



Man-Machine-Environment System Engineering in System of Systems Content

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Abstract. Aiming at the problem that the traditional man-machine-environment system engineering (MMESE) revolves around system, there is a lack of consideration in the design process of the new form of man-made engineering system, the system of systems (SoS). On the basis of summarizing and analysing the new characteristics of SoS and SoS engineering, a man-machine-environment system engineering model in the content of the SoS is proposed, which focus on the social network constructed by men in the SoS, the system network constructed by machines, the adversary system in the environment, and the mission planning and command and control of the commander's use of the SoS, and some main points of consideration of the above contents are analysed This paper provides a reference for carrying out man-machine environment system engineering work in the content of the SoS.

Keyword: MMESE · System of systems · SoS engineering · Social network

1 Introduction

Man-made engineering systems are people's integration and application of existing technologies, built through the engineering management process, and serve the purpose of transforming the objective world [6]. A man-made engineering system involves the interaction and coexistence between the system and the environment, and involves the information interaction process between people and the system and the decision-making process of people when they use the system. Therefore, man-made engineering systems are often typical man-machine-environment integrated systems, and the human-machine-environment system engineering is used as the design method. The human-machine-environment system engineering is a discipline that uses system science theories and system engineering methods to correctly handle the relationships between the three elements of human, machine and environment, and further study the optimal combination of the man-machine-environment system. [1] Man-machine-environment system engineering was proposed by Long Shengzhao and developed under Qian Xuesen's recognition and concern.

Man-machine-environment systems engineering plays an important role in improving the efficiency of man-machine interaction and ensuring the safe coexistence of people, systems, and the environment. However, as the scale of man-made engineering

systems becomes larger and the composition becomes more and more complex, a super system composed of multiple independent systems appears, which is called a system of systems or a system. Especially in the process of joint operation design of the US military, the independent operation and management of weapons platforms from different arms and arms need to work together. The traditional systems engineering method has obvious deficiencies in the process of building the management system, so it is emphasized that the system is different from the general system development process, the theoretical research of system and system engineering is vigorously promoted. At present, system engineering has become two new directions of INCOSE system engineering development together with MBSE [2].

A system of systems is a collection of multiple independent collaboratively interacting systems. The new features of the SoS that are different from general systems bring new challenges to human-computer interaction in the context of the SoS. First of all, the system is a socio-technical system. The influence of the organizational relationship between human during the operation of the system, and the cooperation between machines through information and control, has not been considered for the system operation process. Secondly, the SoS is not only network-centric, connects and cooperates through the network, but also needs to consider the self-organization ability in the case of unreliable network. Thirdly, the addition of a large number of unmanned equipment has brought about subversive changes in the traditional human-computer interaction-based human factors engineering design.

The application of human factors engineering in the analysis of accident causes is studied in [7], and in [8], the London bombing is also used as an example to analyze the content of human factors analysis in the context of the SoS. While the research of human factors in SoS content is really less. Therefore, on the basis of analyzing the new features of the SoS that are different from general systems, this paper puts forward the key consideration that need to be considered in man-machine environment systems engineering in SoS content, which providing reference guidance for the application of human-machine environment system engineering in SoS design, especially in military equipment SoS design.

2 SoS and SoS Engineering

2.1 Characteristic of SoS

It is an inevitable trend of technological development to connect multiple independent systems to form larger systems through collaboration and interaction. It is the US military that put the system concept on the research agenda. In 1996, Manthorpe [3] clearly proposed that SoS is a new opportunity and challenge for systems engineering in the military field. The U.S. Department of Defense takes joint operations as the main guiding ideology of its equipment development, and has developed a series of SoS-oriented technical and management standards from the aspects of equipment development requirements (JCIDS), SoS architecture design (DoDAF), and SoS engineering guidelines (SE for SoS) [4]. Mayer [5] proposed five characteristics for how to distinguish the SoS from the general system, namely Operational Independence, Managerial Independence, Evolutionary Development, Emergent Behavior and Geographic Distribution. We take the

NIFC-CA SoS of the US military as an example to illustrate these basic characteristics. First of all, the NIFC-CA SoS is composed of multiple weapon platforms whose operation and management are independent of each other, such as the F35 fighter jet, early warning aircraft, CEC network communication system, Aegis missile launch platform, etc. They are connected through the network and cooperate with each other through information exchange to achieve over-the-horizon strike targets, and they are also deployed in different geographical locations.

