Analysis of error probability in aero ordnance maintenance

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Abstract. Aero ordnance maintenance is a very important part in aviation maintenance, which has such characteristics as elusive, inconvertibility and danger. The specificity of aero ordnance maintenance is analyzed, and the error model fitting well with the actual situation is built. The maintenance error probabilities are calculated by Bayesian network. Besides, the influences of organization management, professional skill and other typical factors are analyzed in this paper. The related results have some reference and guiding meaning to the aero maintenance work.

1. Introduction

Due to North Korea’s continuous test firing of medium and long-range missiles and South Korea’s determination to deploy the Thaad system (Terminal High Altitude Area Defense System), the security of China’s peaceful development is seriously threatened. As the leading force in modern warfare, the advanced nature and integrity of Air Force’s ordnance equipment has an important effect on the outcome of the war. The existing data show that maintenance errors in aviation ordnance support are an important reason for professional ordnance flight accidents and ground accidents. Therefore, in-depth research on errors in maintenance support is of great significance for reducing the probability of accidents and improving the reliability of the ordnance equipment.

Among the current public materials, there is no specific study on the maintenance errors of aviation ordnance support. The research results in related fields can provide ideas and references for the study of this paper. Shengbin Chen et al. [1] used the fault tree method to find problems or maintenance errors in helicopter design, maintenance and use management. Yongsheng Shi et al. [2] proposed a recognition framework for aircraft maintenance error pattern, and built an aircraft maintenance error recognition model based on scenario framework elements. In addition, the well-known theories of Murphy’s Law [3][4], SHEL Model [5][6], REASON Model [7][8] have also been applied to the study of aviation equipment maintenance errors. These theories have their own characteristics, revealing the general formation mechanism of accidents and maintenance errors, and their conclusions are consistent with the experience of front-line support work. However, theoretical researchers often lack practical work experience and cannot obtain reliable samples for data verification. Also, due to the limited conditions, maintenance technicians are unable to combine theoretical models with actual work. As a result, the current maintenance error analyses are mostly written work summary and narration, lacking effective data support, and the guidance significance is limited.

This article analyzes the particularity of aviation ordnance support work, establishes an error model consistent with actual work, and uses Bayesian network to calculate maintenance errors. The influence
of typical factors such as organizational management and business level on ordnance support is analyzed, and the conclusions have certain reference and guidance significance to the outfield work.

2. Maintenance Error Model in Aviation Ordnance Support

2.1. Characteristics of Maintenance Errors in Aviation Ordnance Support

Different types of aviation ordnance equipment have many differences, but it can be basically divided into four categories: bombing equipment, fire control (missile) equipment, shooting equipment and other equipment. Each equipment is equipped with corresponding detection tools and instruments. Ordnance system maintenance is an important part of aviation maintenance support, and the behavioral activity is affected by many factors. Errors may occur from time to time, and have the following characteristics:

(1) Concealment. Flight crew's operating mistakes or errors can be recorded in relevant equipment through electronic data for backtracking and analysis. Correspondingly, the mistakes made by ordnance support personnel during the maintenance process may still be hidden in the equipment, which has certain concealment. Only when the triggering conditions are met, it may be found and may even cause an accident.

(2) Irreversibility. Aviation ordnance support work involves a wide range of ammunition, fuze and other initiators and pyrotechnics. For live ammunition, it is single-use and has irreversibility. Even if training bombs are used, they are often no longer recovered by fighter support units after they are thrown into designated shooting ranges. This requires that the ordnance system equipment must have good working conditions and reliability. Once problem occurs, it is difficult to make up for them.

(3) Dangerous. The most obvious difference between combat aircraft and ordinary aircraft is the ordnance equipment they carry. Aviation ordnance is a sharp sword that stabs the enemy, so at the same time, it places higher requirements on the maintenance work of the aircraft crew. A little carelessness may lead to accidents, or damages to the aircraft, or even endanger the lives of comrades.

