Formal Information Representation for Tactical Reconnaissance System Organization Model

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Abstract: The purpose of this paper is to explore formal information representation for tactical reconnaissance system (TRS) organization model, i.e. to describe its framework and analyze its description logic to form organization information in establishing a logical simulation model for the real organization system. This paper establishes system caste diagram, analyzes task, role and entity for TRS organization, and uses Object-Z specification language to design relevant formal models of organization, roles and entities in TRS. It further presents a method in transforming Object-Z class tree to TRS task tree organization, and checks these formal models by implementing simulation. This work proposes a novel approach of formal information representation for a complex warfare system organization model through transforming subsystem-level representation to Object-Z representation, till task tree that reflects system organization information. The application in tactical reconnaissance task decomposition modelling and simulation demonstration system proves that this approach is feasible and effective.

Keywords: Formal Information Representation, System Organization, Organization Information, Simulation, Object-Z.

1. Introduction

The term organization is used to represent partitions and groups of entities such as departments, communities and societies. Warfare system is a dynamical complex organization system with lots of intelligent entities and is characterized by these elements and the time-dependent development of their states. One kernel in complex warfare system, e.g. tactical reconnaissance system (TRS) organization model is formal information representation, i.e. how to design its framework and analyze its semantic knowledge and description logic [1] to form organization information in establishing the simulation model for the real organization system.

Especially in this age of the network, military organization is turning to “chaoplexity” and the scientific way of warfare is characterized by chaoplexic warfare [2-3]. Correspondingly, some systems and complexity theories are presented [2-6]. E.g., Adaptive Transformation is the proposed intellectual and operational approach to adequately address Armed Forces’ evolution in the 21st century [4]. As for their applications in system organization modelling, an important issue is to explore formal information representation for complex warfare system organization model.

Some authors [6-7] propose a set of models, tools and systems aimed at virtual or real technical, industrial, and commercial organizations. But all of them assume social events, and are not focused on warfare procedures. The focus on prior evaluation and analysis of such procedures, i.e., on formal information representation for complex warfare system organization model, would increase greatly the understanding of the response to military operations. The results of formal information representation can then also be used as a starting point for scenario understanding and prediction in future warfare behaviours.

In some papers [8-10], complex warfare system organization and entities’ architecture are studied. However, in most current research fruits, the principal description logic is usually ignored since appropriate formal specification lacks. Thus, the analysis and comprehensive understanding of TRS is extremely difficult without formal information representation approach.

As for formal information representation, there are some methods and tools, such as dynamic description logics [1]. It is obvious that Object-Z [11-13] has an object-oriented advantage. Thus, based on describing system caste and analyzing task, role and entity, by applying Object-Z specification language, a novel formal information representation approach to TRS organization model is proposed through transforming subsystem-level representation to Object-Z representation, till task tree that reflects organization information. The application in TRS modelling and simulation proves its feasibility and validity.

2. System Framework Description

Organizations can define sub-organizations as soon as the complexity of the system increases. Organizations also define rules (norms or laws) that are expressed in terms of general organization constraints (or axioms). Organizations and their sub-organizations are immersed in environments where the elements, i.e., entities execute and interact with each other. The organization relationship is used to represent the relationship between entities and the environments that they inhabit.

Complex warfare system is essentially a distributed intelligent system that can be defined as a coordinated group of individuals who collaborate for a common military task, on the basis of some tactical rules and resources. The system caste diagram (See Figure 1) shows that complex warfare system consists of a number of entity members.

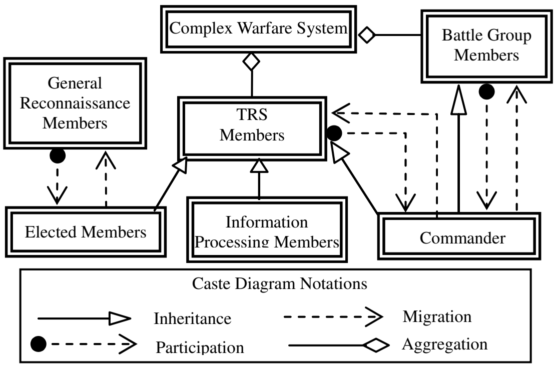


Figure 1. System caste diagram.

