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MODELOWANIE I SYMULACJA ZABEZPIECZENIA MATERIAŁOWEGO JEDNOSTKI BOJOWEJ UKIERUNKOWANEGO NA REALIZACJĘ MISJI

MODELING AND SIMULATION OF MISSION-ORIENTED COMBAT UNIT MATERIEL SUPPORT

W artykule przedstawiamy ramy modelowania i symulacji ukierunkowanego na realizację misji Systemu Zabezpieczenia Materiałowego Jednostki Bojowej (Combat Unit Material Support System, CUMSS). Opisujemy proces zabezpieczania materiałowego, analizujemy jego charakterystyki i optymalizujemy zasoby. Prezentowany model opiera się na obszernej analizie procesu eksploatacji oraz procesu wykorzystania zasobów. Skonstruowano strukturę federacyjną i model obiektowy federacji dla zabezpieczenia materiałowego jednostki bojowej. Przedstawiono, na podstawie przykładowej misji, federacje dla zdarzeń dyskretnych, zdarzeń ciągłych i procesu podejmowania decyzji. Do analizy charakterystyk CUMSS w przedstawionym przykładzie misji użyto symulacji.

Słowa kluczowe: *Jednostka bojowa, wsparcie materiałowe, modelowanie i symulacja, ukierunkowany na realizację misji.*

In this paper, we present a framework for modeling and simulation of a mission-oriented Combat Unit Materiel Support System (CUMSS). We describe the process of materiel support, analyze its performance, and optimize the resources. This model is based on a comprehensive analysis of the maintenance process and the resource utilization process. A federation framework and a federation object model are constructed for combat unit materiel support. For an example, mission, we provide the federations for the discrete events, the continuous events, and the decision-making process. Simulation is used to analyze the performance of CUMSS for this example mission.

Keywords: *Combat unit, materiel support, modeling and simulation, mission-oriented.*

1. Introduction

A combat unit is a military unit in the army organization that can be used to execute battle and training missions. Due to the different requirements of such missions, the tasks to be executed by the combat unit change accordingly. Considering the requirements of future high-tech warfare, the combat unit relies increasingly on an effective material support system. Such a system is a key factor that may determine the victory or defeat of the warfare. It is important to evaluate the operation of a mission-oriented combat unit material support system [9].

In this paper, we adopt the ontology modeling method, utilizing the ideas of systems engineering and taking the federation development (FEDEP) model as a reference. We propose a conceptual model of CUMSS based on a comprehensive analysis of its operation. Using the established conceptual model as a reference, we divide the large-scale complex system into small modules. Following the High Level Architecture (HLA) standards, we simulate the support command process, the maintenance process, the material supplement process, and the logistics transportation process. The federates interact, cooperate, and synchronize with one another within the HLA framework, which compose a mission-oriented combat unit material support simulation system.

2. The combat unit materiel support system

The CUMSS is created for executing a mission via a series of activities of material supply, material management, and equipment maintenance. The combat unit materiel support system relies on various resources including hardware, software, and personnel to establish and maintain the required scale of materiel and in perfect technology state.

The CUMSS implements the support task under the direction of the local and upper operation command departments in cooperation with local logistics command departments. The CUMSS mainly consists of the entities such as combat unit materiel support command department and materiel support force (maintenance department and depot). The combat unit materiel support command department directs materiel support activities. Materiel support forces are responsible for salvage, repair, technical support, and supply of various ammunitions and maintenance materials [2-4, 8, 10]. Figure 1 describes the relationship among the entities of the CUMSS and parties it interact with.

