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# Key Technology of Pilot's Cognitive Decision-making Capacity Evaluation Based on Distributed Computing

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ABSTRACT: To provide effective technological means for evaluation of the pilot's information processing capacity for combat missions, tactical capability, command capability and cognitive decision-making capacity to compensate for the deficiency in the paper and pencil test, psychological dynamoscopy and other technological means used for traditional pilot's cognitive decision-making capacity evaluation. Based on distributed computing technology, build a topological structure of the evaluation system, design a background of typical combat mission, and simulate combat control interface and process; based on software engineering, establish records, manage and analyze the evaluation technology of process data. The result of this study is that a scientific method and objective measurement means need to be provided for "real" evaluation of the pilot's cognitive decision-making capacity.

*Keywords*: distributed computing; pilot; cognitive decision-making capacity; for combat; objective evaluation

## 1 INTRODUCTION

The pilot's cognitive decision-making capability is not only a comprehensive reflection of the pilot's psychological quality, and a foundation of the level of flight technology, but also a core element for the pilots to ensure safe flight and successful completion of flight mission. With the increase of the degree of automation of the fighter, the intelligent load components gradually increase in the flight loads borne by the pilots, thus requiring the pilots to possessing good attention, judgment, decision-making capacity, spatial orientation capability and so on.

The contemporary aviation medical community highlights an important role of cognition and decision-making in flight activities based on viewpoint of information processing [1], analysis of flight labor and cognitive psychology model established on this basis. The key link of information processing is cognition and decision-making, while more specific links are attention, memory and judgment. Thus, the pilot's cognitive decision-making capability evaluation needs to adopt multiple targets to evaluate its capacity, which is a comprehensive evaluation method for multi-variables. Its basic idea is to translate the pilot's technical capability, mental capability, cognitive capability and multiple indicators into an indicator that can reflect comprehensive capacities for evaluation.

This paper builds a network platform based on distributed information technology [2], and designs the system structure of the pilot's cognitive decision-making capacity evaluation system under a background of battlefield mission, and carries out development, deployment, commissioning, maintenance and technical support based on the method of software engineering [3], thus providing the pilots with operation training equipment the environment with a background of virtual battlefield mission, and realizing the cognitive decision-making capability evaluation for the pilot's combat mission through data recording management and analysis of the evaluation process, and thereby providing an effective technical support for the pilot selection.

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## 2 EVALUATION DESIGN

### 2.1 *Evaluation model*

For the comprehensive evaluation of the pilot's cognitive decision-making capacity, there is a first need to decompose targets to be evaluated based on the combat mission, carry out comprehensive evaluation on this basis, and give out evaluation conclusion according to the mission, operation and evaluation process, analyze the pilot's cognitive decision-making capacity, determine whether there is a risk attitude, and propose preliminary advice on each evaluation.

For the analysis of cognitive decision-making capacity, currently, there are eight-part model and two-part model that are commonly used internationally. Eight-part model is alertness, recognition of problems, diagnosis of problems, generation of optional scheme, risk analysis, background issues, decision-making and actions. Two-part model is DECIDE model. DECIDE model is commonly used internationally to observe the judgment of the pilot, improve professional skills, and withstand five kinds of risk attitude. This paper adopts such model.

(1)Detect: the pilot should be able to detect factors that may have an impact on combat missions;

(2)Estimate: the pilot should be able to accurately estimate possible impact and consequences under different situations;

(3)Choose: the pilot should be able to choose an action plan that is the most suitable for the current combat conditions in the schemes generated;

(4)Identify: the pilot should be able to carry out risk analysis for the scheme selected, and determine whether this scheme is able to change impediments that are unfavorable to the combat;

(5)Do: the pilot implements mission based on the combat plan selected;

(6)Evaluate: the pilot supervises and evaluates the effect of implementation.

