Summary of Reliability Analysis Methods of Remote Tower System

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Abstract. The remote tower technology can provide remote control services for small airports in remote areas with low passenger and cargo throughput[2]. In the 1990s, European and American countries began the research and development of remote towers. In 2015, Sweden's Sundsval Airport approved the use of remote tower operations. In 2019, China Xinjiang Airport Group started the remote tower pilot construction. As a new thing, the remote tower system is different from the traditional tower, and its safety and reliability have not been systematically studied in China. This article introduces several methods that can be used to analyze the reliability of the remote tower system in detail. These methods are analyzed and compared. Finally, this article summarizes the methods applicable to the reliability analysis of China's remote tower system.

1. Introduction
The remote tower technology was originally applied to provide remote control services for small airports in remote areas with low passenger and cargo throughput. The remote tower collects real-time information about the airport and traffic operations. Then the real-time conditions of the controlled airport scene, weather and traffic are presented on the remote tower screen. In order to provide the airport with comprehensive airport air traffic control services including approach guidance, surface surveillance and release management. As there is no need to build new or fewer towers and other air traffic control projects, it reduces the number of on-site staff, which has obvious low cost and convenience. European countries began the research and development of remote towers as early as the 1990s. In 2015, Sweden's Sundsval Airport approved the use of remote tower operations, marking that remote tower technology has entered the practical stage. In recent years, the construction of remote towers in European and American countries has been fully launched.

In 2019, China Xinjiang Airport Group started the pilot construction of remote towers at Fuyun and Nalati Airports. Although the remote tower technology is relatively mature, basic research on the safety and reliability of the remote tower system has not been carried out in China. This article will discuss the methods and ideas for reliability analysis of remote towers based on reliability engineering technology and the remote tower system of Xinjiang Airport.

2. System Reliability Analysis Methods[4][5]
System reliability analysis methods are generally divided into qualitative analysis methods and quantitative analysis methods[7]. The qualitative analysis method is to obtain the possible failure modes of the system or the possible combination of events leading to the system failure, find the weak links of the system, and make targeted improvements to improve the system reliability. Quantitative analysis method is an analysis method based on system reliability data[8]. It collects reliability data...
during the development, production, and use of the system or unit product, and uses probability statistics to give quantitative estimates of various reliability indicators of the system.

![Figure 1. Classification of reliability analysis methods.]

3. Qualitative Analysis Method for Reliability of Remote Tower System

3.1. Failure Mode Effect and Criticality Analysis (FMECA)
FMECA analyzes all possible failure modes of the system and their possible effects, and classifies them according to the severity of each failure mode and its probability of occurrence[1]. FMECA is mainly divided into three parts: failure mode and impact analysis, criticality analysis, and FMECA report. Among them, failure mode and impact analysis (FMEA) needs to complete the system definition, failure mode analysis, failure cause analysis, failure impact and severity analysis, failure detection method analysis, design improvement and compensation method analysis; Criticality analysis (CA) is According to the severity of each failure mode and the comprehensive impact of the probability of occurrence of the failure mode, the products in the system are classified, and the hazard analysis includes two methods: the risk priority number method and the hazard matrix method.

FMECA is a very mature system reliability analysis method. Through the final FMECA report, we can clearly and intuitively see the weak links of the system, and see the cause of each failure mode and the impact on the system. At the same time, improvements and preventive measures for each failure mode can be seen. However, FMECA is generally a static single-factor analysis method. For complex systems such as remote towers, multi-factor and dynamic analysis is often required. Therefore, if a comprehensive analysis of the system is implemented, it should be combined with other analysis methods.

3.2. Fault Tree Analysis (FTA)[11][13]
FTA is a top-down interpretation of the system oriented by system failures[9], which is a multi-factor reliability analysis method. The purpose of FTA[10] is to use the deductive method to analyze level by level, to find various possible causes leading to a certain failure event (top event), down to the most basic cause, and to determine the potential hardware and software defects through logical relationship analysis, so as to take improvement measures[21]. The procedure of fault tree analysis is shown in Figure 2.
Choose a reasonable top event

Figure 2. FTA analysis program.

By analyzing the fault tree of each top event, we can get the minimum cut set of each top event[12]. A minimum cut set represents a failure mode of the system. Therefore, when we find out all the minimum cut sets of the system as much as possible, we can effectively reduce the risk of potential accidents in the system[14]. The minimum cut set contains all possible factors that lead to the occurrence of the top event, and can guide the fault diagnosis and maintenance of the system. FTA requires the analyst to have a deep and comprehensive understanding of the system, and FTA cannot clearly show the structure of the system like FMECA analysis. Therefore, for the reliability analysis of the remote tower system, you can choose to combine FTA and FMECA, so that a more comprehensive reliability analysis result of the remote tower system can be obtained[18][19][20].

3.3. GO Method[22][23]
The GO method is an image-based reliability analysis method developed by Kaman Science Corporation, funded by the US military in the 1960s, to analyze the reliability of weapon systems[24][25]. The idea of this method is similar to the reliability block diagram model and FTA. First, the corresponding visualization model is constructed through the analysis of the system, this model is called the GO diagram; Then use the GO chart to qualitatively and quantitatively analyze the system, find the weak links of the system, and calculate the reliability index of the system.

Compared with the FTA method, the GO method is success-oriented. It can not only evaluate the combination of events leading to system failures, but also analyze the combination of events in all possible states of the system. The reliability analysis of the GO method is more comprehensive, but it also leads to the shortcomings of more complex operator types. This method not only requires the analyst to be very familiar with the system, but also has a sufficient understanding of the GO method. For remote tower systems, when only possible event combinations of system failures are needed, the FTA method is more convenient and faster.

