A scenario construction and similarity measurement method for navy combat search and rescue

ZHAO Qingsong*, DING Junyi, GUO Yu, LIU Peng, and YANG Kewei

College of Systems Engineering, National University of Defense Technology, Changsha 410073, China

Abstract: Navy combat search and rescue (NCSAR) is an important component of the modern maritime warfare and the scenario of NCSAR is the basis for decision makers to rely on. According to the core elements in the NCSAR process, the NCSAR scenario structure is constructed from seven perspectives based on the multi-view architecture framework. According to the NCSAR scenarios evolution over time, the NCSAR scenario sequence is analyzed and modeled based on the concept lattice method. Then, the incremental construction algorithm of the NCSAR scenario sequence lattice is given. On this basis, the similarity measurement index of NCSAR scenarios is defined, and the similarity measurement model of NCSAR scenarios is proposed. Finally, the rationality of the method is verified by an example analysis. The NCSAR scenario and similarity measurement method proposed can provide scientific guidance for rapid making, dynamic adjustment and implementation of the NCSAR program, and thus improve the efficiency and effectiveness of NCSAR.

Keywords: navy combat search and rescue (NCSAR), scenario, similarity, measurement, concept lattice.

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1. Introduction

The joint search and rescue (SAR) of the sea battlefield refers to the joint SAR operations of people who have fallen into the enemy battle zone or disappeared in the sea battlefield. The main tasks include the SAR forces transfer, the battlefield SAR, the evacuation of the wounded and sick, and the supplement of drugs and equipment. The area covers the entire space of land, sea and airspace, involving strategic, operational and tactical levels.

The international aeronautical and maritime search and rescue (IAMSAR) manual provides guidance for the SAR [1]. Maritime SAR has been receiving attention since World War II. The world’s military powers generally build battlefield rescue as an important or even direct combat force [2–5].

The US military regards soldiers as the most important factors and key links. The US military attaches great importance to the SAR work of the battlefield personnel. According to the US military regulations, the battlefield SAR refers to the special missions carried out by the rescue forces to recover people in distress in uncertain or hostile circumstances and prohibited areas [6,7]. The US military has established a force system which is in the charge of the Department of Defense, supported by the relevant departments of the military and the local, and involves other organizations in the national rescue system and the civilian rescue forces.

The remainder of this paper is organized as follows. Section 2 introduces the related works of the scenario construction and similarity measurement method. Section 3 analyzes the missions, the processes, and the core elements of the navy combat SAR (NCSAR). In Section 4, based on the multi-view modeling method, the NCSAR scenarios are constructed from seven perspectives, and 13 view products about NCSAR and their influence elements are given. Section 5 analyzes the NCSAR scenario sequence and proposes the concept lattice-based NCSAR scenario sequence lattice construction method. Section 6 illustrates the similarity measurement model of NCSAR scenarios. In Section 7, a sample analysis is involved. Finally, Section 8 presents final conclusions of this study.

2. Related works

By analyzing related literature of the scenario construction and similarity measurement method for NCSAR, we find that the similar problems of NCSAR have rarely been discussed. Most existing works have talked about the SAR in the non-military field and discussed the scenario construction and similarity measurement. Next, we discuss the related works from the aspects of SAR, scenario construction and similarity measurement.
In the research of marine SAR decision-making, many decision evaluation theories have been applied [8–10]. Liang et al. [11] proposed a heuristic SAR scheduling method according to the situation of limited resources in marine disaster rescue. Kratzke et al. [12] studied the problem of optimal SAR at sea based on the concept of the success rate. Guo et al. [13] proposed a multi-resource allocation method aiming at the problem of long-range marine SAR. Otote et al. [14] applied the optimal search theory to the SAR decision algorithm at sea. Kim et al. [15] proposed a method for formulating a SAR plan based on a model for quickly locating victims.

In the real SAR process, there are very complex influencing factors and various uncertainties [16,17]. Agent-based modeling (ABM) is a useful tool for describing the overall macro behavior caused by micro-interactions between multiple entities. Li et al. [18] proposed a novel method (agent action diagram) to ensure the consistencies between the simulation model and the conceptual model. With respect to decision-makers’ psychological behavior characteristics under the uncertain emergencies, a dynamic emergency decision-making method based on utility risk entropy was built by analyzing the dynamic reference point and psychological perception of decision-makers in [19].

The emergency decision-making of unconventional emergencies should be based on scenarios. The understanding and grasp of the scenario is the basis for decision making. However, most of the researches on development of the maritime SAR plan are carried out under the premise of specific SAR scenarios, that is, the maritime SAR plan has a great dependence on a given SAR scenario, which has resulted in the adaptability of the SAR plan fluctuating with the change of SAR scenarios. Moreover, even the plan may not adapt to the new SAR scenarios. The potential risks of unrecognized scenarios due to the complexity of the influencing factors make it more and more difficult to correctly identify hazards in safety reports [20].

The similarity problem of emergency events is a difficult problem to be solved when the occurring emergency events in the case-based reasoning technology are used for the auxiliary decision-making.

