Analysis of Subway Fire Accident Based on Bayesian Network

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Abstract. Subway stations and trains are densely populated public places. Once fire breaks out, it will cause casualties and seriously threaten people's life and property safety. In order to explore the deep causes of subway fire and prevent subway fire accidents, this paper makes statistics on the causes of subway fire in various countries in recent years and classifies them. On this basis, the Bayesian network for subway fire causes is constructed, the probability of subway fire occurrence and the posterior probability of each basic event are calculated by using the prior probability of each basic event, and the corresponding safety management measures are proposed. The results show that the method can find out the probability of each basic event in subway fire by quantitative calculation, and the method is scientific and effective, which can provide reference for subway safety management.

Keywords. Subway fire, Bayesian network, Minimum path set, Safety management measures.

1. Introduction

Urban rail transit, with its characteristics of green, environmental protection, energy saving and speed, has become the framework and main form of urban transportation development together with conventional public transportation. In recent years, China's urban rail transit construction has entered a period of rapid development, and it is the country with the fastest development and largest scale of rail transit in the world. Due to the advantages of fast speed, high punctuality rate and high safety, people tend to choose the subway when they travel. Subway stations and trains are densely populated public places. Once a fire breaks out, it will cause serious social impact and threaten people's life safety. Therefore, fire prevention in subway is very important.

Bayesian network is a tool for applying probability statistics to complex fields, performing uncertain reasoning and data analysis. Bayesian networks can be studied without complete data. Zhi-jun Liu [1] and others used Bayesian network to analyze the ship engine room fire. Volkan Sevinc [2] and others used Bayesian network models to predict the possible causes of forest fires, and analyzed the multilateral interaction between them. Beatriz Molina-Serrano [3] and others used the Bayesian network to analyze the sustainability parameters of port operations and management, so that the best decisions can be made to enable the port to carry out sustainable planning and development.

In the research on subway fire accidents, Sun Yong [4] and others analyzed the Subway fire in Daegu in South Korea, A tunnel fire that occurred in Kapulun in Austria, and fire in Luxor Metro in Egypt. Lei Peng [5] used fuzzy analytic theory to evaluate subway stations Fire risk, multi-level analysis and research on subway station fires, and the established comprehensive evaluation index system can reflect the impact of various factors on subway station fire risk. Wen-yu Yan [6-7] and other used the system dynamics model to analyze the causes of subway fires and gave correlation equations reflecting the relationships between variables.
This article makes statistics on the causes of subway fires in countries around the world as a basis for constructing Bayesian networks. By calculating the probability of the top event and the posterior probability of each basic event through the reasoning ability of the Bayesian network, the cause of the subway fire is obtained, and the corresponding safety management measures are proposed to provide a decision basis for the prevention of subway fire.

2. Characteristics of Subway Fire Accidents

2.1. Difficulties in Evacuation and Difficulty in Rescue
Subway is usually built about 10 meters underground, with a large vertical height with the ground. Since most passengers are not very familiar with the layout of the fire passage in the subway, it will be difficult to evacuate if a fire breaks out. At the same time, due to the lack of access, it will also affect the access of firefighters and large fire equipment.

2.2. Few Escape Routes for the Subway
Except for a small number of fire exits, there are only step ladders, escalators and vertical elevators for disabled persons. When a fire occurs, the personnel at the station enter these escape routes at the same time, which can lead to congestion of the escape routes and even trampling.

2.3. The Fire Spread Quickly
Because the subway tunnel has good ventilation conditions, a large amount of fresh air enters the tunnel after the fire, which promotes the spread of the fire. Studies have shown that the ignition time of the train when the tunnel is on fire is about 5 min.

2.4. Short Escape Time
Because the subway station is relatively closed, a large amount of smoke will quickly gather in the station after the fire, and the oxygen concentration in the station will be reduced. Therefore, passengers need to leave the station in a very short time, otherwise it will cause breathing difficulties and even coma.

3. Bayesian Network
Bayesian network is a probabilistic technology based on the combination of graph theory and probability theory. It consists of nodes and directed edges, which represent the variables and logical relationships between the nodes. The node includes a parent node and a child node, and the connection strength between the nodes is determined by a conditional probability.

Let N and E be two random variables, N = n is a certain hypothesis, D = d is a set of data. When D = d is not considered, the probability estimated P (N = n) of the event N = n is called a priori probability. When considering the D = d condition, the probability estimate P (N = n | D = d) of the event N = n is called the posterior probability. Bayes' theorem is shown in equation (1).

\[
P(N = n | D = d) = \frac{P(N = n)P(D = d | N = n)}{P(D = d)}
\]

In the formula: P (N = n | D = d) is the likelihood of N = n, which is written as L (N = n | D = d).

