Performance-oriented Adaptive Design for Complex Military Organizations

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Abstract—**Traditional military organizations are designed mainly based on the missions, categorized as mission-oriented design. The paper proposes a new framework that revises the design process, aiming at the organization performance, which comes from the new semantic model eFINC and performance metrics. First, a complete model of military organization is proposed, i.e., eFINC, which extends semantic contents of functional units in complex military organizations, provides the formulization method for the nodes, edges and visual representation. Secondly, the performance metrics of military organizations are defined for eFINC model normatively. The metrics are classified as Response Speed, Coordination Capacity, Execution Capacity and Information Support. And then, the adaptive design model is proposed based on the eFINC model and metrics. Two design strategies are introduced which will lead to a high-performance design of military organizations. Then, Performance Rate is defined as the main reference for the adaptive organization design. The adaptive design procedure for military organizations is illustrated in detail. Finally, the practical case study is conducted to demonstrate the effectiveness of our model.**

Keywords- Complex Military Organization; eFINC model; Performance-Oriented;Adaptive design

I. INTRODUCTION

A. Motivation

The term C4ISRK is used by the US army to refer to the complex systems to carry out missions by military forces [1, 6], can also be viewed as a ‘super-system’ comprised of varied functional units that are themselves complex, interacting with each other to achieve the common shared goals of military systems [3]. The structure of traditional C4ISRK is typically hierarchy. With the development of networking and computer technology, more and more varied modes of C4ISRK system structures come into being. Meanwhile, the ideas of modern military operations heavily rely on more flexible and more robust structures, such as Network Centric Warfare (NCW) [2]. Network Centric Warfare is becoming the major type of wars, which focus on overall performance of military systems instead of that of individual component for single task.

Military organizations can be viewed as a subset or ‘overlay network’ of C4ISRK system, which are designed to execute some mission over them. Given a fixed C4ISRK system, how to design an efficient military organization to meet the need of some mission is a challenging problem. Military organizations are assigned to accomplish varied tasks. The challenges that military organization designers are facing upon are how to describe their structures, and how to analyze their performance under uncertain and changing environment. Levchuk had proposed the normative design of task-based organization in the way of three-phase process [7,8,9]; however, the effort is insufficient for organization design, especially in the networking environment. All the subsequent improvements for Levchuk’s work are based on the similar ideas [8, 9]. These works can be categorized as mission-oriented design. Military organizations with mission-oriented design strategies are difficult to adapt to the complex and volatile external changing. These organizations will reduce the adaptability of the structure while only aiming at the pursuit of mission efficiency.

It has become an essential need to make design for adaptive military organizations to achieve the high performance for military missions. It have coming into being that the military organizations with adaptive features will play an important role in the war. Traditional organizations are designed mainly based on the organization efficiency. The paper proposes a new framework that revises the design process, aiming at the performance, not just the task efficiency of the corresponding organizations.

B. Related Work

Many researchers have conducted much research work in this field. Anthony put forward four principles for the evaluation of NMO architecture based on Social Network Analysis (SNA) and FINC methods [5, 16, 17]. SNA performs network analysis of relations between individuals within the organization, and is originally inspired from graph theory, and is often applied in military organizations, sociology and anthropology. FINC (Force, Intelligence, Networking and C2) method is used to evaluate effectiveness of different organization architecture, the evaluation metrics include information delay, collaboration delay, intelligence factor and other indices. FINC method proposes some ideas of modeling and analysis of military organizations, but has some difficulties to describe the formal characteristics of military organizations. Anthony also researched the relationship

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between the robustness and organization structure based on FINC model [5, 16, 17]. Jeff has also researched the problems of distributed networked operations, building the networked models for military organization [13]. But these models do not have the abilities of performance analysis over the organization structures.

Kathleen have put forward a PCAN method to model C2 organization by using the network form [4, 12]. PCAN model is consisted of multiple networks, but each network is isomorphism (All the nodes are of same types.), and each network is deterministic (all the nodes are connected or disconnected). The work of Kathleen focuses on analysis for networked features of military organizations. The analysis is independant to the design of military organizations.

