Chapter 69
Integrated Analysis of System Reliability and Safety by Man-Machine-Environment System Engineering

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Abstract To solve the problem that the efficiency of the traditional system reliability and safety analysis is not high, and the problem that the human factor analysis is usually ignored, an integrated analysis method of reliability and safety based on man-machine-environment system engineering (MMESE) is proposed. This method integrates the system reliability, safety, environment adaptability, and human factor analysis and considers the human factor as the important element of the analysis; thus, the efficiency of the analysis is evidently improved. Finally, this method is applied in the reliability and safety analysis of a shipborne fueling station.

Keywords MMESE · Reliability analysis · Safety analysis · Human factor analysis · Environment adaptability analysis · Object failure mode analysis

69.1 Introduction

It is an effective way to improve the quality of weaponry by conducting analysis and design of reliability and safety during the R&D process of weaponry, and this approach has gained much attention. In current practices of analysis and design, there exists a prominent problem, namely the contradiction between micro-perspective of reliability and macro-perspective of safety. Reliability analysis for the product only considers the product itself, while the factors of environment and human are seldom considered. For safety analysis, although the above factors are all included, the factors incurring severe consequences are considered only, instead of systematic and overall analysis. In regard of the two analyses, two problems are

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obvious. The first problem is the exclusion of the reliability analysis and safety analysis, i.e., some repeated works are done, and for example, efficiency is decreased if FMEA is conducted in both analyses. The second problem is the absence of comprehensive analysis for the environment and human factors [1]. Concerning these problems, this paper put forward an integrated analytical method for reliability and safety from the MMESE perspective. FMEA is carried out for the MMESE. Factors including reliability, safety, environment adaptability, and human are all covered. Thus, the efficiency of analysis is improved. And the human factor is regarded as the crucial part. Object-FMA [2, 3] is introduced to analyze each object comprehensively. This approach is applied for the analysis of reliability and safety of a shipborne fueling station, so as to verify its feasibility and effectiveness.

69.2 Macro-perspective of Reliability by MMESE

69.2.1 Micro-perspective of Reliability and Macro-perspective of Safety

Traditional definition of reliability is that the product completes its required function in specified conditions and period. The specified conditions consist of the environmental condition, service condition, and maintenance condition. The product itself is considered only while the environment and human factors are excluded as the assumed conditions. Environment factor is considered in the environmental engineering and human factor in the human factors engineering. This is a local, isolated perspective, instead of a systematic one. Environment and human factors will affect the function realization of the product, particularly the human factor. According to the analysis of civil aviation accidents by ICAO, around half of the accidents are caused by human [4]. Therefore, this paper defines the traditional reliability as the "micro-perspective of reliability."

The traditional definition of safety is the ability to prevent accidents [4]. Causes of accidents include not only the product itself, but also hazardous factors in the environment and operation factors of human. Thus, the traditional safety analysis corresponds to the MMESE. This paper defines it as the "macro-perspective of safety."

69.2.2 Analysis of Reliability and Safety from Macro-perspective

Reliability focuses on the ability of product to realize the expected functions. It is the main content analyzed by the traditional reliability to consider the product

itself firstly. However, before the full automation of products, human are necessary to operate and monitor them. Without the participation of human, whatever perfect functions cannot be realized. Skills and mental and physical state of the operators will affect the output. Thus, human factor is the indispensible part for the realization of product function. Moreover, product and human are both in the environment, which will influence the product state and the physical and mental state of human, too. Environment is also an important factor. In short, the reliability of product should include the whole system of man, machine, and environment, which is called the "macro-perspective of reliability."

The macro-perspective of reliability not only considers the original product itself, but also the environment and human factors. And correspondingly, analyses regarding the failure of product, hazards in the environment, and operation failures of human, which might cause severe consequences, are the contents of safety analysis. Thus, this macro-perspective of reliability solves the problem of exclusion between the two analyses and low efficiency. Meanwhile, this new approach can better consider the interrelations between the three factors, making the analysis more thorough.

69.3 Analytical Method for Reliability and Safety by MMESE

FMEA is the most used method for reliability analysis. Suggestions for improvement are brought up from the analysis of the potential failure mode and influences. This paper adopts FMEA to analyze the man-machine-environment for the product, covering the traditional reliability, environmental adaptability, safety, and human factor. In order to better analyze the potential failure mode, this paper introduces a systematic method, namely Object-FMA. This method is object oriented. Steps of the integrated analysis of reliability and safety by MMESE are as follows.

69.3.1 Set Up MMESE Model

Man, machine, and environment are interrelated as shown in Fig. 69.1. The operator receives the information and feedback from the machine and processes them. Then, the brain will lead the body to operate the machine. The machine will function as per the input and output the expected products. The activities of machine and human will affect the microenvironment, which will affect the machine and human state, too. In the actual analysis, the MMESE model should be firstly set up for the product object according to the actual conditions.

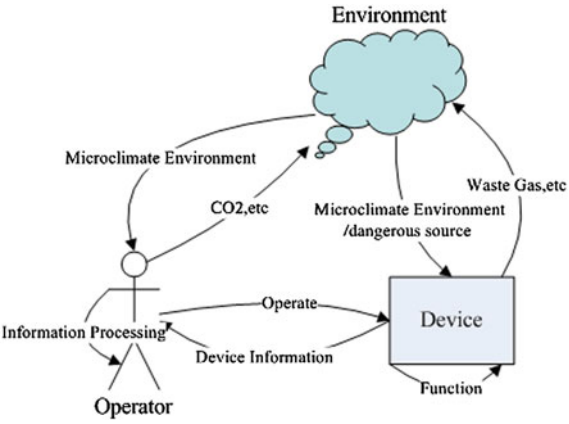

Fig. 69.1 Information interactive of man-machine-environment system

69.3.2 Failure Model Effectiveness Analysis of Man, Machine, and Environment

Failure model effectiveness analysis will be conducted for the man, machine, and environment, respectively.