4. Construct a Bayesian Network of Subway Fires

4.1. Cause of Fire
General accidents are caused by unsafe behaviors of people or unsafe conditions of subways. The occurrence of subway fire accidents is no exception. We have collected statistics and classified the causes of subway fire accidents that have great influence at home and abroad. The results obtained are shown in table 1.
### Table 1. Subway fire risk analysis

| Code and name                                                                 | Node code | Node name                                           |
|-------------------------------------------------------------------------------|-----------|-----------------------------------------------------|
| $A_1$ Fire caused by human behavior                                           | $X_1$     | Arson                                               |
| $B_1$, Mechanical equipment failure                                           | $X_2$     | Terrorist attacks                                   |
| $A_2$ Fire caused by equipment failure                                         | $X_3$     | The train caught fire after derailment              |
| Spark a fire                                                                  | $X_4$     | The train caught fire                               |
| $B_2$, Electrical equipment cause                                             | $X_5$     | Short circuit and fire                              |
| $A_3$ Accidental fire                                                         | $X_6$     | Transformer, current collector, equipment room caught fire |
| $A_4$ Fire caused by human behavior                                           | $X_7$     | Overheated air conditioner                          |
| $X_8$ Cigarette butt does not go out                                          | $X_9$     | Garbage burning                                     |
| $X_{10}$ Seat caught fire                                                     | $X_{11}$  | Other decoration materials                          |
| $X_{12}$ Staff leave the post or fire skills are unqualified                  | $X_{13}$  | Insufficient or invalid fire-fighting equipment     |
| $X_{14}$ Staff leave the post or fire skills are unqualified                  | $X_{15}$  | Insufficient or invalid fire-fighting equipment     |

#### 4.2. The Establishment of Bayesian Network

By analyzing the relationship between top events, intermediate events, and basic events, a conditional probability table of Bayesian network, each intermediate event, and top events is formed, as shown in figure 1 and table2:

![Figure 1](image-url)  

**Figure 1** Cause analysis of subway fire Bayesian network.
Table 2. Conditional probability table of fire caused by human behavior.

| $X_1$ | State0 | State1 | State0 | State1 |
|-------|--------|--------|--------|--------|
| $X_2$ | State0 | 1      | 1      | 1      |
|       | State1 | 0      | 0      | 0      |

By calculating the proportion of the frequency of each basic event to the total frequency of the event, the prior probability of the basic event can be obtained, as shown in Table 3. The probability of each intermediate event and the top event can be calculated by using the forward thrust computing capacity of the Bayesian network model and the software GeNIe2, as shown in Table 4.

Table 3. Prior probability of basic events.

| Code | Name                                      | Priori probability |
|------|-------------------------------------------|--------------------|
| $X_1$ | Node name                                 | 0.091              |
| $X_2$ | Arson                                     | 0.073              |
| $X_3$ | Terrorist attacks                         | 0.034              |
| $X_4$ | The train caught fire after derailment    | 0.021              |
| $X_5$ | The train caught fire                     | 0.293              |
| $X_6$ | Short circuit and fire                    | 0.111              |
| $X_7$ | Transformer, current collector, equipment room caught fire | 0.014 |
| $X_8$ | Overheated air conditioner                | 0.015              |
| $X_9$ | Cigarette butt does not go out            | 0.015              |
| $X_{10}$ | Garbage burning                          | 0.009              |
| $X_{11}$ | Seat caught fire                         | 0.018              |
| $X_{12}$ | Other decoration materials caught fire    | 0.056              |
| $X_{13}$ | Defective or malfunctioning fire protection system design | 0.463 |
| $X_{14}$ | Insufficient or invalid fire-fighting equipment | 0.347 |

Table 4. Probability of intermediate events and top events.

| Event type   | Node code and name                      | Probability of occurrence |
|--------------|-----------------------------------------|---------------------------|
| $A_1$        | Fire caused by human behavior           | 0.157                     |
| $A_2$        | Fire caused by equipment failure        | 0.414                     |
| $A_3$        | Accidental fire                         | 0.056                     |
| Intermediate event | $B_1$ Mechanical equipment             | 0.054                     |
|             | $B_2$ Electrical equipment cause        | 0.38                      |
|             | $T_1$ Spark a fire                      | 0.534                     |
| Top event    | $M$ Fire                                | 0.357                     |
|             | $T_2$ Failure to remedy in time         | 0.669                     |

It can be concluded that the construction fire risk value is 35.7%, indicating that the construction fire is more likely to occur, and the fire prevention should be strengthened. Therefore, the Bayesian
network model’s reverse reasoning ability is used to calculate the current construction fire. When the risk must occur, the probability of the top event is 1, and the probability value of each basic event can be obtained, as shown in Table 5.