The sudden, confrontational and complex characteristics of joint operations make the battlefield joint SAR face difficulties such as time limitation, complex circumstance and limited information resources. It has the characteristics of high information loss, insufficient precursor, high urgency, high burstiness, high uncertainty and high risk. The outbreak of the SAR incidents in the sea battlefield changes rapidly. The prediction is extremely difficult and even impossible, leading to the traditional “predictive-response” type SAR mode “failed”. Therefore, the scientific understanding of the NCSAR scenarios has become the premise and basis for the effective formulation and implementation of the NCSAR plan.

Scenarios can be used to prepare for possible eventualities in a more flexible and more innovative way [21]. Scenarios are the description of a future scenario and the events which give the paths from the current to the future scenario [22].

In order to formulate a joint battlefield SAR plan faster and better, it is generally to find similar joint SAR events that have occurred in history under the condition of time constraints, and to find knowledge and experience that can be learned from its SAR plan. Therefore, the emergency decision-making of the battlefield joint SAR should be based on the situation. The understanding and grasp of the situation is the basis for the decision-makers to make decisions. However, the joint SAR incidents in different battlefields can only be similar in some respects. It is difficult to find events that are completely similar and useful for reference. Therefore, the primary problem of joint SAR on the battlefield is to study the similarity between different scenarios of the joint SAR. According to the similarity of the battlefield joint SAR scenarios, the case of existing joint SAR can be utilized to the maximum extent, so that the SAR plan can be quickly generated.

As it helps to describe the uncertainty and complexity, the scene planning technology is more and more widely used [23–26]. Gershuny [27] thought that the scenarios were general descriptions of future conditions and events. Scenarios can help organizations to prepare for the future events. Schnaars [28] summarized some guidelines for the use of scenarios according to the comparison and evaluation of them. Paltrinieri et al. [20] provided a new model for the identification of the typical accident scenarios including their occurrence, causes, consequences and lessons learned. Paltrinieri et al. [29] analyzed the hazard identification in the field of carbon capture and transport. Zhang et al. [30] constructed the scenario chain in the order of time sequence based on the key decision points scenario and put forward the constitutive model of “event-scenario-emergency tasks emergency action” in the vertical aspect.

Overall, few studies have focused on the scenario construction and similarity measurement method for NCSAR. Little research has used the multi-view architecture framework to build the NCSAR scenario structure and used the concept lattice method to describe and analyze the scenario sequence. Moreover, most of them only focus on the stage of search instead of the stages including the SAR. There are few research about the construction and analysis of SAR scenarios that focus on the characteristics of NCSAR with ignoring the impact of the combat opponent in the NCSAR operation.

This paper is oriented to the scenario construction and similarity measurement problem in the NCSAR. The main contributions are as follows. Firstly, compared with the
current research where the maritime SAR problem is mainly about merchant ship, this paper takes the NCSAR as the research background. The unique characteristics of NCSAR, such as the personnel importance, war zone and enemy threats, are considered. The scenario of NCSAR is established from seven perspectives, which helps to extend the maritime SAR problem. Secondly, the existing research analyzing the similarity of the SAR scenarios is mainly from the static perspective, that is, without considering the fact of the scenarios changing with time. This paper analyzes the sequence of the NCSAR scenarios over time based on the concept lattice method and proposes a scenario similarity measurement method based on the NCSAR from a dynamic perspective, which extends the scenario similarity analysis method. Thirdly, an incremental construction method of the NCSAR scenario sequence is proposed to cope with the rapid scenario changes from time to time, which accelerates the efficiency of NCSAR scenario lattice constructing.

3. NCSAR core factors analysis

NCSAR is the action including the SAR taken after receiving the distress information at sea. The purpose of the navy combat search is to locate the distressed people. The purpose of the NCSAR is to give the on-site treatment for the injured and sick people and transfer them to safe places.

The SAR process describes the long-range simplified maritime SAR operation process as three stages: alarm receiving, search operation, and rescue operation [13]. The implementing stages of SAR can be divided into the following stages including distress alert, self-rescue and mutual rescue, organizing and planning, maritime search, maritime rescue, fast delivery and so on. The task of each stage is as follows.

(i) Distress alert: After the danger occurs, the distressed people send a message through a special communication channel. After receiving and confirming the alarm information, the corresponding organization shall make a SAR emergency response according to the procedure.

(ii) Self-rescue and mutual rescue: After encountering an emergency situation at sea, personnel should use the life-saving equipment to organize self-rescue protection according to the injury situation before the arrival of the SAR force, and try to control the spread of the danger.

(iii) Organizing and planning: After receiving the distress message, the command organization will formulate a SAR action plan based on relevant information.

(iv) Maritime search: According to the SAR plan, use the formulated plan for maritime search.

(v) Maritime rescue: After finding the people to be rescued, carry out on-site rescue and treatment according to the situation.

(vi) Fast delivery: The rescued personnel will be quickly delivered to the rescue agencies in the safe area for follow-up treatment.

There are many influencing factors involved in the NCSAR process. It is not feasible to take all influencing factors into account in the method. In order to ensure the representativeness of the analyzed elements, the 5W1H method is used to analyze the core factors in the NCSAR process.

5W1H is a method to describe the details of a fact by the description of who, what, where, when, and how questions [31]. Similarly, NCSAR covers distinct knowledge during the stages. Based on the 5W1H method, the core elements of NCSAR includes “5W1H”, which are who (SAR objects), where (SAR positions), what (equipment on SAR objects), when (SAR time), why (SAR targets) and how (SAR steps).