2.2. Classification of the Causes of Maintenance Errors in Aviation Ordnance Support

During maintenance, there are many reasons for errors. Depending on the specific situation, there are about three attributes, which are people, equipment, and environment. What needs to be explained here is that as the support work has certain maturity and inheritance, this article ignores conditions such as non-standard technical documents based on the actual daily work of the army, and assumes that the staff have no extreme work habits. Take several errors of a unit in the maintenance and support of bombing equipment as an example.

2.2.1. Human Factors.

(1) Some staff have low sense of responsibility and career. Their professional loyalty decreases, and they lack of initiative. Due to inadequate education on the sense of ambition and responsibility, some crew members are not very responsible and work loosely. For example, some may forget to install the guide when loading and unloading the bomb, causing the bomb to be close to the skin, and the lifting hook to scratch the skin of the aircraft.

(2) Weak sense of the concept of rules and regulations and security, and the security rules are not strictly enforced. For example, before loading the toolbox, the cable direction was not checked in accordance with the regulations, blindly mounted and damaged the cable; the interlock switch of the ammunition door was not disconnected as required before the ammunition was hoisted.

2.2.2. Equipment Factors

(1) Bad design of preventive maintenance of ordnance equipment. For example, if some adjacent plugs do not have error-proof design, it is easy to make mistakes when working at night or with insufficient light.
(2) Defects in tools, instruments and equipment. If the range design of a certain type of trailer truck is not comprehensively considered, the missile body is prone to excessive swinging during fine tuning, causing safety risks.

2.2.3. Environmental Factors
(1) Improper organization and management, disorder at the command site. For example, the division of labor during the process of ammunition is not clear, making the work scene chaotic, and accidents such as mistakes, forgetfulness and missing are very easy to occur.

(2) The working environment is harsh. For aircraft parked in the open air, the working environment is poor, and the support personnel are susceptible to errors caused by the severe weathers such as coldness and heat, frost, rain and snow.

3. Analysis of Maintenance Errors Using Bayesian Method

3.1. Bayesian Networks
Bayesian network (BN) is a directed acyclic graph used to describe and analyze uncertain and probabilistic problems. In the BN model, nodes represent random variables, directed arcs represent the relationships between the variables, and the direction of the arc has a causal meaning. Each node has its own Conditional Probability Table (CPT). The distribution status of the root nodes and the conditional probability between each node reflect the analyst’s understanding or opinion on the research situation.

3.1.1. Conditional Probability and Bayes' Formula. Let A and B be the two events in the basic event set E, \( P(A) > 0 \) and \( P(B) > 0 \), so there is

\[
P(B|A) = \frac{P(A|B)P(B)}{P(A)}
\]

In the formula, \( P(B|A) \) is the probability of occurrence of event B under the condition of event A, and \( P(A|B) \) is the probability of occurrence of event A under the condition of event B. The above formula is the most basic Bayesian formula.

3.1.2. Chain Rules. For events \( A_1, A_2, ..., A_n \), and \( P(A_1) \geq P(A_2) \geq ... \geq P(A_n|A_{n-1}) \), the generalized multiplication formula can be

\[
P(A_1A_2...A_{n-1}) = P(A_1)P(A_2|A_1)...P(A_n|A_1A_2...A_{n-1})
\]

The above formula is called a chain rule. The basis of uncertainty reasoning using Bayesian networks is the Bayesian formula and chain rules.

3.2. Establishing a Bayesian Network for Maintenance Errors in Aviation Ordnance Support
The establishment of a maintenance error model using Bayesian networks can be divided into the following steps:

(1) Establish a network structure diagram that is in line with reality. This article uses Netica software to complete this step, as shown in Figure 3.

(2) Determine the conditional probability table of the nodes. The causal relationship between various factors needs to be carefully considered. The data sources for the CPT assignment in this article mainly include expert interviews, questionnaires, and historical data from related literature.

(3) Improvements and amendments. Gradually modify and improve the network structure and node data in practice. Over time, the influencing factors are not static, and the process of improvement and modification helps to further expand the applicability of the model.
4. Analysis of Examples
As can be seen from the foregoing, aviation ordnance support work has a tandem nature, but it does not mean that as long as the work habit is bad or the business level is low, human errors will definitely occur. Under the current relatively mature security system, failure to meet the standards in one link may lead to an increase in the probability of human error, but only when problems occur in all related links can an accident occur. This section uses three typical examples to illustrate the process of human error analysis using the Bayesian network, which provides a basis for managers to implement job importance ranking and cause investigation after an accident.

