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Air Combating System-of-systems Effectiveness Analysis based on Modeling in Macro and Micro Perspective and Simulation

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Abstract

Large-scale helicopter group is an important part of the Air Combating System of Systems (ACSoS).How to plan the scale of helicopter group and achieve the best operational effectiveness is a focus of the ACSoS capability requirement analysis. Based on the macro-micro characteristic of the system of systems and the individual system, Air Combating combat models are divided into three types separately in macro and micro perspective. A UML/MM modeling method for Air Combating combat is proposed and the models are built in UML and mathematic method (MM) respectively. In addition, an Air Combating combat simulation system is developed and thirteen simulation plans of different scale values are designed as the inputs of the system .The optimal scale value of helicopter group under the certain scenario is gained through the analysis of the effectiveness based on the simulation results. In this scale condition, the ACSoS achieves its optimal survival and time effectiveness.

Keywords: *UML/MM integrated modeling and simulation, Air Combating system of systems (ACSoS), capability requirement analysis*

1. Introduction

With the great developments of aviation technology, weapons equipment, and air combat theory in recent years, the Air Combating System of Systems (ACSoS) integrates a number of weapons and equipment systems. Capability-based requirements analysis thoughts and methods have gone increasingly deep into the development of Weapon System-of-Systems (WSoS) [1]. The helicopter group is an important part of ACSoS, and its scale requirement analysis under the given missions is become more and more necessary with the improved amounts of helicopter. How to plan and arrange the scale of the helicopter of ACSoS and maximize the controlling degree and combat effectiveness are meaningful for the ACSoS capability requirement analysis [2-3].

ACSoS not only consists of a great amount of weapons equipment, but also lots of complex relationship of them, especially for the large-scale helicopter group. The traditional analytic method for capability requirement analysis of the system with uncertain information is difficult to gained scale requirement of the large-scale helicopter group [4]. Operations simulation is thought of as practical to solve the gray system [5-7]. Based on the macro-micro characteristic of the system of systems and the individual system, Air Combating combat models are divided into three types separately in macro and micro perspective. A UML/MM modeling method for Air Combating combat is proposed and the models are built in UML and mathematic method (MM) respectively. In addition, an Air Combating combat simulation system is developed and thirteen simulation plans of different scale values are designed as the inputs of the system .The optimal scale value of helicopter group under the certain scenario is gained through the

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analysis of the effectiveness based on the simulation results. In this scale condition, the ACSoS achieves its optimal survival and time effectiveness.

2. A Forces Constitution Model of ACSoS

In the simulation, the way of operation is the confrontation between red and blue SoS. The forces constitution of the red and blue is illustrated as follows:

The red combat forces contain early firepower military forces as well as large-scale helicopter fleet. The fleet includes two types of helicopter, gunships and transport helicopters. The ratio of helicopter gunships and transport helicopters is approximately 1:2. The gunships carry two kinds of arms, airborne shells and missiles, and transport helicopters are not configured to assault weapons.

The blue combat forces consist of the three-level fire defense system. The first one is for long-range firepower 12-30km from the helicopter), called the missile defense system. The second one is for medium-range firepower (5-12km from the helicopter), called the anti-aircraft guns defense system. The third one is for short-range firepower (5000m from helicopters), called the single use weapons defense system.

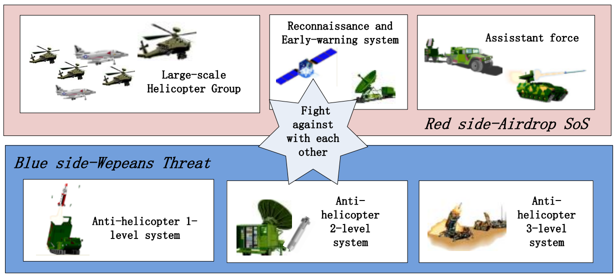

Figure 1. Forces Constitution Model of ACSoS

3. The Modeling of the Combat of ACSoS based on UML / MM

3.1. The division of Model Space

A large-scale complex system with many different relations, The modeling process of the ACSoS should take into account the common characteristics of the SoS and the system. From the perspective of SoS, we can study and describe all the behavior characteristics of the systems in whole. It is a macro and abstract description. From the perspective of the system, the behavior characteristics of the independent system itself are concerned. It is a specific and accurate description. Then the model space of the Air Combating operations can be divided into macro-model space and micro-model space. It is shown in Figure 2.

