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"Adapting C2 to the 21st Century"

Assessment of Hierarchical Command and Control organization structures[1]

Topic 5

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Abstract: Assessment of C2 organization structures becomes very important now. On the one hand, the suggestion to develop newly networked organization structures seems to be accepted by most people; on the other hand, almost all the C2 organization structures are actually pyramid hierarchical ones. Concerning a specified military organization, whether its C2 structure is suitable or not? How to select a “better” structure for it from several candidates? Many issues require to be answered. In this paper, we propose a methodology to quantitatively analyze hierarchical C2 organization structures. Firstly, we associate the assessment with the task that the assessed military organization is expected to perform by mapping the task into the group military units that are needed to perform it directly. Secondly, we suppose that a military organization with a good C2 structures can responses tasks quickly and forms the required group units cooperating effectively. Then by affecting the information transmitting speed and the communicating quality of the different group units the C2 structure affect the organization’s reactivity and cooperation efficiency respectively. The approach is based on multi-dimensional tree (MDT) that is introduced to describe the C2 hierarchical structures of military organizations.

1 Introduction

Nowadays, the study of C2 organizational structure is becoming a very urgent task, and a lot of problems are to be solved. Our knowledge of C2 organizational structure is not consistent with the reality. On the one hand, the traditional pyramid C2 structure is not flexible enough in the face of the information technology and does not respond readily to the battlefield situation, and as a result the battle efficiency is greatly affected[1,2]. On the other hand, all government armies, including that of America, all adopt the pyramid C2 structure without exception.

Take the American army for example. Ever since the concept of NCW is brought up in the 1990’s, American army has achieved a lot in constructing “flat” C2 structure, but these research achievements have not been widely put into use. At the same time, it can be noticed that there are oppositions against putting aside hierarchical command and control form. Dr. Milan Vego, Professor of Operations at the Naval War College, has pointed out those NCW theorists who suggest reducing command levels fail to consider “Clausewitzian thoughts on the nature of war, the relationship between policy and use of military power, and the effect of fog of war and friction.”[3] He warns that it is not simple to adopt decentralized command and control (C2) forms or centralized ones [4]. Also, available experimental data have indicated that it’s not that pyramid structure is not suitable in all cases [5]. Environment and task type play an important role in this.

The fundamental technological reason that flat command and control form has not been widely used lies in that a lot of things related to C2 organizational structure are still not clear. Among these, a typical one is the rationality assessment of C2 organizational structure: given a certain organization, how to scientifically and quantitatively decide whether the C2 structure is suitable or not and how suitable it is; if it is not suitable, what is the cause and how to improve it, etc. The importance of rationality assessment study of C2 organizational structure is obvious and it provides assessment criteria for the design of C2 organizational structure.

Because of the complexity of C2 organizational structure and the interactions between various factors, it is very difficult to construct models. Up till now, researchers have either modeled from a certain angle or certain level, failing to grasp a holistic view of C2 structure, or prescribed strict premises which cannot be found in the actual situation, thus having very little application value [5, 6, 7, 8].

2 Different opinion about C2 structure

It is found during the research that the most prominent feature of C2 structure is that it involves multidimensional, and multilevel interactions. In order to assess it, it is necessary to have a holistic view. Next, the implications of C2 structure will be analyzed in three aspects and during this process its assessment methodology will also be studied.

First of all, in the aspect of time span, C2 structure is not limited to the wartime, as most researchers have argued. If we only pay attention to the wartime, we could be too involved in the study of command and control links and relations, which is far from holistic. It should be noticed that wartime command and control relations are based on everyday relations. These include both the formal organization relations and implicit, informal ones. All of them are gradually formed and strengthened during long-time non-wartime activities such as learning, training, rehearsing and preparing. Therefore, the assessment of C2 organizational structure should consider the influence of everyday activities on wartime C2 structure.