To express and illustrate organization information about the entities and their tasks and roles is the key. Traditional analysis on task / sub-task and entity, always centres on a tighten coupling of task-entity, as shown in Figure 2. All these interactive activities imply the need for a clear policy for co-ordination. The larger the number of different possibilities and the set of the identified constraints for entities' joint work are, the richer the co-ordination policies will be.

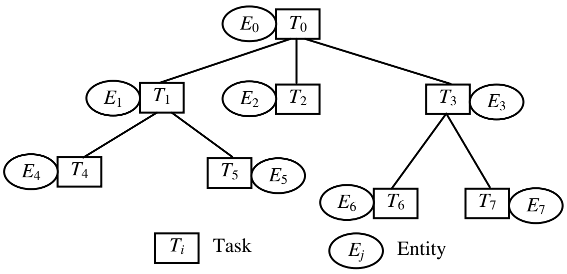


Figure 2. Tighten coupling of task-entity.

Task decomposition in the context of TRS could be considered in the scope of co-ordination of the entity's activities in a dynamic environment where resources may be scarce.

Based on the above analysis, we can obtain task-decomposition system framework description method by establishing a role-entity mapping mechanism, shown in Figure 3, in which an entity can play a role, as an entity agent, to fulfill task decomposition with more flexibility in the TRS model.

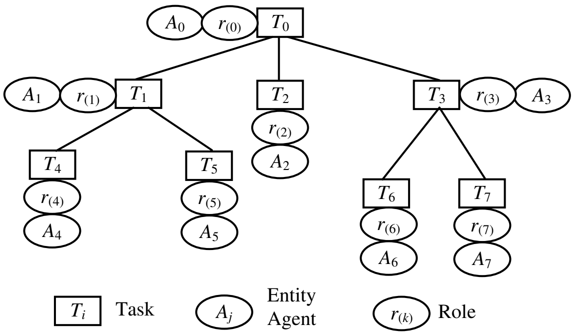


Figure 3. Flexible coupling of task-role-entity agent.

By this method, we can conveniently implement formal information representation for establishing the models of role, interaction and organization.

3. Formal Information Representation

The most important feature of Object-Z is the class schema [12-13]. The class schema may include local type or constant definitions, at most one state schema and an initial state schema together with zero or more operation schemas. A class schema takes the form of a named box, optionally with generic parameters. It extends the graphical component of Z (boxes) to define its classes, providing an immediate visual indication of the scope of the definition. In Object-Z, a class is represented as a named box with zero or more generic parameters. Figure 4 shows the form of the Object-Z "box".

ClassName [generic parameters]

visibility list
inherited classes
type definitions
constant definitions
state schema
initial state schema
operation schemas
history invariant

Figure 4. Object-Z class schema.

In Object-Z class schema, the operations define the behavior of the class by specifying any input and output together with a description of how the state variables change. Refinement is formally addressed in the context of Object-Z specifications as follows:

Definition (Downward Simulation in Object-Z): an Object-Z class C is a refinement (through downward simulation) of the class A if there is a *retrieve relation* R on A.State$\wedge$C.State so that every visible abstract operation Aop is mapped into a visible concrete operation Cop thus the following holds:

(Initialization)$\forall$C.State•C.init$\Rightarrow$ ($\exists$A.State•A.init$\wedge$R)

(Applicability)$\forall$A.State;C.State•R$\Rightarrow$(preAop$\Rightarrow$ preCop)

(Correctness)$\forall$A.State;C.State;C.State'•R$\wedge$pre Aop$\wedge$Cop$\Rightarrow\exists$A.State'•R'$\wedge$Aop

TRS Organization

Organization Model

general reconnaissance platform: $\mathbb{P}$ *General Reconnaissance Platform*
intelligence processing platform: $\mathbb{P}$ *Intelligence Processing Platform*
resource: $\mathbb{P}$ *Battlefield Intelligence*