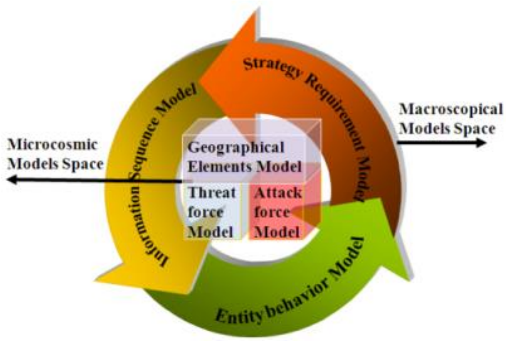

Figure 2. ACSoS Operation Model Space Division

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3.2. The Principle of Macro and Micro Modeling using UML/ MM

ACSoS modeling process can be expressed as follows:

Step1: Draw Use Case Diagram. Build the strategic requirements model of the ACSoS.

Step2: Draw UML Class Diagram. Build behavior model of the ACSoS.

Step3: Draw UML Sequence Diagram. Build the timing model of the ACSoS.

Step4: Build geo-spatial mathematical model. It includes the ground-span design and a high degree of airspace design. And it uses the Monte Carlo method to generated enemy's number and target position randomly.

Step5: Build offensive space mathematical model. It includes helicopter fleet route design, mathematical coordinate model of the single helicopter, as well as the helicopter flight analytical model. Monte Carlo method and probabilistic method are used to calculate the escape probability and the being hit probability of the helicopter flight. Probabilistic method is used to design the effect of the auxiliary combat forces.

Step6: Draw UML Activity Diagram. Build all the activity models of the helicopter. It contains three kinds of defense threats in order to finish the task: taking off, Assault enemy targets and avoiding the threat of enemy.

Step7: Build threat space mathematical model. It includes personal weapons defense system, ground anti-aircraft guns defense system, the mathematical model of the ground-to-air missile defense system, the success probability of the Assault using the force generated by Monte Carlo method. In accordance with the three different heights of the attack, the defense force is divided into three levels: height, hollow, low-level zoning.

Step8: Draw UML Activity Diagram. Build the activity models of the ground anti-aircraft guns defense system, missiles defense system, personal weapons defense system and artillery shells and missile launching, hitting and destroying activities.

Thus, Step1 to Step 3 study the macro modeling process; Step4 to Step8 study micro modeling process.

3.3. ACSoS Macro and Micro Modeling

3.3.1. Strategic Requirements Model: In a viewpoint of system development, strategic requirements of ACSoS can be modeled by a use case diagram, as shown in Figure 3.

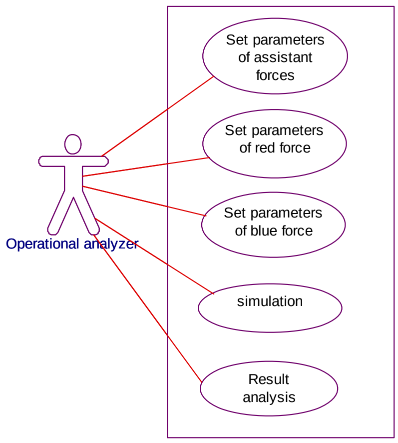

Figure 3. Use Case Diagram of Strategic Requirements of ACSoS

3.3.2. Entity Behavior Model: Entity behavior model includes entity classes, relationships between classes, and groupings of classes. Relationships include association, aggregation, composition, generalization and dependency. All entity classes and their relationships are shown in Figure 4.

