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C^{3}I cooperative decision system simulation and optimization based on genetic algorithm for surface warship formation

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Abstract. The C^{3}I cooperative decision system is the guarantee for combat capabilities of surface warship formations. At present, research on the C^{3}I system simulation lays more emphasis on finding structural logic defects by executing the simulation model, lacking the application of intelligent optimization algorithms to optimize parameters in the system. In this paper, the cooperative decision-making process of surface warship formation defense system is studied. Meanwhile, modelling and optimization methods for cooperative decision system are proposed. Based on simulation models built on the ExtendSim platform, this paper optimizes the staffing strategy of decision makers based on the genetic algorithm, to improve the per capita decision efficiency. The optimized staffing strategy meets objectives and requirements. The research in this paper can provide a scientific and objective reference for relevant decision-makers and researchers.

1 Introduction

With the continuous progress of the performance of equipment such as remote cruise missiles and stealth aircrafts, surface warship formation is facing various types of threats.[1] A significant factor to ensure the coordinated operation of equipment on surface warship formation is the efficiency of ship-borne C^{3}I systems. The C^{3}I system is a military electronic comprehensive information system, connecting various subsystems such as command, control, communication and intelligence. Although the C^{3}I system has no direct lethality, it can coordinate killing weapons to achieve maximum combat effectiveness. [2]

To model the C^{3}I system, both static characteristics and dynamic behaviors should be considered. Numerous scholars used Petri net to simulate and analyze the C^{3}I system. *Li Dajian*[3] set up a Petri net model of air defense C^{3}I decision system for the camp and brigade decision organization. *Chen Xingyou*[4] established an air defense C^{3}I system model based on hierarchical fuzzy colored Petri net. *Zuo Xiaofeng*[5] built a colored Petri net simulation model for the warship formation combat C^{3}I system, and the system decision delay was analyzed. *Zhao Yanquan*[6] applied the object colored Petri net to analyze the relationship of the composition of ship-borne C^{3}I system. Researchers mostly focus on

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finding logic defects in the C^{3}I system by executing simulation models, or manual optimizations by modifying the system structure. Current research lacks using heuristic algorithm to search optimal solutions of parameters in C^{3}I system, which ignores the optimization ability of simulation models.

In this paper, the *ExtendSim* software is used to simulate and analyze the decision-making process of C^{3}I cooperative decision system of surface warship formation. The genetic algorithm is applied to optimizes the parameters, which improves the efficiency of decision-making.

2 Study on C^{3}I cooperative decision system of surface warship formation

In order to disperse the combat decision pressure, the cooperative decision system is adopted by surface warship formations.

2.1 Classification rules for threat targets

When the scouting system detects threat enemies, it will report parameters including direction, velocity, quantity and distance to C^{3}I system to complete the battle decision.

According to parameters of targets, decision-makers obey rules to cooperate and determine the category and the threat level of targets, which helps the defense system complete interceptions.

Table 1. Category classification rules.

Velocity (km/h) / Quantity	≤400	400~800	>800
<8	F	S	B
8~12	B	B	F
>12	B	B	B

Table 2. Threat level classification rules.

Distance (km) / Category	>120	15~120	<15
S	Small	Small	Small
F	Small	Median	Great
B	Median	Great	Great

Note: S means less lethality; F means moderate lethality; B means great lethality.

2.2 The flow of warship formation cooperative combat decision making

Faced with "Saturated Attacks", an effective tactic, warship formations will be threatened by high-density attacks of different types from all directions.[7] In this case, the cooperative combat decision making system is used to relieve the pressure of defense system. The combat area is divided into 12 equal sector areas (r1~r12), meanwhile, 2 primary decision makers (DM1, DM2) and 4 secondary decision makers (DM3, DM4, DM5, DM6) are appointed to be responsible for 12 areas.[8]

R1~r6 are under the jurisdiction of the primary decision maker DM1, in which r1~r3 are assigned to the subordinate secondary decision-maker DM3, and r4~r6 are assigned to the subordinate secondary decision-maker DM4; r7~r12 are under the jurisdiction of the primary decision maker DM2, in which r7~r9 are assigned to the subordinate secondary decision-maker DM5, and r10~r12 are assigned to the subordinate secondary decision-maker DM6.