The core factors of NCSAR involve time, place, process, personnel and other aspects. The relationship among the various implementation stages of NCSAR, the SAR factors and the scene factors are shown in Fig. 1.

![Fig. 1 Core factors and their relationship in NCSAR](image-url)
4. NCSAR scenario construction based on multi-view method

A scenario is a description of the state of a property on a particular time segment for an unconventional emergency in an uncertain circumstance. The NCSAR scenario is a description of the state of the property at a certain time in the future that affects the SAR process and effects. The various factors affecting the NCSAR play different roles in the SAR process.

The perspective is used to indicate aspects of interest to the target system. The perspectives of the NCSAR scenarios include the following.

(i) Personnel perspective: Describe the type of SAR objects and the situation of the injury. Different types of objects lead to different importance and priority. The different injuries of SAR objects also determine the urgency of SAR and the choice of treatment plan during the SAR process, all of which will affect the formulation of the NCSAR plan.

(ii) Time perspective: The time period during which SAR occurs. Whether the NCSAR occurs in wartime or in peacetime has a great impact on the life safety of SAR objects and the formulation of SAR plans.

(iii) Spatial perspective: Describe the spatial location of the NCSAR. The requirements for SAR forces in the offshore and remote seas are not the same. Whether they occur in the war zone or the non-combat zone will have a great impact on the formulation of SAR plans.

(iv) Circumstance perspective: Describe the circumstance conditions in the NCSAR process. Seawater temperature has a great impact on the survival time of SAR objects. The meteorological conditions and wave heights on the sea surface will also have a great influence on the formulation of SAR plans.

(v) Equipment perspective: Describe the equipment carried by the NCSAR objects. Carrying different life-saving equipment will have different effects on the survival time and threat response of SAR objects, which in turn will affect the formulation of SAR plans.

(vi) Threat perspective: Describe the operational threats during the NCSAR. Different levels of enemy combat threats will seriously affect the formulation of SAR plans.

A view product is a detailed description of a certain aspect of the target system from a multi-view related point of interest. Fig. 2 shows the multi-view construction of the navy combat search and 209 rescue scenarios. The composition of the view products based on the joint SAR of the sea battlefield is shown in Table 1.
The NCSAR task continues for a period of time. During this period, the level of the influencing factors of the maritime SAR scenario is likely to change. Therefore, the sequence of scenarios that evolve over time is described as a lattice in NCSAR circumstances, the longest SAR time is predicted as $t^m$. The NCSAR scenario changes in the interval $[t^1, t^m]$.

5. Construction of scenario sequence lattice in NCSAR

The NCSAR task continues for a period of time. During this period, the level of the influencing factors of the maritime SAR scenario is likely to change. Therefore, the sequence of scenarios that evolve over time is described as shown in Fig. 3.

The occurrence of the maritime SAR incidents is often sudden, and the response time is urgent. Formulating the SAR plan from scratch often misses the golden time of SAR. The maritime SAR plan is developed based on the specific situation of the SAR scenario. Therefore, in practice, it is often based on the existing SAR plan. Therefore, measuring the similarity of different maritime SAR scenarios is an important task for the maritime SAR.

Denote the distress alert time point as well as the NCSAR start time point as $t^1$. According to the sea temperature, equipment carried by the SAR objects and other circumstances, the longest SAR time is predicted as $t^m$. The NCSAR scenario changes in the interval $[t^1, t^m]$. 