To achieve the requirements above, the objective of combat mission shall be simple and explicit. On one hand, it shall be able to reflect a variety of cognitive capability; on the other hand, it shall be able to make a variety of cognitive decision-making capability decoupled, and avoid accuracy of cross-impact evaluation. Thus, in the design of mission scheme, the following principles shall be abided by:

(1)Practicality: Under practical conditions, it can truly reflect the factors that impact the comprehensive ability of the pilots, which is conducive to the pilots to find their own weaknesses, so as to improve timely and effectively;

(2)Integrity: it fully considers the link and influence between various indexes. The mission types are definite and have their own characteristics, so that the index system has a wide coverage, systematically and completely reflecting the pilot's comprehensive capability from the whole;

(3)Hierarchy: as a whole with an interactive element, the pilot's comprehensive capability has a certain hierarchical structure;

(4)Usefulness: in the evaluation process, after pre-analysis of the importance of all indexes, the secondary index shall be ignored, and less than two indexes selected shall be as main investigation objects. For some complex combat missions, a certain step of the mission can be extracted as a separate mission for evaluation;

(5)Reliability: to ensure the reliability of the index data, the quantitative index should be in accordance with statistical data, and the qualitative index should ensure its legitimacy and feasibility as much as possible and ensure the reliability of evaluation results on a fair and equitable basis.

According to the principles above, the evaluation system designs typical combat missions, investigates the pilot's detection, estimation, selection, identification and implementation capacity, and embodies its cognitive decision-making capacity. To realize real-time monitoring, evaluation and postmortem analysis of the pilot's mission plans, the system establishes a network structure based on distributed information technology to provide data and information support for the pilot's cognitive decision-making capability evaluation.

## 2.2 *System design*

Considering that the evaluation system has a higher requirement on the timeliness of simulation, the architecture based on the Client / Server (C / S) is adopted. The front desk computers respectively perform their respective functions as Client. The Server mainly provides offline programming, data management, data sharing, data and system maintenance, concurrency control and other functions.

The evaluation system includes four terminals: evaluation management terminal, evaluation terminal, evaluation supervision terminal and evaluation analysis terminal. Each terminal is equipped with an independent human-machine interaction interface, which can be used by the user at the corresponding terminal after landing. The specific evaluation process may possess four types of users, that is, evaluation organizing personnel, evaluation object, evaluation supervision personnel, analysis and record keeping personnel for the evaluation results. The user's role and function are determined by the evaluation deployment mode.

The topological structure of evaluation system is shown in Figure 1.

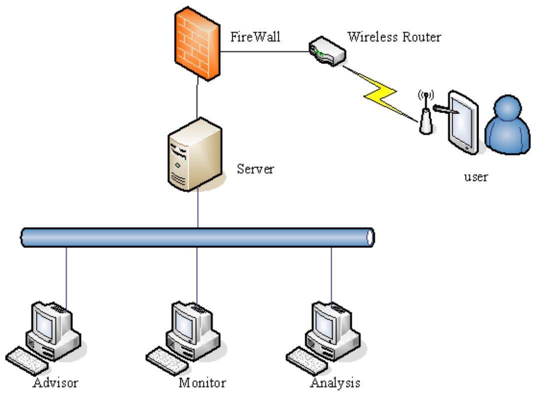


Figure 1. Schematic diagram of the topological structure of the evaluation system

The system is divided into the following five software configuration items according to the user type:

(1)The software configuration item of the evaluation organizing personnel can be referred to as a director terminal when the system starts, which mainly completes system initialization, environment setting, mission setting, and simulation scenario function;

(2)The software configuration item of the evaluation supervision personnel can be referred to as a monitor terminal when the system starts, which mainly completes state inspection and observation, and globally or locally amplifies, shrinks and switches the display function of man-machine interface;

(3)The software configuration item of the evaluation analysis personnel can be referred to as an analysis terminal when the system starts, which mainly completes data statistics, processing and display of evaluation results;

(4)The software configuration item of the measured object can be referred to as an operating terminal when the system starts, which mainly completes input and output interaction between human and machine. The pilot can obtain all background information required for the completion of missions, and enter decision instruction and action according to cognitive decision-making results;

(5)The software configuration item of the system maintenance personnel can be referred to as a server when the system starts, which mainly completes offline solution, mission logic, offline programming algorithm and data processing, data management, data sharing, data and system maintenance and other functions.