Levchuk had proposed the normative mission-based design of organization in the way of three-phase process He presents a design methodology for synthesizing organizations to execute complex missions efficiently. It focuses on devising mission planning strategies to optimally achieve mission goals while optimally utilizing organization's resources. Effective planning is often the key to successful completion of the mission, and conversely, mission failure can often be traced back to poor planning. First, corresponding to this framework, military organizations are designed based on highly abstracted system models, without considering constrains of basic characteristics of existing C4ISRK systems. Secondly, Levchuk has provided only simple metrics to evaluate the performance of target organizations, i.e., task accomplishment time and so on. Jincai and Baoxin has researched other metrics to measure the performance, but the improvement can be viewed as the extension of time-based metrics [10, 11, 15]. The effort of these works is insufficient for performance-oriented design.

C. Our Contributions

By extending the FINC model, this paper provides a new approach for organization performance evaluation and builds a new performance-oriented design methodology. Our contributions of this paper are following:

(1) A complete model of military organization is proposed, i.e., eFINC, which comes from the FINC model. Contrary to the traditional FINC model, eFINC extends semantic contents of functional units in organizations, provides the formulization method for nodes, edges and visual representation.

(2) The performance metrics of military organizations are defined for eFINC model normatively. The metrics are classified as *Response Speed*, *Coordination Capacity*, *Execution Capacity* and *Information Support*. Contrary to these of FINC model, the metrics are systematic and meaningful.

(3) The adaptive design model is proposed based on the eFINC model and its metrics. First, two design strategies are introduced which will lead to a high-performance design of military organizations. Then, *Adjusting Value (AV)* is defined, which implies the performance rate, as the main reference for the adaptive organization design. At last, the adaptive design procedure for military organizations is illustrated in detail.

(4) Finally, the practical case study is conducted in Section V to demonstrate the effectiveness of our model.

II. The Extended FINC Model for Complex Military Organization

The traditional FINC model is leveraged to describe the military organizations consisting of force units, intelligence units, networking units and C2 units. As we mentioned before, FINC model is constrained with its semantic representation for nodes and edges. Based on the graph theory, the paper extends the semantic expression of varied functional units in the military organizations and provides a method of visual representation for the organization topology. The new model here is named as eFINC.

A. Node Model of eFINC

On the basis of FINC model, there are four types of organization functional units: C2 unit (*C2*), intelligence unit node (*I*), force unit (*F*) and communication unit (*Comm*). Communication unit is a special type of units, which builds a relation between different other units. Here, nodes are modeled as *C2*, *I* or *F*. Communication unit will be discussed, together with EDGE model in next section.

$NODE ::= < C2 | I | F >$

(1) *C2*. C2 units receive information transferred from ***I*** or *F*, makes decisions, and takes charge of ***I*** and ***F***. The representation form is as follows:

$$C2 ::= < Delay, InEdges, OutEdges >$$

where *Delay* is the time delay for information handling, *InEdges* and *OutEdges* are respectively the input and output edges of the C2 unit.

(2) *I*. Intelligence units includes the detection and surveillance systems that provide space information about entities in the battle fields, receives and transfers these information to C2 unit or force units. Scouts, radars, early-warning aircrafts and satellites are typical examples. The representation form is as follows:

$$I ::= < Quality, Radius, InEdges, OutEdges >$$

where *Quality* represents the intelligence quality offered by intelligence units; *Radius* represents the detecting radius accordingly.

(3) *F*. Force units are any entities that can be able to receive orders from C2 units and take actions to the targets and feedback the action effects to C2 units, such as tank bands, armored vehicles, fighters. The representation form is as follows:

$$F ::= < Radius, InEdges, OutEdges >$$

where *Radius* is the combat radius of the force units.

B. Edge Model of eFINC

Edge indicates a relation between two different nodes, which is constrained with a communication unit in military organizations. The number of types of arbitrary directed relation between different units with unit types is 9, named as $E_{C2\text{-}C2}$, $E_{C2\text{-}I}$, $E_{C2\text{-}F}$, $E_{I\text{-}C2}$, $E_{I\text{-}I}$, $E_{I\text{-}F}$, $E_{F\text{-}C2}$, $E_{F\text{-}I}$, $E_{F\text{-}F}$. Each edge is dependant with some communication unit. All the

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relations are sharing same basic parameter structure, defined as below:

EDGE :: =<EdgeType, Delay, Accuracy, InPort, OutPort>

where *Delay* indicates the delay time from start node *InPort* to end node *OutPort*, *Accuracy* is the information transferring accuracy, and *EdgeType :: = <* $E_{C2\text{-}C2}$| $E_{C2\text{-}I}$| $E_{C2\text{-}F}$| $E_{I\text{-}C2}$| $E_{I\text{-}I}$| $E_{I\text{-}F}$| $E_{F\text{-}C2}$| $E_{F\text{-}I}$| $E_{F\text{-}F}$*>*.