### Table 1  Multi-view products of NCSAR scenario

| View                  | Product     | Description                                                                 | Level range of scenario factors |
|-----------------------|-------------|-----------------------------------------------------------------------------|---------------------------------|
| Personnel view (PV)   | PV1         | Describe the importance of SAR objects, which are classified into primary, intermediate and advanced ones, indicating that the level of importance of SAR objects is getting higher and higher. | $t_1$: primary, $t_2$: intermediate, $t_3$: advanced |
| Personnel injury      | PV2         | Describe the injury situation of the SAR objects, classified into severely injured, light injured and not injured. | $t_1$: not injured, $t_2$: lightly injured, $t_3$: severely injured |
| Time view (TV)        | TV1         | Describe the time property when the SAR occurs, divided into two types: wartime and peacetime. For the SAR at wartime, the decider should take the threat from enemy into consideration. | $t_1$: peacetime, $t_2$: wartime |
| SAR period            | TV2         | Describe the period property when the SAR occurs, divided into day and night. | $t_1$: day, $t_2$: night |
| Spatial view (SV)     | SV1         | Describe whether the SAR object carries positioning equipment. The situation is divided into yes and no. | $t_1$: yes, $t_2$: no |
| SV2                   | PV1         | Describe whether the SAR object carries rescue equipment. According to the condition of rescue equipment, the situation is divided into none, primary and advanced. | $t_1$: advanced, life rafts, non-powered ships, life-saving kits, etc., rescued personnel from the seawater immersion environment, able to carry out general self-help, $t_2$: primary, simple life-saving equipment such as life jackets, lifebuoys, life-saving kits, etc., the rescued personnel are still in seawater immersion, able to conduct simple self-rescue, $t_3$: none, no rescue equipment carried |
| Circumstance view (CV)| CV1         | Describe the sea temperature which helps to judge the life span and formulate the SAR plan. According to the influence of sea temperature on human life span, divide it into three levels: under $4°C$, $4°C$ to $10°C$ and above $10°C$. | $t_1$: $4°C$ to $10°C$, $t_2$: under $4°C$, $t_3$: above $10°C$ |
| Wave height CV2       | Describe the wave height which helps to judge the life span and formulate the SAR plan, and divide it into low, medium and high. | $t_1$: low, wave height $0 – 2.5$ m, $t_2$: medium, wave height $2.5 – 6.0$ m, $t_3$: high, wave height $>6.0$ m |
| Wind speed CV3        | Describe the wind speed which helps to judge the life span and formulate the SAR plan, and divide it into low, medium and high. | $t_1$: low, wind speed $0 – 10.7$ m/s, $t_2$: medium, wind speed $10.8 – 20.7$ m/s, $t_3$: high, wind speed $>20.7$ m/s |
| Visibility CV4        | Describe the visibility which helps to judge the life span and formulate the SAR plan, and divide it into good, medium and bad. | $t_1$: good, no precipitation or light rain, clear air, $t_2$: medium, heavy rain, light fog or moderate rain, $t_3$: poor, dense fog, heavy fog or heavy rain |
| Location device EV1   | The situation is divided into yes and no. | $t_1$: yes, $t_2$: no |
| Rescue equipment EV2  | Describe whether the SAR object carries rescue equipment. According to the condition of rescue equipment, the situation is divided into none, primary and advanced. | $t_1$: advanced, life rafts, non-powered ships, life-saving kits, etc., rescued personnel from the seawater immersion environment, able to carry out general self-help, $t_2$: primary, simple life-saving equipment such as life jackets, lifebuoys, life-saving kits, etc., the rescued personnel are still in seawater immersion, able to conduct simple self-rescue, $t_3$: none, no rescue equipment carried |
| Hostile threat THV1   | Describe whether there will be hostile threat during the SAR activity or not. | $t_1$: no, $t_2$: yes |
Let $S = \{s_1, s_2, \ldots, s_m\}$ represent the scenario set in the scenario sequence in NCSAR. $m$ is the number of scenarios.

$V = \{PV1, PV2, TV1, TV2, SV1, SV2, CV1, CV2, CV3, CV4, EV1, EV2, THV1\}$ is the scenario factor in NCSAR and $L = \{l_1, l_2, \ldots, l_r\}$ is the set of factor levels. According to Table 1, $r = 3$.

According to Table 1, take $l_r(v)$ to denote the set of factor levels of the scenario influencing factor $v$, in which $v \in V$ and $l_r(v) \subseteq L$. Take $\text{card}(l_r(v))$ to denote the number of elements in the set $v$.

According to Table 1, the symbol $v_1l_j$ is used to describe that the factor $v_1$ is at level $l_j$, in which $v_1 \in V$ and $l_j \in l_r(v_1)$. For example, when $v_1 = PV1$, $v_1l_2$ means that the factor temperature is high, that is, at the level $l_2$. When $v_7 = CV1$, $v_7l_2$ means that the factor sea temperature is from 4°C to 10°C, which is at the level $l_2$.

Denote $P = \cup\{v_1l_j\}$, in which $\forall v_1 \in V$, $\forall l_j \in l_r(v_1)$ is the property set of NCSAR, then $\text{card}(P) = \sum_{i=1}^{n} \text{card}(l_r(v_1))$.

The relationship between the NCSAR scenario set $S$ and the scenario property $P$ is described by the mapping matrix $K = (S, P, R)$, $R \subseteq S \times P$ is the binary relationship between $S$ and $P$, $(s, p) \in R$ ($s \in S, p \in P$) represents that the scenario $s$ influences properties.

For the subset of scenario $A \subseteq S$, define the export operator $\varphi(A)$: $\varphi(A) = \{p \in P \mid \exists s \in A, (s, p) \in P\}$, denoted by $A'$. Correspondingly, for the subset of scenario properties $B \subseteq P$, define the export operator $\psi(B)$, $\psi(B) = \{s \in S \mid \exists p \in B, (s, p) \in R\}$, denoted by $B'$.

The concept of a scenario in the scenario sequence of NCSAR is defined as a two-tuple $(A, B)$ in the mapping matrix $K = (S, P, R)$, $A \subseteq S$, $B \subseteq P$. If $A' = B'$, $B' = A$, then $A$ is called the extension of the scenario concept $(A, B)$ and $B$ is called the intension of the scenario concept $(A, B)$. Let $(A, B)$ and $(C, D)$ be random scenario concepts in $K = (S, P, R)$, if and only if $B \subseteq D$ (equivalently, $C \subseteq A$), denoted as $(C, D) \preceq (A, B)$, that is, $(C, D) \subseteq (A, B)$. Then, $(A, B)$ is defined as the hyper-concept of $(C, D)$ and $(C, D)$ is defined as the sub-concept of $(A, B)$. Based on the relation, an ordered set $H(K) = (K, \preceq)$ is defined as the scenario sequence lattice in NCSAR.

The NCSAR situation keeps changing with time, and the scenarios also keep increasing, so it is necessary to continuously reconstruct the scenario sequence lattice of NCSAR.