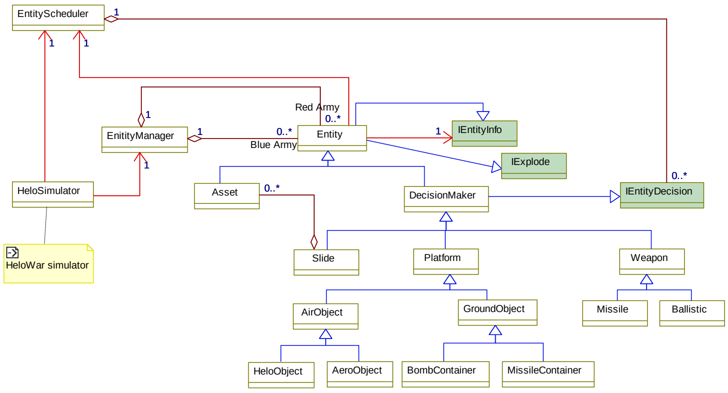

Figure 4. Entity Classes and Relationships of ACSoS

3.3.3. Information Sequence Model: Sequence Diagram describes message sending events and their occupancy order between different system objects. It is often used to refine behavior sequence of use case. Collaborations of system objects can be clearly described in a use case with Sequence Diagram.

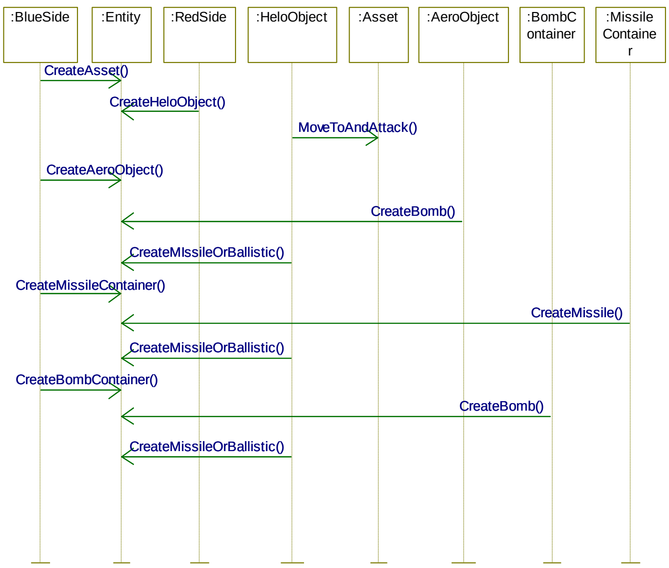

Figure 5. Information Sequence Model of ACSoS

3.3.4. Geographic Space Model: A geographic model should be created to provide positions for operational entities during simulation. Amounts of ground targets are determined previously, and their positions are randomly generated. When any simulation begins, a position generation process is triggered.

3.3.5. Assault Space Model: Assault space model mainly means activity model of gunship. An activity model of gunship is described by Activity Diagram from UML in Figure 6.

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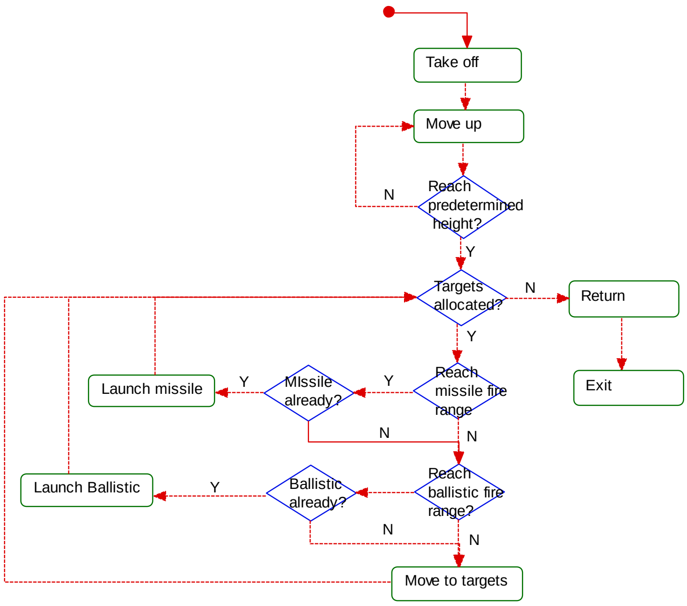

Figure 6. Activity Model of Gunship

3.3.6. Threat Force Model: Fire control system should calculate the exact coordinates that ballistic may hit target. A graphic model of antiaircraft gun interception is shown in Figure 7.