C. Edge Model of eFINC

The complete model of eFINC can be described as a three-tuple:

eFINC ::= <NODE,EDGE,VP>

where *NODE*, *EDGE* are defined in Section II.A and II.B respectively, which describe the components and structure of military organizations. Accordingly, *VP* defines the visual primitives for nodes and edges in eFINC, as shown in Figure 1. The square nodes represent fire units (*F*) , rounded boxes nodes represent intelligence units (*I*) , circle nodes represent *C2* units *(C2)*, lines with arrows are one-way information flows, while lines without arrows are two way information flows, and the weights on the lines are delay time when the information is transmitted through them.

In order to more clearly illustrate our model, here the paper gives an example of eFINC, shown in Figure 1, with 10 elements [1].

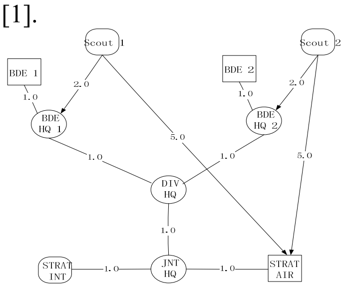

Figure 1. Military Organization Structure based on FINC

According to the organization shown in the figure, the parameters are assumed as below (the delay of each edge is depicted in Figure 1):

Radius (Scout1) = Radius (Scout2) = 100;
Radius (STRAT INT) = 400;
Radius (BDE1) = Radius (BDE2) = 100;
Radius (STRAT AIR) = 400;
Quality (Scout1) = Quality (Scout2) = 0.5;
Quality (STRAT INT) = 0.3;

III. ORGANIZATION PERFORMANCE MODELING

The role of eFINC model is to evaluate organization performance according to organization networking topology and node capacities. These performance metrics directly determinate the adaptability of military organizations while they execute missions. Performance metrics are modeled from four aspects, i.e., response speed, cooperation degree, execution capability and information support. These performance metrics are based on the process of OODA process, which is the C2 model for military organizations [2].

A. Response speed analysis

Response speed is concerned with the mean speed of information flows from intelligence units, via C2 units, to force units, indicating the speed of the whole progress from intelligence-obtaining to intelligence-employing. The main consideration is the delay time on the links between intelligence units and force units.

On the link *<I(p)-F(q)>*, the information delay time from intelligence unit *I(p)* to force unit *I(q)* is the sum of total edge delay time and total C2 delay time, namely, *delay(I(p)-F(q))=∑delay(Edge*$_i$*)* + *∑delay(C2*$_i$*)*. The *Information Flow Coefficient* (*IFC*) defined in this paper is used as the metric to measure the organization response speed. When the organization consists of *n <I-F>* links, the *IFC* can be represented as below:

$$IFC = \frac{1}{\sum delay(I(p), F(q)) / n} \quad (1)$$

IFC implies the control ability and response speed of military organizations over emergency situations. The larger *IFC* is, the faster the response speed is, and the stronger the control ability is.

In terms of the military organization from Figure 1, the delay time of each *<I-F>* link is:

delay (Scout-BDE1) = 4.0;
delay (Scout2-BDE1) = 8.0;
delay (STRAT INT-BDE1) = 7.0;
delay (Scout1-BDE2) = 8.0;
delay (Scout2-BDE2) = 4.0;
delay (STRAT INT-BDE2) = 7.0;
……

B. Coordination capacity analysis

Coordination capacity is very important especially when the C4ISRK system is highly networked. Coordination implies an organized group of units working together aiming at bringing about a purposeful task such as attacking a plane. Here, only coordination between two units with the same type, such as two force units, C2 units or intelligence units, are considered.