General Reconnaissance Platform

Role Model

obligations: $\mathbb{F}$ *Obligation*
qualifications: $\mathbb{F}$ *Battlefield Reconnaissance*
dependencies: {*Scouting_Advance*, *Alertness_Reconnaissance*, *Cooperating_and_Intercommunion*, *Reporting_to_Intelligence_ Processing_Platforms*, *Awaiting_Orders*}

*d*1: *dependencies•d*1*.name="Scouting_Advance"*$\Rightarrow$
*d*1*.dependee=Intelligence Processing Platform*$\wedge$*d*1*.dependum=Goal*
*d*2: *dependencies•d*2*.name="Alertness_Reconnaissance"*$\Rightarrow$
*d*2*.dependee=Intelligence Processing Platform*$\wedge$*d*2*.dependum=Task*
*d*3: *dependencies•d*3*.name="Cooperating_and_Intercommunion"*$\Rightarrow$
*d*3*.dependee=Intelligence Processing Platform*$\wedge$*d*3*.dependum =Resource*
*d*4: *dependencies•d*2*.name="Reporting_to_Intelligence _Processing_Platforms"*$\Rightarrow$
*d*4*.dependee=Intelligence Processing Platform*$\wedge$*d*4*.dependum=Task*
*d*5: *dependencies•d*5*.name="Awaiting_Orders"*$\Rightarrow$
*d*5*.dependee=Intelligence Processing Platform*$\wedge$*d*5*.dependum=Task*

Intelligence Processing Platform

Role Model

obligations: $\mathbb{F}$ *Obligation*
qualifications: $\mathbb{F}$ *Battlefield Reconnaissance*
dependencies:
{*Intelligence_Synthesis*,*Reconnaissance_Requirement_Announcement*, *Target_Information_Announcement*, *Reconnaissance_Task_Assignation*, *Reconnaissance_Task_Adjustment*}

*d*1: *dependencies•d*1*.name="Intelligence_Synthesis"*$\Rightarrow$
*d*1*.dependee=General Reconnaissance Platform*$\wedge$*d*1*.dependum=Resource*
*d*2: *dependencies•d*2*.name=*
"Reconnaissance_Requirement_Announcement"$\Rightarrow$*d*2*.dependee=General Reconnaissance Platform*$\wedge$*d*2*.dependum=Goal*
*d*3: *dependencies•d*3*.name="Target_Information_Announcement"*$\Rightarrow$
*d*3*.dependee=General ReconnaissancePlatform* $\wedge$*d*3*.dependum=Resource*
*d*4: *dependencies•d*4*.name="Reconnaissance_Task_Assignation"*$\Rightarrow$
*d*4*.dependee=General Reconnaissance Platform* $\wedge$*d*4*.dependum=Task*
*d*5: *dependencies•d*5*.name="Reconnaissance_Task_Adjustment"*$\Rightarrow$
*d*5*.dependee=General ReconnaissancePlatform* $\wedge$*d*5*.dependum=Task*

Figure 5. TRS organization, general reconnaissance platform role and intelligence processing platform role.

The system organization specification determines what each intelligent entity does, and it also handles failure of members to achieve their goals [9]. The intelligent entities play roles defined in organizations. The intelligent entity roles have associated goals, duties, rights and protocols that influence the execution of the entity that is playing the role. Thus, roles played by entities in organization and inter-entity interaction are the kernel on formal information representation for TRS organization model.

Bisht et al. [9] think that inter-entity relationship is an essential requisite for success in any organizational activity. In any military operations, all the warfare entities must be integrated into closely knit teams to perform their collective objectives. However, it is essential that a role reflecting entities interaction is mapped into a relevant intelligent entity. Unfortunately, there is a lack of resolution to the problem, i.e., how establish the entity model in describing organization information.