$K = (S, P, R)$ is a formal context. Denote $E = \{(p_i, s_i) \mid (s, p) \notin R, s \in S, s_i \subseteq S, p_i \in P\}$. Define $F_E = \{(p_i, s_i) \mid (p_i, s_i) \in E\}$. Denote $s_m = \{s_{i_1}, s_{i_2}, \ldots, s_{i_m}\}$. Define $F_E = \{(S \setminus s_m, p_n) \mid (s_m, p_n) \in F_E\}$.

**Theorem 1** $F_E$ is the concept set of the formal context $K = (S, P, R)$.

**Proof** If $(s_m, p_n) \in F_E$, for $\forall s \in S \setminus s_m, \forall p \in P_n$, then $(s, p) \notin R$. Otherwise $\forall p \in P_n, (s, p) \in R$. And $(s_m, p_n) \in F_E$, then $(S \setminus s_m, p_n) \in F_E, \exists p \in P_n, s \in S \setminus s_m$ subject to $(s, p) \in E$, which is contradictory to $(s, p) \in R$, and thus $P_n' = s_n$. Similarly, $s_m' = P_n$, so $(s_m, p_n)$ is the concept of the formal context $K = (S, P, R)$.

For each $s_i \in S$, construct $\tilde{s}_i = \{s_m \mid s \in S_m \text{ and } (s_m, p_n) \in F_E\}$, which is the set containing all concepts of the object $s$.

**Theorem 2** For any concept $(s_m, p_n) \in F_E$, the hyper-concept of concept $(s_m, p_n)$ is $\bigcap_{i_1 \leq i \leq i_m} \tilde{s}_i$.

**Proof** Suppose that $(s_{m'}, p_{n'})$ is concept $(s_m, p_n)$’s hyper-concept, then $s_{m'} \supseteq s_m$. Thus for $\forall i_1 \leq i \leq i_m$, $s_{m'} \supseteq s_i$, that is, $s_{m'} \subseteq \tilde{s}_i$. Also, due to the randomness of $i$, $s_{m'} \subseteq \bigcap_{i_1 \leq i \leq i_m} \tilde{s}_i$. On the contrary, assume that $s_{m'} \subseteq \bigcap_{i_1 \leq i \leq i_m} \tilde{s}_i$, then for $\forall i_1 \leq i \leq i_m$, $s_{m'} \subseteq \tilde{s}_i$, and hence $s_{m'} \supseteq s_i$, that is, $s_{m'} \supseteq s_m$, and $(s_{m'}, p_{n'})$ is concept $(s_m, p_n)$’s hyper-concept. When the formal context changes, the increment maintenance algorithm of the concept lattice under the circumstance of properties and objects increasing is considered in this paper.

Suppose that $K = (S, P, R)$ is a formal context and $F_E$ represents the existing concept set. Define $s_{m'} = \{s_{i_1}, s_{i_2}, \ldots, s_{i_m}\}$, $p_{n'} = \{p_{j_1}, p_{j_2}, \ldots, p_{j_m}\}$, then...
The similarity of the NCSAR scenarios depends on the similarity between the factors in the scenario sequence lattice for adding the property $(S_m, P_m) \in F'_E$, representing that $(S_m, P_m)$ is a concept in the formal context $K$. Define $F_E = \{(S \setminus S_m, P_m) | (S_m, P_m) \in F'_E\}$.

Suppose that property $p_i$ is added to the formal context $K = (S, P, R)$, that is, $P' = P \cup p_i$, denoted as $\overrightarrow{p_i} = \{s \in S \mid (s, p_i) \notin R\}$.

**Algorithm 1** Increment construction of the scenario sequence lattice for adding the scenario

BEGIN
According to $F'_E$, find $F_E = \{(S \setminus S_m, P_m) | (S_m, P_m) \in F'_E\}$

FOR EACH $(S_m, P_m) \in F_E$ DO

IF there exists concept $(S_m', P_m') \in F_E$, subject to

$\overrightarrow{p_i} \cup S_m = S_m'$, THEN

$P_m' = P_m' \cup p_i$;

ELSE

$F'_E = F'_E \cup (S/(S_m \cup \overrightarrow{p_i}), P_m \cup p_i)$;

END IF

IF there exists $(S_m, P_m) \in F'_E$, $(S_m', P_m') \in F'_E$, subject to $S_m = S_m'$, THEN

$F'_E = F'_E \setminus ((S_m, P_m) \cup (S_m', P_m')) \cup (S_m, P_m \cup P_m')$;

END IF

END

In the initial formal context, each property $p_j \in P$, and define $\overrightarrow{p_j} = \{s \in S \mid (s, p_j) \notin R\}$. Suppose that object $s_i$ is added, $S' = S \cup s_i$. In the new formal context, define $\overrightarrow{p_j} = \{s \in S' \mid (s, p_j) \notin R\}$.