2.2 Characteristic of SoS Engineering

The SoS requirements analysis, design, integration, verification and validation process is called SoS engineering. Compared with traditional systems engineering, SoS engineering has two distinct characteristics. First, because the SoS consists of multiple independent systems, the SoS engineering is divided into two levels: SoS level and system level. At the SoS level, the mission of the SoS is mainly decomposed into the requirements for constitute systems, which are used as the input for systems development. After the development of the constitute systems are completed, the integration and verification of the SoS will be carried out. At the system level, the requirements of the system are implemented, and this process is guided by traditional systems engineering. Second, the constitute systems that make up the SoS are heterogeneous and are in different engineering stages. Most constitute systems reuse existing systems, and some need to be modified, and there are only a small number of systems that need to be developed as a new one.

3 MMESE in System of Systems Content

3.1 Traditional MMESE Design

There are many concepts for studying the design of human-system interaction, which are called Ergonomic in Europe, Human factor or man-machine engineering in the United States, and Human Engineering in Japan. These concepts are relatively close with man-machine-environment system engineering, and the difference is that the man-machine-environment system engineering emphasizes the highest principle of economic benefits after the comprehensive balance of the three, reflecting the characteristics of systems engineering. Man-machine-environment system engineering research focuses on human characteristics, machine characteristics, environmental characteristics, man-machine relationship, human-environment relationship, machine-environment relationship, and the overall performance of the man-machine-environment system [1].

The traditional man-machine environment system engineering is centered on human characteristics, and also considers the human-computer interaction factors of the operator in the process of using the system, the interaction factors between humans and the environment, the system are restricted by the environment, and the system output affects the environment. influence, etc. Human characteristics mainly study human physical characteristics, physiological characteristics, psychological characteristics, and social characteristics. Human physical characteristics refer to the dimensional characteristics

of the human body as a motion system. This characteristic determines the range of motion of the human body when operating the equipment, and is a necessary reference for equipment design. Human physiological characteristics refer to the physiological phenomenon characteristics exhibited by the human body in the process of maintaining its own life functions and interacting with equipment and the environment. Human psychological characteristics refer to the characteristics of human information processing and decision-making process in the process of human interaction with equipment and the environment, as well as psychological factors such as human values, personality, motivation, and emotions in this process. The social characteristics of human refer to the characteristics that people show when they are influenced by other members in a social group, mainly including social facilitation effect, social standardization tendency, social concern tendency, and social conformity tendency [9].

These all belong to the design category of a single system, and in the context of the SoS, which consists of multiple independent systems with different geographical distributions (in different environments), The relationship between people and between systems in the process of interaction between the constituent systems is a new addition to the traditional man-machine environment system engineering, and for the system, the environment is not limited to the natural environment and the microclimate environment where the systems are located, but also includes external systems. In terms of the military combat SoS, the enemy's combat SoS should also be counted as its environment, and the capabilities displayed by the SoS are different for different adversary.

3.2 Man-Machine Environment System Engineering Model in SoS Content

Considering the relationship between SoS engineering and system engineering and their essential differences, first of all, in the context of the SoS, man-machine environment system engineering also has two levels, one is the level of all constituent systems in the SoS, at this level, in the process of each member system design, it is necessary to consider the content of man-machine-environment system engineering, and carry out comprehensive trade-off design of man-machine-environment characteristics; one is the SoS level, at this level, the operators of different member systems form a social network, in this network there is a relationship between commanding and being commanded, and there is also a relationship of collaborative operation. The constituent systems form a system network with a certain topology structure, realize information exchange through different connection approach, and complete specific tasks that cannot be completed by a single system. Although due to the geographical distribution of the SoS, different member systems are in different geographical environments, however, for the SoS, the environment also includes the objects that the system tasks deal with. For the combat system as example, it is the combat adversary SoS. Different the combat adversary SoS, different the performance of own SoS. Another important feature of the SoS is the application. The composition and structure of the SoS are limited, but the application of the SoS is infinite, and the application of the SoS is the embodiment of human intentions. Through mission planning, command and control, the SoS as a whole can give full play to the mission efficiency of $1 + 1 > 2$. The man-machine-environment system engineering model in the content of SoS is shown in Fig. 1.