General Reconnaissance Platform

EntityClass 《*Entity*》

battlefield intelligence_name:*Name*
intelligence importance: $\mathbb{N}$
intelligence count: $\mathbb{INT}$
get_battlefield_intelligence 《*goal*》 :*Booleam*

Scouting_Advance

stereotype: 《*qualification*》
input?: $\mathbb{F}$ *Location of Enemy Deployment*
output!:*Position of Enemy Equipment Platforms*

Alertness_Reconnaissance

stereotype: 《*qualification*》
search conditions?: *Battlefield Situation*
result_battlefield_intelligence!: $\mathbb{F}$ *Battlefield Intelligence*

…

Intelligence Processing Platform

EntityClass 《*Entity*》

battlefield intelligence_name:*Name*
intelligence importance: $\mathbb{N}$
intelligence count: $\mathbb{INT}$
process_battlefield_intelligence 《*goal*》 :*Booleam*

Intelligence Synthesis

stereotype: 《*qualification*》
search conditions?:*Obtained Real-time Intelligence*
result_battlefield_intelligence!: $\mathbb{F}$ *Battlefield Intelligence*

Reconnaissance_Requirement_Announcement

stereotype: 《*qualification*》
input?: $\mathbb{F}$ *Task to be Announced*
output!: *Reconnaissance Scheme*

…

Figure 6. Platform entities in TRS organization.

Based on the above role-entity mapping mechanism, we can further propose TRS roles and entities models which play important roles in forming organization information, since they provide description logic to reflect the static caste structure and dynamic interaction relationships of TRS. Thus, a logical simulation model for the real organization system can be obtained as the basis of simulation for TRS.

Relevant representations by Object-Z are shown as Figure 5 and Figure 6.

4. Approach Application

From class tree to task tree

Since Object-Z always involves a number of additional class definitions (for instance, one class being the root of all objects, and another class being the root of all classes), system organization can be described in Object-Z as class tree, which describes the functionality of an ordered binary tree abstractly by defining an infinite tree structure, a subset of the nodes of which denote the actual tree. This subset necessarily includes the root node of the infinite structure. An example of the class is shown in Figure 7.

The state of class Tree is defined recursively in terms of two subtrees *left_tree* and *right_tree*. It also has a variable *val* denoting the value in the root node of the tree (or sub-tree) and a Boolean-valued variable *null* denoting whether or not the root node is part of the actual tree. To facilitate specifying the properties of an ordered binary tree in the state schema's predicate, a constant nodes denoting the set of all nodes in the infinite structure, is declared.

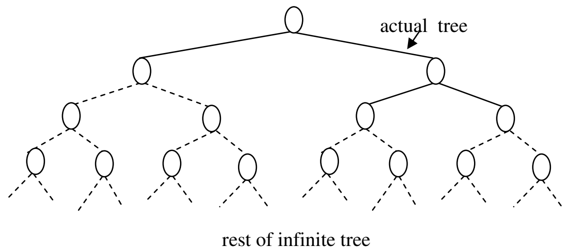


Figure 7. Abstract representation of a binary tree.

According to class tree in Object-Z, we can establish task tree, by which we can decompose task for TRS and thus further explore its organization information. The decomposed task manifests a hierarchy like a tree. The task tree's rootstalk is in fact the total objective of tactical reconnaissance and the coequal or same hierarchy crunodes have an *And*/*Or* relationship. We assume that there are n borders from cru-node T leading to the crunodes ST_1, ST_2, …, ST_n. If n borders have an *And* relationship in logic, then $T = ST_1 \wedge ST_2 \wedge \ldots \wedge ST_n$, which means the fulfillment of task T depends on the final fulfillment of all subtasks. If n borders have an *Or* relationship in logic, then $T = ST_1 \vee ST_2 \vee \ldots \vee ST_n$, which means the fulfillment of task T only depends on the fulfillment of a discretional subtask.