Second, in the aspect of horizontal associations, longitudinal command and control relations and horizontal function allocation, region allocation, etc. form the organizational structure, which is the basis of organizational operation. Here it can be seen that C2 organizational structure is an organic component of the organizational structure. Behind the static command and control relations between units of C2 structure, there is a dynamic mechanism including information exchange, incident handling and so on. The concrete static command and control relations are only a reflection of the dynamic mechanism in a certain aspect and at a certain moment. The essence of this kind of dynamic mechanism is that the organization achieves its purposes by making use of the organization resources to the greatest extent through function allocation and coordination. Therefore, factors such as information exchange, incident handling, function allocation and coordination and so on will also affect C2 organizational structure.

Third, in the aspect of application, C2 organization is designed for mission tasks. Usually the task is not specific but within a certain range. This means that the assessment of C2 organizational structure must be based on a certain task range, at least a certain force assignment demand range. Talking about whether certain C2 organizational structure is good or not disregarding task and force assignment demand does not amount to anything at all, for there is no C2 organizational structure which fits every situation.

According to the above analysis, since most current C2 structure uses the pyramid C2 organizational structure, the “task-based hierarchical C2 organizational structure efficiency assessment framework” is proposed in this paper and the multidimensional, and multilevel factors will be described and analyzed by using multi-dimensional tree tools.

3 Overview of the Model

Figure 1 shows the assessment framework of task-based hierarchical C2 organizational structure efficiency.