(1) Coordination analysis of force units

The cooperation capacity of force units indicates the cooperation degree while they executing a mission. The main consideration is the delay time in information transmission between force units. The less the delay time is, the faster they exchange information with each other and the higher the degree of coordination is. The shortest link between force unit *F(p)* and *F(q)* is marked as *<F(p)-F(q)>*, and the transmission delay as *delay(F(p),F(q))*. The metrics defined to measure coordination extent between force units is denoted as *Force Coordination Coefficient (FCC)*.

$$FCC = \frac{1}{\sum delay(F(p), F(q)) / n} \quad (2)$$

In terms of the military organization in Figure 1, the delay time of each link is 7, and ***FCC***=0.1433.

(2) Coordination analysis of C2 units

The Coordination analysis of C2 units mainly shows the transmission efficiency of C2 network and the

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connectivity of C2 network. *C2 Coordination Coefficient (C2CC)* is defined to weigh the coordination degree between C2 units.

$$C2CC = \frac{1}{\sum delay(C2(p), C2(q))/n} \quad (3)$$

(3) Coordination analysis of intelligence units

Coordination analysis of intelligence units demonstrates the performance of intelligence network, and then reflects the organization capabilities of information obtaining and sharing. Similarly, *Intelligence Coordination Coefficient (ICC)* is defined to weigh the coordination degree between intelligence units.

$$ICC = \frac{1}{\sum delay(I(p), I(q))/n} \quad (4)$$

C. Execution capability analysis

Execution capability is to indicate the capabilitiues of taking orders and executing missions with the use of obtained intelligence information. In this paper, *Execution Capability Coefficient (ECC)* is defined to value the execution capability of force units. The larger ***ECC*** is, the more obvious the advantage of intelligence is, and also the better the execution capability of the force unit is.

$$ECC = \sum_{q} R(F(q))^2 \times EIQ(F(q)) \quad (5)$$

where，*(F(q))* is the combat radius of force unit *F(q)*, and *EIQ(F(q))* is the effective intelligence quality that force unit *F(q)* receives. Effective intelligence quality is the value which *Q(I(p))* is divided by *delay(I(p), F(q))*.

D. Information support analysis

As we all know, intelligence is also an important basis of C2 to carry out situation evaluation and decision making. The analysis of information support capacities is to measure timeliness, accuracy and sufficiency of intelligence. *Information Support Coefficient (ISC)* is defined in this paper to measure the information support capacities.

$$ISC = \sum_{i} IG(C2(i)) \quad (6)$$

IG(C2(i)) is the total information quantity that C2 unit ***i*** obtains. Assume that *IG=R×R×Q* is the initial information quantity that the intelligence unit supplies for. Because of the changing combat environment and the transmission error, the total information quantity *IG* becomes *IG×Accuracy/delay* after transmission.

IV. The Adaptive Design based on Performance Rate

In practice, the structure and performance is hardly optimally matched in the progress of mission executing. Generally speaking, mission enforcing organization could hardly run with the best performance, which calls for an exploration of an adaptive organization design method to adjust the organization structure so as to achieve better performance.

Even the performance metrics of military organizations can be calculated and evaluated; there are still many choices for adjusting the structure. It concerns with the matter of adjusting strategies. The following two strategies are to be complied with to adjust the structures of organizations to achieve better performance.

(1) *Completeness Strategy:* ensuring the completeness of basic command and control relationship, precluding the isolated units. Organizations heavily rely on the proper working state of every basic functional unit, and the task couldn’t be executed successfully with the deficiency of any basic command and control relationship. As a result, the completeness of command and control relationship is essential to the performance of organization structure. Meanwhile, as we see in Section III, performance will decrease dramatically while a link is broken (It means that the delay time is infinite.)

(2) *Tightness Strategy:* strengthening the information exchange between different task modules. Different task modules maybe exist simultaneously corresponding to the multiple tasks which are executed at the same time. They have very strong internal connections but weak external connections, which cause negative effect in term of coordination of the whole mission. So it is vital to strengthen the information exchange between different task modules.

The above two strategies will lead the adaptive organization design to the right direction, where the performance is optimal. These strategies emphasize the importance of organization structures, not just the abilities of single unit as in previous models.

