ISSN 2278-3091
Volume 9, No.5, September - October 2020
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse100952020.pdf
https://doi.org/10.30534/ijatcse/2020/100952020

Method of the Effort Coordination Chart Creation

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ABSTRACT

The search for new approaches and the development of tools based on them to support the commander decision to organize the interaction of forces in the course of modern combat operations, which are characterized by rapid changes in the situation, has recently been the subject of intensive research. One of the promising areas of such research is the development of special software used to form a chart of the forces' efforts coordination during the joint implementation of their combat missions.Research into the development of such programs has led to new requirements for the formation of these charts. First, the chart should take into account not only data of the operational and tactical situation, but also its changes in the real time mode. Secondly, during the formation of the efforts coordination chart in the software there should be a knowledge base about its organization, which is formed and constantly updated on the basis of previous experience of conducting operations. For the software development that will be able to form a high-quality form and content of the coordination chart a formalized mathematical apparatus is required. The article describes one of the approaches to formalizing the process of forming a chart of Ground Based Air Defense efforts with Air Defense Aircraft coordination, which is based on the theory of schedules and the method of a multicriteria problem decomposition.

Key words: effort coordination chart; scheduling; multicriteria task; Air Defense

1. INTRODUCTION

The effectiveness of air defense (AD) is largely determined by the degree of AD Plan implementation at all levels from a single unit to a group of troops as a whole [1]. One of the most important components of operational planning is the organization of interaction, i.e. coordination of forces actions which jointly carry out the same missions, and the document developed for this purpose is the efforts coordination chart (ECC) which is intended for forces actions coordination by missions, time and directions (area) during operations [1]. In modern conditions of operations, the most difficult is to coordinate the actions of air and ground components of troops (forces), examples of which are fighter aircraft (AD Aircraft) and anti-aircraft missile systems of anti-aircraft missile forces (GBAD), performing joint missions in air defense system (AD system). The active control tool for active air defense (ADA) components – GBAD and AD Aircraft – and at the same time the basis for choosing a rational way of their joint action is also ECC, which reflects the participation of all ADA components in operations throughout the enemy air strike rebuff. In this case, a reasonable choice of rational methods of joint action is a rather difficult task, due to the cross-area order of destruction of the Air enemy and the variety of shooting ways on it. Currently, the problematic issue is the complex process of forming the ECC, which is carried out in the headquarters operational units almost "manually" and requires a long time for designing. In addition, there is a problem with the use of ECC in combat operations, i.e the constant need to adjust its content due to the inconsistency of the actual situation with what was predicted during the planning of operation.

To solve these problems, it is proposed to introduce the methodics of forces ECC formation during the operation to the commander decision support system software.

Problem formulation. Thus, the main document of the armed forces coordination is the ECC, a structure of which is the same with the structure of schedules, where also ordering is needed, in different words, to determine the sequence of actions, or use any forces and components by missions, place and time. Solving of the ordering problems, where is a choice of this or that sequence of actions (distribution of tasks in production, schedule of aircraft landing, travel schedule, customer service, etc.)take place, is provided on the basis of schedule theories [2]-[3].

Therefore, the formation of ECC, which takes into account the general and partial tasks and the conditions of their implementation is an urgent and important scientific and practical task, the solution of which may allow:

- in terms of developing mathematical formalization:

- ✓ reduce computational difficulties and simplify the solution of a complex multicriteria problem;
- ✓ ensure harmonization of partial criteria with the global criterion of optimality;
- ✓ prove the need for “manual” adjustment of the ECC taking into account the knowledge accumulated in the databases;

• in terms of development of ECC formation methodics:

- ✓ reduce the complexity of performing manual operations during the formation of ECC;
- ✓ to implement an effective system of error and logical discrepancy control in the ECC formed;
- ✓ take into account as much as possible the purpose of the operation (combat operations) and the features of forces use in the specific operation conditions.

