A dynamic optimization model on decision-makers and decision-layers structure (DODDS) in C2-organization

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Abstract

The highly-complexity, environmental uncertainty, and structure changes bring more requirements for the agility and resilience of its core command and control C2-organizations. In order to better understand such organization's dynamic and emergence behaviours as a system of systems, we establish time-domain based metric model to evaluate C2 organizational decision-making capability. We develop an optimization model of organizational structure. The model is based on decision-makers and decision layer dynamics. The model aims at helping gain an optimal organizational structure with higher operational flexibility, low cost and high performance.

Keywords: Operational System of Systems (SoS), Command and Control, Adaptive Optimization, Simulated Annealing

1 Introduction

The characteristics of system antagonism in war are more prominent due to its high complexity and dynamic uncertainty in information warfare. It is also due to contemporary war styles such as network-centric warfare and modern organization models like "Power to the Edge" [1, 2]. The models represent new principles of operations, enabling advanced organizational resources and potential features. The models also help adapt the environmental uncertainty and complexity by changing and evolving the system structure and its behaviours. This way, the organization can accomplish more complex tasks with a low cost and high performance even in worse and complicated situations. In military management science, such models can be equipped with the "brain" and "hub" functions to induce an information-centric warfare. The functions are established by implementing Command and Control (C2) ingredients to an organization. The C2-organizations take in charge of many critical tasks such as Trend Observation (TO), Information Processing (IP), Decision Making (DM) and Command Operations (CO), etc. For a C2-organization, the ability to dynamically optimize and quickly change its structure is critical to obtain the advantages of antagonism in today's information-centric war. Therefore, the dynamic optimization becomes one of the key issues in the System of Systems (SoS)-based C2 organization. Organization characteristics or behaviours like complexity, uncertainty and dynamics [1] should be carefully considered in a SoS Engineering (SoSE) perspective.

Based on the theories of organization design, most successful organizations become more flexible during its structure evolution. An efficient organization should dynamically adjust its structure according to environment changes [3, 4] in order to improve and increase its operational performance. However, such adjustment may increase its technical complexity [5, 6]. Alternatively, people may adopt a more authoritarian model to protect outside changes. Such model's organization is framed in terms of a hierarchy network. However, such defensive model, on the other hand, weakens its structure [7] and become a close system. In many models, the organizational structure, centralized/decentralized decision-making mechanism, and performance outputs were intensively investigated under various conditions of different complexities and environmental uncertainties. The various system relationships between environmental changes and organizational structure were studied by corresponding computer simulations [8]. The simulation models were used to investigate various influences of environmental uncertainty, decision-making module and operational structures on the system performance. Unfortunately, such impacts have not been rigorously addressed in both temporal and spatial dimensions. Such transient influences (dynamic impacts) due to the system environmental changes in time-space domain should be considered in a contemporary model of C2 systems.

To address this issue requires a strong background and knowledge in multi-disciplines such as computational and mathematical organization theories [9-12], system of systems engineering [13-15], information and organizational management [16, 17] etc. For example, through a series of US-based scenarios and the Adaptive

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Architectures for Command and Control (A2C2) experiments, investigators developed many outstanding frameworks to establish various relationships in a C2-organization, hence to quickly build forces organizations in battlefield space. A typical framework commonly contains a multi-stage approach. The framework employs a series of algorithms developed to rapidly-construct military units in a battlefield. By using an adaptive optimization process, the organizational mission planning is divided into multiple stages. The degree of matching participated organizational structures is measured at all stages. The optimal adjustment of structural strategy is proposed throughout the structure changes, cost, and performance. For example, Liu et al. [3] grouped the similar resources and tasks together to facilitate the planning and tasks implementation. The classification is based on the modern group technology such as Nested Genetic Algorithm (NGA). In this way, they can simultaneously accomplish their missions on tasks-to-platforms and the allocations by platforms-to-decision-makers. Krackhardt and Carley proposed an improved organizational model, called Precedence, Commitment of Resources, Assignment, Network and Skill (PCANS) [13]. The model focuses on the description of information and their exchanges in the organization. They studied how to design an information exchange structure to satisfy the C2 requirements.