According to expert's experience, the initial probability distribution of each basic link (data has been processed) is given first. Among them, Good represents a good state and Bad represents a poor state, as shown in the following table:

### Table 1. Initial probabilities of basic elements

| Name of Causes          | Good | Bad | Name of Causes          | Good | Bad |
|-------------------------|------|-----|-------------------------|------|-----|
| Design                  | 99%  | 1%  | Learning Ability        | 80%  | 20% |
| Equipment and Tools     | 98%  | 2%  | Hands-on Practice       | 90%  | 10% |
| Habits                  | 85%  | 15% | Organizational Management| 99.5%| 0.5%|
| Disciplines             | 95%  | 5%  | Environmental Factors   | 99%  | 1%  |

4.1. Probability of Human Error under the Condition of Disordered Organization and Management
Both environmental factors and organizational management can affect the physical and mental health of the personnel. Suppose when performing a task, the weather condition is good, but the organizational management is chaotic, that is, P (organizational management = Bad) = 100%, P (environmental factors = Good) = 100%, and other conditions are normal. According to the Bayesian reasoning rule, the calculated probability of human error is 9.44%. Set the parameters again, assuming that the organization and management are methodical, but the weather is extremely bad, that is, P (organization management = Good) = 100% and P (environmental factors = Bad) = 100%. According to Bayesian inference, the calculated probability of human error is 8.67%. It can be seen that the impact of organizational management in human error is greater than environmental factors, so improving the organizational capacity of management cadres can make tasks in an orderly manner. At the same time, strengthening the construction of software and hardware conditions in the outfield and
the camp area, creating safe working environment and comfortable living environment for the crews are of great significance to reduce maintenance errors.

4.2. Probability of Human Error under Low Business Conditions
The low level of business is closely related to factors such as the learning ability and hands-on ability of the protection staff, and it is also the most fundamental cause of human error. By reasoning calculation, under normal conditions, when the business level is good P (business level = Good) = 100%, when the business level is normal P (business level = Normal) = 100%, and when the business level is bad P (business level = Bad) = 100%, the probabilities of human error are 1.99%, 6.94%, and 22.8%. For aviation ordnance equipment support, the goal is zero error, and the probability of human error of 22.8% is intolerable. In order to improve the professional level of the support personnel, on one hand, it is necessary to improve the induction mechanism for new students and new recruits, and select teachers with good business standards and outstanding working ability to teach them. On the other hand, the army can regularly organize business learning, knowledge competition and other activities to form a continuous learning atmosphere.

4.3. Probability of Human Error Due to Failure to Follow the Inspection Route (Compliance with Rules and Regulations)
In the process of ordnance equipment support, there is a mature and complete set of maintenance procedures. If the security personnel and review personnel operate strictly in accordance with the procedures, human errors can be largely avoided. However, in actual work, for the sake of convenience or time saving, some people did not follow the procedures and did not check the routes, which greatly increased the probability of human error. After calculation, under the condition of human error, that is, P (human error) = 100%, the probability of being caused by the reason of not following the inspection route (compliance with rules and regulations) is 13.7%, which is far greater than the design defect (1.98%), equipment and tools (2.78%), organizational management (1.01%) and other related factors. It can be seen that the task of improving the awareness of laws and regulations of the crew is imperative, so that the crew not only “knows the law” but also “obeys the law”, making them have no excuses of mentality.

5. Conclusion
Aviation ordnance support maintenance errors have the characteristics of concealment, irreversibility, and danger. A little carelessness may cause accidents, and in some serious cases, it may cause damages to aircraft, or even endanger the lives of comrades. There are various reasons for maintenance errors, but in the final analysis, it is the human factor. It includes both the organizer and the implementer of the job. By sorting and summarizing the frequency of the causes of human errors, a Bayesian network prediction model of human errors is established, which provides a basis for managers to implement job importance ranking and cause investigation after an accident. It also has realistic meaning for the outfield maintenance work.

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