Analysis of recent research and publications. Recently, researches in the field of scheduling developing methods have been conducted. Most of them are directed at forming an optimal schedule based on one or more criteria [4], taking into account the specific requirements for a particular schedule and its uniformity in the level of performed tasks complexity [5]-[8]. As well, research works are widespread, where the formation of schedules is carried out on the basis of graph theory [9], genetic [10] and heuristic algorithms [11] with their subsequent implementation in software. However, existing computer scheduling programs based on existing models, focused on the conditions of specific production or have excessive versatility of the implementation of common functions [8], [12]-[15] and high market value and cannot be adapted to solve the problem of forces coordination during the operation.

The purpose of the article iscreation of forces' ECC forming methodics during the operation at the example of GBAD and AD Aircraft, which may be the basis for creating software to automate the formation and refinement of ECC during real time combat operations providing.

2. PROPOSED METHODOLOGY

The first step of the methodics creating is the formation of ECC hierarchical structure by performing the decomposition of the general process on the following grounds: by the elements of the process; by quality criteria and its implementation stages [3].

Carrying out the procedures of ECC formation process decomposition on plural objects of its formation process allowed to allocate its structural elements (Figure 1):

− sheets of the working chart E_1,where are placed both the input information for ECC forming (E_{11}, E_{12}),and the planned results of its implementation − the actual ADA combat tension (E_{13}),as well as quality indicators of the formed ECC (E_{14});

− user element (E_2),which implements the basic technological operations for the formation and verification of ECC (E_{21}, E_{22}).

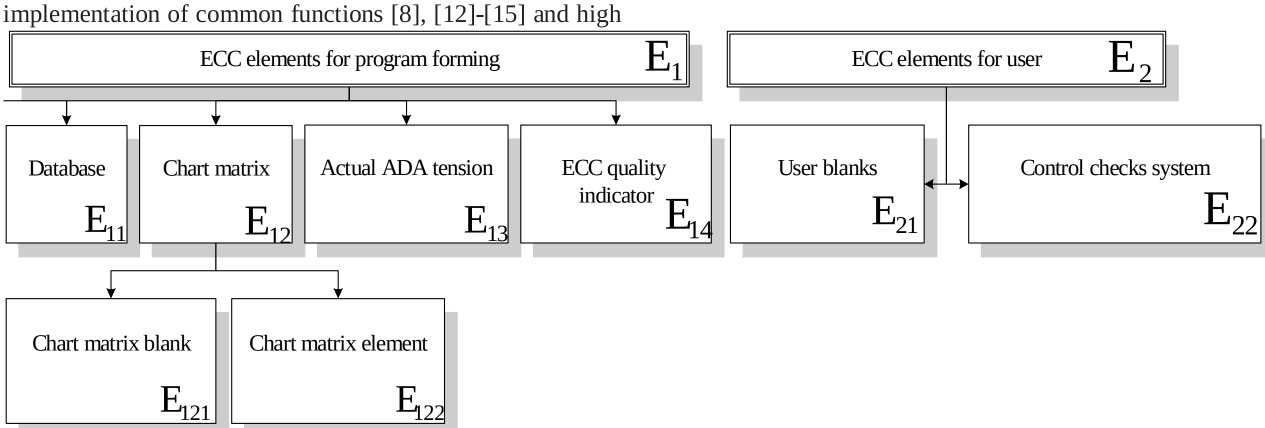

Figure 1: Decomposition of theECC forming process by structural elements

Analysis of the ECC formation process quality criteria allows to determine two groups of local criteria (figure 2):

− ECC form quality criteria (C_{sq});

− ECC content quality criteria (C_{qc}).

Optimization of the quality level by indicator C_{sq} is performed taking into account the quality components (C^i_{sq}), where (i) is the index of the 2nd hierarchy level local criterion ($i = 1, I$):

− database quality (C^1_{sq});

− user interface quality (C^2_{sq});

− ECC reporting quality (C^3_{sq}).

Each of the defined ECC matrix form quality criteria is also decomposed into groups of 3rd hierarchy level local criteria ($C^i_{sq\,j}$),where(j)is the index of the 3nd hierarchy level local criterion($j = 1, J$) (Figure2).

