Research on Maritime Operations Scheme Making Model Based On Collaboration

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Abstract. With the purpose to improve the ability of collaborative command of maritime, based on systematically analyzing the ways of collaboration to make operations scheme, operations scheme collaboration domain (OSCD) is designed, and relations of its inner elements are analyzed, based on which operations scheme collaboration model (OSCM) is constituted, which will provide foundational underprop for demonstrating and developing intending maritime command and control system.

1. Introduction
With the development of military information construction, the interconnection and interoperability of marine operations will be greatly enhanced, and the marine information network will provide a good support for system-based advantage. Based on architecture of marine command system in future, a unified decision-making space (UDS) will be gradually established. UDS is a system, which can support the multi command level and the multi operations commanders’ integrative collaborative command. In UDS, commanders can share and exchange data, information, knowledge and ideas, and can closely coordinate. Operations scheme is the intuitive result of command of maritime, and is the basis of operations. It is a crucial problem how to make use of UDS to generate the operations scheme in the way of distributed collaboration, so it is necessary to build the collaboration model of generating the marine operations scheme.

2. Operations scheme generation method
According to whether the operations scheme is broken down in the making process, the collaboration mode of operations scheme generation can be divided into two types.

2.1. Unified collaboration
In this mode, operations scheme will not be divided into sections and highly coordination is emphasized. When the commanders are concentrated together, they communicate face to face and formulate the operations scheme with the same interface [1]. When they are in different places, the commanders interact through support terminals and make a unified operations scheme on their support terminals (distributed unified collaboration). In this mode, real-time collaboration will be supported, and all the related factors of operations scheme will be analyzed clearly. But the participants must have global understanding of the operations scheme. It is difficult to realize this collaboration mode...
2.2. Division of labor and coordination
In this mode, operations scheme will be divided into sections and coordination basing on division of labor is emphasized. First, we divide the task of formulating operations scheme from top to bottom (Top-Down) into sub tasks of formulating operations scheme, and then integrate the sub schemes from bottom to top (Bottom-Up). The collaborators focus on the tasks that they undertake. The sub schemes can be integrated after being completed. The sub schemes can also be integrated periodically or in real time during the formulation of the scheme. This way decomposes complex problems, which is conducive to the simplification of problems. However, when integrating the sub schemes, conflicts may arise and the coordination will be difficult.

In marine operations, command nodes and decision units at all levels have the characteristics of distribution, the command and decision organization has the characteristics of hierarchical structure, and there is a functional division among commanders at all levels. Therefore, the mode of division of labor and cooperation is going to be used to formulate the operations scheme [2].

3. Construction of operations scheme collaboration domain
For a command level in a command decision organization, the commander in charge of making the scheme can divide it into sub schemes and assign the sub schemes to the subordinate commanders to formulate. Thus a relatively autonomous cooperative group is formed.

3.1. Operations scheme collaboration domain
The operations scheme collaboration domain (OSCD) is defined as a relatively autonomous collaborative component formed to generate a certain operations scheme in Collaboration with the support of UDS. The architecture model of OSCD, as shown in Figure 1, can be expressed as

OSCD = (ID, Cmder, OST, SurSys, Res)

Where: ID is the only identification of the OSCD; Cmder is the finite set of collaborative subjects who will formulate the operations scheme; OST is the task to formulate the operations scheme; SurSys is the finite set of the support systems in OSCD; Res is a limited set of combat resources such as warships, submarines, and so on.

![Figure 1 architecture model of OSCD](image_url)
3.1.1 Collaborative subject. A collaborative subject can be expressed as: $\text{Cmdr}= (\text{ID}, \text{rank}, \text{fun}, \text{role})$

Where: $\text{ID}$ represents the unique identity of the collaborative subject; $\text{rank}$ represents the grade of the collaborative subject; $\text{fun}$ represents the function of the collaborative subject; $\text{role}$ represents the role of the collaboration subject in the OSCD, $\text{role} \in \{\text{FResp}, \text{PResp}\}$. $\text{FResp}$, as a global responsibility role, takes full responsibility for the generation of operations schemes (parent schemes) in the OSCD, and has the right to divide the operations scheme into sub schemes and assign them down; $\text{PResp}$, as a global responsibility role, is responsible for generating the sub scheme. The collaborative subject carrying the global responsibility role is called the full responsibility subject, and the collaborative subject carrying part of the responsibility role is called the sub responsibility subject.