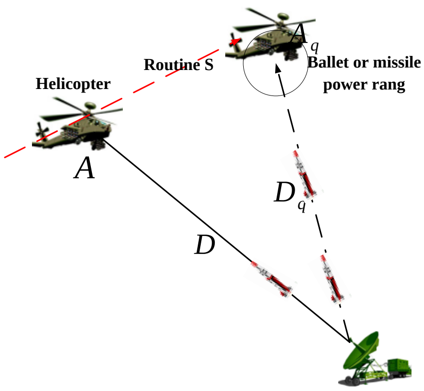

Figure 7. Graphic Model of Antiaircraft Gun Interception

The gun is firing at position D. Target locates in point A in time t. Distance between target and gun is D. Without considering random factors, ballistic can reach point A after some time, but the target would reach point A_q at that time. So the ballistic cannot hit target. To succeed in interception, gun should aim at point A_q at time t, then ballistic and target can meet at point A_q. Mathematical model of gun intercepting gunship is Equation 1 [8].

$$\begin{cases} X_q = X + f_x(t_f) \\ Y_q = Y + f_y(t_f) \\ H_q = H + f_H(t_f) \\ D_q = g(t_f) = \sqrt{X^2{}_q + Y^2{}_q + H^2{}_q} \\ t_f = f(D_q, H_q) \end{cases} \quad (1)$$

In equation 1, X, Y, H denote current coordinates of targets, X_q, Y_q, H_q denote meet points of targets and ballistics. Function $f_x(t_f)$, $f_y(t_f)$, $f_H(t_f)$ denote variance of three rectangle angles during flying, its form depend on assumptions of the law of motion.

Operational process of three interception systems and the gun are modeled in Activity Diagram from UML, as shown in Figure 8 and Figure 9. Activity diagram can help SoS analyst to understand and communicate.