3.4. Sneak Circuit Analysis (SCA)
SCA technology was born in the United States in the early 1960s, and Boeing first systematically adopted this technology in the Apollo program. The so-called "potential pathway" refers to the unexpected pathway that appears under the specific conditions of the system. Its appearance can cause functional abnormalities or inhibit the realization of normal functions. SCA is to analyze and find those potential pathways that cause abnormal system functions or inhibit the realization of normal functions by assuming that all components in the system are working normally. The process of SCA is shown in Figure 3.
4. Quantitative Analysis Method of Reliability of Remote Tower System

4.1. Precise Method of System Reliability Data Analysis

When performing a quantitative analysis of the reliability of the remote tower system, we can get very little overall system data, but the components or sub-systems that make up the system usually have more reliability data, so you can make full use of the components or sub-systems data for reliability data analysis. The accurate method of system reliability analysis is to convert the reliability data of the lower-level functional units in the system to the upper level, and finally calculate the overall reliability index of the system.

When using this method to calculate the reliability of the remote tower system, the most important thing is to determine the life distribution of each hardware device and how to convert the lower-level reliability data to the higher-level. Generally speaking, the life distribution of hardware equipment is relatively easy to determine, and external factors have little influence on it, but when the reliability data of lower-level hardware equipment is converted into the reliability of the upper-level subsystem,
the mutual influence between equipment and the contribution of equipment to the reliability of the subsystem need to be considered. Generally speaking, the accurate method of system reliability analysis is a more accurate method to calculate the reliability index of the remote tower system, but this method has very strong requirements for the composition structure of the system and the type of equipment data, and calculation is difficult, and not conducive to project realization.

4.2. Approximate Method of System Reliability Data Analysis

For large and complex systems, when there are many components in the system and the system classification is very complicated, the calculation of the precise method will be very complicated and difficult to achieve. Therefore, approximate methods are often used in engineering, and the most commonly used are the LM method and the MML method. The LM method is simple to calculate and easy to understand, and is suitable for general series systems; the MML method is more suitable for comprehensive analysis of pyramid systems. Both of these methods use the reliability data of the subsystem to calculate the lower confidence limit of the system reliability. For subsystems with different life distributions, the method of calculating the lower confidence limit of the system is also different.

This approximate method only needs to calculate the lower confidence limit of the system reliability index. Compared with the precise method, the calculation amount is small and easy to implement, and the data of different distribution types can be approximately converted into data of the same distribution type, then use the LM method or MML method to calculate. It has relatively loose requirements for system structure and data, and is convenient for calculation.

4.3. Bayesian Method of System Reliability Data Analysis

The Bayesian method of system reliability data analysis actually uses the Bayesian method to calculate the confidence limit of the reliability index concerned in engineering. Generally speaking, as long as the Bayesian posterior distribution of the variable of interest is given, the corresponding confidence limit can be directly given according to the posterior distribution. Therefore, the key to this method is to give the posterior distribution of the system reliability index.

To perform Bayesian reliability analysis of the remote tower system, first select the prior distribution of the equipment life distribution parameters according to the life distribution type of the component equipment; then use the reliability data of the equipment and the selected prior distribution to calculate the posterior distribution of equipment reliability. Generally speaking, the posterior distribution of system reliability can be obtained by simulation, but it is difficult to obtain the remote tower system-level test data. Therefore, it is difficult to realize the reliability analysis of the remote tower system using Bayesian method.

4.4. Monte Carlo Method for System Reliability Data Analysis

For systems with complex structure, different life distributions of the equipment, and most of the actual equipment life data types are censored data, it is difficult to give analytical expressions for system reliability indicators in engineering, at this time, the calculation advantages of Monte Carlo method can be fully utilized to solve the calculation problem of system reliability data analysis. The Monte Carlo method must first clarify the composition structure and reliability block diagram of the system, and then calculate the reliability index of the system according to the reliability data of the equipment. When the equipment data is as abundant as possible, the accuracy of the system reliability assessment will be higher.

5. Conclusion

Through the introduction of various reliability analysis methods, combined with the characteristics of the remote tower system, this article draws the following conclusions:

(1) The combination of FMECA method and FTA method is suitable for the qualitative analysis of the reliability of the remote tower system. The former can give all the failure modes and severity of the system, the latter can analyze all possible factors that cause each failure mode of the remote tower system based on the failure mode obtained by the former.
The approximate method of system reliability data analysis and Monte Carlo method are suitable for the quantitative analysis of reliability of remote tower system. The former has relatively loose requirements for the system structure and data, and is convenient for calculation; For the latter, as long as the equipment data information that composes the system is sufficiently rich, the reliability analysis results with higher accuracy can be obtained.

The human factor of the controller in the remote tower system has a great impact on the reliability of the system, and the Sneak circuit analysis method has a certain feasibility for the analysis of human error. However, traditional reliability analysis pays more attention to the reliability analysis of system hardware or software. For systems where controllers such as remote towers are an important part of the system, traditional reliability analysis methods cannot be fully satisfied. Therefore, for the remote tower system, the influence of human factors on the reliability of the system should be further studied.

When conditions permit, a certain amount of remote tower system-level reliability tests should be carried out as far as possible to obtain the reliability index data of the remote tower system. System-level test results can be effectively compared and verified with system reliability data analysis results, and can also be applied to system reliability data analysis.

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7. References
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