Optimization of the ECC quality content by indicator (C_{qc})involves reaching the extremes of the following local criteria (C^i_{qc}), where(i)is the index of the 2nd hierarchy level local criterion($i = 1, I$):

− the quality of taking the missioninto account in the ECC (C^1_q);

− the quality of ADA involvement to perform the mission (C^2_{qc}).

Each of the formed components of the ECC content quality, in turn, can be decomposed into groups of the 3rd hierarchy level local criteria ($C^i_{qc\,j}$)where(j)is the index of the 3nd hierarchy level local criterion($j = 1, J$)(Figure2).

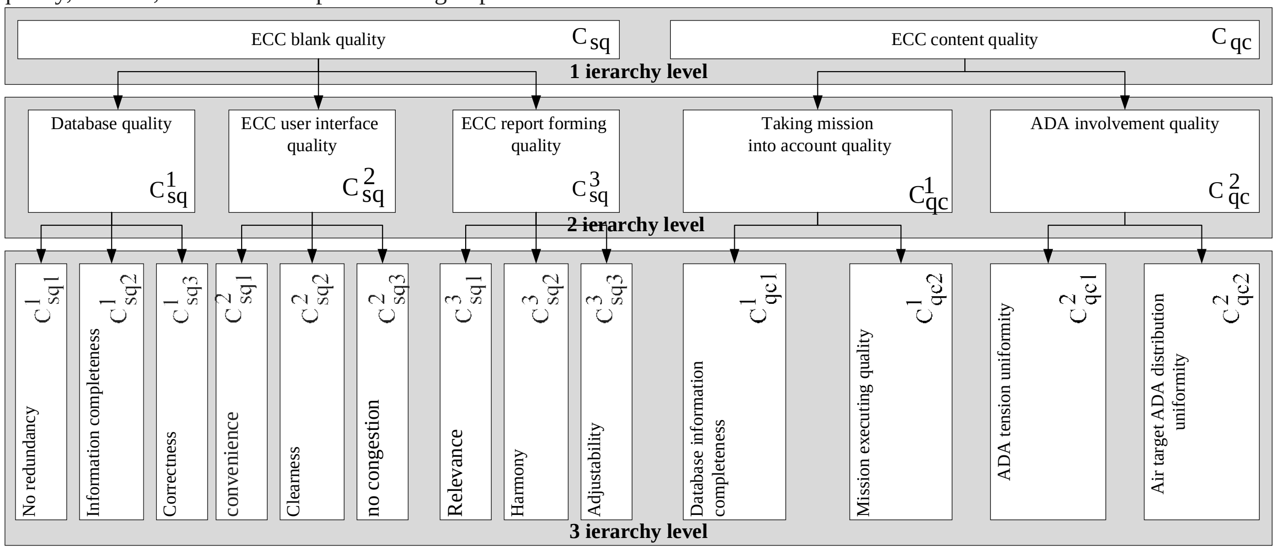

Figure 2: Decomposition of the ECC forming process by quality criteria

Analysis of plural local problems obtained by synthesizing the results of two types of decomposition (Figures 1, 2), allowed to identify the following composition of stages and phases of the hierarchical structure of the process of forming ECC (Figure 3), the mathematical formalization of which is as follows:

− phase of design and ECC database forming in the areas of tasks performed

$$T_{11} = E_{11}\left\{C^1_{sq}\right\}; \quad (1)$$

− phase of the ECC blank formation

$$T_{12} = E_{121}\left\{C^2_{sq}, C^1_{sq2}\right\}; \quad (2)$$

− the phase of the user form forming, that provides the source information for filling the ECC

$$T_{21} = \left\{E_{21}, E_{122}\right\}\left\{C^2_{sq}, C^3_{sq2}, \left\{C^1_{sq2}, C^1_{sq3}\right\}, \left\{C^1_{qc11}, C^1_{qc12}\right\}\right\} \quad (3)$$

