Optimization Method of Surface Ship to Air Combat Deployment Based On Time Window

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Abstract. In order to shorten the response time of surface ships to air combat, improve the efficiency of surface ships' combat command, and optimize the air combat deployment, a time window index was introduced to model and analyze the time performance of surface ships to air combat deployment. This model used the optimization techniques of fuzzy mathematics and dynamic programming to find the critical path of air combat deployment design. Considering the time urgency of the incoming target, the operational efficiency of the two air combat deployment design modes is compared and verified by taking the priority fire resistance and our minimum resources as the objective function. The simulation results show that the air-to-air combat deployment optimization technology based on time window can effectively simplify the air-to-air combat process and improve the command efficiency.

Keywords: Time Window, Air Combat, Dynamic Programming, Critical Path, Deployment Optimization

1. Introduction

Ship deployment is the arrangement of the position and responsibilities of the ship's personnel on the ship. Reasonable ship deployment can effectively improve command efficiency and overall combat effectiveness of ships. The deployment of surface vessel to air combat relies on the surface vessel to air combat resources and makes overall arrangements for the combat positions of the personnel to which the vessel belongs, so as to maximize the combat effectiveness of the combat resources. Surface vessel air combat includes early warning reconnaissance, air defense combat resource selection, soft and hard weapon system fire parameters calculation, interception feasibility judgment, weapon launch and damage assessment, etc. It is a combination of a series of operational stages. The optimization and analysis of the operational process can not only shorten the response time of surface ships to air combat and improve the combat effectiveness of the system, but also integrate the system of air combat resources, reasonably plan the force firepower and improve the capability of continuous combat [1].

The design and development of the Chinese navy's surface vessel combat procedures follow the provisions of the surface vessel deployment design, and show different combat functions and characteristics according to the operational characteristics and command mode of each vessel [2].
2. Design of Surface Ship Deployment

Vessel deployment is the basis for a vessel to perform its mission and task, the basis for its daily management, combat readiness training and combat operations, the basic rules and regulations for the daily service and combat operations of a vessel, the basic basis for the rational organization and performance of personnel and equipment, and the normative and guiding role for vessel combat readiness training and combat operations. The rapid development of information technology in the new stage of the new century is constantly changing the face of war. The form of war is changing from mechanized war to informationized war [3]. Under the condition of informationization, the combat time is compressed, space is expanded and dimensions are increased, and the design and optimization of combat organization of warship become the basic problem to improve the operational efficiency of warship. For many years, the ships deployed as vessels task-oriented organization form, the implementation of the operation, daily combat readiness and training play an important role, but with constant expansion of naval mission, mission of diversification, existing ships deployed cannot meet the needs of direction more threat, diverse tasks, should be carried out in accordance with the modern naval battle style to design and optimization, realize the coordinated, post personnel in liability of operations as a whole [4].

Mission for naval vessels, combat task list, a variety of deployment status, and the timing requirements, grasp the combat patrol, the combat ships deployed in the daily management of the training and practice, through the inheritance, development and optimization of ships deployed, strive to establish new ships deployed category, name, connotation and personnel and equipment such as the content, the level of organic integration, synergy and were divided, operational use and commanding password, daily management and responsibility confirmation of denotation, keep both ships deployed the continuity and stability of the specific content and forward-looking, and can realize one has duty, have charge, utmost to mobilize and use of all vessels and living resources. To meet the needs of warship combat operations, to facilitate management and training in peacetime, and to facilitate operations and command in wartime. It is of solid practical and profound historical significance for the naval forces to complete their missions in the new era [5].

3. Analysis Method of Surface Ship to Air Combat Flow Based On Time Window

The purpose of scheduling policy is to solve the conflict resolution problem in resource occupation. Therefore, when using priority to represent the advantages and disadvantages of scheduling strategy, each priority should be given weight first. When resource occupancy conflict occurs, first compare the priority of conflict transition, first execute the transition with higher priority, and then wait for the transition with lower priority. The advantage of this approach is that it simplifies the computation and is easy to implement.