### 2.3 *Key technology of evaluation*

The key technology of the pilot's cognitive decision-making capacity evaluation is mainly reflected in three aspects: first, how to investigate the pilot's operating skill; second, which kind of technology is adopted to give out ideal solution of mission; third, how to manage the pilot's mission execution process and effectiveness. Table 1 sets up three kinds of mission types and system index demands:

Table 1. Mission index demand of the evaluation system

| **Function name** | **Performance classification** | **Index** |
|---|---|---|
| Mission setting | Type of mission | Three types: air interception, extreme low altitude penetration, target search |
| Environment setting | Extreme low altitude penetration | Five types of terrain |
| | Air interception | Five types of terrain |
| | Target search | Five types of terrain |
| | Illumination | Noon, morning / evening, night |
| | Weather | Sun, haze, rain, fog and snow |
| | Intensity of weather | Strong, medium, weak |
| Scenario delivery | Network response time | <1s |
| | Network data transmission throughput | <1Kbps |

#### 2.3.1 *Investigation of the pilot's operating skills*

The knowledge base can be used for flight action recognition [4], and investigation of the pilot's operating skills: read flight data frame by frame, and match each rule in the knowledge base by the inference engine. When the match of flight action rule is successful, based on the content specified by the knowledge base, there is a need to output the name of flight action, completion time and the associated flight parameters to the computer screen and the established data file.

The evaluation of flight capability based on the action recognition technology is a flight parameter to determine each flight action of the pilot with respect to the effective action, and determine the extent of satisfaction, that is, to make clear of the process of flight utility, and finally, to give out the judgment of the measured object with regard to the efficiency of such capacity. Due to dynamic changes of flight action, the judgment needs to consider certain fuzziness, randomness and uncertainty, and adopts traditional mathematical programming and modeling to seek for the optimal solution or carry out empirical decision-making, which is often difficult to meet the application requirements. This paper introduces a fuzzy set theory [5] to solve complex decision-making problems with fuzzy uncertain factors. Combined with the specific needs of flight mission, comprehensively considering the requirements of different parameters on different projects, the measured object shall be evaluated based on the expert evaluation criteria and measured value after fuzzy transformation.

According to the characteristics of flight evaluation, triangular and lower semi-trapezoidal comprehensive fuzzy distribution pattern can be mainly used to determine membership function, that is, to assume that each evaluation factor is triangular distribution or lower semi-trapezoidal distribution for the membership function of each evaluation level. Then the statistical analysis method is adopted to integrate the triangular fuzzy distribution function and lower semi-trapezoidal fuzzy distribution function through analysis of a large number of training samples, so as to obtain a membership function of comprehensive fuzzy distribution (see Figure 2):

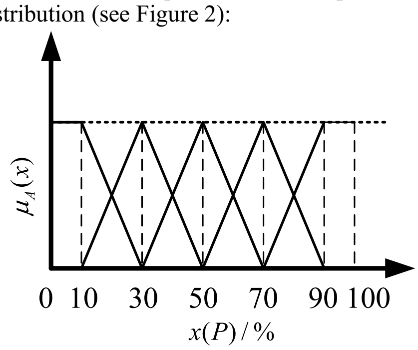


Figure 2. Membership function of the comprehensive evaluation on flight capability

2.3.2 *Calculation of ideal solution to complete missions*

Taking low-altitude penetration mission as an example, the condition of mission accomplished is closely related to the pilot's track. The ideal solution to the system can be obtained by the track planning. The track planning requires to comprehensively considering the terrain risks, electromagnetic threats (enemy radar, electromagnetic interference and surface-to-air missile) and maneuvering characteristics of the fighter, so the weighing method of the minimum threat, maximum shielding effect and the shortest track are used to establish the track cost function as follows:

Where, F (R) is the cost of the entire track. Calculation factors include: two adjacent nodes of the track, cost of a certain side, fuel cost of a certain segment; comprehensive threat cost of a certain segment includes comprehensive cost of terrain, detection threat (such as radar) and fire threat (such as surface-to-air missile, antiaircraft gun and so on), which indicates the capacity of track avoidance threat. The high cost of segment indicates the match capacity of the track terrain; the weighting coefficients (w1, w2, w3) can select the decision-making preference based on different missions. Considering that the value of three quantities - track length, height and threat is often not the same order of magnitude, and even possibly with a discrepancy of several orders of magnitude. For example, the track length and height are dozens of kilometers, which will inevitably make the result of track planning extremely insensitive to the weight values (w1, w2, w3). Various index variables are unidirectional in the cost function, requiring that the shorter the track length, the lower the track height, and the smaller the track threat. Therefore, the normalization processing can be done for the index in the cost function, and various indexes are converted into non-dimensional value between 0 and 1.

Mathematical model of ant colony algorithm can be described as follows:

Assuming that a collection of nodes is a route weight collection connected by nodes in C, the concentration of pheromone on the path (i, j) at the time of t, and a collection of residual pheromone concentration on the path (i, j) at the time of t, and the pheromone concentration on each path at the initial time is the same, and simultaneously assuming that the ant colony algorithm is realized by a digraph;

Assuming that the number of ants on node i at the time of t is the total number of ants, then each ant has the following features:

(1) Ants select the next node based on a certain probability function, of which the probability function is a function of weights between nodes and edge pheromone concentration.

(2) Each artificial ant can only follow the legal route, except that a traversal is finished, and it is not allowed to switch to nodes passed through. This process is controlled by a tabu list of ants, which is used to record a collection of nodes passed through by the ant k currently. If ants go through node i, the node i will be added to the tabu list, indicating that the node i could not be further selected, so that the collection may have a dynamic adjustment with the moving process.

(3) When a traversal is finished, the ants leave behind corresponding pheromone on each edge passed through.

At the initial time of algorithm, m number of ants is (are) randomly put into n nodes, and simultaneously the tabu list is updated. At this time, the pheromone on each route is the same, which is a constant. Next, in the moving process, the ants determine their transition directions according to the pheromone concentration on each path. In the search process, the ants calculate the state transition probability according to the pheromone on each path and heuristic information of the path. The state transition probability of the ant k at the time of t during transition from the node i to the node j is shown as follows:

Where, the pheromone factor indicates the relative importance of path, and reflects, in the moving process of the ants, the role of pheromone accumulated in the motion of ants. The greater the value, the stronger the interoperability between ants, and more inclined to select path passed through by other ants; the heuristic factor indicates the relative importance of visibility, and reflects, in the moving process of the ants, the degree of concern of the heuristic information in the path selection of ants. The greater the value, the closer to the greedy rule for the state transition probability; the heuristic function indicates the desired degree of ant k ant at the time of transition from the node i to the node j; allowed $_k$(i) is a collection of nodes that can be selected in the next step by the ant k at the node i.

To avoid that the heuristic information is overwhelmed by the residual information due to excessive residual pheromone, after completion of a traversal of the diagram by each ant, there is a need to update and handle residual information. Such update strategy imitates features of human brain memory. With continuous storage of new information in the brain, the old information stored in the brain is faded gradually, and even forgotten as time goes on. Thus, the pheromone on the path (i, j) at the time of t+n is adjusted by the following rules:

Where, the pheromone polatility indicates the residual factor of information, so as to prevent infinite accumulation of the information on the initial time; (t) indicates the pheromone of the ant k left behind on the path (i, j) in this cycle.

According to three kinds of update strategies for the pheromone, they are respectively called as Ant-Cycle model, Ant-Quantity model and Ant-Density model, whose difference lies in different calculation methods of (t).