− the phase of the ECC matrices filling, which are responsible for information about the state and position of the ADA

$$T_{22} = \left\{E_{21}, E_{22}, E_{122}\right\}\left\{C^2_{sq}, C^3_{sq3}, \left\{C^1_{sq2}, C^1_{sq3}\right\}, C^1_{qc1}, C^1_{qc2}\right\} \quad (4)$$

− phase of the report information forming on ADA tension and distribution of all tasks set

$$T_{31} = E_{13}\left\{C^1_{sq2}, C^1_{sq3}, \left\{C^3_{sq1}, C^3_{sq3}\right\}\right\}; \quad (5)$$

− the formed phase of ECC quality indicators calculation

$$T_{32} = E_{14}\left\{C^2_{qc}\right\}; \quad (6)$$

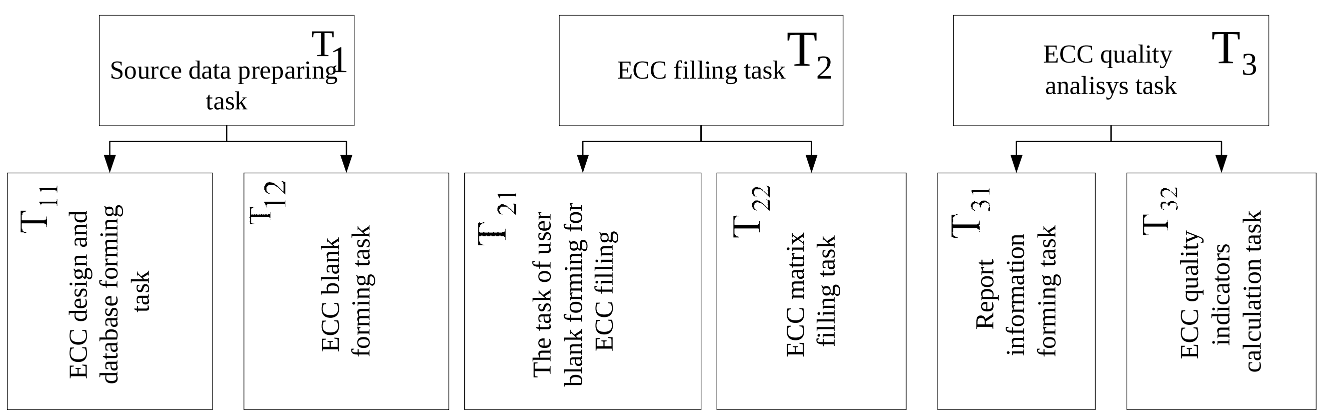

Figure 3: Decomposition of the ECC forming process by stages and phases

The second step in methodics creating is the ECC forming phases mathematical formalization, which means the local tasks formalization and includes:

– selection of the local criterion method and algorithm development of for solving each task;

– coordination of the information exchange process between tasks;

– correction of the task solution in accordance with the general optimalty criterion.

In general n -thtask can be represented as follows:

$$f_n\left(X_n, Y_n, Z_n\right) \rightarrow \text{extr} \tag{7}$$

where Z_n – local optimalty criterionof n -thECC forming task;

X_n – input information of n -thECC forming task;

Y_n – outputinformation of n -thECC forming task.

ECC forming methodics is represented at figure 4 as a scheme of information interaction and coordination between the formation tasks.

Implementation of T_1stage of source information preparing of for the ECC forming involves tasks solving in phases $T_{11}$and T_{12}. During first phase $T_{11}$the database forming and filling task with source information for the ECC blank forming is solved. The mathematical formalization of task (1) can be written as follows:

$$f_{11}\left(X_{11}, Y_{11}, Z_{11}\right) \rightarrow \text{extr} \tag{8}$$

where X_{11} – set of input information elements (X_{111} –normative capabilities for application and interaction for each ADA, X_{112} – tension distribution matrix for each ADAand Y_{22} – the results of the task solving of ECC blank matrix editing which are responsible for information about the ADA status and position) for task solving during T_{11} phase;

Y_{11} – set of output information elements (Y_{111} –“Combat Capabilities Application Plan” table and Y_{112} – “Combat ADA tension” table) after task solving;

$Z_{11} = k_1 C^1_{sq1} + k_2 C^1_{sq2} + k_3 C^1_{sq3} \rightarrow \max$ – task solving optimalty criterion during T_{11}phasewhich determines the ADA interaction database design quality by maximizing the sum of its weighted components: no redundancy C^1_{sq1}, information completeness C^1_{sq2}, correctness C^1_{sq3} taking into account the weights of their significance– k_1, k_2, k_3.