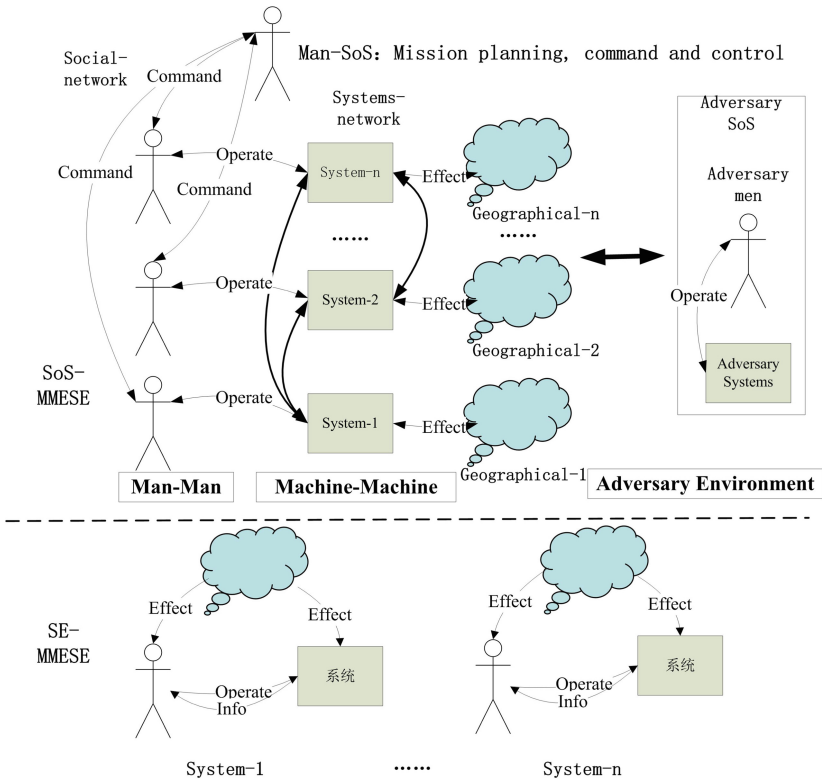


Fig. 1. Man-machine-environment system engineering model in the content of SoS

3.3 Consideration of MMESE in SoS Content

According to the contents of Fig. 1, we sorted out the important design points to be considered in man-machine environment system engineering in the content of SoS, as shown in Table 1.

Table 1. Consideration points table of MMESE in SoS content

Level	Category	Consideration points
System	Man	Physical characteristics, physiological characteristics, psychological characteristics and social characteristics
	Man-machine	Efficiency, comfort and error prevention of human-computer interaction
	Man-environment	Influence of environment on human physiology, operation efficiency and correctness

(continued)

Table 1. (continued)

Level	Category	Consideration points
	Machine-environment	Adaptability of system equipment to environment and impact of system output on environment
	Man-machine-environment	The comprehensive efficiency of human, machine and environment
SoS	Man-man	People in the SoS form a social network, and each operator in the network is not only affected by his responsibilities in the constituent system, but also by his social functions, such as his position, family responsibilities, and country and national consciousness
	Machine-machine	The systems in the SoS are connected through various networks to form a system network with a certain topology. In the SoS design, the relationship between machines and machines focuses on the following three points: 1) To realize the interconnection between multiple heterogeneous systems, the standardized design of the interface is the key point. Considering that most of the systems in the system are already developed, it is usually realized by the middleware interface translation; 2) Since there are multiple reachable paths between two points in the network, it provides convenience for the reconstruction of network connection between machines. In the case of some node failures, the system function can be restored through the structural reconstruction of the network. This is the core idea of the engineering resilient system theory; 3) With a large number of unmanned platforms, the autonomous decision-making of unmanned systems has become a new technological key point
	Adversary environment	The design of the SoS is always aimed at transforming the objective world, and the SoS always operates in an adversary's environment, especially for the military combat system, the member systems that make up the SoS are selected according to the strength of the adversary. Therefore, in the SoS design process, the system demonstration, requirement analysis and simulation verification process are inseparable from the support of the opponent's environmental simulation model
	Man-sos	The SoS is integrated by a limited number of member systems according to a specific architecture, but the application of the SoS is infinite. A specific commander formulates a mission plan for the use of the SoS according to the mission intent, and commands the operators of each member system to achieve the mission intention

4 Conclusion

The system of systems has become a common new form of man-made engineering system. The traditional man-machine-environment system engineering around the system design lacks the consideration of the new characteristics of the SoS. On the basis of analyzing the basic characteristics of the SoS and the SoS engineering, this paper constructs the man-machine-environment system engineering model in SoS engineering, and proposes that the man-machine-environment system engineering under the SoS background should focus on the social network constructed by humans in the SoS, the system network constructed by the machines in the SoS, the adversary SoS in the environment, and the application of the whole SoS by the conductor people. It provides a reference for carrying out man-machine-environment system engineering work in the content of SoS.

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