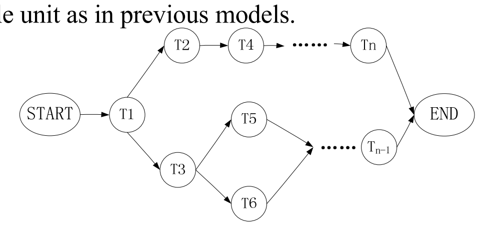

Figure 2. The Tasks Sequence of Mission ***M***

A certain mission *M* is assigned to the C4KISR system, which is composed of multiple tasks. These tasks are organized as shown in Figure 2.

Before the mission to be executed, there exists a certain initial organization O_0 whose structure will turn to O_1, O_2... with the changing of tasks. Here, we only consider the situation where adjustments are triggered by the tasks in turn. When task T_1 over O_0 is in its turn, *IFC*, *CC, ECC* and *ISC* can be calculated. After a certain adjustment, O_0 turning to O_0', these four metrics will changed to *IFC´*, *CC´*, *ECC ´*and *ISC´*. Now *Adjusting Value (AV)* is defined, which implies the performance rate, as the main reference for the adaptive organization design.

$$AV = \frac{IFC' - IFC}{IFC} + \frac{CC' - CC}{CC} + \frac{ECC' - ECC}{ECC} + \frac{ISC' - ISC}{ISC} \quad (7)$$

In term of a certain adjustment, the positive *AV* value is indicative of that this adjustment makes the overall performance increase, the greater the value is obtained, the more significant that, after this adjustment, the overall performance of the organization has been enhanced, then

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the necessity of this adjustment will become increasingly obvious. Otherwise, the negative value of *AV* shows the downside of the adjustment. The adjustment will be accepted, which accords with the maximum performance value to generate a new organization structure O_1 while it can meet the needs of the task T_1. The process can be formalized as below:

$$O_i = \arg\max \{AV(O_{i-1}', O_{i-1}) \mid O_{i-1}' \text{ supports task } T_i \} \quad (8)$$

Subsequently, a similar process is used to obtain the structures of T_2, T_3 ... T_n, and their optimal organizational structures O_2, O_3 ...O_n until the mission is finished. The flow of the adaptive organization design based on performance rate is shown as the following Figure 3.

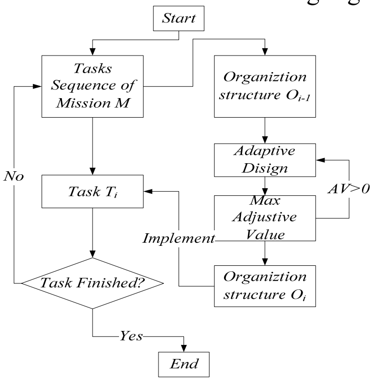

Figure 3. The adaptive organization design flowchart based on performance rate

To save the space of this paper, how to search the satisfied organization for a task is not elaborated here (please refer to [7, 8]). Here, based on the example in Figure 1, the adjustment process is illustrated as below.

Assuming that the organization will execute the task T_i over O_{i-1}, then *IFC*=0.175, *CC*=0.6433, *ECC*=47659.2, and *ISC*=84630.0. Under the precondition that certain link needs to be added and removed in the terms of task T_i, the *Adjusting Value (AV)* corresponding to the adjustment is obtained. Such as, *Adding a link BDE HQ1- BDE HQ2 makes AV*=0.2792; *Removing a link BDE HQ1-DIV HQ, AV*=-2.1719.

The facts show that better performance value can be gained due to some link adjustment. However, negative value can also be acquired. That indicates these adjustments could cause negative effects on the organization performance. In the process of adaptive organization design, the searching of the maximum *AV* could lead the organization to better performance. The optimal organization O_i of Task T_i is acquired when the *Adjusting Value* is not positive any longer.

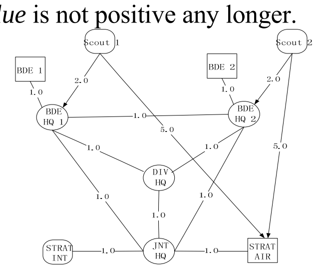

Figure 4. Optimal Structure of the Military Organization for Task T_i

After three adjusting periods, O_i is gained and shown in Figure 4, and it shows that compared with original tree structure, the networking structure has more performance advantage.