If the threat is attacking at the jurisdiction boundary (r1, r6, r7, r12) of primary decision makers, DM1 and DM2 will cooperate to complete the decision. For example, if the threat is attacking at r1 (under the jurisdiction of DM1), the decision-making authority will be assigned to DM1, and the proposal authority will be assigned to DM2. DM1 will complete the battle decision by referring to the proposal from DM2, obeying rules as Table 3. This method is also applicable to two secondary decision makers subordinate to a same primary decision maker.

The flow chart of the cooperative combat decision making is as Figure2.

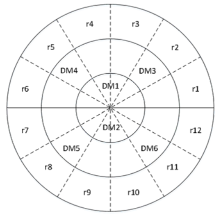

Fig. 1. Division method of certain warship formation combat area.

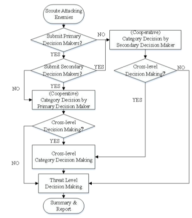

Fig. 2. Flow chart of C^3I cooperative combat decision system for warship formation.

Table 3. Decision Rules for Cooperative Decision Making.

Proposal DM Result / Decision Making DM Result	S	F	B
S	S	F	F
F	S	F	B
B	F	F	B

Primary decision makers and secondary decision makers cooperate by the following rules:

If the target distance is shorter than 15km, the primary decision maker is assigned decision-making authority and the secondary decision maker is assigned no authority. If target distance is between 15km and 120km, the primary and second decision maker are assigned proposal authority and decision-making authority respectively. If the distance is longer than 120km, the secondary decision maker is assigned decision-making authority and the primary decision maker is assigned no authority.

3 Research on modelling and optimization method of C^3I cooperative decision system for surface warship formation

3.1 Modelling method of C^3I cooperative decision system for surface warship formation

This paper mainly focuses on the decision process of the C^3I cooperative decision system of surface warship formation.

Hypothetical conditions are as follows:

- The incoming target stream obeys Poisson distribution, whose direction a, velocity v, quantity q and distance d are independent random variables.
- $NumDM_i$ represents the quantity of staffs equipped by the decision maker DM_i.
- The number of attacking targets in time period t_0 is $NumAttacking(t_0)$.
- The discrepancy of decision makers' ability is not taken into consideration.

- The processing time $t(S_i)$ for decision makers to complete the certain decision S_i obeys normal distribution, namely $t(S_i)\sim N(\mu,\sigma^2)$.
- A decision cycle is defined as the process from detecting the targets to summary and report. The number of decision cycles completed in time t_0 by cooperative decision-making system is recorded as $NumDecision(t_0)$.
- In time t_0, the target decision rate $r(t_0)$ of the decision system is defined as $NumDecision(t_0)/NumAttack(t_0)$. If $r(t_0)$ >90%, the cooperative decision system is considered to have a strong threat processing ability.

The objective function is:

$$\max W_p = \frac{NumDecision(t_0)}{t_0 \times \sum_{i=1}^{6} NumDM_i} \qquad \text{s.t.} \begin{cases} \dfrac{NumDecision(t_0)}{NumAttack(t_0)} \geq r(t_0), t_0 > 0; \\ NumDecision, NumAttack, NumDM_i \in N_+ \end{cases}$$

3.2 Optimization method for staffing strategy of C3I system based on genetic algorithm

Genetic algorithm is an iterative probability optimization algorithm based on the natural selection principle. The application of genetic algorithm in optimizing staffing strategy of C3I cooperative combat decision system is as follows.

3.2.1 Coding method

In order to facilitate the coding, decoding, cross and mutation on the computer, a binary encoding method is adopted. A chromosome contains 6 segments, each consisting of m genes. Genes in 6 segments represent the number of staffs equipped in 6 decision makers respectively, of which values are integers in the closed interval from 0 to 2^m-1.

3.2.2 Fitness function

To ensure the sufficient influence from the number of staffs, the fitness function is defined as W, taking out the constant t_0 from the denominator of the per capita decision-making efficiency W_p. The fitness function is $W = NumDecision(t_0) / \sum_{i=1}^{6} NumDM_i$.