**Table 5.** Posterior probability of basic events.

| Code | Name                                           | Posterior probability |
|------|------------------------------------------------|-----------------------|
| $X_1$ | Node name                                      | 0.171                 |
| $X_2$ | Arson                                          | 0.137                 |
| $X_3$ | Terrorist attacks                              | 0.064                 |
| $X_4$ | The train caught fire after derailment         | 0.039                 |
| $X_5$ | The train caught fire                          | 0.549                 |
| $X_6$ | Short circuit and fire                         | 0.208                 |
| $X_7$ | Transformer, current collector, equipment room caught fire | 0.026             |
| $X_8$ | Overheated air conditioner                     | 0.028                 |
| $X_9$ | Cigarette butt does not go out                 | 0.028                 |
| $X_{10}$ | Garbage burning                               | 0.017                 |
| $X_{11}$ | Seat caught fire                               | 0.034                 |
| $X_{12}$ | Other decoration materials caught fire         | 0.084                 |
| $X_{13}$ | Defective or malfunctioning fire protection system design | 0.692             |
| $X_{14}$ | Insufficient or invalid fire-fighting equipment | 0.519                |

The probability of the occurrence of basic events is ranked as follows:

$$P(X_{13}) > P(X_5) > P(X_{14}) > P(X_6) > P(X_1) > P(X_2) > P(X_{12}) > P(X_3) > P(X_4) > P(X_{11}) > P(X_9) = P(X_8) > P(X_7) > P(X_{10})$$

It can be considered that the key events affecting the occurrence of the top event are due to inadequate or failure of fire extinguishing equipment, short circuit of the circuit, fire or staff leaving the post, or unqualified fire-fighting skills.

4.3. Results Analysis

It can be seen from the above calculation results that, on the premise of knowing all the basic events, the Bayesian network can be used to predict the occurrence probability of the out-of-roof event is 35.7%, indicating that the probability of the subway fire accident is relatively large and preventive measures should be taken. When the top event is set, it can be seen from the posterior probability of each basic event that the probability of fire extinguishing equipment inadequacy or failure is the largest, which is 69.2%. In view of this phenomenon, subway staff should strengthen the inspection of fire extinguishing equipment.

5. Safety Management Measures

Set up fire-fighting facilities matching the scale of the subway. Fire extinguishing equipment and automatic sprinkler fire extinguishing equipment are provided in station halls, platforms and rooms where important equipment is placed, fire extinguishing equipment in train compartments, fire extinguishing equipment in stairs, elevators, pedestrian passages, fire exits and tunnels, emergency
lighting, alarm phone and safety exit signs.

Strengthen the overhaul of subway equipment, especially electrical equipment, prevent fires due to equipment failures, find some potential hazards in time and carry out maintenance.

Strengthen the training of subway staff. Train staff on fire safety knowledge so that staff can use all kinds of fire-fighting equipment in the station proficiently and have certain fire prevention, extinguishing and escape capabilities. The staff should be more vigilant when on duty to find and eliminate some daily fire hazards in time.

6. Conclusion
This paper uses Bayesian network to predict the probability of subway fire, and obtains the posterior probability of each basic event when the top event occurs. Provide a reference for subway fire prevention. As the collected data has certain limitations, the applicability of the conclusions needs to be further explored.

References
[1] Liu Z J, Ji Z S and Lin Y 2010 Fire risk analysis of ship engine room based on Bayesian network China shipbuilding 51 (03) 199–205.
[2] Volkan S, Omer K and Merih G 2020 A Bayesian network model for prediction and analysis of possible forest fire causes Forest Ecology and Management 457
[3] Beatriz M S, Nicoletta G C and Francisco S F 2020 Analysis of the port sustainability parameters through Bayesian networks Environmental and Sustainability Indicators 6
[4] Sun Y, Qiao X R and Zhang S 2016 Statistics and preventive measures of railway vehicle fire accidents at home and abroad Science and Technology Innovation Herald 13 (07) 40–42
[5] Peng L, Xu X J and Yang L 2019 Fuzzy hierarchy comprehensive evaluation model and application analysis of subway station fire risk Civil and Architectural Engineering Information Technology 11 (04) 127–132
[6] Yan W Y, Wang J H and Jiang J C 2016 Subway fire cause analysis model based on system dynamics: A preliminary model framework Procedia Engineering 135
[7] Zhu W M 2018 Fire Risk Assessment of Subway Operation Based on Fuzzy Accident Tree (Beijing: Beijing Jiaotong University)