**Algorithm 2** Increment construction of the scenario sequence lattice for adding the property

BEGIN

FOR EACH $p_j \in P$ DO

IF $\overrightarrow{p_j} \neq \overrightarrow{p_j}$, THEN

FOR EACH $(S_m, P_m) \in F_E$ DO

IF $\overrightarrow{p_j} \subseteq S_m$, THEN

$S_m = S_m \cup \overrightarrow{p_j}$

ELSE

$F'_E = F'_E \cup (S/(S_m \cup \overrightarrow{p_j}), P_m \cup p_j)$

END IF

END IF

IF there exists $(S_m, P_m) \in F'_E$, $(S_m', P_m') \in F'_E$, subject to $S_m = S_m'$, THEN

$F'_E = F'_E \setminus ((S_m, P_m) \cup (S_m', P_m')) \cup (S_m, P_m \cup P_m')$;

END IF

END

END

END

6. NCSAR scenarios similarity measurement

The similarity of the NCSAR scenarios depends on the similarity between the view products from every perspective, that is, the similarity between the levels of the view products’ scenario factors. The purpose of the NCSAR scenario analysis is to provide a basis for the formulation and implementation of the NCSAR plan. Therefore, the similarity between the products of the NCSAR scenario view should be analyzed from the perspective of the degree of influence of the SAR plan, and cannot be simplified as the complete agreement between the levels of the view product scenario factors. For example, for the wave height CV2, the SAR plan that can adapt to the factor level $l_3$ must also be able to adapt to the factor levels $l_2$ and $l_1$. However, the opposite is not true.

Therefore, we should firstly define the similarity measurement method between the view products of the NCSAR scenario.

The formulation of the NCSAR plan depends on the SAR scenario. The effectiveness of the plan depends on whether it can adapt to various factors in the scenario. The SAR plan made for a certain scenario may not be effective in another scenario. For example, the plan formulated for the situation where the wave height is low will be less effective when the wave height becomes medium. However, the plan formulated for the situation where the wave height is medium will be still effective when the wave height becomes low. That is because the difficulty faced by the plan becomes higher when the wave height changes from low to medium and the difficulty becomes smaller when the wave height changes from medium to low.

The effectiveness of the plan for different scenarios depends on the similarity between the factors in the scenarios.

For $K = (S, P, R), \forall v_k \in V, \forall v_h \in V$, the similarity between $v_k l_i$ and $v_h l_j$ is defined as

$$\text{Simila}(v_k l_i, v_h l_j) = \begin{cases} 1, & i \geq j; k = h \\ 1 - \frac{i - j}{\text{card}(lr(v_k))}, & i < j; k = h \\ 0, & k \neq h \end{cases} \quad (1)$$

That is the similarity between the factor $v_k$ at level $l_i$ and the factor $v_h$ at level $l_j$.

It is obvious that $\text{Simila}(v_k l_i, v_h l_j) \in [0, 1]$.

In the time-varying maritime SAR scenario sequence $S$, for any given time period $[t^i, t^j] (1 \leq i \leq m, 1 \leq j \leq m, i \leq j)$, the scenario set $X = \{s_i, \ldots, s_j\}$ during $[t^i, t^j]$ is able to correspond to an extension of the scenario concept in the maritime scenario concept lattice. For any given time period $[t^i, t^j] (1 \leq i \leq m, 1 \leq j \leq m, i \leq j)$, and $[t^k, t^l] (1 \leq k \leq m, 1 \leq l \leq m, k \leq l)$, in the maritime
SAR scenario sequence $S$, the similarity between the scenario set $X = \{s_i, \ldots, s_j\}$ during $[t^i, t^j]$ and the scenario set $Y = \{s_k, \ldots, s_l\}$ during $[t^k, t^l]$ is defined as

$$\text{SIMILA}(X, Y) = w \cdot \text{Simila}(X, Y) + (1-w) \cdot \text{Simila}(X', Y')$$

(2)

in which $w$ denotes the influence weight of the SAR scenario to the similarity of scenario sequence, $w \in [0, 1]$.\nsimila\(\text{Simila}(X, Y)\) represents the similarity between scenario sets $X$ and $Y$. The more same scenarios are in both sets, the more similar the two sets will be. Thus, the similarity between scenario sets $X$ and $Y$ is defined as

$$\text{Simila}(X, Y) = \frac{|X \cap Y|}{\max(|X|, |Y|)}.$$  

(3)

Simila\(\text{Simila}(X, Y)\) $\in [0, 1]$.\nsimila\(\text{Simila}(X', Y')\) represents the similarity between influencing factors belonging to scenario sets $X$ and $Y$, which is defined as

$$\text{Simila}(X', Y') = \frac{\sum_{x \in X'} \sum_{y \in Y'} \text{Simila}(x, y)}{\max(|X'|, |Y'|)}.$$  

(4)

Simila\(\text{Simila}(X', Y')\) $\in [0, 1]$.\nThe formulation of the NCSAR plan depends on the SAR scenario. $\text{Ad}_{ij-kl}$ denotes the adaptiveness of the plan $R_{p_{ij}}$ formulated aiming at the $[t^i, t^j]$ scenario during $[t^i, t^j]$ towards the SAR scenario in $[t^k, t^l]$. Let

$$\text{Ad}_{ij-kl} = \text{SIMILA}(X_{ij}, Y_{kl})$$

(5)

in which $X_{ij}$ stands for the NCSAR scenario sequence during $[t^i, t^j]$ and $Y_{kl}$ stands for the NCSAR scenario sequence during $[t^k, t^l]$.\n
It is obvious that $\text{Ad}_{ij-kl} \in [0, 1]$.

Let $\theta$ denote the adaptiveness threshold value of the NCSAR plan to the SAR scenario, $\theta \in [0, 1]$. $\text{Ad}_{ij-kl} < \theta$ means that the SAR plan $R_{p_{ij}}$ aiming at the scenario during $[t^i, t^j]$ no longer adapts to the SAR scenario during $[t^k, t^l]$.