4 Simulation model and optimization analysis of surface warship formation C3I cooperative decision system based on *ExtendSim*

In this paper, *ExtendSim*, a universal simulation platform based on the C language, is used to build a simulation model for the warship formation C3I cooperative decision system, and optimize the parameters in the system. [9]

4.1 Simulation model building with ExtendSim

The simulation model is divided into 4 main functional modules as follows:

4.1.1 Target stream generation module

Target flow is the premise of the simulation operation. This paper assumes that the target flow obeys Poisson distribution, of which the average interval time is 3 minutes. Other attributes are set randomly.

4.1.2 Decision-making authority allocation module

Decision-making authority allocation is fundamental to ensure orderly cooperation among decision makers. C^3I system assigns authorities to different levels of decision makers according to the attributes of the target. The primary-level authority allocation process is introduced as follows.

The routing item divides targets into 12 paths according to directions: targets from r2, r3, r4, r5 are submitted to DM1 alone; targets from r8, r9, r10, r11 are submitted to DM2 alone; targets from r1, r6, r7, r12 are submitted to both DM1 and DM2 to make cooperative decisions.

4.1.3 Target category cooperative decision module

This module is divided into 3 parts: cooperative decision making of primary decision makers, cooperative decision making of secondary decision makers, and cross-level decision making.

The cooperative process of primary decision makers is as follows. The routing item determines decision-making authorities and proposal authorities according to the target direction. For example, the action of DM1 is divided into 3 cases: independent decision making, accepting proposals from DM2, send proposals to DM2.

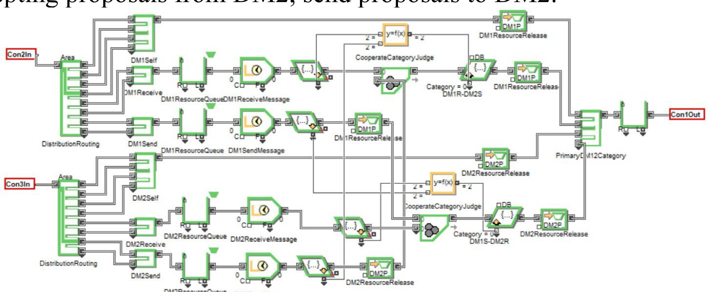

Fig. 3. Cooperative decision of target category module.

4.1.4 Target threat level decision making and summary module

Decision makers determine the threat level with category and distance attributes. A summary of decisions is sent to the defense system of the warship formation, as the end of the simulation.

4.2 Model optimization and analysis

On the basis of the simulation model, this paper attempts to improve the per capita decision-making efficiency and find an optimal solution for the staffing strategy for cooperative decision. The model is optimized by the "Optimizer" item in *ExtendSim*, applying genetic algorithm.

Parameters of resources occupied by each decision are set up. Time consumption of activities follows normal distribution, whose variances are 1 and mean values are as follows.

Table 4. Resource occupied by decision-making activities.

Decision-Making Activities	Time Consumption (Minute)	Human Resource (Person)
1. Authority Allocation for Different Decision Levels	1	/
2. Subdividing Authorities in Each Level	1	/
3. Determine Target Category by Decision Makers Alone	3	2
4. Target Category Decision by Decision Makers in the Same Level (Send Proposals)	2	1
5. Target Category Decision by Decision Makers in the Same Level (Receive Proposals and Make Decisions)	4	2
6. Target Category Decision by Cross-level Decision Makers (Send Proposals)	3	1
7. Target Category Decision by Cross-level Decision Makers (Receive Proposals and Make Decisions)	5	2
8. Determine the Target Threat Level by Decision Makers	3	2
9. Decisions Summary and Report	1	2

The target of optimization is to find an optimal solution for staff strategy to enhance the per capita decision-making efficiency, while ensuring the value of target decision rate.

The optimization-related variables are cloned into the "Optimizer" item to set the objective function in genetic algorithm. The numbers of the staffs are integers in the closed interval from 1 to 15 (on account of the coding method of 4 bit binary), and the simulation time is set to 1440 minutes (24 hours).

The number of running times is set to 1000 times; a single sample runs 5 times at most; the mean of samples is used as the comparison standard; the standard of convergence degree is over 96% (checked after 100 generations). Taking the first round of optimization as an example, the process of optimization costs 19 minutes (140 generations). The optimization curve is shown in Figure 4.