Unfortunately, most measures of C2 organizational-decision-making-capacity is only based on the entire mission period. In other words, in their models a large time scale has been used throughout the model simulations. Obviously, the models often fail to observe the mission performance during a transience or short period of time. That is somehow explain why these models in sometimes cannot well maintain organizational capability [14-16]. People start to consider how to divide a large mission time is divided into short ones; thus, the time-domain should be considered at small scales precisely in order to describe system dynamics. This consideration arise an important issue, i.e. is how to create a dynamic and optimal model that can instantaneously measure and rapidly adjust C2 organizational structure from time to time.

Motivated by the foregoing thinking, we propose a transient optimization model and its corresponding algorithms to measure and simulate dynamic C2-organizational structure. The model is built based on Dynamic Optimization of Decision-makers Decision-layer Structure (DODDS) in C2-organization to be depicted in the following. The model utilized an optimal time-domain division on the transient execution status of the operational tasks.

The rest of the paper is organized as follows: Section 2 introduces the C2-organizational system terminology and mechanism to measure its decision-making capacity. Section 3 presents the proposed dynamic structure optimization model. A brief conclusion is provided in Section 4.

2 Measure of decision-making capacity for C2 organization

The A2C2 experiments and adaptive organization designs [19, 23] commonly include decision-makers work load, communication and relationships. The C2 organizational elements can simply be classified into Platforms (P), Decision-makers (DM) and Tasks (T), respectively. C2 organization’s intelligent layers can be divided into Decision-Making Layer (DM-L) and Scheduling Layer (S-L). DM-L considers two relationships: the hierarchical relationships between DMs (R_{DM-DM}) and the control relationships between DM and platform (R_{DM-P}). S-L is composed by the allocation relationships between platforms and tasks (R_{P-T}) and the sequence relationships for task allocation (R_{T-T}).

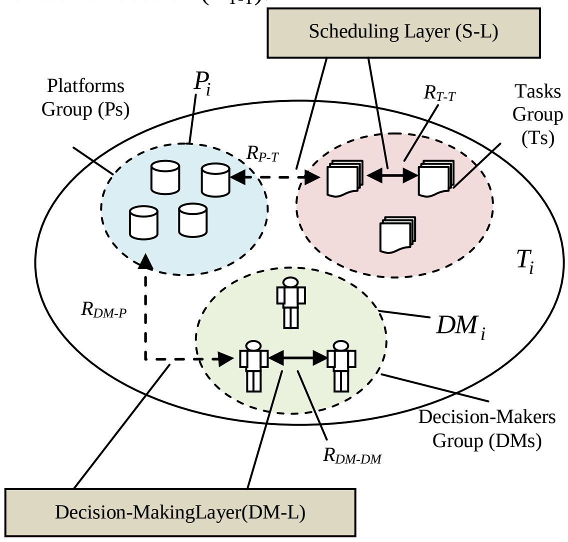

FIGURE 1 Illustration of C2-organization composition (dash arrow line stands for control relationships and solid arrow line refers to the command relationship)

The series of decision-makers in DM group can be denoted as $\{DM_i, i=1,2,3,\ldots,M\}$. The subscript i for the i-th DM. M is the total C2 decision-makers. The platform set can be expressed as $\{P_j, i=1,2,3,\ldots,N\}$, where is P_j the j-th platform. N is the total number of C2 platforms. Similarly, a set of tasks in C2 can be referred as $\{T_k, k=1,2,3,\ldots,L\}$, where T_k is the k-th task. The total number of tasks under consideration is L. They can be expressed in terms of vectors as

$$DM=\begin{bmatrix} DM_1 \\ DM_2 \\ \vdots \\ DM_M \end{bmatrix},\ P=\begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_N \end{bmatrix},\ \text{and } T=\begin{bmatrix} T_1 \\ T_2 \\ \vdots \\ T_L \end{bmatrix} \quad (1)$$

These scale parameters are used to describe the organizational structure characteristics. Each element in the vector represents an organizational entity. The structure with different element setting may lead to different organizational effectiveness. The relationships among decision-makers, platforms and tasks can be catalogued into five relationships. They are: (1) control relationship R_{DM-P} between decision-maker and platform, (2) allocation relationship R_{P-T} between a platform and a task, (3) hierarchical relationship R_{DM-DM} between two decision-makers, (4) the execution relationship R^{E}_{DM-T} between policy-maker and task, and (5) the command relationship R^{C}_{DM-T} among tasks. The fourth and fifth ones are two induced relationships through the DM-P and P-T relationships. The structure can be mathematically expressed as a group set $G_{OR}=(R_{P-T},R_{DM-P},R_{DM-DM},R^{E}_{DM-T},R^{C}_{DM-T})$. These variables become physical quantitates to measure the structure and its relations. The expressions of these variables are introduced in the following.