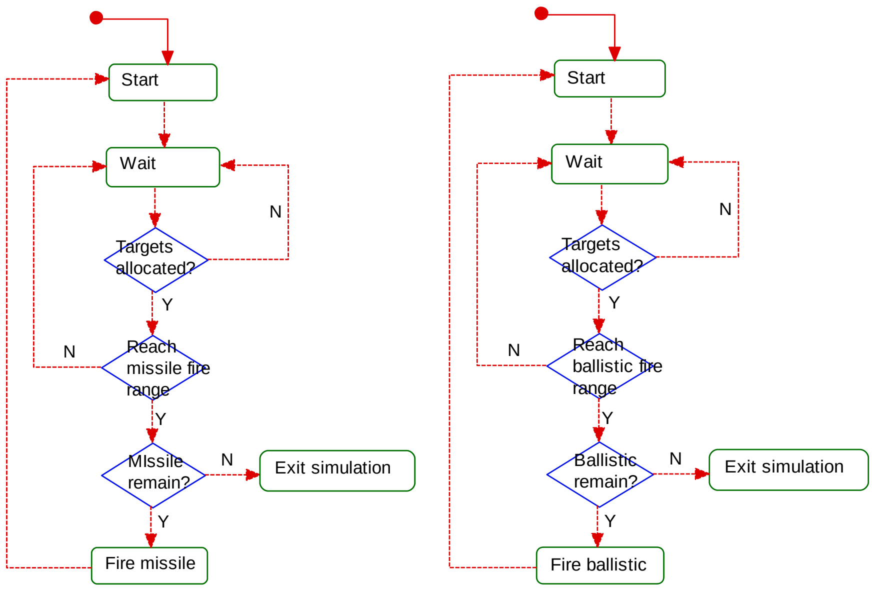

Figure 8. Activity Diagrams of Missile and ballistic Launch

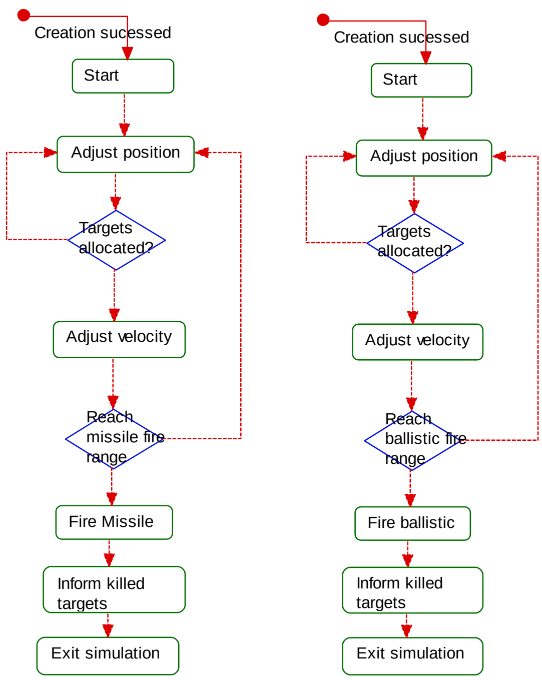

Figure 9. Activity Diagram of Missile and Ballistic Motion

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4. The ACSoS Simulation System and Case Study

4.1. ACSoS Simulation based on Semi-Autonomous Agent Model

Agent-oriented software engineers often work with models tested on toy systems in order to construct systems with certain aspects and properties of their concentrating system through Agent based simulation. The operations of single SA agent must be combined into the community of agents, the SoS evolution could be shaped properly through interactions of various agent. And desired results and emergent behaviours are observed within the outputs of simulation of multi agent systems. To adjust the four variables controlling the internal action of single SA agent, we can take greatly different actions from tidy agents. A group of such kind of SA agents are taken into a MAS simulation environment, the different results of reduplicative simulations with purpose setting of configuration will give us a guidance when we meet certain aspects or conditions. SA model can be applied not only in the simulation but also in the embedded unmanned equipments which will exhibit half autonomy half controlling character. More and more unmanned systems are used not only in the military affairs but also in high risk working environment.

Nature SoS provide insight into the nature and principal of complexity which also potentially exist in the artificial SoS. Especially military SoS is more complex when viewed in terms of their number of constituents, the dynamic system-wide structure of their interconnections, the tactic game between friend and foe, the enormous number of possible combination of interactions, and the consequences of unanticipated external influences. The figure 1 shows a diagram of process of capability arising from the bottom in SoS. The modelling of such interactions, interconnections and other related factors is a critical work for capturing the valuable information and deduced principle of SoS evolution in order to support the decision maker select a proper solution in the early stage. Even essentially for the quick response to the emergence during the operation stage, whereby the military soldier like behaviours cannot be represented thoroughly by the normal intelligent agent, which owns the simple action and rules and plays in a high abstract grid space.

Military SoS is often very messy. The operators in the battlefield choose the next action determined through a procedure which is classified by his rank (with different powers and duties), the situation (personal or holistic) and the objectives. The operator often acts according to the combination of self-profit and his upper commander's order which always prefer to the global rights but conflicting with individual's. Therefore the agent play a role of elements in the battlefield which own a varied degree of autonomy, normally an autonomous agent behaves entirely according to his profit judgement criterion. We propose an enhanced agent-inspired model: semi-autonomous (SA) agent who is designed purposely to meet the certain aspects and properties of constitutes of military SoS in an intricate battlefield scenario. The SA agent encapsulates autonomy and restriction in one body, tradeoffs will be made by the individuals with the diversities of intents, as it is precise to represent the reality action selection mechanism of actual elements of battlefield SoS.