In order to enhance the probability of getting the global optimized solution, the optimization is processed by multiple rounds, of which 10 rounds are shown as Figure 5.

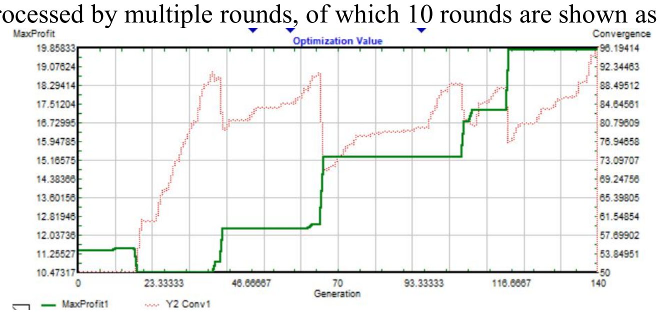

Fig. 4. Process optimization curve. (Note: The green full curve is the objective function, which reaches 19.86. The red imaginary curve is the convergence curve, which reaches 96.2%.)

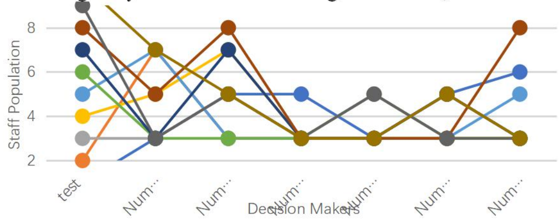

Fig. 5. Results of 10-round optimization.

The result with the maximum objective function value is selected to be the optimized staffing strategy for the C^3I cooperative decision system.

Table 5. Optimized staffing strategy for cooperative decision system.

Decision Maker	DM1	DM2	DM3	DM4	DM5	DM6
Staff Quantity (Person)	3	5	3	5	3	3

The target decision rate of the above staffing strategy is calculated to be 93.9%, which conforms to the minimum constraint of 90%. Consequently, with the optimized staffing strategy, it is believed that the C^3I cooperative decision system has a strong threat processing capability.

5 Future research

Modelling and optimization methods as well as the final result in this paper have scientific and objective reference significance for relevant researchers. Future research can focus on the aspects:

- Priority can be introduced to targets, so that targets of close distance can be treated first.
- The difference of personnel decision-making ability can be considered.
- The parameters of the incoming target flow can be further studied, such as the probability distribution types of frequency, direction, speed, quantity and distance of the target.

References

1. ZHU Chuan-wei, YANG Xing-bao, LU Yong-hong. Research on Anti-Missile System of Warship Formation Network-Centric[J]. Journal of Sichuan Ordnance, 2015(2):12-14
2. YUE Liang, HUANG Zheng, TAN Meng-quan. Methods For Air Defense Operation Mission Reliability Modeling of Warship Formation[J]. Ship Electronic Engineering, 2015(9):123-126
3. LI Da-jian, WANG Feng-shan. Petri Net-based Model Analysis for Air Defense C^3I Decision System[J]. Systems Engineering and Electronics. 2005(27):1600-1602
4. CHEN Xing-you, YUE Xiao-bo, CAO Wei, ZHOU Kai-qing. Modeling and Analysis of Anti-aircraft C^3I System Based on Herarchical Fuzzy Colored Petri Nets[J]. Computer Engineering & Science.2016(38):102-107
5. ZUO Xiao-feng. CPN in Modern Formation of Naval Vessels Combat Teamwork C^3I System Modeling Simulation Application [D]. Xian: Xidian University, 2008
6. ZHAO Yan-quan. Colored Petri Net for Ship-borne C^3I System Based on Objects[J]. Fire Control & Command Control. 2004(2)
7. XIE Yu-peng, WANG Zong-jie, YANG Shi-feng, ZHONG Ling. Research on Anti-saturation Attack Model of Ship Formation to ASM[J]. Fire Control & Command Control. 2014(39):23-26
8. HAN Qiang. Model and Application of C^3I System for Aircraft Carrier Groups Based on Petri Nets[D]. Xian: Xidian University, 2007
9. QIN Tian-bao, WANG Yan-feng. Application Oriented Simulation Modeling and Analysis with ExtendSim[M]. Beijing: Tsing-hua University Press, 2011.