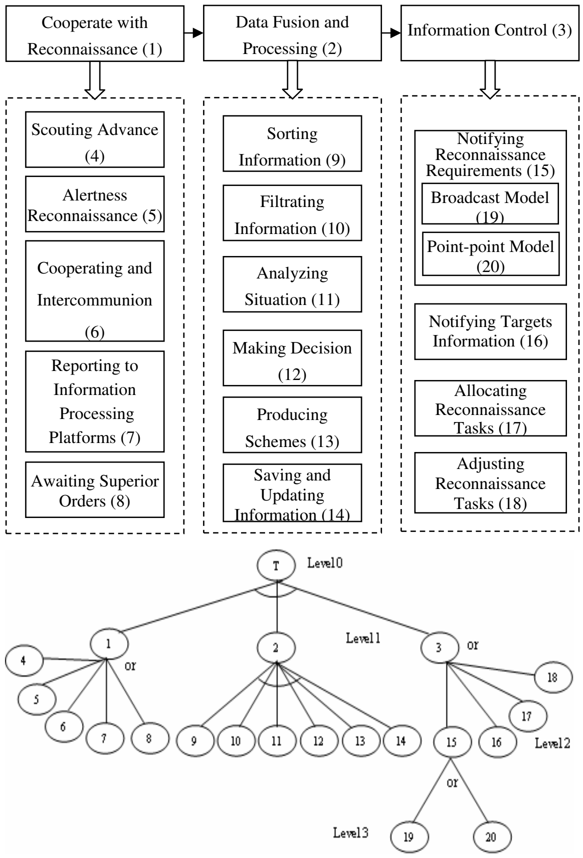


Figure 8. Task decomposition and corresponding task tree of TRS.

Then, we decompose the subtasks into lower hierarchy in term of the correlation and logistic relationship [10]. Thus we can get organization information in decomposition of task for TRS, as illustrated in Figure 8.

By this decomposition method, the Object-Z class tree is transformed to the tactical reconnaissance task tree. During this course, static formal information representation is transformed to dynamic entity task relationship.

Implementing simulation and checking models

In the simulation demonstration system that we set up, multi-entity interactions relationship in dynamic and real-time military reconnaissance operations is given in Figure 9, in which T and t represent task inputs for Red Force entities and Blue Force entities respectively.

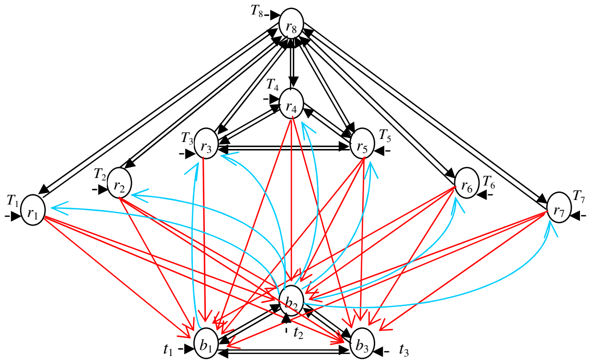


Figure 9. Multi-entity interactions relationship.

The designed entities in this simulation demonstration system are listed as follows:

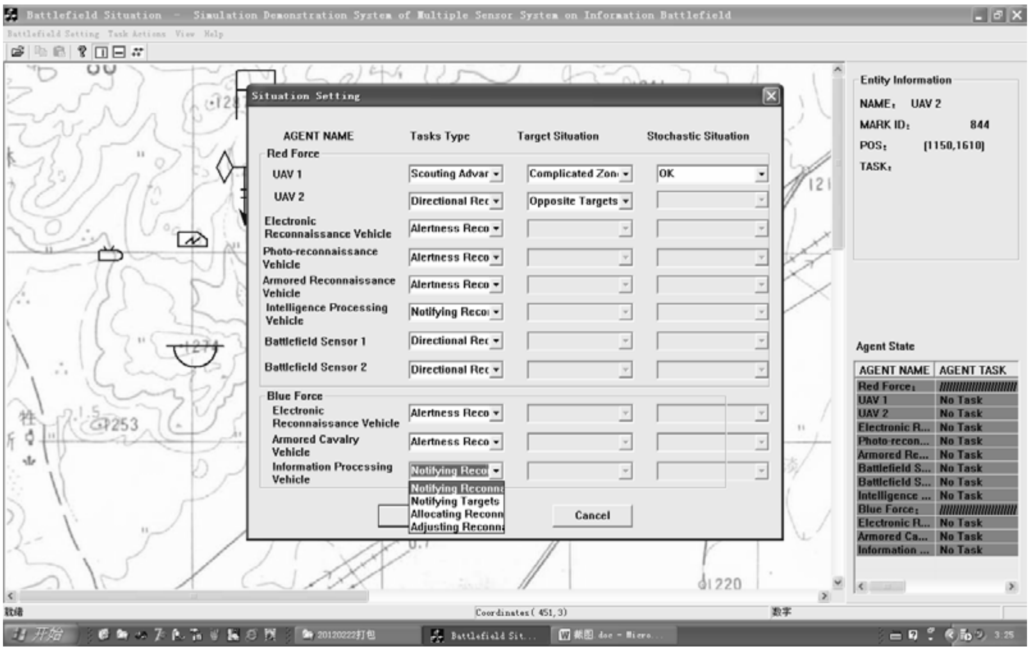
r_1 : UAV Entity 1 (Red Force);

