Research on Simulation Experiment Method and Process in Joint Operations System

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Abstract—To meet the requirements of joint operations simulation experiment, a framework of joint operations simulation experiment is proposed, design elements in basic scenario before the experiment, design and screening method of experiment factors, characteristics and modeling elements of simulation models during the experiment are studied particularly, and the optimal control flow of the experimental process is designed.

1. Introduction

Joint operation is a complex military problem, which involves many complex factors such as different military deployments, various equipment performance parameters, using conditions, using modes, various operations, operations coordination. The joint operation simulation experiment is to design and plan many joint operation plans according to the operation intention and background, considering many possible factors. Then carry out large sample simulation experiments before the operation, analysis and find out the key factors related to the objective of the joint operation experiment by the experimental data. In this paper, the design flow and the joint operations simulation experiment method are studied. The joint operation factor selection, the key points and difficulties of the simulation modeling are discussed.

2. Experimental framework of the joint operations simulation

Joint operation is the main form of war in the future, which relates to land, sea, air, sky, electricity and network with all kinds of battle units and integrates all kinds of battle elements. The large number of entities involved in the joint operation system, the complex entity relations, and the diversity of operation styles make the simulation experiment generate a large space of scenario and sample, the experiment is difficult to focus, and the key elements are found. Based on the exploratory experimental method, a simulation experimental research framework is presented in this paper, which is shown in figure 1.
Fig. 1 Framework of Joint Operations Simulation Experiment

Firstly, Analyse the experiment requirements. According to the typical joint operation task, analyzing the requirement of the joint operation experiment task and forming the experiment subjects that can be verified;

Secondly, Design experiment scenario according to the selected experiment item. The experiment scenario is the basis of the experiment script, including the equipment object of the joint operation, the disposition of forces, the creation of the operation plan and so on. Design the experimental point based on the experimental assumption. The experiment point takes the experiment evaluation index and the operation task flow as the input condition. Analyze the mapping relationship between the experiment task and the key elements, and combine the influence factors in the experiment design from different angles such as the system level and the business field to guide the determination of the final experimental factor.

Thirdly, Design and construct models. Select the suitable model combination and configuration according to the requirement, and construct the running environment of the simulation experiment quickly.

Fourthly, Focus and optimization the experiments. The simulation experiment is carried out, according to the experimental data collection, the results are analyzed by statistical methods and the experimental factors and evaluation indexes are adjusted continuously with feedback.

Finally, The simulation experiment is run to study the offset value of the experimental factors to the results, and finally achieve the goal of experimental analysis[2].

3. Experimental demand analysis

The experiment requirement is the goal of simulation experiment and the initial input of the whole experiment flow. The experiment items are designed according to the concrete experiment requirements. In this paper, two kinds of experimental requirements of joint operations are considered:

Capability verification of new-type equipment and key equipment [3] is to verify the effectiveness of new equipment and key equipment in the overall joint operations. The performance parameters, data transmission mode, operational characteristics of the equipment can be adjusted in the experiment to verify the combat capability of the equipment. The different combination relationship of equipment and other combat forces flexible combination, extraordinary use can be adjusted to innovative different tactical actions and verify the combat capability of equipment in the joint operation system confrontation and the dynamic tactical adjustment reflected.

Verification and optimization of the joint operations plans is to optimize and choose joint operation plans in different operation modes. The joint operations plan contains the deployment plan and action plan. Through the experimental deduction, the time and space conflicts in those plans can be found and eliminated, and operation coordination can also be carried out more effectively. Many operations plans of different operation style and equipment allocation are deduced, compared and optimized to
find out the best one. According to the experimental requirements, the typical experimental items are divided into sub-subjects, and according to the corresponding evaluation indexes of the subjects, the contents of the following experimental designs are clearly guided. The corresponding evaluation indexes of the experimental subjects are not invariable, when the selected evaluation index cannot reflect the experimental results, we can dynamically select and adjust index from the index database.

4. Experiment Design
Based on the requirement analysis of simulation experiment, the experiment design mainly includes two parts, the standard scenario design and the key points design. The standard scenario design [4] is mainly used to design static content, such as initial state of battlefield environment, entity attributes and initial combat force. The key point design is mainly used to design dynamically content, such as key equipment parameters and decision points adjusted according to the experimental aim. The standard scenario design is the premise of key points design. The content of the standard scenario should be relatively stable. The experimental factors in the key points design are adjusted dynamically based on the standard scenario, in the course of the experiment, we compare the experimental data, focus on it continuously. Key factors are found which affect the experiment.