Platforms (such as hardware, software, devices, tools, facilities etc.) can usually be allocated to a special task. Such allocation relationships define the connections between platforms and tasks. It basically builds a network system. For example, one single platform can be used in multiple tasks, while a task often requires multiple platforms. According to [17-19], these C2 allocation relationships can be mathematically expressed as follows:

$$R_{DM-P}(i,j)=\begin{cases}1 \text{ if } P_j \text{ is allocated to } DM_i \\ 0 \quad\quad\quad \text{else}\end{cases}, \tag{2}$$

where DM_i is the i-th decision-maker and j is the j-th platform. The control relationship matrix can be given as:

$$R_{DM-P}=[R_{DM-P}(i,j)]=\begin{bmatrix} R_{DM-P}(1,1) & R_{DM-P}(1,2) & R_{DM-P}(1,3) & \cdots & R_{DM-P}(1,N) \\ R_{DM-P}(2,1) & R_{DM-P}(2,2) & R_{DM-P}(1,3) & \cdots & R_{DM-P}(2,N) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ R_{DM-P}(M,1) & R_{DM-P}(M,2) & R_{P-T}(M,3) & \cdots & R_{DM-P}(M,N) \end{bmatrix}_{M\times N} \tag{3}$$

For example, if there are 3 decision-makers and 4 platforms in the C2-organization. M=3 and N=4. DM_1 has P_2 and P_4. DM_2 has P_1 and P_2. DM_3 has P_1, P_3, and P_4. Then R_{DM-P} matrix is $R_{DM-P}=\begin{bmatrix}0&1&0&1\\1&1&0&0\\1&0&1&1\end{bmatrix}_{3\times 4}$.

Similarly, the allocation relationships can be mathematically expressed as follows:

$$R_{P-T}(j,k)=\begin{cases}1 \text{ if } P_j \text{ is allocated to } T_k \\ 0 \quad\quad\quad \text{else}\end{cases}, \tag{4}$$

where T_k is the k-th task and P_j is the j-th platform.

Therefore, the allocation relationship R_{P-T} between a platform and a task can be expressed in terms of a $M\times N$ matrix.

$$R_{P-T}=[R_{P-T}(j,k)]=\begin{bmatrix} R_{P-T}(1,1) & R_{P-T}(1,2) & R_{P-T}(1,3) & \cdots & R_{P-T}(1,L) \\ R_{P-T}(2,1) & R_{P-T}(2,2) & R_{P-T}(1,3) & \cdots & R_{P-T}(2,L) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ R_{P-T}(N,1) & R_{P-T}(N,2) & R_{P-T}(N,3) & \cdots & R_{P-TP}(N,L) \end{bmatrix}_{N\times L}. \tag{5}$$

For example, if there are 4 platforms and 3 tasks in the C2-organization. N=4 and L=3. T1 requires P1 and P4. T2 needs P1 and T2. T3 requests P2, P3, and P4. Then R_{P-T} matrix is $R_{P-T}=\begin{bmatrix}1&1&0\\0&1&1\\0&1&1\\1&0&1\end{bmatrix}_{4\times 3}$.

The command relationships between the decision-makers can be treated as a hierarchical and directional tree. It is composed of the decision-makers nodes (except root node) and the other decision-makers that have only one father decision-maker node. The expression for command relationships is given as:

$$R_{DM-DM}(m_1,m_2)=\begin{cases}1 \text{ if the link between } DM_{m1} \text{ and } DM_{m2} \\ 0 \quad\quad\quad \text{else}\end{cases}, \tag{6}$$

where m_1 and m_2 are two decision-makers. The command relationship matrix is a square matrix that can be expressed as:

$$R_{DM-DM}=[R_{DM-P}(m_1,m_2)]=\begin{bmatrix} R_{DM-DM}(1,1) & R_{DM-DM}(1,2) & \ldots & R_{DM-DM}(1,M) \\ R_{DM-DM}(2,1) & R_{DM-DM}(2,2) & \ldots & R_{DM-DM}(2,M) \\ \vdots & \vdots & \vdots & \vdots \\ R_{DM-DM}(M,1) & R_{DM-DM}(M,2) & \ldots & R_{DM-DM}(M,M) \end{bmatrix}_{M\times M}. \tag{7}$$

