1, X_2, X_3, \ldots, X_n) = \prod_{i=1}^{n} P(X_i | \pi(X_i))
\]  

(2)

Electric bicycle is a product that integrates controller, electric circuit, battery power and vehicle. The product fire accident is not a one-to-one mapping relationship with a component failure, but shows the uncertainty relationship between the accident and the failure of each component. Utilizing the superiority of Bayesian analysis for uncertainty, the fire of electric bicycle is the top event T. This paper constructs a Bayesian network model of the fire risk of electric bicycles. Based on comprehensive survey data analysis, this paper constructs a Bayesian network topology model from multiple perspectives, such as batteries, chargers, circuit layouts, flame-retardant materials, and charging conditions, as shown in Fig 3. The codes and meanings of basic events and intermediate events are shown in Table 1.

![Fig 3 Bayesian network topology of electric bicycle fire risk](image-url)
2. Factors.

"Very environment original bicycles Using 4 theory, the operation of Bayesian network needs to determine the prior probability and conditional probability of the corresponding nodes with the help of sample data. However, in practice, data is often incomplete, and some events are even difficult to quantify. This paper mainly uses the fuzzy set theory proposed by the American Zadeh. With the help of fuzzy set theory and Bayesian network theory, the feasibility of inference calculation is improved.

3.2 Fuzzy Bayesian Network

The empirical research needs to determine the prior probability and conditional probability of the corresponding nodes with the help of sample data. However, in practice, data is often incomplete, and some events are even difficult to quantify. This paper mainly uses the fuzzy set theory proposed by the American Zadeh. With the help of fuzzy set theory and Bayesian network theory, the feasibility of inference calculation is improved.

4 Empirical Research

Using the established Bayesian network fire risk topology model, analyze the fire risk of electric bicycles in use by a brand. This vehicle has been purchased and used for 6 years. The charger is an original charger, and the battery is a non-original battery. Cycling roads are urban roads. The charging environment is mixed with the charging pile and plug-in board.

The risk of electric bicycle fire is difficult to express with exact values. This article introduces "very low, low, few low, medium, few high, high, very high" to indicate the level of risk of various factors. At the same time, one-to-one correspondence with triangular fuzzy numbers is shown in Table 2.

Table 1 Event codes and meanings

| Code | Event | Code | Event | Code | Event |
|------|-------|------|-------|------|-------|
| T    | Electric bike catches fire | X3   | Loose components inside the charger | X10  | Battery case is not flame retardant |
| A    | Charger failure | X4   | Charger does not match battery | X11  | Insulation failure in wiring arrangement |
| B    | Battery failure | X5   | Battery aging | X12  | Insufficient creepage distance in route layout |
| C    | Line layout failure | X6   | Battery overcharge | X13  | Loose connector in wiring arrangement |
| D    | Charging failure | X7   | Unbalanced battery cell capacity | X14  | The patch panel connected during charging is faulty |
| X1   | Charger case is not flame retardant | X8   | Battery pack connecting wire with small copper diameter | X15  | Charging pile failure during charging |
| X2   | Charger fan failure | X9   | Battery pack wiring is not standard | X16  | Failure to use flying leads while charging |

Table 2 Correspondence between evaluation set and triangular fuzzy number

| Risk level | Triangle fuzzy number | Probability range |
|------------|-----------------------|-------------------|
| very low   | (0.0 0.0 0.1)         | [0, 1%)           |
| low        | (0.0 0.1 0.3)         | [1%, 10%)         |
| few low    | (0.1 0.3 0.5)         | [10%, 33%)        |
| medium     | (0.3 0.5 0.7)         | [33%, 66%)        |
| few high   | (0.5 0.7 0.9)         | [66%, 90%)        |
| high       | (0.7 0.9 1.0)         | [90%, 99%)        |
| very high  | (0.9 1.0 1.0)         | [99%, 100%]       |
In combination with the charger, battery, circuit layout, and charging conditions of the electric bike mentioned above, 7 expert groups were invited to evaluate the probability of occurrence of 18 evidence nodes. After averaging, the triangle fuzzy number statistics table of expert rating is obtained, as shown in Table 3. Then, the triangle fuzzy number is calculated using the mean area formula. The normalized conditional probability of each node is shown in Table 4.