4.1. Standard Scenario Design
The standard scenario design mainly describes the basic background of the experiment. There are some main elements:

1. Map information, including center point, area scope and map layer.
2. Battlefield environment, including meteorological information, hydro logical information and clouds information;
3. Equipment resource list, including equips, attributes and mounting devices;
4. Area information list, including special points, special area, war zone and duty area;
5. Route information list, including truing points and etc.;
6. Fixed facility list, including airport, haven, command post, warehouse and control tower;
7. Operational action plan, including force strength of both sides, action type, action start time, action end time and logical and sequential relations of all actions.

The standard scenario in this paper is different from the scenario in the simulation experiment. The standard scenario is a comparison standard to the experiment schema. In addition to the original content, it also includes the multi-level and multi-system plan content of the joint operation system confrontation experiment.

4.2. Experiment Factor Design
The experimental point design is designing experimental factors. Standard scenario is the basis of experimental design, and experimental point design is the key of the experimental design. It should be objective and sensitive to the experimental results. It leads to the focus direction of the experiments. The experimental points involved in this paper include experimental factors and decision points.

1. Factor value design
The experimental factor can be the attribute and performance parameter of an experimental object in the standard scenario, and the factor value can be adjusted to find how to make the most efficiency of the object in the Joint Operation experiments. Experimental factors can be single or multiple. There are many classic experimental design methods for single factor, such as factorial design, Latin Square design, orthogonal design or uniform design. The single factor also has different value types. For example, discrete experimental factors, such as weather conditions (sun, rain, fog, etc.) can be designed by enumeration or orthogonal design, while continuous experimental factors, such as flight speed, heading, can be designed by Latin square or uniform design; operational rule-based experimental factors, such as missile interception strategy, can be designed by enumeration design.

The experimental point composed of several experimental factors is called multi-factor experiment. This kind of experiment design should consider not only the value of single factor but also the
combination of different value points of multi-factor. As the number of factors increases, the number of experimental samples will increase exponentially. So the number of factors and the number of values of factors should be appropriate. Too many factors will cause the experimental workload; too few factors will not be able to achieve the experimental purposes. Generally speaking, the determination of experimental factors is initially selected manually, then adjusted and selected through repeated experiments and feedback, then finally determined. At present, there are some representative experimental factor filter methods, such as the ordering branches, SB-X, CSB and so on[10-14].

(2) Factor value design

The decision point design is designing the decision branch of the joint operation Plan. Different operations are triggered according to the judgment of the environment and conditions at the decision point. When designing the joint operation Experiment Scheme, the top-down layer decomposition method [15] is generally according to the specific experiment purpose and operation background, as shown in figure 2.

![Diagram](image)

**Fig.2 Decision point design of Joint Operation plan**

The joint operation mission is divided into several joint operation plans. The joint operation plans are divided into several joint operation tasks. The operational tasks can be further divided into operation sub-tasks, which can also be divided into many operation actions according to the decisions.

The decision points are mainly time-type decision points, space-type decision points, loss-type decision points, mixed type decision points and so on. Time-type decision point means the time to a certain point is the trigger condition for action; Space-type decision-point means is an combat object move to an area is the trigger condition for action; Loss-type decision point means the loss of the combat entity is the trigger condition, and the mixed type decision point is a multi-condition decision point which is formed by several trigger conditions by dominating "and" and "or".

There are two kinds of trigger condition: static trigger and dynamic trigger. The static trigger is a preset condition before the simulation starts. The trigger condition, action object, action type and other factors are structural designed into the program file and can be read by the computer to deduce automatically. Dynamic trigger is set manually during the simulation, such as sending instructions, adding or deleting targets, changing the situation of the battlefield, which can influence the choice of the decision branch.
5. Simulation model design

It is necessary to construct the corresponding simulation model and build the experimental environment to carry out the simulation and deduction when the experiment scheme is generated.

The main modeling elements of the Joint Operation Simulation experiment include:

(1) Operational environment model, which mainly simulates the operational environment, including the meteorological conditions, such as temperature, humidity, wind, rainfall, snow cover, visibility; topographic conditions, such as ground undulation, slope, concealment, Concealment; electromagnetic environment, including active interference and passive interference, which simulate the function and characteristic parameters of electromagnetic environment.

(2) Force formation model, which simulates the combat entities of both sides, such as aircraft, ships, tanks, artillery, reconnaissance vehicles, etc. The mission/combat model simulates single entity or aggregated object, which mainly reflects the operational effectiveness of the whole combat force and the capability of multi-platform units to accomplish a specific combat task. The engagement model mainly simulates the function, process flow and interaction of the combat nodes at all levels. A higher resolution model is needed to focus on the issues of concern if you don’t get what you want with low-resolution models.

(3) Static entity model, including airport, port, command post, tower and so on, mainly simulates the characteristics of geographical position, three-dimensional shape, country attribute and so on.