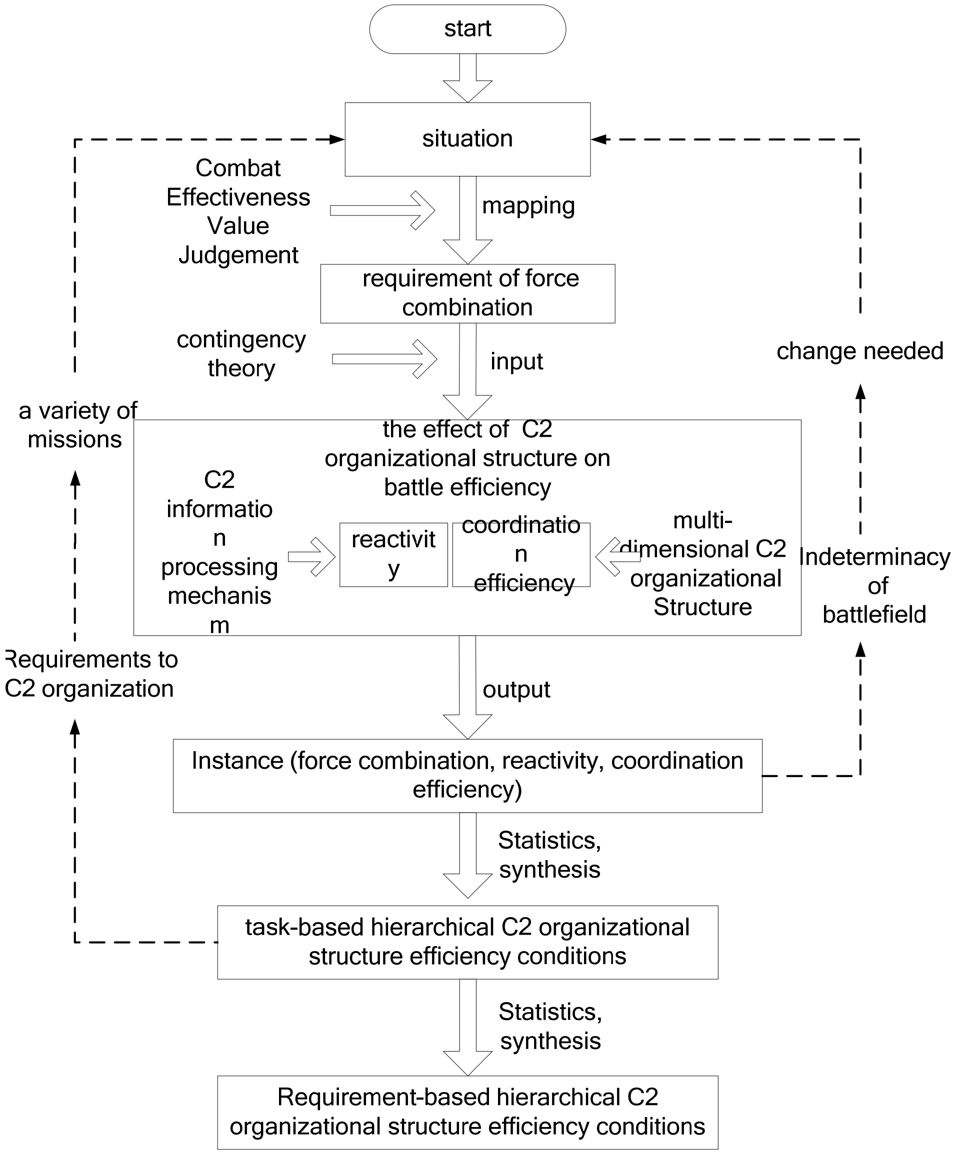

Figure 1 task-based hierarchical C2 organizational structure efficiency assessment framework

Two theories are accepted as the preconditions of the model. One is contingency theory and the other is combat effectiveness value judgment. The main point of contingency theory is that no organizational structure can satisfy all of the organizations as the environment that organizations exist in is constantly changing. The satisfying structure must be consistent with the environment that the organization exists in and depends on. In the model the influence that the external environment has exerted on the C2 organizations is modeled as various requirement of force combination. The other precondition is that the requirement of the force can be estimate according the situation. Combat effectiveness value judgment that is. In fact, this precondition has been accepted and used in most practice relevant to decision-making and simulation.

Then, the effect of C2 organizational structure on battle efficiency can be understood by calculating the organization’s reactivity and coordination efficiency. This conclusion is concluded by conceiving and analyzing the ideal or expected condition when organizations execute tasks. This is the ideal condition that can be achieved when C2 organization carries out battle tasks: first, after the task demand is generated, the assessed C2 organization can make the best strategies in the shortest time, which include deciding the best force combination to accomplish the task, that is, which force units to assign and how they would cooperate. Then, the task operation command is delivered to each battle unit. Finally, each battle unit will try to coordinate smoothly with each other and achieve the highest efficiency in order to accomplish the task. Here, C2 organizational structure will mainly influence the ideal effect of the battle force in the respects of reactivity and coordination efficiency.

After that, based on a certain force assignment demand range and further a certain task range, the assessment of C2 organizational structure can be achieved.

4 Explanation of the Methodology

In the following text, the methodology is explained with a fictitious example showed by Figure 2 and the calculating details are presented in appendix.

4.1 Measures calculating

Reactivity refers to the time span between generation of the task demand and start of operation. C2 organizational structure influences the reactivity of the battle force in two respects: First, the determination of responsible decision-making unit corresponding to specific task demand depends on concrete command and control structure and is closely related to the reporting mechanism in task processing. Second, it takes some time for the decision to reach every battle unit, which is caused by the information transmit delay of the command and control links of C2 structure.

The influence on the coordination efficiency refers to the phenomena that since different force units belong to different departments, there might be differences in understanding and lack of trust, which may result in communication difficulty and low coordination efficiency. The coordination efficiency is affected by many factors of C2 organizational structure and is closely related to the familiarity developed in everyday activities.