V. CASE STUDY

To illustrate our model, here a practical detailed case is given. The proposed model in Section III, IV will be demonstrated.

Figure 5 shows a C4ISRK system architecture for some military operation scenario. In order to block the attack of RED Army, the BLUE army is ordered to defend the towns Alpha and Beta. The main attack mission consisting of force defense and cannon defense provided by *Force A*, *CAN A*, *Force B*, and *CAN B* (square boxes). The secondary mission is asked to support the main attack provided by *AID A* and *AID B* (square boxes). The C2 units are coordinated by small headquarters elements, *A HQ* and *B HQ*, in towns of Alpha and Beta, and by an intermediate headquarters in *GAMMA*, but are ultimately organized form a military headquarters back *MIL HQ*. The secondary attack, on the other hand, is coordinated form the mining town of *DELTA*, and also ultimately organized from aid headquarters *AID HQ*. Form the original organization structure, we cannot find any coordination of main attack and secondary attack, namely there is no military and aid efforts whatsoever. What's more, the intelligence units mainly include *Weather*, *Satellite*, *Political*, *CIS* , etc. [1, 16].

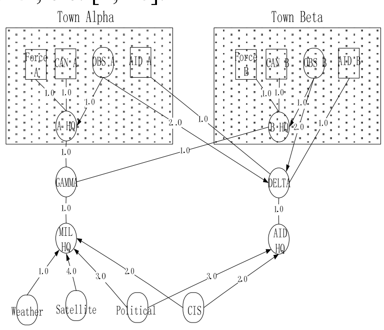

Figure 5. The original organization structure

The detailed parameters of this organization are showed in the following.

Radius (OBS A) = Radius (OBS B) = 100;
Radius (Force A) = Radius (CAN A)
= Radius (Force B) = Radius (CAN B) = 100;
Radius (AID A) = Radius (AID A) = 100;
Accuracy = 0.9; Quality = 1.

Based on the performance model, we now obtain the four main metrics values as shown in Table I (*Value for Figure 5*).

Then the adaptive organization design can be carried out based on the performance rate, in which the *AV* of all the probable organizations can be obtained. According to the model mentioned in Section IV, we will get the improved organization structure shown as Figure 6. The main coordination site now is GAMMA, and then a coordination planning could be done there by main attack

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staff and secondary attack staff together. This is a good choice, since *GAMMA* is in fact the most central node in the original structure. All information (other than reports from the field) is now provided directly to the shared headquarters at *GAMMA*.

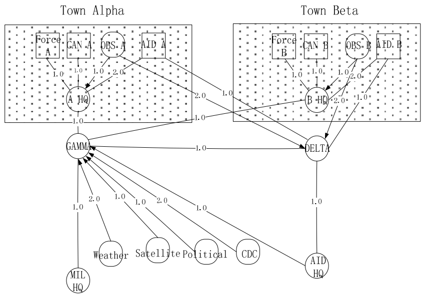

Figure 6. The Improved Organization Structure

The performance metrics improved of organization structure are shown in Table I (*Value for Figure 6*) . The obvious improvements have achieved, which is expressed by the *Advance Extent* in the table.

TABLE I. THE IMPROVED ORGANIZATION EFFICIENCY METRICS

Indices	*Metrics*	*Value for Figure 5*	*Value for Figure 6*	*Advance Extent*
Response Speed	*IFC*	0.145	0.2	37.9%
Coordination Capacity	*CC*	0	0.53	∞
Execution Capability	*ECC*	33285.7	41481.5	24.6%
Information Support	*ISO*	845442	1313100	55.3%

VI. CONCLUSION

We have presented a methodology for representing organization structures, which is called as eFINC. By this methodology, we perform a new way to evaluate the performance of the organization on the basis of functional unit's abilities and network topology. In terms of response speed, coordination capacity, performing capability and information support effectiveness, this paper proposes a quantitative explanation, and proposes four types of metrics. Based on the metrics, the process model of adaptive organization design is put forward. The case study can show that the model is effective.

To the best of our knowledge, there are still not any models which take account into performance while designing the organization. Our method is performance-oriented, not just other methods that are task-oriented. Performance-oriented design will be more suitable to the networking and dynamic combat fields where military organizations are performing the tasks.

VII. ACKNOWLEDGEMENT

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