### 7. Case analysis

The two sides are engaged in a certain sea area. During the battle, a pilot is missing at sea and needs to conduct a maritime SAR. The duration of the SAR is 24 h. The SAR situation is updated every 4 h. According to the change of the SAR situation, the SAR plan will be adjusted. The time when the emergency occurs is $t^0$. The scenario of the NCSAR at this time is $s_1$. The formed scenario sequence of the NCSAR is shown in Table 2.

$$C = \{c_1, c_2, c_3, c_4, c_5, c_6\}, V = \{v_1, v_2, \ldots, v_{12}\},$$

and $L = \{l_1, l_2, l_3\}$, $l r(v_1) = l r(v_2) = l r(v_7) = l r(v_8) = l r(v_9) = l r(v_{10}) = \{l_1, l_2, l_3\}$ means that the factors $v_1, v_2, v_7, v_8, v_9, v_{10}$ can be at the levels $l_1, l_2$ and $l_3$ according to the change of the SAR situation. $l r(v_3) = l r(v_5) = l r(v_7) = \{l_2\}$ means that the factors $v_3, v_5, v_{11}$ can be at the level $l_2$. $l r(v_{12}) = l r(v_6) = l r(v_2) = l r(v_{13}) = \{l_1, l_2\}$ means that the factors $v_4, v_6, v_{12}, v_{13}$ can be at the levels $l_1$ and $l_2$.

| Scenario | $s_1$ | $s_2$ | $s_3$ | $s_4$ | $s_5$ | $s_6$ |
|----------|-------|-------|-------|-------|-------|-------|
| PV1-v1   | $l_1$ | $l_1$ | $l_2$ | $l_2$ | $l_5$ | $l_3$ |
| PV2-v2   | $l_1$ | $l_1$ | $l_2$ | $l_2$ | $l_3$ | $l_3$ |
| TV1-v3   | $l_2$ | $l_2$ | $l_2$ | $l_2$ | $l_2$ | $l_2$ |
| TV2-v4   | $l_1$ | $l_1$ | $l_1$ | $l_2$ | $l_2$ | $l_2$ |
| SV1-v5   | $l_2$ | $l_2$ | $l_2$ | $l_2$ | $l_2$ | $l_2$ |
| SV2-v6   | $l_2$ | $l_2$ | $l_2$ | $l_1$ | $l_1$ | $l_1$ |
| CV1-v7   | $l_1$ | $l_1$ | $l_2$ | $l_2$ | $l_3$ | $l_2$ |
| CV2-v8   | $l_1$ | $l_1$ | $l_2$ | $l_2$ | $l_3$ | $l_3$ |
| CV3-v9   | $l_2$ | $l_2$ | $l_2$ | $l_3$ | $l_3$ | $l_3$ |
| CV4-v10  | $l_1$ | $l_2$ | $l_2$ | $l_3$ | $l_3$ | $l_3$ |
| EV1-v11  | $l_2$ | $l_2$ | $l_2$ | $l_2$ | $l_2$ | $l_3$ |
| EV2-v12  | $l_1$ | $l_1$ | $l_2$ | $l_2$ | $l_2$ | $l_2$ |
| THV1-v13 | $l_2$ | $l_2$ | $l_2$ | $l_1$ | $l_1$ | $l_1$ |

| Factor   | Value |
|----------|-------|
| $P = \{v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{10}, v_{11}, v_{12}, v_{13}\}$ |

Taking 4 h as the time interval, the similarity between scenarios in each time interval is shown in Table 3. Let $w = 0.1$.

### 8. Conclusion

The two sides are engaged in a certain sea area. During the battle, a pilot is missing at sea and needs to conduct a maritime SAR. The duration of the SAR is 24 h. The SAR situation is updated every 4 h. According to the change of the SAR situation, the SAR plan will be adjusted. The time when the emergency occurs is $t^0$. The scenario of the NCSAR at this time is $s_1$. The formed scenario sequence of the NCSAR is shown in Table 2.

Table 2: SAR scenario sequence

| Parameter | Value |
|-----------|-------|
| Time      | $t^0$, $t^1$, $t^2$, $t^3$, $t^4$, $t^5$, $t^6$, $t^7$, $t^8$, $t^9$, $t^{10}$, $t^{11}$, $t^{12}$, $t^{13}$, $t^{14}$, $t^{15}$ |
| Scenario  | $s_1$, $s_2$, $s_3$, $s_4$, $s_5$, $s_6$, $s_7$, $s_8$, $s_9$, $s_{10}$, $s_{11}$, $s_{12}$, $s_{13}$, $s_{14}$, $s_{15}$ |
| Factor    | Value |
|-----------|-------|

Taking 4 h as the time interval, the change trend of similarity between scenario sequences in every time interval and that in later time intervals is shown in Fig. 4.

In the NCSAR process, the SAR plan is based on the SAR scenario, which means that the effectiveness of the SAR plan depends on the scenario. It can be seen from Fig. 5 that as time progresses, the adaptiveness of the SAR plan decreases.
plan specified in the time interval $[t^0, t^1]$ falls within the time period $[t^1, t^2]$ to 0.83. The adaptiveness in the time period $[t^2, t^3]$ drops to 0.73, and the adaptiveness in the time period $[t^4, t^5]$ decreases to 0.55. The adaptiveness in the time period $[t^5, t^6]$ increases slightly compared to the previous time period, reaching 0.57. That is to say, the SAR plan specified for the SAR scene in the time period $[t^0, t^1]$ will gradually reduce its adaptiveness to the subsequent SAR scenarios, that is, the targeting and effectiveness of the SAR plan is gradually reduced. Therefore, the SAR plan needs adjustments.