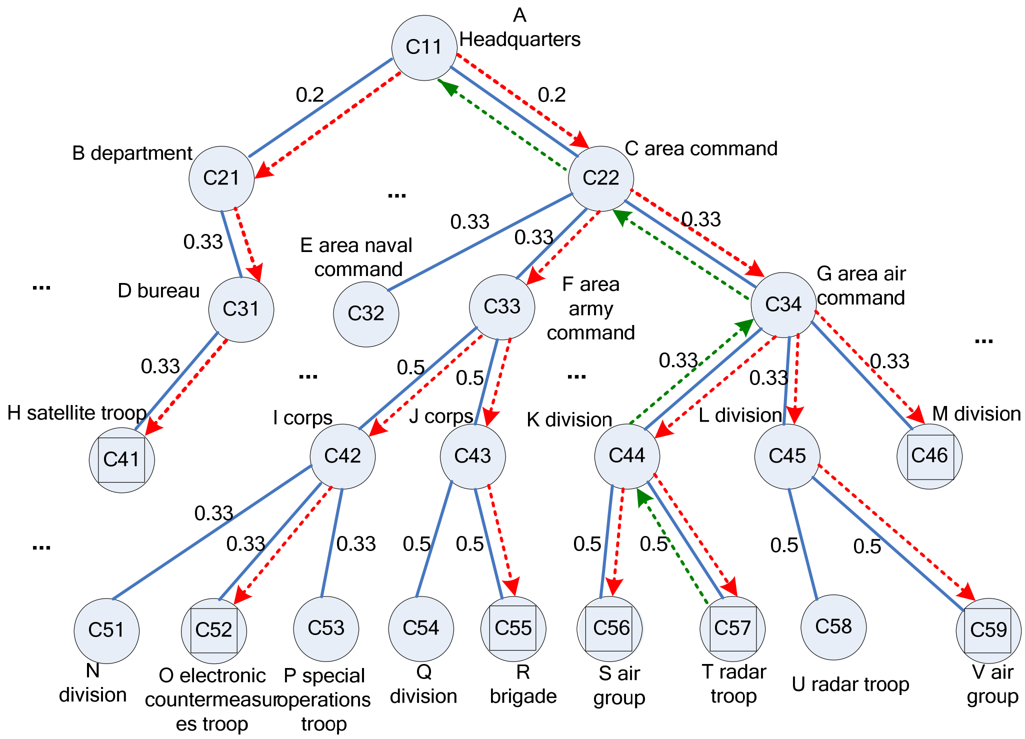

Figure 2 an example of C2 organizational structure of a battle force.

Figure 2 shows the pyramid C2 organizational structure of a battle force. An operation of this force can be described as follows:

At a certain moment, the command and control node $c(57)$ of battle force E receives a report about the situation S from sensors, and estimates that the force resource combination $R(S)=\{c(41),c(52),c(55),c(56),c(57),c(59),c(46)\}$ is beyond its control range. Those units are identified with square frames in Figure 2. Since $c(57)$ cannot handle effectively by itself, it reports the situation to the senior command and control unit $c(44)$. After the command and control links $c(34),c(22),c(11)$ have reported upward level by level, finally $c(11)$ gets the situation report and finds that this mission task is within its own capacity range, and therefore makes a mission plan and delivers command. After $c(21),c(22)$ delivers the command downward level by level, the command is transmitted through 7 command and control links and finally reaches the force combination $R(S)$ and mission is executed. Units in the force combination $R(S)$ coordinate with each other to execute the mission task according to the mission plan and after some time the mission is completed.

The effect of the C2 structure on battle efficiency can be assessed by finding the answer to the following question. By calculating the time span from the moment when $c(57)$ gets the report about situation S till the moment when force combination $R(S)$ starts the mission, the reactivity of the force E can be measured. And by calculating the coordination proficiency extent of the interior units of the force combination $R(S)$, the coordination efficiency of E can be measured.

4.1.1 Reactivity

Take Figure 2 for example. The responding time of this force can be interpreted as the total time spent for the information flow to go from $c(57)$ to $c(11)$ and to the seven nodes in $R(S)$. Suppose that the force combination is composed of N force units. Then there are N links $L(j), j=1,2,\cdots,N$. Take the longest time of information flow as the responding time. For mission M, the responding time of battle force E is:

$$T(E,M)=\max_{j}\sum_{i\in L(j)}(T_{i1}+T_{i2}+T_{i3}) \quad (1)$$

T_{i1},T_{i3} correspond respectively to the information reception delay and information transmit time of each node i on $L(j)$. Since they are usually unrelated to the mission itself and relatively stable, they can be obtained by recording the information processing time of corresponding nodes in peacetime training and maneuvering. For each node, its decision-making activities can be classified into three types: first, decide whether the force demand of the mission is within its own control range. This activity corresponds to time $T_{i2}(1)$. Second, if the demand is within its own range, assign the force to execute the mission. This activity corresponds to time $T_{i2}(2)$. Third, make a detailed mission plan to carry out the superior's command. This activity corresponds to time $T_{i2}(3)$.

Since the command and control nodes are very specific about their force assignment capacity, if most of the force demand combination units do not belong to its own control range, a conclusion can be reached in a relatively short time; but if they do belong to the range, the time needed will be longer.