When $m_1=m_2$, the self-relation always exists, but such relation is ignored in the paper. Therefore, the diagonal elements are always 0. As a hierarchical tree, there must be (M-1) and only (M-1) edges. For example, if there are 5 decision-makers within the system. M=3. DM_1 links to DM_2, DM_3. The command relationships matrix can be expressed as $R_{DM-DM}=\begin{bmatrix}0&1&1\\0&0&0\\0&0&0\end{bmatrix}_{3\times 3}$.

Such directional relationship can be illustrated as single and double arrow lines (Fig. 1)

The execution relationship R^{E}_{DM-T} between decision-maker and task can be given as:

$$R^{E}_{DM-T}(m,i)=\begin{cases}1 \;\; \exists P_j,\, R_{DM-P}(m,j)=1, R_{P-T}(i,j)=1 \\ 0 \quad\quad\quad \text{else}\end{cases} \tag{8}$$

It means that one of the tasks of DM_m is T_i, if there is a P_j allocated to DM_m and assigned to T_i.

$$R^{E}_{DM-T}(i,k)=\begin{cases}1 \;\; \exists P_j,\, R_{DM-P}(i,j)=1, R_{P-T}(k,j)=1 \\ 0 \quad\quad\quad \text{else}\end{cases} \tag{9}$$

$$R^E_{DM-T} = R_{DM-P} \times R_{P-T} = [R^E_{DM-T}(i,k)] = \begin{bmatrix} R^E_{DM-T}(1,1) & R^E_{DM-T}(1,2) & \cdots & R^E_{DM-T}(1,L) \\ R^E_{DM-T}(2,1) & R^E_{DM-T}(2,2) & \cdots & R^E_{DM-T}(2,L) \\ \vdots & \vdots & \vdots & \vdots \\ R^E_{DM-T}(M,1) & R^E_{DM-T}(M,2) & \cdots & R^E_{DM-T}(M,L) \end{bmatrix}_{M\times L}. \quad (10)$$

For example, in this scenario, the R^E_{DM-T} is as follow under R_{DM-P} and R_{P-T}

$$R^E_{DM-T} = \begin{bmatrix} 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

The command relationship R^C_{DM-T} among tasks is given as

$$R^C_{DM-T}(m,i) = \begin{cases} 1 \ \exists m \in DM,\ n \in DM^{T_i}, \\ satisfy \prod_{m_i \in DM^{T_i}} P(m,n) = 1, \\ \text{and } \forall m' \in \left\{ m' \middle| \prod_{n \in DM^{T_i}} P(m',n) = 1 \cap m' \neq m \right\} \\ satisfy\ P(m,m') = 0 \\ \\ 0, \quad \text{else} \end{cases}. \quad (11)$$

$DM^{T_i}(i = 1,2,3,..L)$ is the subset of decision-makers who involve in implementing tasks T_i. $DM^{T_i}_m$ is the element of subset DM^{T_i}. $DM^{T_i}_n$ is another element of subset DM^{T_i}. $P(m,n)$ is the directional connection that determines the matrix of decision-makers. It can be expressed as

$$P(m,n) = \begin{cases} 1 \text{ if existing a direct link between } DM^{T_i}_m \text{ and } DM^{T_i}_n \\ 0 \qquad \text{else} \end{cases}.$$

$$R^C_{DM-T} = P(R_{DM-DM}) \times R^E_{DM-T} = [R^C_{DM-T}(i,k)] = \begin{bmatrix} R^E_{DM-T}(1,1) & R^E_{DM-T}(1,2) & \cdots & R^E_{DM-T}(1,L) \\ R^E_{DM-T}(2,1) & R^E_{DM-T}(2,2) & \cdots & R^E_{DM-T}(2,L) \\ \vdots & \vdots & \vdots & \vdots \\ R^E_{DM-T}(M,1) & R^E_{DM-T}(M,2) & \cdots & R^E_{DM-T}(M,L) \end{bmatrix}_{M\times L}, \quad (12)$$

where $P(R_{DM-DM})$ is the reachability matrix of R_{DM-DM}.