At the actual battlefield, the operator (soldiers or weapons operated by soldiers are viewed as elements of military SoS) will implement a sequence of actions to accomplish the pre-assigned tasks which are parts of thousands of battle plan arrangements according to the objectives and situation acquired before the engagement. The operator has to justify his actions plan due to his living situation and modified orders to acquire the dominance in the engagement with enemies. Such decision making and action selection of operator can hardly be represented by the normal agents who often running in lattice by the simple rules. The SA agent can fill the gap that the normal agent poorly represents the core characters of battlefield elements of military SoS in the simulation for test "building-in"

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the expected macroscopic behaviours. The semi-autonomous character of SA agent means that its operation is partly under the control of other agents, as the operator dose in the real world, nevertheless SA agent still be in charge of his own behaviours which is determined by his tradeoffs of upper orders, individual profit, personal desire and team atmosphere. The decision process will be discussed in the following subsection.

We can find that the selected action of SA agent is the interactions of personal profit and whole values, controlled by autonomous behaviours and global plan acts. The agent's independent motivation to optimize individual utility causes them to selectively act with other agents, therefore the global situation force some agents to act against their own intent so that the SoS as a whole becomes more likely to find combinations of behaviours that resolve conflicts and result in higher global utility in a nontrivial sense. Such flexible and agile properties of SA agent specifies the true characters of operator in battlefield avoiding a mechanical simple rule based operation, which bring an opportunity indicating the emergent behaviours in the real world. The semi-autonomous properties are represented by the complicated module Decision of Part Head of SA agent. A bounded rational decision model is propose to be applied in the SA agent module Decision in the following subsection.

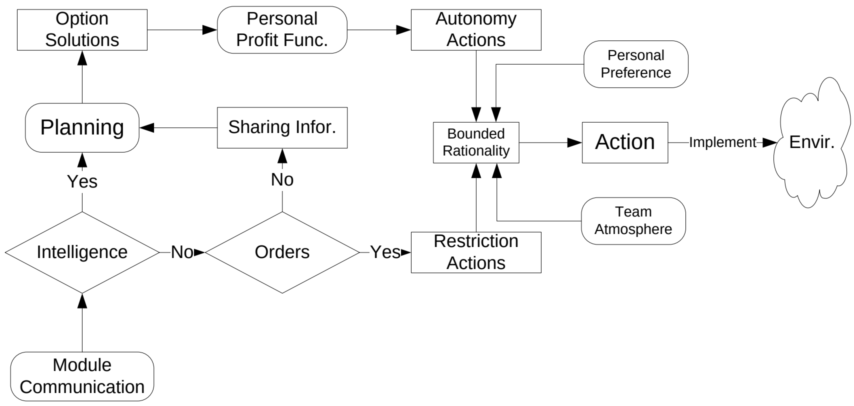

Figure 10. The Process of SA Agent Action

And Figure 10 depicts the process of SA agent action generation. Initially the information transferred from the Module communication. If the information is "Intelligence" about enemy or situation, it is inputted into Module Planning. Otherwise such information is judged with whether or not the orders from upper commanders. If answer is "yes", such orders are sent and transformed to the "Restriction Actions" which is its potential following behaviors. If answer is "no", it means that the information is transferred from the lateral agents, such as sharing intelligence, coordination request, et, al. which is also taken as the input variables to Module Planning. After an internal calculation of individual values by its "Personal Profit Function", SA agent will get a optimal "Autonomy Action" on his own perspective. Autonomy actions and restriction actions are taken into consideration and judged combined with the "Personal Preference" and "Team Atmosphere", the subjective and invisible constraints, to deduce the final action implemented to the environment. The tradeoffs among the above four variables are not a rational decision model. Any operators cannot have all the needed information; it is impossible to spend long time to analysis the options because of the battlefield emergency; and no one can transform the desire, troop culture and other mental factors into accurate mathematic parameters.