Rd correspond to the extent that $c(i)$ can satisfy the force demand combination units：

$$Rd(R(S),R(c(i)))=\frac{n_1}{N} \quad (2)$$

Here N is the number of force units of $R(S)$, n_1 is the number of units that do not belong to $c(i)$ control range. Besides, we suppose that $T_{i2}(1)$ is calculated in the following way:

$$T_{i2}(1) = K_1 \frac{e^{a+bRd(R_1,R_2)}}{1+e^{a+bRd(R_1,R_2)}} Ts_i \tag{3}$$

Here Ts_i is the standard time needed for this node to make decisions.

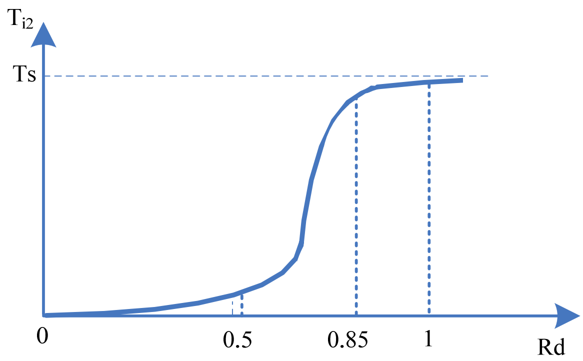

Figure 3: the relation between T_{i2} and Rd

$T_{i2}(2)$, $T_{i2}(3)$ are both about force resources combination making mission plans. Suppose that they are negatively correlated with the decision-making ability of each node and are positively correlated with the force resource scale of mission demand:

$$T_{i2}(2) = K_2 \frac{P(R(S))}{Com_i} \tag{4}$$

$$T_{i2}(3) = K_3 \frac{P(R(S))}{Com_i} \tag{5}$$

K_1 , K_2 and K_2 are the coefficients of decision-making activity type, and $0 < K_1 \leq K_3 \leq K_2 \leq 1$.

It has been mentioned above that the configuration of pyramid C2 structure makes sure that each node can satisfy the corresponding command and control demand, that is, each node has commanding and decision-making ability over the force resources assigned to it. Therefore, the decision-making ability is measured with the force resource scale and corresponding decision-making time as the standards:

$$Com_i = \frac{P(c(i))}{Ts_i} \tag{6}$$

$P(c(i))$ is the scale of the force resource controlled by node i. $T_{i2}(2)$ and $T_{i2}(3)$ are the decision-making activity time needed for node i to estimate the capacity and make a plan, which is relative to the force resource scale demanded by the mission. So, the following can be obtained:

$$T_{i2}(2) = K_2 \frac{P(R(S))}{P(c(i))} Ts_i \tag{7}$$

$$T_{i2}(3) = K_3 \frac{P(R(S))}{P(c(i))} Ts_i \tag{8}$$

The ratio of scales of force resource combination $\frac{P(R(S))}{P(c(i))}$ is the key variable, which can be calculated in the following way:

Suppose $P(R(S)) = \{rs_1, rs_2, \cdots, rs_m\}$, $P(c(i)) = \{rc_1, rc_2, \cdots, rc_n\}$, then

$$\frac{P(R(S))}{P(c(i))} = \sum_{j=1}^{n} \sum_{i=1}^{m} \frac{P(rs_i)}{P(rc_j)} \tag{9}$$

In the above formula, if there is a path $\{rs_i, \cdots, rc_k, rc_j\}$ between rs_i and rc_j , then $\frac{P(rs_i)}{P(rc_j)} = w(rs_i) \cdots w(rc_k)$; if not, it will be 0.

Here, $w(k)$ is the ratio of node k to its father node.

4.1.2 Coordination efficiency

It has been mentioned above that besides the longitudinal command and control hierarchical relations; there also exist relations generated by other divisions between each unit of the pyramid C2 organizational structure. These factors interact with each other and influence the familiarity and understanding between units, thus affecting the coordination efficiency during wartime. In order to analyze the influence of these factors upon coordination efficiency, the multi-dimensional tree will be introduced to describe the relationship between organization units.