3. Conceptual modeling of combat unit materiel support based on ontology

3.1. Ontology modeling of combat unit materiel support
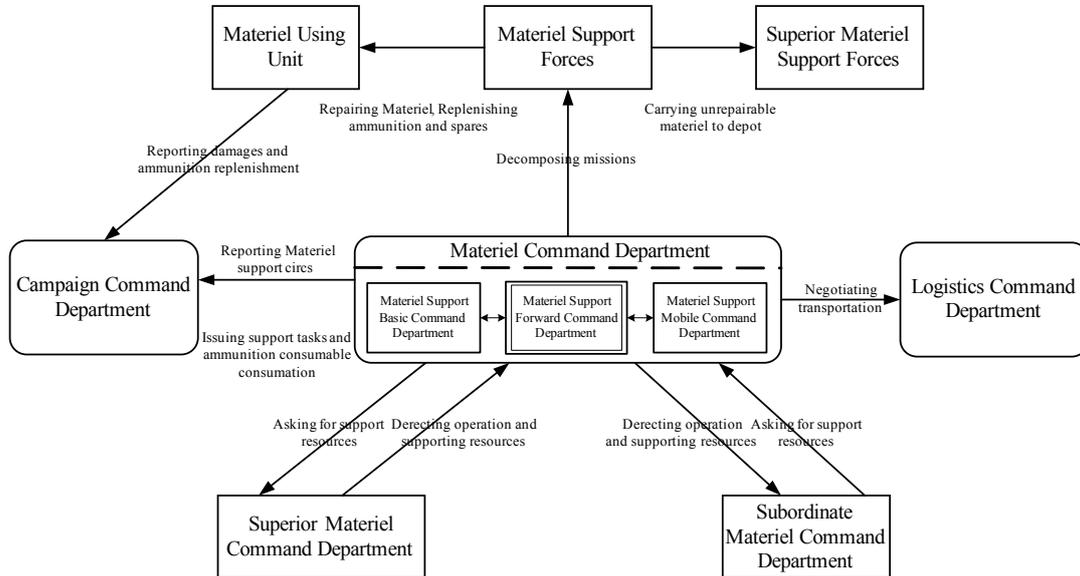
Fig. 1. The relationship between entities of CUMSS

The mission-oriented combat unit materiel support system is a complex dynamic system. In the modeling process of the support system, it is difficult to obtain knowledge concerning combat unit materiel support because it is difficult for the experts in the domain and staff of system development to communicate with each other. This results in a slow progress in system development and affects the quality of the developed system. At the same time, traditional support models that were established for specific purposes can hardly be reused in new projects. In view of this situation, constructing a conceptual model for combat unit materiel support based on ontology is feasible. With ontology, we will be able to clarify the domain knowledge structure, obtain the related knowledge, unify the related terminology and concepts, provide the common semantic foundation for the interactions between different applications, and achieve domain knowledge sharing and reusing.

The ontology of combat unit materiel support is composed of five basic elements which are concept, relation, attribute, axiom and instance. A clear description of these elements is essential for representation of knowledge in the domain of combat unit materiel support. The core is to describe explicitly the concepts, the attributes of the concepts and the relationship between the constraint conditions and the concepts.

3.2. Combat unit materiel support ontology structure system

The combat unit materiel support ontology consists of a group of glossaries with specific meanings or semantic contents [5]. These glossaries compose of the most fundamental terminolo-

gy of materiel support and form a basis of combat unit materiel support conceptual model which can be shared and understood. According to the ontology modeling ideas, the concept set and the ontology in the domain of combat unit materiel support are formally defined as follows [11]:

The combat unit materiel support domain ontology ESCO $= <C, R, f, A, I>$, in which $C=\{c_1,c_2,...,c_n\}$ is the concept set; $R=\{r_1,r_2,...,r_n\}$ is the set of relationships between the concepts, where $r_i \subseteq C \times \cdots \times C \rightarrow \{True, False\}$, if $i \in [1,n]$; f is the injective axiom function; $A=\{A_1,A_2,...,A_n\}$ is the attribute set; and I is the instance set.

With the combat unit materiel support domain being the object to be modeled, the combat unit materiel support ontology is one by which the common attributes in the domain are classified and the level relations of classes are marked, and the interdependence relationships between different objects are stated. The structure of the ontology is shown in Figure 2.

3.3. Constructing the combat unit materiel support ontology

Based on the combat unit material support ontology system established above, the ontology can be constructed according to the following procedures:

1) Enumerating the Domain Concept Terminology: In the process of systematically analyzing CUMSS operation, it is necessary to enumerate the primary concept terminology in the domain and to present them in a hierarchical and structural manner. Take the resource ontology as an example. The concepts enumerated in parentheses are subordinates to those outside the parentheses. The resources are support establishment, manpower and personnel, storage and transportation, provision support (ammunition, maintenance part), support equipment (general equipment (lathe, drill press), special equipment (equipment for examine of artillery, support equipment)), technology information, training and training support, and computer resource.
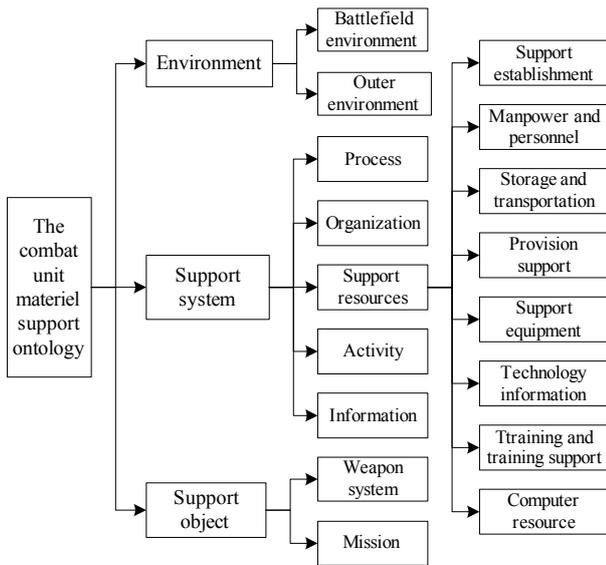
Fig. 2. The structure of the combat unit material support ontology