r_2 : UAV Entity 2 (Red Force);

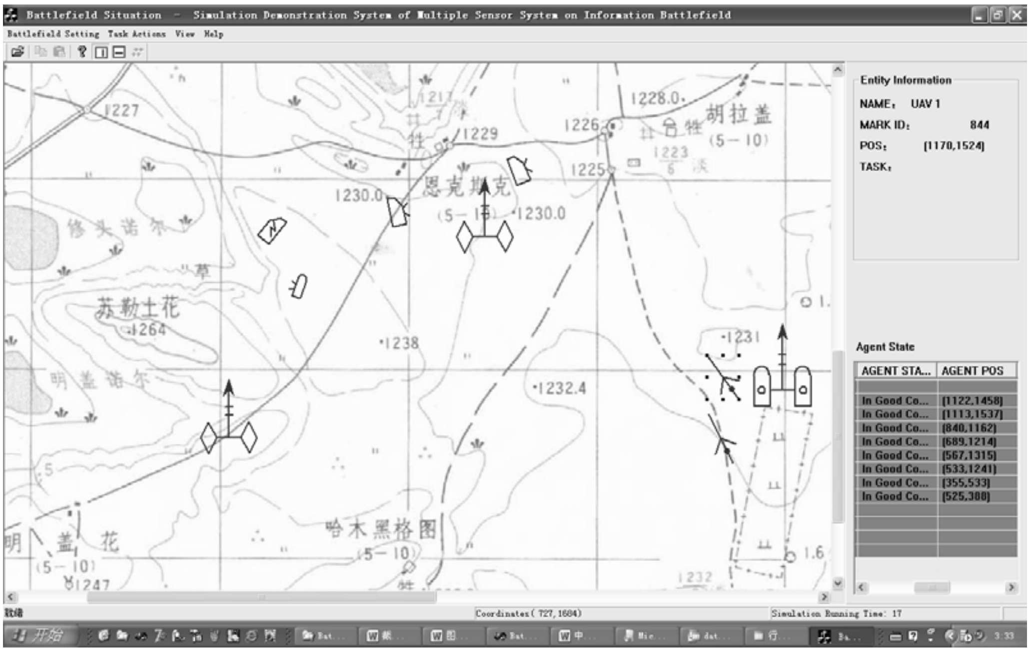
r_3: Electronic Reconnaissance Vehicle Entity (Red Force);

…

b_3: Information Processing Vehicle Entity (Blue Force)



(a)



(b)

Figure 10. Simulation demonstration system.

Since each intelligent entity has certain sensing and actuating capabilities, and it can observe what happening around as private events. TRS members act in coordination by being given goals according to the specification, and they are themselves responsible for determining how to specify those goals. Also, several tactical reconnaissance entities may observe the same external task that becomes a common task among them. In addition, a private task can be broadcasted among tactical reconnaissance entities to become a common task, as well. Thus, the global specification is established based on the TRS organization, i.e., the union of all members' reconnaissance tasks. For example, the information processing vehicle entity is driven by the task of "Notifying Reconnaissance Requirements" and takes its tactical actions. Entity-oriented specification using Object-Z and its corresponding task tree is essentially reflects TRS organization behaviours. By this formal information representation for TRS organization, we can apply the conceptual model to simulation model and implement it.