Suppose each unit of C2 organization is located in a multidimensional space. The spatial distance between two units is negatively correlated to the extent of their familiarity and understanding. That is, the longer the distance is, the lower the familiarity extent and the greater the difficulty of coordination will be. Each dimension corresponds to one classification standard, which can be force branch, command and control level, and region, and so on. Figure 3 shows the multidimensional space which the force resource combination in Figure 2 is located.

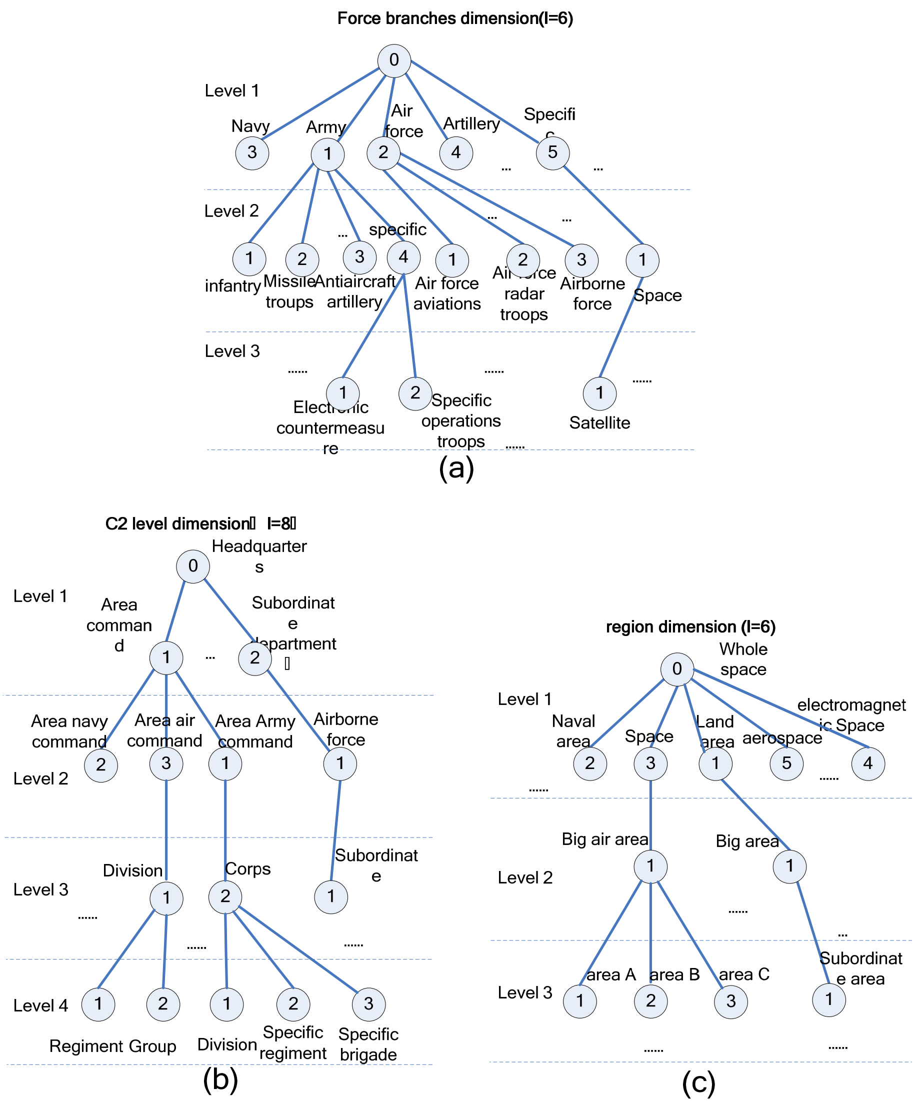

Figure 4: the multidimensional tree of the force resource combination in figure 2

It can be found that multidimensional space is different from the usual three-dimensional space. Their differences include: (1) The relationship structure between coordinates is not linear but tree like; (2) Suppose the distance between any pair of father and son units as $1/l$ (l is the longest distance between nodes of the tree). According to figure 3, the multidimensional tree coordinates of $c(57)$ is (22, 1312, 311).

Notice that while describing the space in which the C2 organization is located by using the multidimensional tree, the selection of dimension is decided according to actual situation and task demand and is not always the same.