For example, in this scenario, the reachability matrix of R_{DM-DM} is itself. Hence, the R^C_{DM-T} is as follow under R^E_{DM-T} and R_{DM-DM}

$$R^C_{DM-T} = \begin{bmatrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

In a C2-organization system design, the system performance is highly related to its elements (platforms, decision-makers, and tasks) relations. How to adjust its elements to maximize the overall organizational effectiveness is one of the key issues. One of difficulties is the dynamic uncertainty of mission environment. Man C2-organizations always cannot be well operated throughout the whole mission operation. A state-of-the-art organizational structure needs to be continuously updated and extended, which prompts our DODDS algorithm development. The following definitions are necessary.

Definition 1: The tasks implementation load of decision-makers DM_m in the task T_i can be expressed as:

$$DM_{imp\,m}^{\ T_i} = w_{imp} \cdot DT_i \cdot DI_i \cdot R^{E\ \ T_i}_{DM-T\,m}, \quad (13)$$

where w_{imp} is the coefficient that accounts for the effect of tasks implementation load, DT_i is a durance or time required to accomplish task T_i (in terms of days or hours). DI_i is the strength of implementation load of task T_i. It is used to estimate how difficult the task T_i is. As essential and nature attributes of a task, both DT_i and DI_i are subjective. In the current study, we take the values from reference [23, 24].

Definition 2: The task collaboration load $DW_{col\,m}^{\ T_i}$ in task T_i. It can be expressed as:

$$DW_{col\,m}^{\ T_i} = w_{col} \cdot DT_i \cdot DI_i \cdot \sum_{m' \neq m}^{N_{DM}} R^{E\ \ T_i}_{DM-T\,m} \cdot R^{E\ \ T_i}_{DM-T\,m}, \quad (14)$$

where w_{col} is the coefficient that accounts for the task collaboration load.

Definition 3: The task command load $DW_{cmd\,m}^{\ T_i}$ in task T_i. It can be expressed as:

$$DW_{cmd\,m}^{\ T_i} = w_{cmd} \cdot DT_i \cdot DI_i \cdot R^{C\ \ T_i}_{DM-T\,m} \cdot \sum_{m' \neq m}^{N_{DM}} R^{E\ \ T_i}_{DM-T\,m}, \quad (15)$$

where w_{cmd} is the coefficient that accounts for the task command load.

Definition 4: The total decision work load $DW^{T_i}_m$ in task T_i accumulates all the above loads together. It can be expressed as:

$$DW^{T_i}_m = DW_{imp\,m}^{\ T_i} + DW_{col\,m}^{\ T_i} + DW_{cmd\,m}^{\ T_i}. \quad (16)$$

Definition 5: The total task decision load DW^{T_i} in task T_i is the sum of all the decision working loads in the task T_i. It is given as:

$$DW^{T_i} = \sum_{DM^{T_i}_m \in DM^{T_i}} DW^{T_i}_m, \quad (17)$$

where DM^{T_i} is the assembly of decision-makers to complete task T_i.

Definition 6: The decision contribution degree of decision-makers $DM_m^{T_i}$ in T_i is the ratio of total decision work load, $DW_m^{T_i}$ to the task decision load DW^{T_i} in task T_i. The ratio represents the importance of $DM_m^{T_i}$ in the task T_i's decision work. It is denoted as $DG_m^{T_i}$ and expressed as:

$$DG_m^{T_i} = DW_m^{T_i} / DW^{T_i} . \quad (18)$$

Definition 7: The decision-makers DM_m's decision work load $DW_m^{T_i}(\Delta T)$ in time-scale ΔT is the sum of decision work load of $DM_m^{T_i}$, where hereby $DM_m^{T_i}$ is the decision-maker that completes the task within ΔT. $DW_m^{T_i}(\Delta T)$ can be expressed as:

$$DW_m(\Delta T) = \sum\nolimits_{i \in T} DW_m^{T_i} \cdot \delta_{\Delta T}{}^{T_i} , \quad (19)$$

where the $\Delta T = [t_{LB}, t_{UB}]$ is a time interval. t_{LB} and t_{UB} stand for the starting time and ending time. $\delta_{\Delta T}{}^{T_i}$ is a sign function judging whether task T_i is executed within ΔT or not. The sign function can be expressed as:

$$\delta_{\Delta T}{}^{T_i} = \begin{cases} 1 & T_i \text{ executed within time-scale } \Delta T \\ 0 & \text{else} \end{cases} . \quad (20)$$