The local information is adopted by the update of pheromone in the Ant-Quantity model and Ant-Density model, that is, the ant updates pheromone on the path after the completion of a step. The whole information is adopted in Ant-Cycle model, that is, the ant updates pheromone on all paths after the completion of cycle, with better performance in solving problems, but slower speed. This paper adopts commonly used Ant-Quantity model as a basic model of ant colony algorithm. If GPU transplantation of ant colony algorithm can be achieved later, Ant-Cycle model can be considered to use. Therefore, this paper adopts the improved ant colony algorithm to plan a rational track in advance, and make the track as an evaluation basis. After completion of the mission, there is a need to compare with the pilot's actual flight track and such track, so as to determine the track quality.

#### 2.3.3 *Function of evaluation system management business*

The function of evaluation process management business at the director terminal is shown in Figure 3.

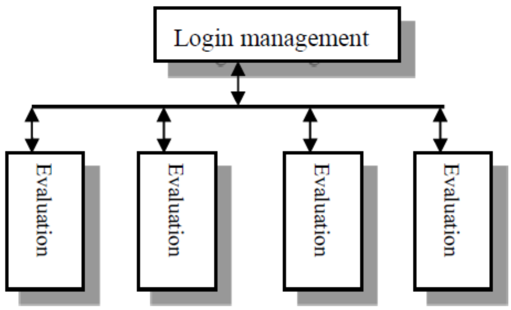


Figure 3. Function of evaluation process management business at the director terminal

The evaluation process management business is mainly to send control commands of evaluation process to other software configuration items, and the process control responses of various configuration items are respectively shown in various software configuration items.

Detailed function items of the management business of the evaluation process are shown in Table 3, which gives out a description and identification of each function.

### 2.4 *System application deployment mode*

A specific evaluation process may have four types of users, which are, evaluation organizing personnel, evaluation object, evaluation supervision personnel, analysis and record keeping personnel for the evaluation results. The user's role and function are determined by the evaluation deployment mode. The user's role and function are determined by the evaluation deployment mode.

In the operational process of the evaluation system, according to different application purposes, the following four deployment modes can be adopted:

(1)Evaluation training mode: comprised by the evaluation organizing personnel and evaluation object. It is applicable to be familiar with the evaluation environment, and understand the evaluation system function and application method, as well as other application scenarios with training nature.

(2)Evaluation test mode: comprised by the evaluation organizing personnel, analysis and record keeping personnel for the evaluation results and evaluation object. It is applicable to the application scenarios of multiple evaluation tests and evaluation for multiple pilots.

(3)Official (complete) evaluation mode: comprised by the evaluation organizing personnel, evaluation supervision personnel, analysis and record keeping personnel for the evaluation results and evaluation object. It is applicable to the application scenarios of evaluation test and evaluation with presentation and report nature.

(4)Evaluation statistics mode: analysis and record keeping personnel for the evaluation results. It is applicable to statistical analysis, extraction, visualization and other application scenarios for the evaluation data.

Table 2. Function demand of evaluation process management business at the director terminal

| **Functional classification** | **Specific content** |
|---|---|
| Evaluation start | Adopt a multicast method to notify other front desk computers and evaluation terminals to start evaluation, start timestamp and regular multicast, and locally start receiving terminal operation and display in a record form |
| Evaluation suspend | Adopt a multicast method to notify other front desk computers and evaluation terminals to suspend evaluation, suspend timestamp, and locally suspend receiving terminal operation and terminate record of update |
| Evaluation recover | Adopt a multicast method to notify other front desk computers and evaluation terminals to recover evaluation, recover timestamp, and locally recover receiving terminal operation and record of update |
| Evaluation finish | Adopt a multicast method to notify other front desk computers and evaluation terminals to finish evaluation, reset timestamp, and locally stop receiving terminal operation |

| | |
|---|---|
| | and record of update |

## 3 CONCLUSION

The intelligent cabin proposes a newer and higher requirement on the pilot's cognitive decision-making capability. Currently, the design mode of cabin presents information leading, comprehensive integration and other features. The design of the pilot's cognitive decision-making capacity evaluation based on the distributed information system can effectively meet the low cost, high fidelity, easy evaluation and other practical needs of the pilot's capacity evaluation. The engineering application of the evaluation design in this paper can meet dual functions, that is, the pilot selection and pilot training, which can effectively improve the efficiency of pilot selection and training.

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