3.1.2 Support system. The support system can be expressed as: $\text{SurSys}= \{\text{SurSchSys}, \text{ArgSys}, \text{Tools}\}$

Where: $\text{ArgSys}$ represents a support system for consultation; $\text{Tools}$ represents a set of auxiliary tools; $\text{SurSchSys}$ represents a distributed collaborative system for generating operations schemes, which includes two types of cooperative nodes and integrated nodes in OSCD. The cooperative node is mainly used to assist the sub responsibility subject to formulate sub schemes. The integrated node is mainly used to assist the full responsibility subject to combine the sub schemes to the parent scheme, and to check and coordinate the conflicts among the sub schemes.

3.1.3 Operations scheme task. The operations scheme task can be expressed as: $\text{OST}=\text{OpeSchf}= (\text{OpeSchz}, \text{DFacet})$

Where: $\text{OpeSchf}$ represents the parent scheme, that is, the operations scheme to be generated in the OSCD; $\text{OpeSchz}= \{\text{OpeSchz}_i | i \leq m \}$ represents the set of sub schemes; and $\text{DFacet}$ represents the dividing facet used to divide the combat scheme into sub schemes.

3.2. The dividing principles

Principle 1 (matching principle): the division of the operations scheme should be matched with the organization structure of the command group and the structure of support system for formulating the operations scheme. Each sub scheme can be allocated to a commander with relevant obligation, and there is a cooperative node to assist the commander. Let $\text{OpeSchz}_i$ be a sub scheme, $\text{cmdr}_j$ is a commander with relevant obligation, and the relationship between sub scheme and commander is $\text{OpeSchz}_i \to \text{cmdr}_j$.

Principle 2 (complete principle): the division of the operations scheme plan must be complete, that is, the set of sub schemes can be integrated into a complete parent scheme. Let $\text{OpeSch}_i$ be a parent scheme whose sub schemes set is $\{\text{OpeSchz}_1, \text{OpeSchz}_2, \ldots, \text{OpeSchz}_m\}$, the completeness of the division of scheme is as follows: $\text{OpeSch}=\text{OpeSchz}_1 \cup \text{OpeSchz}_2 \cup \ldots \cup \text{Principle 3}$ (independent principle): after the parent scheme is divided into sub schemes, the sub schemes should be independent, that is, the boundary between the sub schemes is clear, and the content of the scheme does not overlap. Let $\text{OpeSch}_{ij}$ and $\text{OpeSch}_{ij}$ be the sub schemes that belong to the same parent scheme, and $i \neq j$, the independence between two sub schemes is as follows: $\text{OpeSch}_{ij}\cap\text{OpeSch}_{ij}=\Phi$.

3.3. The dividing facets

The division of the operations scheme is the premise that can use the division of labor and coordination to generate the operations scheme. Therefore, many dividing facets are defined as the dividing basis of the operations scheme, and each dividing facet represents a dividing method.

Operations facet: according to aspects of operations such as anti-air operation, anti-ship operation and anti-submarine operation, the operations scheme is divided into sub scheme of anti-air operation, sub scheme of anti-ship operation, sub scheme of anti-submarine operation, and so on.

Arms facet: according to the mission tasks, the operational methods and the characteristics of the surface warships, submarines and air forces, the operations scheme is divided into the sub schemes of the surface warships, submarines and air forces.
Group facet: the combination of different combat forces is a task group. According to different task groups, the operations scheme is divided into sub schemes of the task groups.