Definition 8: The quality of decision-making $q_m(\Delta T)$ can be calculated based on the ratio of quality of decision-makers $DM_m^{T_i}$ within ΔT, λ. The ratio is defined to measure the effectiveness required to complete the decision-making by $DM_m^{T_i}$ within ΔT. It depends on the $DM_m^{T_i}$'s decision work load $DW_m(\Delta T)$ and the upper limit of the working load within ΔT, DWB_m. It is expressed as:

$$\lambda = (DW_m(\Delta T) - DWB_m) / DWB_m . \quad (21)$$

It can be called loading capacity ratio of decision-makers. Its value is between 0 and 1, the value of $DW_m(\Delta T)$ must be less than DWB_m limit. As $DW_m(\Delta T)$ exceeds that limit, it cannot provide adequate decision-making capability. Usually $DM_m^{T_i}$ have a certain robustness to withstand a certain degree of over-load.

If the ratio λ is small, the gradient of decline in the quality of the work decision-making is relatively slow, and the value is close to unity. If λ takes a medium, in rang form 0.3 to 0.7, the decision-making quality of $DM_m^{T_i}$ declines rapidly. If λ becomes larger, the decision work load of $DM_m^{T_i}$ is far beyond its up-load. The quality of the work of decision-making is very low and even reaches to zero.

Therefore, we define the quality of decision-making $q_m(\Delta T)$ as:

$$q_m(\Delta T) = \begin{cases} 1 & \lambda < 0 \\ \dfrac{\exp^{10(1-2\lambda)}}{1+\exp^{10(1-2\lambda)}} & \lambda \geq 0 \end{cases} \quad (22)$$

Definition 9: The task's quality of decision-making $DQ^{T_i}(\Delta T)$ is defined as the summation of all the quality of decision-making participated in the task pool. It can be calculated as:

$$DQ^{T_i}(\Delta T) = \sum_{DM_m^{T_i} \in DM^{T_i}} DG_m^{T_i} \cdot q_m(\Delta T) \cdot DA_m(\Delta T) \cdot \delta_{\Delta T}{}^{T_i} . \quad (23)$$

This value represents the total quality of accomplished decision-making work.

Definition 10: The temporal mean value of all quality of decision-making tasks, $DC(\Delta T)$, represents the organizations' effective measure of decision-makings. It estimates the whole capability of C2 organizational decision making system.

Given the ability of C2 organizational decision making within ΔT, $DC(\Delta T)$ can be given as:

$$DC(\Delta T) = \sum_{T_i \in T(\Delta T)} \frac{Min(t_{UB}, tf_i) - Max(t_{LB}, ts_i)}{|\Delta T|} \cdot \frac{DQ^{T_i}(\Delta T)}{|T(\Delta T)|} , \quad (24)$$

where ts_i and tf_i stand for the starting time and ending time, respectively. $|\Delta T|$ is a period time required for a task executing within ΔT. There is some idle period of time in the time domain ΔT due to no task executed during the period. It can be ignored since it is not related to the organization decision-making capacity. $T(\Delta T)$ is the tasks assembly within ΔT. The numerator $Min(t_{UB}, tf_i) - Max(t_{LB}, ts_i)$ refers the time length of executing task T_i within ΔT. The ratio of $[Min(t_{UB}, tf_i) - Max(t_{LB}, ts_i)] / |\Delta T|$ occupies significant part of computation for $DC(H)$.

When $t_{UB} \to t_{LB}$, $|\Delta T| = 0$, ΔT represents the transient time at t_{LB}. Therefore, one has:

$$\lim_{t_{UB} \to t_{LB}} DC(\Delta T) = \sum_{T_i \in T(t_{LB})} \frac{DQ^{T_i}(t_{LB})}{|T(t_{LB})|} . \quad (25)$$

At this point $DC(\Delta T)$ can be signed as $DC(t_{LB})$ denoted the organization decision-making capacity at the transient time at t_{LB}. The equation above can be understood that there is a major task during that period in the context of a period of the time domain. The tasks become important at that moment. If there is main task, all tasks could reach to the equal level of importance.

3 Dynamic optimization of decision-maker and decision-layer structure (DODDS) model

The proposed DODDS model considers both the adjustable costs of the structure and dynamic decision-making capacity. The details of model algorithm are following.