(4) Entity relationship model, which simulates all kinds of relations between entities of both sides, including communication, organization, coordination, accusation, belligerency and so on, can be flexibly assigned.

(5) Capability model, which mainly simulates capability composition, capability correlation. It also provides support for system capability analysis, including intelligence reconnaissance ability, command and decision ability, action control ability, firepower attack ability and so on. This kind of models is low resolution model.

(6) Operation Rule model, describes the simulation entity according to the operation rules. It builds decision rule set according to the equipment technical and tactical parameters.

6. Optimal control of experimental process

The joint operation simulation experiment involves many kinds and large quantities of combat entities. The interactions between the entities are complex. Each combat entity may carry out many kinds of combat actions, some combat entities also have certain intelligence, Its behavior pattern cannot be forecasted. Therefore, the experiment sample space will be huge; the solution space will be magnanimity characteristic. In order to improve the experiment efficiency, we must optimize the experiment process, cut out some samples which are not in the scope of concern, reduce the experiment times [16] effectively, and improve the experiment efficiency.

(1) Optimal control of factor value.

Experiment factor is an important factor of producing a large number of samples. Adding a factor or expanding the scope of the factor value may produce a large sample space. We can reduce number of samples greatly by finding and discarding some meaningless combination or contrary experimental factors.

We can use method of hierarchical decomposition [17] to optimal control factor value. We construct the experimental factor tree by dividing experiment aim, experiment factor and factor value into three levels. The experiment aim is the root of the tree. The evaluation index is the branch node of the tree. The experiment factor that affects the index is the branch node of the index branch node. The value of the experiment factor is the leaf node. During the process of exploration, the blade is continuously pruned for the purpose of focusing optimization, as follows:

- To reduce the range of factor values, we can adopt single factor experiment. We adjust the factor value by setting other factors default value. Then we analyze the influence, if the trend of result is opposite to the indicator demand, the non-conformities are eliminated.
Identify important factors. In single factor experiment, we can judge which factors are important according to the difference of the results caused by the adjustment of factor value. Then we can further focus the experiment key points.

Reduce multi-factorial combinations. If the factorial method is used in multi-factor experiments, the experiments time will increase exponentially, the workload is huge and it is not conducive to result analysis. In fact, some factors have mutual influence and restriction, not all combinations are reasonable. Therefore, according to the relationship between the factors, the conflict combination will be removed, reducing the sample space. For example, in the phase of anti-missile interception, if a weapon that has already carried out an interception mission or is short of ammunition, it is unable to carry out a second interception of the missile, the combination containing the weapon can be removed.

Reduce the value range of experiment factor combination. On the basis of important factor selection, we judge the influence of factor combination on the final result; analyze the upward trend and downward trend, eliminate the demand trend part. Then, reduce the value space further.

(2) Optimal control of intervention

The experimental process is a zoom-in and zoom-out analysis process. The zoom-out is to select the key part by the simulation results. The zoom-in is to zoom in the content of key part [18]. In the course of the experiment, the running trend of the experiment deviates from the expected result sometimes, and it is necessary to intervene, change the experimental conditions in time, and pull the experiment back to its expected range, so that the experimental results can support the aim of the experiment analysis. There are also the cases that the results are different from what we expected. We can use interventions to tap into deeper or previously ignored concerns.

The optimal control of intervention mainly has the following situations:

- Add or remove entities, change troop deployments. For example, there is a great disparity in strength between the enemy and us. It’s hard to enter the anticipated confrontation. You can increase the strength of one side and balance the both sides’ conditions.
- Modify the simulation parameters of the simulation entity and change the performance of the combat entity. For example, the maximum detection range of radar is enlarged so that a certain target can be detected, so as to carry out follow-up experiments. This kind of intervention is in order to achieve the condition which the experiment runs needs to satisfy.
- Send intervention command to trigger the action of the entity. For example, send return to base command to an aircraft that is on patrol.
- Send command to change command/operation relationship between entities. For example, Such as command of changing a plane commanded under an aircraft carrier to an AWACS aircraft.
- Through intervention, the existing experimental status can be carried out as expected avoiding re-modification of the experiment scenarios. The experiments are improved effectively.

7. Conclusion

In this paper, the flow and method of simulation experiment design for joint operations are studied, and the simulation experiment frame of joint operations is put forward, the simulation model design and the optimization control of the experimental process are studied in detail. The experimental factor filter method is a difficult problem. It cannot be limited to only one method. We can design and develop the corresponding auxiliary tools according to the rule-based reasoning filter method to accomplish the intelligent selection of experimental factors. In addition, the analysis, evaluation and comparison of the experimental results after the experiment are also important and difficult, which have not been covered in this paper. The following work will do the further research in these aspects.
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