Unit facet: according to the different units used, the operations scheme is divided into sub schemes of units.

Target Facet: the forces that strike the same target or many targets in the same area are regarded as a whole, and the operations scheme is divided according to the different targets to be stricken.

Space Facet: the forces in the same region are regarded as a whole, and the operations scheme is divided according to the different regions.

Time facets: the operations scheme is divided according to the stage of the operational process. For example, the operations scheme of surface warships attacking ships with missiles can be divided into sub schemes, such as navigation, expansion, attack and withdrawal.

Space-time / time-space facet: mainly embodies the characteristics of the echelon of operational forces, and the operations scheme is divided according to different echelons.

Operational method facet: according to the different methods of operations or different weapons used to divide the operations scheme, for example, the anti-submarine scheme can be divided into torpedo attack scheme and navigation evasion scheme.

In summary, according to the characteristics of the operational task, the granularity and characteristics of the parent scheme and dividing principles, suitable dividing facet should be choose to divide the operations scheme.

3.3.1 Combat resources. [Combat resources] Res = \{OU_1, OU_2, ..., OU_n\}

Combat resources are the set of operational units available in OSCD, and OU represents a operational unit.

OU = (Name, ID, Cap, Sta, Rst)

Where: Name represents the name of the operational unit; ID represents the unique identification of the operational unit; Cap represents the ability attribute set of the operational unit, mainly including operational capability, combat object, combat range, endurance, maneuver speed, stealth property, communication capability, etc., and Sta shows the state attributes of the operational unit, mainly including platform damage state, weapon state, position state, task state and so on. Rst represents the use constraint of the operational unit, which mainly describes in what circumstances the operational unit should be used in priority or should not be used.

3.4. Internal relations of the OSCD

As a whole, the OSCD has a hierarchical structure. The layer of collaborative subjects generates the operations scheme through the support system layer, that is, the use of combat resources is planned. The relationships among key elements within the OSCD are shown in Figure 2.

4. Operations scheme collaboration model

The OSCD is the basic collaborative component for the collaborative generation of the operations
scheme. Based on the OSCD, an operations scheme collaboration model (OSCM) can be established, which can be expressed as

$$\text{OSCM} = (\text{AOSCD}, \text{Rel})$$

Where: AOSCD represents the finite set of OSCDs; Rel represents the finite set of the collaboration relationship.

4.1. Collaboration relation

Collaboration relation can be expressed as

$$\text{Rel} = (\text{Relv}, \text{Relh})$$

Where: Relv represents the vertical collaboration relations, which are the relations between the upper level OSCD and the lower level OSCD, such as assignment and control; Relh represents the horizontal collaboration relations, which are the relations between the OSCDs of the same layer scheme, such as negotiation and collaboration. They are not only related to each other, but also have certain independence.

4.2. Affiliation relation

$\leq$ represents the binary affiliation relation between OSCDs, $\subseteq \text{AOSCD} \times \text{AOSCD}$, which has characteristics of reflexivity, transitivity and boundness. Reflexivity: $\forall \text{OSCD}_i \in \text{AOSCD}, \text{OSCD}_i \leq \text{OSCD}_i$; Transitivity: $\forall \text{OSCD}_i, \text{OSCD}_j, \text{OSCD}_k \in \text{AOSCD}, \text{OSCD}_i \leq \text{OSCD}_j \land \text{OSCD}_j \leq \text{OSCD}_k \Rightarrow \text{OSCD}_i \leq \text{OSCD}_k$; Boundness: $\forall \text{OSCD}_i, \text{OSCD}_j \in \text{AOSCD}, \text{AOSCD}_i = \{\text{OSCD}_k | \text{OSCD}_k \leq \text{OSCD}_i \}$ is a finite set.

$<$ represents the strict binary affiliation relation between OSCDs: $\forall \text{OSCD}_i, \text{OSCD}_j \in \text{AOSCD}, \text{OSCD}_i < \text{OSCD}_j \Leftrightarrow \text{OSCD}_i \leq \text{OSCD}_j \land \text{OSCD}_i \neq \text{OSCD}_j$.