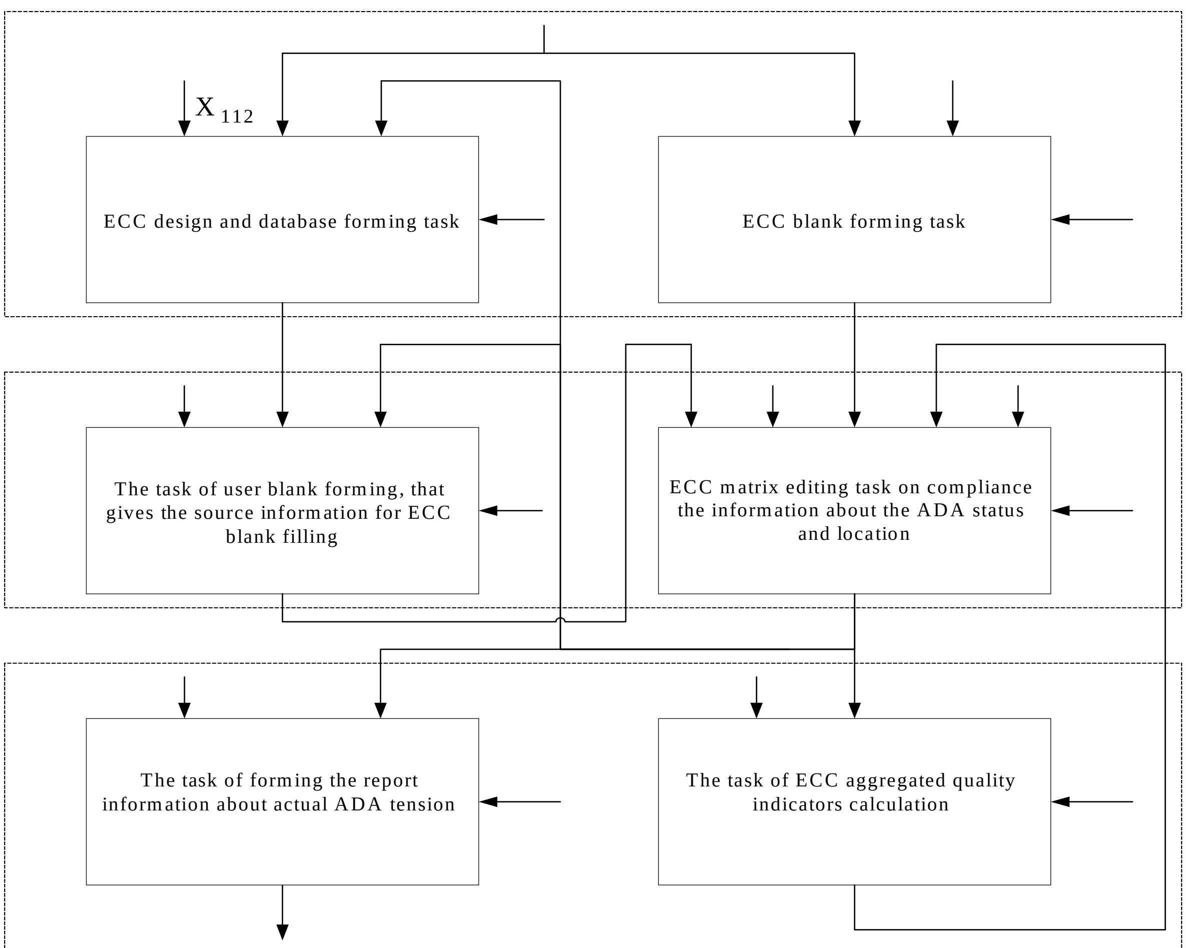

Figure 4:ECC forming methodics

"Combat Capabilities Application Plan"table Y_{111} structure is formed basing the normative staff documents of eachADA type X_{111}.