Once the dimension and coordinates have been decided, the spatial distance $D(A,B)$ between unit A and B can be calculated in the following way:

$$D(A,B)=\sqrt{w_1 d_1(A,B)^2+w_2 d_2(A,B)^2+\cdots+w_n d_n(A,B)^2} \qquad (10)$$

Here, $d_i(A,B)\in[0,1]$, $\sum_{i=1}^{n} w_i =1, i=1,2,\cdots,n$

$d_i(A,B)$ is the distance between two units in the space of i dimension; w_i is the weight value, which reflects the extent to which the i dimension influences the whole space distance and the concrete value of which needs to be decided according the actual situation.

Suppose that the coordination efficiency between unit A and B $E(\{A,B\})$ is inverse relation to their multidimensional space distance, it can be calculated in the following way:

$$E(A,B) = 1 - D(A,B) \quad (11)$$

On the basis of (12), the coordination efficiency $R(S) = \{rs_1, \cdots, rs_m\}$ can be calculated in the following way:

$$E(rs_1, \cdots, rs_m) = \frac{1}{m}\sum_{i=1}^{m}\sqrt[m]{\prod_{j=1}^{m} E(rs_i, rs_j)^{w(rs_i, rs_j)}} \quad (12)$$

In the above formula, if there is coordination demand between rs_i and rs_j, $w(rs_i, rs_j) = 1$; if not, it will be 0.

4.2 synthesis

The above sections have studied how to analyze the reactivity and coordination efficiency according to the demand of force combination of a single mission. In the assessment of C2 structure efficiency of the force; this is just an initial step. What any force will face is not a single mission, but a long-term, wide-range possible mission demand. On the one hand, since the battlefield environment is indeterminate, the mission demand of the force cannot be predicted and analyzed accurately and mission type and concrete force resource demand will vary in a wide range; on the other hand, the establishment of C2 structure will cost a lot of resources and time, which means the structure serves a mission range. It is possible to find out about the efficiency of C2 structure of the force only if the demand is expanded to a certain extent and a number of efficiency assessment results are analyzed comprehensively.

It seemed that synthesis practice may be realized by classifying the possible force combinations or mission types, setting the relative weights, using probability to describe indeterminate factors and then inferring the corresponding force combination according the situation. However, the results will depend on greatly the knowledge and experience of the specialists.

5 Conclusion

This paper sets out to assess the effectiveness of forces adopting pyramid hierarchical C2 structure in the respects of reactivity and coordination efficiency. The main characteristic of the assessment methodology lies in that a comprehensive analysis of various factors of C2 structure has been conducted. On the one hand, associating the C2 structure with capacity reflects the capacity training aim consistent with C2 structure. On the other hand, the multi-dimensional tree is introduced to describe the multidimensional space where C2 units are located.

6 Acknowledgements

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Appendix

Table1 time spent for each node transmitting the information and making the decision

C \ T	$c(57)$	$c(44)$	$c(34)$	$c(22)$	$c(11)$	$c(22)$	$c(34)$	$c(44)$	$c(56)$	$c(45)$	$c(59)$	$c(46)$	$c(33)$	$c(42)$	$c(52)$	$c(43)$	$c(55)$	$c(21)$	$c(31)$	$c(41)$	$c(57)$
T_{i1}	5.0	5.8	6.7	8.0	9.9	8.9	7.8	7.0	6.0	7.2	5.76	7.4	8.0	6.0	6.2	6.8	6.1	8.4	6.3	3.2	6.1
T_{i3}	6.0	7.0	8.4	9.6	9.0	7.6	5.85	5.6	4.7	6.5	4.6	6.3	6.4	5.3	4.7	5.1	4.9	7.6	5.1	2.7	5.5
Ts_i	27.5	40	58	88	106	83	53	40	28	41	26	46	60	31	27	37	30	89	41	16	28
u	0.009	0.038	0.084	0.92	0.106	0.417	0.833	1.0	1.0	0.5	1.0	1.0	0.417	0.333	1.0	0.5	1.0	0.111	0.333	1.0	1.0
K	$K_1 = 0.1$				1	$K_3 = 0.35$															
T_{i2}	0.026	0.152	4.872	8.096	11.19	12.10	15.46	14.0	9.8	7.175	9.1	16.1	8.75	3.605	9.45	12.95	10.5	3.465	4.78	5.6	9.8