The adaptiveness of the SAR plan specified during the time interval $[t^1, t^2]$ falls to 0.8 to the scenario in $[t^2, t^3]$ and gradually decreases to 0.58 in $[t^5, t^6]$ by time. The SAR plan developed in the remaining time period has a similar trend in the targeting and effectiveness of the SAR scenarios in the subsequent time.

The adaptiveness of the SAR plan developed in different time periods to the SAR scenarios in other time periods is shown in Fig. 5. It is shown in Fig. 5 that when $\theta = 0.8$, the SAR plan formulated in $[t^0, t^1]$ still fits in $[t^1, t^2]$ without adjustment. However, it will not be adaptive for $[t^2, t^6]$, and adjustment is needed. The SAR plan formulated in $[t^1, t^2]$ is still adaptable for the $[t^2, t^3]$ scenario but it should be adjusted for $[t^3, t^6]$ scenarios. When $\theta = 0.7$, the adaptive period for the plan formed in $[t^0, t^1]$ is $[t^0, t^3]$. Moreover, the adaptive period for the $[t^1, t^2]$ plan is $[t^1, t^3]$. When $\theta = 0.5$, none of the plans formulated in each time interval needs adjusting.

Taking 8 h as the time interval, the similarity between scenarios in each time interval is shown in Table 4. Let $w = 0.1$.

| Time interval | $[t^0, t^2]$ | $[t^2, t^4]$ | $[t^4, t^6]$ |
|---------------|-------------|-------------|-------------|
| $[t^0, t^2]$  | 1           | 0.5         | 0.5         |
| $[t^2, t^4]$  | 0.63        | 1           | 0.55        |
| $[t^4, t^6]$  | 0.6         | 0.68        | 1           |

Taking 8 h as the time interval, the change trend of similarity between scenario sequences in every time interval and that in later time intervals is shown in Fig. 6.
remains 0.5 in \([t^4, t^6]\), which means that the plan formulated based on the scenario in \([t^0, t^2]\) becomes less adaptive when facing the subsequent scenarios with time. If we set the time interval at 8 h, the effectiveness of the SAR plan would decrease heavily which is bad for keeping up with the scenario change. To improve this situation, the SAR plan should be adjusted or the time interval for plan adjusting should be shortened.

The SAR plan formulated in \([t^2, t^4]\) shows a declined adaptiveness in \([t^4, t^6]\) at 0.55. Other plans’ effectiveness and pertinence in subsequent time intervals also show the similar trend.

The adaptiveness of the SAR plan formulated in different time intervals to SAR scenarios in other time intervals is displayed by Fig. 7.

![Fig. 7 Adaptiveness of SAR plan to SAR scenarios in different time intervals (8 h interval)](image)

8. Conclusions

Maritime combat is an important part of modern warfare. The NCSAR is of great significance for improving the combat capability of naval battlefields. The formulation and implementation of the NCSAR plan is highly dependent on the NCSAR scenarios. The analysis and similarity measurement of the NCSAR scenarios are conducive to the rapid development of the NCSAR plan and the improvement of the targeting and effectiveness of the NCSAR plan. The focus of this paper is on the characteristics of the NCSAR. Based on the multi-view theory method and the mission process of the NCSAR, the NCSAR scenarios and their influencing factors are analyzed from different perspectives. Aiming at the regularity of the NCSAR situation with time, the NCSAR scenario sequence is constructed. Based on this, the NCSAR scenario similarity measurement model is proposed, which provides theoretical support for the construction and similarity analysis of the NCSAR scenario. However, the elements of the NCSAR scenarios summarized in this paper are not comprehensive enough, and the analysis of the influencing factors is not detailed enough. For example, the drift phenomenon of SAR objects is not considered, which needs further improvement in the next research.

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Biographies

ZHAO Qingsong was born in 1975. He is a Ph.D. and a professor in National University of Defense Technology. His research interests are system integration, defense acquisition and system of systems architecture design and optimization, and complex system analysis.
E-mail: zhaojingsong@nudt.edu.cn

DING Junyi was born in 1995. She received her M.S. degree from National University of Defense Technology. Her research interests include system of systems modeling and evaluation, network modeling, and temporal constraint resolving.
E-mail: Lexi.ding9512@gmail.com

GUO Yu was born in 1993. She is a Ph.D. candidate in National University of Defense Technology. Her research interests are system of systems modeling and optimization, decision making and emergency management.
E-mail: guoyunudt@163.com

LIU Peng was born in 1981. He is currently a Ph.D. candidate in the College of Systems Engineering, National University of Defense Technology. His research interests include system of systems engineering, complex systems, and systems evaluation and optimization.
E-mail: liupeng81@nudt.edu.cn
YANG Kewei was born in 1977. He is a Ph.D. and a professor in National University of Defense Technology. His research interests are system of systems (SoS) requirements modeling, SoS architecture design and optimization, and system modeling and simulation.
E-mail: kayyang27@nudt.edu.cn