$\pi$ Represents the direct binary affiliation relation between OSCDs: $\forall \text{OSCD}_i, \text{OSCD}_j, \text{OSCD}_k \in \text{AOSCD}, \text{OSCD}_i \pi \text{OSCD}_j \Leftrightarrow \text{OSCD}_i \leq \text{OSCD}_j \land (\neg \exists \text{OSCD}_k (\text{OSCD}_i \pi \text{OSCD}_k \land \text{OSCD}_k \leq \text{OSCD}_j))$.

4.3. Equal cooperation relation

$\approx$ Represents the binary equal cooperation relation between OSCDs, which has characteristics of reflexivity, transitivity, boundness and symmetry. Symmetry: $\forall \text{OSCD}_i, \text{OSCD}_j \in \text{AOSCD}, \text{OSCD}_i \approx \text{OSCD}_j \Leftrightarrow \text{OSCD}_j \approx \text{OSCD}_i$.

$\approx'$ Represents the strict binary equal cooperation relation between OSCDs: $\forall \text{OSCD}_i, \text{OSCD}_j \in \text{AOSCD}, \text{OSCD}_i \approx' \text{OSCD}_j \Leftrightarrow \text{OSCD}_i \approx \text{OSCD}_j \land (\neg \exists \text{OSCD}_k (\text{OSCD}_i \approx \text{OSCD}_k \land \text{OSCD}_k \neq \text{OSCD}_j))$.

$\approx^*$ Represents the direct binary equal cooperation relation between OSCDs: $\forall \text{OSCD}_i, \text{OSCD}_j \in \text{AOSCD}, \text{OSCD}_i \approx^* \text{OSCD}_j \Leftrightarrow \text{OSCD}_i \approx' \text{OSCD}_j \land (\neg \exists \text{OSCD}_k (\text{OSCD}_i \approx^* \text{OSCD}_k \land \text{OSCD}_k \neq \text{OSCD}_j))$.

Based on the above two binary relations, the vertical collaboration and horizontal collaboration can be expressed as:

$$\text{Rel}_v = \{\langle \text{OSCD}_i, \text{OSCD}_j \rangle | \exists \text{OSCD}_k (\text{OSCD}_i \pi \text{OSCD}_k \leq \text{OSCD}_j)\}$$

$$\text{Rel}_h = \{\langle \text{OSCD}_i, \text{OSCD}_j \rangle | \exists \text{OSCD}_k (\text{OSCD}_i \pi \text{OSCD}_k \land \text{OSCD}_k \leq \text{OSCD}_j)\}$$

4.4. Assignment relation

Let ACmder is the finite set of the commanders who participate in the formation of the operations scheme, and AOpesSch is the finite set of the sub schemes which the operations scheme is divided into. Commander hierarchy relation: $\text{CH} \subseteq \text{ACmder} \times \text{ACmder}$, $\langle \text{cmd}_i, \text{cmd}_j \rangle \in \text{CH}$ represents that cmd$_i$ is the superior cmd$_j$, cmd$_i$ can assign scheme task to cmd$_j$. 
Scheme hierarchy relation: $SH \subseteq AOpeSch \times AOpeSch$, $\langle OpeSch_i, OpeSch_j \rangle \in SH$ represents that $OpeSch_i$ is the parent scheme of $OpeSch_j$, and there is a containing relation between them.

Scheme charge relation: $SC \subseteq ACmder \times AOpeSch$, $\langle cmder_i, OpeSch_i \rangle \in SC$ represents that collaborative subject $cmder_i$ is responsible for generating operations scheme $OpeSch_i$; $SC \subseteq AOSCD \times AOpeSch$, $\langle OSCD_i, OpeSch_i \rangle \in SC$ represents that $OSCD_i$ is responsible for generating operations scheme $OpeSch_i$. $OpeSch_i$ is the operations scheme that the full responsibility subject is responsible for, namely, the operation scheme task $OST_i$ of the $OSCD_i$.