In the above table, the values of T_{i1}, T_{i3}, Ts_i are all estimated. Here, $T_{i2} = K \cdot u \cdot Ts_i = \begin{cases} K_1 \cdot \dfrac{e^{a+bRd(R_1,R_2))}}{1+e^{a+bRd(R_1,R_2))}} \cdot Ts_i \\ K_2 \cdot \dfrac{P(R(S))}{P(c(i))} \cdot Ts_i \\ K_3 \cdot \dfrac{P(R(S))}{P(c(i))} \cdot Ts_i \end{cases}$

$$T_{i2}(1) = K_1 \frac{e^{a+bRd(R_1,R_2)}}{1+e^{a+bRd(R_1,R_2)}} Ts_i = K_1 \frac{e^{-6.07+9.94Rd(R_1,R_2)}}{1+e^{-6.07+9.94Rd(R_1,R_2)}} Ts_i, (a=-6.07, b=9.94)$$

Table 2 the time spent on the different paths of chain

path of chain	Total time
C57→C44→C34→C22→C11→C22→C34→C44→C56	84.196
C57→C44→C34→C22→C11→C22→C34→C45→C59	76.747
C57→C44→C34→C22→C11→C22→C34→C46	75.536
C57→C44→C34→C22→C11→C22→C33→C42→C52	66.706
C57→C44→C34→C22→C11→C22→C33→C43→C55	77.171
C57→C44→C34→C22→C11→C21→C31→C41	44.666
C57→C44→C34→C22→C11→C22→C34→C44→C57	**84.286**

From the above table, we can find the longest time of information flow is 84.286 that is the responding time.

Calculating the coordination efficiency

$$D(A,B)=\sqrt{\sum_i w_i d_i(A,B)^2}=\sqrt{\frac{4}{9}d_1(A,B)^2+\frac{1}{3}d_2(A,B)^2+\frac{2}{9}d_3(A,B)^2}$$

Table 3 the spatial distance and the coordination efficiencies of every two units in $R(S)$

$D(X,Y)$ $(E(X,Y))$	S	V	M	O	R	H	T
S	0 (0)	0.157 (0.843)	0.246 (0.754)	0.771 (0.229)	0.640 (0.360)	0.850 (0.150)	0.265 (0.735)
V	0.157 (0.843)	0 (0)	0.246 (0.754)	0.771 (0.229)	0.640 (0.360)	0.850 (0.150)	0.308 (0.692)
M	0.246 (0.754)	0.246 (0.754)	0 (0)	0.703 (0.297)	0.578 (0.422)	0.771 (0.229)	0.640 (0.360)
O	0.771 (0.229)	0.771 (0.229)	0.703 (0.297)	0 (0)	0.480 (0.520)	0.870 (0.130)	0.771 (0.229)
R	0.640 (0.360)	0.640 (0.360)	0.578 (0.422)	0.480 (0.520)	0 (0)	0.850 (0.150)	0.640 (0.360)
H	0.850 (0.150)	0.850 (0.150)	0.771 (0.229)	0.870 (0.130)	0.850 (0.150)	0 (0)	0.850 (0.150)
T	0.265 (0.735)	0.308 (0.692)	0.640 (0.360)	0.771 (0.229)	0.640 (0.360)	0.850 (0.150)	0 (0)

In $R(S)$, $w(rs_i,rs_j)=\begin{cases}0, if\ rs_i=H,\quad rs_j=O, or\quad rs_i=O, rs_j=H\\ 1,\qquad else\end{cases}$

$$E(R(S))=\frac{1}{m}\sum_{i=1}^{m}\sqrt[m]{\prod_{j=1}^{m}E(rs_i,rs_j)^{w(rs_i,rs_j)}}=\frac{1}{7}\left[E(S)+E(V)+E(M)+E(O)+E(R)+E(H)+E(T)\right]$$

$$=\frac{1}{7}[0.4789+0.4748+0.5324+0.7659+0.6719+0.8780+0.5793]\approx 0.6259$$