2) Defining the Attributes of Concepts and Their Relationships: The ontology attribute is a description of the semantic characteristics of a concept that need to meet the requirements of clarity, uniformity, completeness, extendibility and applicability [7]. The resource attributes include general attributes [6] (resource label, name, type, position, model and so on), organization attributes (respective organization, person in charge, and so on), use attributes (usability, reusability, priority, and so on), and ability attributes (list of resource functions).

Establishing the Ontology Model: An original domain ontology model is set up following the steps outlined above and then the domain ontology model can be established in the Protégé-2000 tool.

4. Designing the mission-oriented combat unit materiel support simulation system

4.1. The framework of CUMSS

According to the constructed combat unit materiel support ontology conceptual model, based on the organization model, the CUMSS federation system is designed. The system consists of ten federates and the following are their functions:

3) Directing and Adjusting Federate: to set the initial simulation situation.
4) Simulation Management Federate: to control the simulation running process.
5) Simulation Evaluation Federate: to meet the need of support concept evaluation and the support command personnel training.
6) Simulation Display Federate: to simulate the virtual battlefield environment.
7) Materiel Using Unit Federate: to simulate the materiel battlefield damage and the malfunction of the services.
8) Basic Command Post Federate: to send orders according to the operation profile in the simulation process.

9) Materiel Support Command Post Federate: to simulate the interior operation of materiel support command department.

Logistics Support Force Federate: to simulate the logistics transportation process.

4.2. The federation object model

The CUMSS is a complex system whose running process involves massive data exchanges. According to the information model, the resource model, and the process model in the conceptual modeling process, the object classes and the interactive classes in the simulation system are designed. Part of the simulation system is described as follows [1]. The object classes in the simulation system include:

10) Equipment Class: It has attributes such as ID, Position, and State.
11) Vehicle Class: It has attributes such as ID, Position, and State.
12) Depot Class: It has attributes such as Position, Material Type, and Material Quantity.
13) Repair Shop Class: It has attributes such as Position and State.

The interactive classes in the simulation system include:

1) Fault Maintenance Application Class: It has parameters such as ID, Part, Part State, and Fault Mode.
2) Load Cargo Class: It has parameters such as ID, Cargo Type, and Cargo Quantity.
3) UnLoad Cargo Class: It has parameters such as ID, Cargo Type, and Cargo Quantity.

Transport Part Command Class: It has parameters such as ID, Part, Part State, and Destination.

5. Developing the federates

5.1. Discrete-event simulation based on Petri-net

We use the ExSpect software developed by Eindhoven University of Technology of the Netherlands to establish the support force federate's maintenance process model and its sub-models of maintenance analysis, resource analysis and repair process, as well as the materiel using unit federate's preventive maintenance model, corrective maintenance model, and so on.

5.2. Simulation of command support decision based on workflow

In simulating the command post federate, the distributed workflow system based on the internet is used to establish the organization structure model, the process model, and the information model for the management departments. Because distributed workflow system is based on the WAN technology, various functions of the management departments can run on remote computers through special-purpose WAN or the Internet as well as on LAN computers in support integration of multi-management departments. At the same time, simulation of "Human-in-Loop" in materiel support system may also be achieved which supports management department personnel's training and decision-making.

5.3. Simulation of other federates

In simulating the transportation process of the logistics support force federate, Simulink of Matlab is used to establish dynamic models of various transportation means. There have been many research achievements. We need to point out that the linkage between transportation means dynamic simulation system and HLA is achieved by Matlab DIS/HLA tool package of MAK Corporation.

6. Conclusion

Following the federation development process, this paper analyzed the running process of materiel support system and established the combat unit materiel support domain ontology conceptual model. Then, based on the ontology model, a simulation system framework was constructed and the object model was developed. Discrete-event, continuous-event, and decision-making federates were developed. Finally, the modeling and simulation for CUMSS were achieved. This paper provides a universal conceptual framework for the domain communication, forms a basis for knowledge sharing, and explores the application of HLA to the materiel support domain.

7. References

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