**Table 3** Triangular fuzzy mean statistics of root event occurrence probability

| node | Mean of triangular fuzzy numbers | node | Mean of triangular fuzzy numbers |
|------|--------------------------------|------|--------------------------------|
| X1   | (0.33 0.53 0.73 )              | X9   | (0.27 0.36 0.44 )              |
| X2   | (0.20 0.39 0.59 )              | X10  | (0.36 0.56 0.76 )              |
| X3   | (0.16 0.36 0.56 )              | X11  | (0.47 0.67 0.87 )              |
| X4   | (0.07 0.21 0.41 )              | X12  | (0.16 0.36 0.56 )              |
| X5   | (0.56 0.76 0.93 )              | X13  | (0.16 0.36 0.56 )              |
| X6   | (0.59 0.79 0.94 )              | X14  | (0.56 0.76 0.91 )              |
| X7   | (0.30 0.50 0.70 )              | X15  | (0.07 0.24 0.44 )              |
| X8   | (0.07 0.24 0.44 )              | X16  | (0.87 0.99 1.00 )              |

**Table 4** Evidence node conditional probability statistics

| node | Fault | OK | node | Fault | OK |
|------|-------|----|------|-------|----|
| X1   | 0.53  | 0.47 | X9   | 0.36  | 0.64 |
| X2   | 0.39  | 0.61 | X10  | 0.56  | 0.44 |
| X3   | 0.36  | 0.64 | X11  | 0.67  | 0.33 |
| X4   | 0.23  | 0.77 | X12  | 0.36  | 0.64 |
| X5   | 0.75  | 0.25 | X13  | 0.36  | 0.64 |
| X6   | 0.78  | 0.22 | X14  | 0.75  | 0.25 |
| X7   | 0.50  | 0.50 | X15  | 0.25  | 0.75 |
| X8   | 0.25  | 0.75 | X16  | 0.96  | 0.04 |

Combined with the accident investigation statistics introduced earlier, expert judgment is used to determine the conditional probability of the node. The prior probabilities of the obtained evidence nodes and the conditional probabilities of the four nodes judged by the experts are input into the Bayesian network. The fire risk of the vehicle was reasoned through Bayesian network, and the fire risk of the product was calculated to be 1.44%, as shown in Fig 1. The risk level of this product is low, in accordance with the classification principle in Table 2. Assume that a fire event has occurred in the product. The parent nodes with a large posterior probability are using of flying leads during charging, overshoot of the battery, failure of the patch panel connected during charging. Their posterior probability is more than 75%. Secondly, the parent nodes with larger posterior probability are aging of the battery and insulation failure in the wiring arrangement. Their posterior probability ranges from 60% to 75%.
5 Conclusion
This paper constructs a Bayesian network topology model of electric bicycle fire risk, from the perspective of products and usage habits. Based on accident investigation and literature analysis, combined with fuzzy set theory and expert decision-making methods, define the prior probability and conditional probability of evidence nodes in Bayesian networks. With the help of Bayesian basic theory, the risk level of the target event is calculated. This method provides a reference for calculating the fire risk of electric bicycles.

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References

[1] Rao qiufei, Li Shanqi. Analysis of fire causes of electric bicycles and Discussion on key points of fire investigation technology [J]. Fire fighting technology and product information, 2016(10):65-67

[2] Feng Changxi. Analysis on the fire of battery and charger of electric bicycle [J]. Fire Services Journal of the day,2019,4(05):42-43.

[3] Zhu Futao. Analysis on the factors causing the electric fire of electric bicycle [C]. Annual meeting of science and technology of China Fire Protection Association(2014)

[4] Yuan Linyan,Zhao Lei,Zhao Xia. Safety and quality analysis of electric bicycle in China [J]. Quality and standardization,2019(09):38-41.

[5] Han Zizhong,Zhao Shuxue,Liu Yaxuan. Experimental study on fire hazard of electric bicycle [C]. Annual meeting of science and technology of China Fire Protection Association (2018)

[6] XIAO Zhongming,WANG Xinjian,ZHANG Wenjun.Analysis for the ship grounding accidents based on the Bayesian network model[J].Journal of Safety and Environment,2017,17(2):418-421.

[7] MA Qingchun,ZHANG Jiwang,ZHANG Laibin. Accident analysis of fire and explosion in gas station based on improved Bayesian network [ J ] . Journal of Safety Science and Technology,2014. 10 ( 6):176-182.

[8] HUANG Guo-zhong,JING Li-wen,XIE Zhi-li. On the chance probability of the stalling accidents in self-balancing vehicles based on the fuzzy Bayesian network[J]. Journal of Safety and Environment,2018,18(06):2081-2085.