Intercepting incoming targets in surface - to - air defense is a multi - stage dynamic process. Therefore, it is difficult to simply solve scheduling policy with priority weighting. However, according to the air defense process of surface ships, each phase corresponds to a time window, which is dynamic [6]. In a certain stage of air defense operations, if the fire unit does not intercept the target effectively in the time window, it will be carried out in the next time window.

The initial moment of formation air defense operations is \( \Lambda_1 \), and the initial moment of phase \( s \) is \( \Lambda_s \). If the following conditions are met:

\[
\begin{align*}
\Lambda_s & \leq \xi(T_{k,l}) \leq \Lambda_{s+1}^i, \\
\Lambda_{s-1} & \leq \bar{\xi}(T_{k,l}) \leq \Lambda_s.
\end{align*}
\]

Then target \( T_{k,l} \) must be intercepted in phase \( [s,s'] \). Each firepower unit corresponds to a time window during the fire distribution. If there is no reasonable battle flow planning, it is easy to lead to the overlapping of battle time Windows and the conflict of interception resources. Therefore, the
time-pressure of target judgment is introduced to weight the dynamic window and perform attribute transformation [7]. For incoming target $T_{k,j}$ in the combat phase $s''$, its time pressure $TP_s(T_{k,j})$ is:

$$TP_s(T_{k,j})=\frac{\bar{z}(T_{k,j})-\Lambda_j}{\Delta(\Lambda)}$$ (2)

In the intercepting airspace of the incoming target, the time urgency increases with the advance of the combat time. When the target enters the final combat phase of the formation, the time urgency is greater than 1, belonging to the target in urgent need of interception. In other combat phases, the target's time pressure is less than 1. If the time crunch is less than 0, the target has been penetrated.

The objective function of the combat effectiveness of surface ships is:

$$f(\phi) = \frac{w_1}{\min(T(\phi))} + \frac{w_2}{\min(C(\phi))} + w_3 \max(Q(\phi))$$ (3)

$$F(\phi) = \frac{f(\phi)}{\max f(\phi)}$$ (4)

Fig.1 Target characteristic diagram time window

Combined with the scheduling policy, the specific algorithm implementation process is as follows:
Step1: determine the intercept probability of $p_0$ is large enough. Let $p = p_0$, if any priority vector $s_1$, determine the number of iterations for each $p$ to determine the chain length of Metropolis.
Step2: repeat step3-step6 for the current interception probability $p$ and $k = 1, 2, ..., L$.
Step3: generate a $s_1$ new priority vector $s_2$ for the random perturbation of the current priority vector $s_2$.
Step4: substitute $s_2$ into the time Petri net model to calculate the increment of $s_2$, where $f(S_1)$ is the cost function of $s_1$.
Step5: Stop and output the priority vector $s_1$ when the termination condition is satisfied. In this case, $s_1$ is the optimal solution. Input the optimal solution into the time Petri net model to obtain the optimization process and end. The termination conditions are as follows: terminate the algorithm when a new priority vector $A$ in the successive Metropolis chain is not accepted, or reach the set intercept probability, otherwise return Step2 after attenuating $p$ according to the attenuation function.

4. Optimization and Evaluation of Surface Vessel Air Combat Flow
In formation to air defense operations, our formation consists of three destroyers and two air defense
frigates, forming an air defense formation, with the surface ship as the command ship. Space-based early warning detection satellites, early warning aircraft, early warning helicopters and various intelligence information can share information with each other through the information system. There are data links between each combat platform in the formation, and the degree of network connection between each weapon platform can support the implementation of collaborative combat missions [8-11]. The time of attack, the direction of attack, the type of target and the degree of threat to the formation are shown in table 1.