FMEA analyzes the object with properties and methods. The properties and methods of object must satisfy certain constraint conditions. Violation of these conditions is deemed as the failure mode. Thus, there are three steps of FMA: (1) analysis of properties and methods of the object; (2) analysis of the constraint conditions for the properties and methods; (3) deem the violation of constrain conditions as the failure mode of the object. Object-FMA accords with the way human recognizes the world. And the analysis can go deep into the object and find the internal rules by analyzing the properties and methods.

FMEA for object "human". In the man-machine-environment system, the operator sees or hears the conditions and output from the machine, processes the information, and then leads to body to operate the machine. During the information process, operator will be affected by his/her mental state, including the character, ability, motive, motion, and will [5]. In addition, the operator is also affected by the physical state. The "methods" for the man are the operations and vary from the actual conditions. Failure mode analysis is conducted at the three steps in Table 69.1. The contents in Table 69.1 can be added or deleted according to the actual conditions.

FMEA for object "environment". It is easier to extract the factors from the environment and determine the constraint conditions by regarding the environment as an object. Environment factor includes two categories. The first category is the microclimate environment, namely the environment in which human and machine work. And considering the constraint conditions, it must be appropriate for the human and machine working without any influence on the mental and physical state, and without damage to the machine. The other category is the source of

Table 69.1 "Man" failure mode analysis

Object	Property/method			Constraints	Failure mode
Human	Property	Receive information	Vision	Read information and recognize color correctly	Fail to read information
					Fail to read information
					Fail to distinguish
			Auditory	Hear and distinguish the sound category correctly	Fail to hear
					Fail to distinguish sound
		Process information (mental state)	Character	Meet the working requirement	Impatient, timid
			Ability	Meet the working requirement	Unskilled
					Fail to meet the requirement
			Motive	Positive	Overactive or negative
			Emotion	Stable	Overexcited
			Will	Good will	Undetermined, afraid of difficulties
		Operation	Physical state	Height, weight, arm length, strength meet the working requirement	Unqualified
			Mental state	Meet the working requirement	Sick state for long term or temporarily
	Method	Specific operations		Meet the working requirement	Misoperation

hazard. GJB/Z99 can be referred to for the hazard sources. The "methods" for the environment are considering the extreme weather or geological disasters. The results of analysis of environment object by the FMEA are as shown in Table 69.2.

FMEA for object "machine". It is the same as the traditional way. First of all, disassemble the machine and get the product tree. Then, analyze each part in the product tree by the Object-FMA.

69.3.3 FMEA of MMESE

Similar to the traditional FMEA analysis of reliability, for the FMEA of man-machine-environment system, analysis table must be filled in, including the reason, influences, grade, and measures. The slight difference lies in the assessment of failure mode which should include not only the influence to the function, but also

Table 69.2 "Environment" failure mode analysis (hint)

Object	Properties/methods			Constraints	Failure mode
Environment	Properties	Microclimate environment	Temperature, humidity, salinity, wind speed, luminance, etc	Comfortable for human, no damage to machine	……
		Source of hazard	Hazard sources specified in GJB/Z99, heat, pressure, radiation, hazardous gas, etc	Avoid hazard or without severe results	……
	Methods	Typhoon, rainstorm, earthquake, etc		Without affecting human and machine	……

damage to the machine and operator (for the sake of safety). In the FMEA for "human," human factor is included and operational and support hazard analysis, as well as some occupational health analysis is also considered. In the FMEA for "machine," traditional analysis for reliability and hazard analysis of system/subsystem for safety are considered. In the FMEA for "environment," environment adaptability analysis and initial hazard analysis, as well as some occupational hazard analysis, are conducted. The coverage of our new approach of the traditional reliability and safety analysis is shown in Table 69.3.

69.4 Application

This approach is applied in the reliability and safety analysis for a shipborne fueling station. For the "human" factor, as the operators all meet the working requirements, the only mental state of "ability" is considered in the FMEA. And for the "methods," namely the operations of humanusing the "machine". The procedures in the product manual are followed, particularly paying attention to the special operations. For the "environment" factor, much attention is paid to the temperature, salinity (corrosion to machine), oxygen density in the microenvironment, as well as the flammable gases, pressure, static electricity, fire, explosion of the hazard sources; for the "methods," rainstorm, hurricane, and lightning are

Table 69.3 The coverage of our approach of traditional reliability and safety analysis

FMEA category	Reliability	Safety	Environment adaptability	Human factor
Man		Covered		Covered
Machine	Covered	Covered		
Environment		Covered	Covered	

considered. For the "machine" factor, disassemble the station into parts, such as filter, relief valve, oil gun, flammable gas density detector, and pressure detector. Object-FMA is adopted firstly to analyze the failure mode and conduct FMEA for all parts. The results show that this approach is more comprehensive comparing with the traditional method, especially for the "environment" (working condition improvement suggestion) and "human" (improvement of operational procedures) factors. Furthermore, the FMEA analysis covers four items which largely raises the efficiency and proves the feasibility and effectiveness of this new approach.

69.5 Conclusions

This paper provides an integrated analytical method of reliability and safety by man-machine-environment system engineering. This method conducts FMEA for the man-machine-environment system of the product, covering not only the content of traditional reliability analysis, but also the safety analysis, environment adaptability, and human factor. Thus, the analytical efficiency is improved entirely, and human factor is regarded as the important part. During the analysis, Object-FMA method is adopted to analyze the failure mode. This method focuses on the object, which accords with the thinking pattern of human, and offers more comprehensive analysis results.

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