Simulation implementation can be illustrated by Figure 10. When we run the system, we can obtain some results, and find that these TRS entities performed successfully intelligence reconnaissance task on tactical virtual battlefield. Although there are only a few entities in the established distributed simulation system, it shows that our model can identify main components and discover their local interactions and behaviours. It is from the local interactions of individual components and their behaviours with their environment that global system behaviours emerge.

TRS simulation results are accordant to real warfare situation. The fact proves that our formal models are reasonable and the formal information representation approach is feasible and effective.

5. Conclusions

In this paper, TRS is researched as a case of complex warfare system and Object-Z specification language is applied to describe its framework and analyze its description logic to form organization information in establishing a logical simulation model for the real organization system. Thus, an original approach to formal information representation for TRS organization model is proposed, which is validated by its application in TRS simulation. The main advantages of our approach may be summarized as follows:

1. It provides a generic method on forming organization information in establishing the logical simulation model for a real organization system.
2. It advances a tool to establishing mapping function of meta-role model to entity model and a series of formal models of organization, roles and entities in organization based on system organization framework description.
3. It develops a transforming mechanism from Object-Z class tree to task tree and therefore constructs a bridge from conceptual organization model to organization behaviours simulation model.
4. It takes a typical warfare system, i.e., TRS, which is a complex organization system with different intelligent entity members, as research object, and performs TRS modelling and simulation, therefore indicates its usability and applicability.

Acknowledgements

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REFERENCES

1. CHEN, L. M., Z. Z. SHI, **A Behaviour Strategy for Agents in the Semantic Web Using Dynamic Des cription Logics**, Information–An International Journal, vol. 14, no. 3, 2011, pp. 993-998.
2. BOUSQUET, A., **Chaoplexic Warfare or the Future of Militar y Organiz ation**, International Affairs, vol. 84, no. 5, 2008, pp. 915-929.
3. BOUSQUET, A., **The Scientific Way of Warfare: Order and Chaos on the Battlefields of Modernity**, Columbia University Press, NY, 2009.
4. LUCAS, C., L. FRANCISCO, **Towards a Theory on the D esign of Adaptive Transformation: A System ic Approa ch**, US Army Command and General Staff College, Kansas, 2010.

5. JURGEN, S., H. BRUCE, **From Complex Conflicts to Stable Cooperation**, Complexity, vol. 13, no. 2, 2007, pp. 78-91.

6. AULA, P., K. SIIRA, **Organizational Communication and Conflict Management Systems**, Nordicom Review, vol. 31, no. 1, 2010, pp. 125-141.

7. CABRERA-PANIAGUA, D., G. HERRERA, C. CUBILLOS, M. DONOSO, **Towards a Model for Dynamic Formation and Operation of Virtual Organizations for Transportation**, Studies in Informatics and Control, vol. 20, no. 3, 2011, pp. 255-264.

8. LI, X., G. T. PAN, Z. M. DONG, D. B. CUI, H. W. AN, **Designing of Multi-Agent-Based of Complex Warfare System Simulation Model**, Dynamics of Continuous, Discrete and Impulsive Systems, Series A, vol. 13, no. S3, 2006, pp. 953-959.

9. BISHT, S., A. MALHOTRA, S. B. TANEJA, **Modelling and Simulation of Tactical Team Behaviour**, Defence Science Journal, vol. 57, no. 6, 2007, pp. 853-864.

10. LI, X., Z. M. DONG, **Platform-Level Distributed Warfare Model-Based on Multi-Agent System Framework**, Defence Science Journal, vol. 62, no. 3, 2012, pp. 180-186.

11. DERRICK, J., E. BOITEN, **Refinement in Z and Object-Z: Foundations and Advanced Applications**, Springer, 2001.

12. SMITH, G., **The Object-Z Specification Language**, Kluwer Academic Publishers, 2000.

13. DUKE, R., G. ROSE, **Formal Object-Oriented Specification Using Object-Z**, MacMillan, 2000.