The assignment relation can be expressed as

$$AR = (SAR, RAR)$$

Where: $SAR$ represents the task assignment relations among $OSCD$s; $RAR$ represents the resource allocation relations among $OSCD$s.

$$SAR = \{ \langle OSCD_i, OSCD_j, OpeSch_j, Dep_j \rangle \mid \langle OSCD_i, OSCD_j \rangle \in Rel, \langle OpeSch_i, OpeSch_j \rangle \in SH, \langle OSCD_i, OpeSch_i \rangle \in SC, Dep_j \geq 0 \}$$

This indicates that $OSCD_i$ assigns the task of formulating sub scheme $OpeSch_j$ to $OSCD_j$, and limits the $OSCD_j$ assignment depth $Dep_j$ to the subprogram. The assignment depth $Dep_j$ represents the number of layers that can be assigned down. $Dep_j = 0$ indicates that it cannot be assigned down anymore. The default value indicates that there is no restriction. If the upper $OSCD$, is limited to $Dep_i$, the $Dep_j$ of lower $OSCD$ should be less than $Dep_i - 1$, which is $Dep_j \leq Dep_i - 1$.

$$RAR = \{ \langle OSCD_i, OSCD_j, Res_j \rangle \mid \langle OSCD_i, OSCD_j \rangle \in Rel, Res_j \subseteq Res \}$$

This indicates that $OSCD_i$ limits the range of combat resources that $OSCD_j$ can choose during formulating $OpeSch_j$.

The principle of assignment relations among collaborative subjects is the same as above.

In addition to the limitation of assignment depth, the assignment of operations scheme tasks should be limited to the following rules,

(1) If the operations scheme can be formulated independently in an $OSCD$, that is, the sub responsibility subjects of the $OSCD$ can generate the sub schemes independently and conveniently, and they do not need to be divided and assigned.

(2) If the sub responsibility subjects of the $OSCD$ cannot formulate the sub schemes independently, the sub schemes should be further divided into lower sub schemes, and new $OSCD$s in lower layer should be organized. The lower sub schemes should be assigned to the new $OSCD$s in lower layer. The sub responsibility subjects will become the full responsibility subjects of the new $OSCD$s in lower layer.

(3) If the new $OSCD$s in lower layer can formulate the lower sub schemes independently, the lower sub schemes do not need to be divided and assigned. Otherwise, they need to be divided and assigned by hierarchical recursion.

4.5. Structure of OSCM

The structure of OSCM is based on $OSCD$ as the basic component, and the top layer $OSCD$ of the marine operations as the beginning point. According to the collaboration relation and the assignment relation, the hierarchical recursive extension is made, and the network nested model structure, as shown in Figure 3, is formed. In the structure, there is a dynamic clientage between collaboration subjects, which is adaptable; the division of the operations scheme is driven by the actual demand, which is flexible; the formulation of the operations scheme is supported by the support system of UDS, which is very efficient; the combat resources cover all the units involved in the marine operations, which are shared well. The impact of dynamic change of combat resources is generated from bottom to top according to the level of $OSCD$s, which can respond as soon as possible and weaken the interference of global collaboration.
5. Conclusion
The naval equipment informatization and integration is to provide strong information assurance for maritime operations and form information superiority. However, in the process of maritime operations, it is essential to transform information superiority into decision-making superiority, and then form striking superiority. The cooperation of combat helps to generate striking superiority, while the cooperation of the combat needs to rely on the collaboration of decision-making. The key part is to formulate a "high coordinated decision plan" in a collaborative way. In view of this, based on division of labor and coordination, the article focuses on collaboration method of formulation of marine operations scheme, and establishes a collaboration model. The model is scalable, adaptable, efficient and easy to share, which can provide a basic support for the argumentation and development of command system of maritime operations in future.

References
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