Definition 11: The adjustable costs of the structure (AC) is defined as the restructure costs due to the changes of command-relationships between decision-makers and of the control-relationships between decision-makers and platforms.

Suppose that the decision-layer-structure is G_{DLS} and optimized value is G'_{DLS}. The adjustable costs $AC(G_{DLS},G'_{DLS})$ can be expressed as follows:

$$AC(G_{DLS},G'_{DLS}) = (\frac{W_D}{N_{DM}})\cdot\sum_{m_2=1}^{N_{DM}}\sum_{m_1=1}^{N_{DM}}\left|R'_{DM-DM}(m_1,m_2)-R_{DM-DM}(m_1,m_2)\right| + \frac{W_p}{2N_p}\cdot\sum_{j=1}^{N_p}\sum_{m=1}^{N_{DM}}\left|R'_{DM-P}(m,j)-R_{DM-P}(m,j)\right|, \quad (26)$$

where the first term accounts for the amount of the changed command links between decision-makers, and the second term represents the amount of the changed control links between decision-makers and platforms. W_D and W_P represent the costs per change in the command and control links respectively. Since there are some direct links, the command-to-change cannot be taken into consideration, repeatedly. N_{DM} and N_p are the total numbers of decision-makers and platforms, respectively. Obviously ACs depends on the organization size. For example, if W_D or W_P remain constant, the larger organization is, the smaller the cost. Therefore, the proportions of the changes become important in evaluating the adjustable costs.

Definition 12: Decision-making capacity (DMC) is defined as the difference of between the organizational-decision-making-capacity and optimal one. According to Definition 10, it can be expressed as:

$$DMC(G_{DLS},G'_{DLS},\Delta T)=DC(G'_{DLS},\Delta T)-DC(G_{DLS},\Delta T), \quad (27)$$

where $DC(G_{DLS},\Delta T)$ and $DC(G'_{DLS},\Delta T)$ stand for the organizational-decision-making-capacities of the decision-layer-structures G_{DLS} and optimal value G'_{DLS} respectively.

Definition 13: The dynamic optimization of decision-layer-structure (DLC) gives the profit for an organization. It can be expressed as:

$$DLC(G_{DLS},G'_{DLS},\Delta T) = W^P\cdot DMC(G_{DLS},G'_{DLS},\Delta T)-W^R\cdot AC(G_{DLS},G'_{DLS},\Delta T), \quad (28)$$

where W^P and W^R are the weights of organizational-decision-making-capacity and the adjustable costs respectively. The smaller the W^R, the more flexible the organization is and the less dynamic adjustable costs. The case $DLC(G_{DLS},G'_{DLS},\Delta T)>0$ implies two facts. One is that the organizational-decision-making-capacity is greater than the adjustable costs. The other is that the organizational decision-making can be improved by using utilizing properly adaptive optimizations.

There exit some constrains [18] that should be satisfied during the dynamic optimization. These constrain conditions (restriction) are as follows.

The restriction on the relationship between decision-makers and platforms:

$$\sum_{m=1}^{N_{DM}} R'_{DM-P}(m,j)=1,\ j=1,2,\ldots,N_P. \quad (29)$$

The restriction on the upper limit of a decision maker controlled platforms:

$$\sum_{m=1}^{N_P} R'_{DM-P}(m,j)\le\overline{CN}, m=1,2,\ldots,N_{DM}. \quad (30)$$

The restriction on the decision tree that has an unique root must satisfy the following one:

$$\sum_{m\ne m^*}^{N_{DM}} R'_{DM-DM}(m,m^*)=0. \quad (31)$$

Any nodes except the root has a single parent node:

$$\forall m'\ne m^*, \sum_{m\ne m^*}^{N_{DM}} R'_{DM-DM}(m,m')=1. \quad (32)$$

From presentation and definitions above, the final DODDS optimization model is summarized as:

$$\max DLC(G_{DLS},G'_{DLS},\Delta T)$$
$$s.t.\begin{cases} G'_{DLS}=(R'_{DM-P},R'_{DM-DM}) \\ \sum_{m=1}^{N_{DM}} R'_{DM-p}(m,j)=1,\ j=1,2,\ldots,N_p \\ \sum_{j=1}^{N_P} R'_{DM-P}(m,j)\le\overline{CN}, m=1,2,\ldots,N_{DM} \\ \sum_{m\ne m^*}^{N_{DM}} R'_{DM-DM}(m,m^*)=0 \\ \sum_{m\ne m^*}^{N_{DM}} R'_{DM-DM}(m,m')=1 \\ R'_{DM-P}(m,j)\in\{0,1\},\ m=1,2,\ldots,N_{DM}, j=1,2,\ldots,N_P \\ R'_{DM-DM}(m_1,m_2)\in\{0,1\},\ m_1,m_2=1,2,\ldots,N_{DM} \end{cases}. \quad (33)$$