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4.1. ACSoS Simulation System and its Experiment

The system uses Microsoft Visual Studio 2010 platform as the development environment which is developed by Microsoft Corporation. The language is used as the primary development language. The ACSoS simulation system main form is shown in Figure 11:

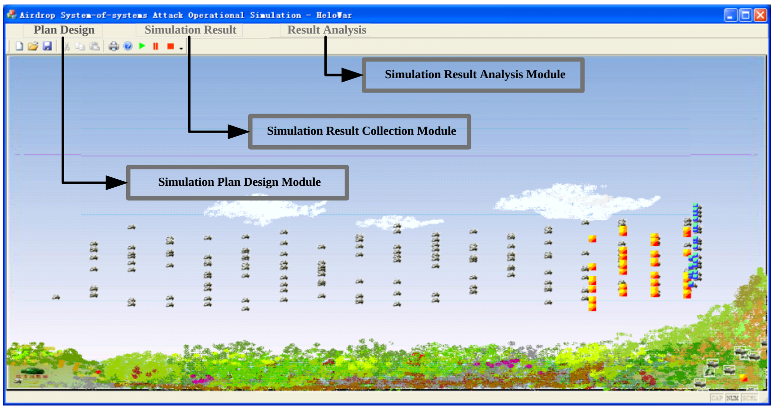

Figure 11. The ACSoS Simulation System Main Form

According to studies of the combat simulation and the relevant data of air combat, the number of the helicopters is set 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5550, 6000, 6500, 7000, 7500, 8000. 13 simulation programs are designed. The other simulation parameters are the avoid probability of helicopter (a random number between 0.4 and 0.5), the number of missiles it carries (76), the hit rate (0.85), the number of shells it carries (1200) and hit probability (0.6). We collect the simulation data after the combat simulation. They are: the number of the red side helicopter losses Mred. The number of the blue side resources loss Rblue, combat duration Time and the ammo consume of the red side Cred.

Table I. 13 Simulation Results of the Combat Simulation Program

Simulation plan	Mred	Rblue	Time	Cred
1	506	760	482	62.72
2	558	760	475	67.85
3	550	760	468	67.95
4	623	760	466	76.82
5	640	760	457	78.53
6	701	760	446	89.93
7	721	760	440	89.96
8	740	760	436	91.23
9	743	760	435	90.12
10	800	760	430	99.63
11	1050	760	441	126.23
12	1304	760	430	158.36
13	1524	760	437	187.29

Based on the simulation results data and the configuration parameters of the red and blue, we can calculate all the performance value of the index, in accordance with performance model.

Table II. 13 Simulation Effectiveness Of The Combat Simulation Program

plan	survival performance	time efficient-
1	0.7470	0.4833
2	0.7768	0.5417
3	0.8167	0.6000
4	0.8220	0.6167
5	0.8400	0.6917
6	0.8442	0.7833
7	0.8558	0.8333
8	0.8655	0.8667
9	0.8761	0.8750
10	0.8769	0.9617
11	0.8500	0.8250
12	0.8261	0.9167
13	0.8096	0.8583

According to the analysis of the impact the helicopter scale on the overall effectiveness, two performance peaks are 0.8769 and 0.9617 when the size of the fleet is 6500. Consider the two performance peaks of the indexes. We can infer that the optimum capability of the large-scale helicopter fleet battle space is 6500. Because the combat missions are limited to the established battle space, the offensive force capability in the battlefield is limited.

5. Conclusions

Large-scale helicopter group is an important part of the Air Combating System of Systems (ACSoS).How to plan the scale of helicopter group and achieve the best operational effectiveness is a focus of the ACSoS capability requirement analysis. A UML/MM modeling method for Air Combating combat is proposed an Air Combating combat simulation system is developed. Thirteen simulation plans of different scale values are designed as the inputs of the system .The optimal scale value of helicopter group under the certain scenario is 6500.In this scale condition, the ACSoS achieves its optimal survival and time effectiveness.

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