| Target batch number | The degree of threat | Assault direction | Time window     |
|---------------------|----------------------|-------------------|-----------------|
| 1                   | 0.77                 | 2                 | [0s, 45s]       |
| 2                   | 0.82                 | 1                 | [5s, 25s]       |
| 3                   | 0.87                 | 1                 | [7s, 45s]       |
| 4                   | 0.76                 | 1                 | [13.5s, 55s]    |
| 5                   | 0.92                 | 2                 | [14s, 30s]      |
| 6                   | 0.74                 | 2                 | [15s, 75s]      |
| 7                   | 0.91                 | 1                 | [17s, 35s]      |
| 8                   | 0.84                 | 2                 | [17s, 55s]      |
| 9                   | 0.81                 | 3                 | [22s, 65s]      |
| 10                  | 0.72                 | 1                 | [23s, 85s]      |
| 11                  | 0.82                 | 2                 | [24s, 75s]      |
| 12                  | 0.83                 | 2                 | [27s, 75s]      |
| 13                  | 0.87                 | 2                 | [28s, 80s]      |
| 14                  | 0.84                 | 2                 | [31s, 80s]      |
| 15                  | 0.85                 | 1                 | [34s, 65s]      |
| 16                  | 0.83                 | 3                 | [77s, 110s]     |
| 17                  | 0.87                 | 3                 | [89s, 115s]     |
| 18                  | 0.85                 | 2                 | [92s, 120s]     |

According to the analysis of the above two operational processes of surface vessel air defense, petri net was introduced to represent the operational process, and its library and changes are shown in table 2.

| Library meaning               | Change | Change meaning                  |
|-------------------------------|--------|---------------------------------|
| Early warning of forces       |        | Providing objective information |
| Fleet command post            |        | Receiving the target information|
| The local unit                |        | Processing target information  |
| The shipboard radar           |        | Finding the target information  |
| The sensor                    |        | Combat unit allocation          |
| Order system                  |        | Firepower unit allocation       |
| The remote ship to air missile|        | Intercepting the target         |
| Electronic countermeasures system |     | Implementing electronic jamming |
| Close range ship to air missile|       | Damage assessment               |
| Abm naval gun                 |        | Redistributing the objective    |
| Cooperative combat unit       |        | Firepower compatibility analysis|
| $P_{12}$ | The shipboard radar | $T_{12}$ | Electromagnetic compatibility analysis |
| $P_{13}$ | The sensor | $T_{13}$ | Evasive maneuvers |
| $P_{14}$ | Order system | $T_{14}$ | The remote target designation |
| $P_{15}$ | The remote ship to air missile | $T_{15}$ | Active radar guidance |
| $P_{16}$ | Electronic countermeasures system | $T_{16}$ | The semi-active radar guidance |
| $P_{17}$ | Close range ship to air missile | $T_{17}$ | Command guidance |
| $P_{18}$ | Abm naval gun | $T_{18}$ | The infrared guidance |

**Fig 2.** The optimized surface ships air defense petri net model

It can be seen that this mode has the superiority of air defense operations, and the feasibility of this mode needs to be further studied. In the combat process of air defense, T2 of reconnaissance and early warning, T3 of information processing and distribution, T4 of command and control system formation, T7 of ship-to-air missile weapon system movement, and T9 of observation effect affect the combat effectiveness of the whole defense process. It can be concluded from the simulation results that the two links of reconnaissance, warning and observation are time-consuming, and the overall process efficiency can be effectively improved if the performance is improved. In the process of air defense, T1→T2→T3→T5→T6→T17→T18 is the critical path of the whole process. In the optimization, parallel business processing can be carried out to shorten the time of key links, thus improving the overall process efficiency [12, 13].

5. Conclusion

In order to enhance the comprehensive integration effect of surface ships, optimize combat resources and improve the scientific design of surface ships system, it is necessary to optimize the deployment of surface ships from the perspective of operational requirements so as to develop traction equipment. The approach target time window evaluation technology optimizes the air combat flow of surface ships theoretically and can be applied in the specific air combat deployment design. However, it should be pointed out that the advantages and disadvantages of the deployment design of surface ships to air combat depend more on the scientific nature of the command mode, so the influence of the
optimization of command mode on the deployment design should be taken into account in the subsequent research.

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