4 Conclusions and future works

This paper presents a model of Decision-makers and Dynamic Optimization of Decision-layer Structure (DODDS) for a C2-structred organization in operational SoS. Through intensive and extensive literature studies and the empirical experiments, we believe that the performance of C2- structured organization is always much lower than expected value because of environmental uncertainty and system changes. To address the issue, we extended the exiting model of C2 decision-layer-structure by introducing the time-domain, by employing the NISA and horizon (time-based) discretization. The model concepts are addressed, terminology are defined, and the optimization objective function of the model with constrains are derived. The model will be implemented in several scenario tests to be presented in the coming paper to demonstrate the model feasibility and applicability.

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References

[1] Thomas A, Turner T, Soderlund S 2009 Net-Centric Adapter for Legacy Systems IEEE *Systems Journal* **3**(3) 336-342
[2] Butterfield M L, Pearlman J S 2008 A System-of-Systems Engineering GEOSS: Architectural Approach *IEEE Systems Journal* **2**(3) 321-332
[3] Liu Z, Yang D S, Wen D, Zhang W M, Mao W J 2011 Cyber-Physical-Social Systems for Command and Control *IEEE Intelligent Systems* **26**(4) 92–96
[4] Qian M, Liu Z, Wang J, Yao L, Zhang W M 2010 Coordination-theoretic Approach to Modelling Grid Service Composition Process *Journal of Systems Engineering and Electronics* **21**(4) 713-720
[5] Carley K M 1995 Computational and Mathematical Organization Theory: Perspective and Directions *Computational and Mathematical Organization Theory* **1**(1) 39-56
[6] Rajan R G, Wulf J 2006 The Flattening Firm: Evidence from Panel Data on the Changing Nature of Corporate Hierarchies *Review of Economics and Statistics* **88**(4) 759-773
[7] Chuma H 2006 Increasing Complexity and Limits of Organization in The Microlithography Industry: Implications for Japanese Science-based Industries *Res Policy* **35** 393-411
[8] Barr J, Nobuyuki H 2008 Organizations Undertaking Complex Projects in Uncertain Environments *Journal of Economic Interaction and Coordination* **3**(2) 119-135
[9] Lin Z 2006 Environmental Determination or Organizational Design: An Exploration of Organizational Decision Making Under Environmental Uncertainty Simulation *Modelling Practice and Theory* **14**(4) 438-453
[10] Carley K M, Prietula M J 1994 *Computational Organization Theory* Lawrence Erlbaum Associates
[11] Carley K M, Lin Z 1995 Organizational Designs Suited to High Performance under Stress *IEEE Transactions on Systems Man and Cybernetics* **25**(1) 221-230
[12] Carley K M, Svoboda D M 1996 Modelling Organizational Adaptation as a Simulated Annealing *Process Sociological Methods and Research* **25**(1) 138-168
[13] Krackhardt D, Carley K M 1998 A PCANS Model of Structure in Organization *Proceedings of the 1998 International Symposium on Command and Control Research and Technology* 113-119
[14] Levchuk G M, Levchuk Y N, Luo J, Pattipati K R, Kleinman D L 2002 Normative Design of Organizations I: Mission Planning *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans* **32**(3) 346-359
[15] Levchuk G M, Levchuk Y N, Luo J, Pattipati K R, Kleinman D L 2002 Normative Design of Organizations II: Organizational Structure *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans*, **32**(3):360-375
[16] Levchuk G M, Levchuk Y N, Luo J, Pattipati K R and Kleinman D L 2004 Normative Design of Project-based Organizations-Part III: Modelling Congruent, Robust, and Adaptive Organizations *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans* **34**(3) 337-350
[17] Meirina C, Levchuk Y N, Levchuk G M, Pattipati K R 2008 A Markov Decision Problem Approach to Goal Attainment *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans* **38**(1) 116-132

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