"Combat ADA tension" table Y_{112} structure includes two groups:

first–fields are formed basing on primary information X_{112} for further correction;

second–fields are corrected basing on executing T_{22} phase results of editing ECC grid components Y_{22}.

During second phase T_{12} of input data preparation stage the task of ECC blank forming is solved.

The mathematical formalization of this taskcan be written as follows:

$$f_{12}\left(X_{12}, Y_{12}, Z_{12}\right) \rightarrow extr; \qquad (9)$$

where X_{12} − set of input information elements (X_{111}, Y_{22}) for task solving during T_{12} phase;

Y_{12} − output information (ECCblank) after task solving during T_{12} phase;

$$Z_{12} = k_2 C^1_{sq2} + k_4 C^2_{sq1} + k_5 C^2_{sq2} + k_6 C^2_{sq3} \rightarrow max −$$

task solving optimalty criterion during (T_{12}) phase, which implements the task of and maximizes the amount of weighted quality indicators components of ECC blank forming(2), i.e. itsconvenience C^2_{sq1}, clearness C^2_{sq2}, no congestion C^2_{sq3} with their weights k_4, k_5, k_6 and its information completeness C^1_{sq2}.

Realisation of ECC matrix filling stage T_2 provides a consistent tasks solution during T_{21} and T_{22} phases(Figure4).

The purposes of a user blank forming task to fill in the ECC blank of T_{21} phase are:

1. Providing the user with the full amount of information to fill in the ECC form and place it on the screen in a user-friendly form.

2. Development and implementation of effective user interface elements to perform a list of technological operations required for the ECC formation in all areas of application, namely:

–revision of the general ADA application plan;

−selecting line the ADA tension which is selected for placement or editing in the ECC grid;

–review of the combat tension of a specific ADA type, which is actually taken into account in the ECC;

− review of the combat tension of a specific ADA type, which must be taken into account in the ECC.

The mathematical formalization of this task(3)can be written as follows:

$$f_{21}\left(X_{21}, Y_{21}, Z_{21}\right) \rightarrow extr \qquad (10)$$

where X_{21} − set of input information elements(X_{211} −rules for the request executing to the tables "Combat Capabilities Application Plan" and "Combat ADA Tensions", Y_{111}, Y_{112}, Y_{22}) for task solving during T_{21} phase;

Y_{21} − set of output information elements (Y_{211} − element of the "Application plan" form (for ADA), Y_{212} − element of the "Combat tension" form (for ADA), Y_{213} − element of the "The actual need of application" form (for ADA) after task solving during T_{21} phase;

$Z_{21} = Z_{12} + Z_{cor21} + Z_{uzg21} \rightarrow max$ − task solving optimalty criterion during (T_{21}) phase, which implements the ECC forming by maximizing the sum of weighted components of correctness Z_{cor21} (11) and harmony Z_{uzg21} (12) indicators.

$$Z_{cor21} = k_3 C^1_{sq3}(k_7 C^1_{qc11} + k_8 C^1_{qc12}), \qquad (11)$$

$$Z_{uzg21} = k_9 C^3_{sq2}(k_7 C^1_{qc11} + k_8 C^1_{qc12}), \qquad (12)$$

where k_7, k_8, k_9 − weights of C^1_{qc11}, C^1_{qc12}, C^3_{sq2} indicators significance.

Output information parameters Y_{21} of user blank forming task include three elements Y_{211}, Y_{212} and Y_{213}.

The purposes of the "Application Plan" form element Y_{211} forming (for ADA) are:

display the results of the request X_{211} to all elements of table Y_{111} of ECC database for certain ADA type and its application directions;

technological operations implementation for revision of Appication plan and selection of the ADA interaction method for editing.

The purposes of "Combat tension" form elements Y_{212} forming (for ADA)are:

− display the results of the request X_{211} to "Combat tension" database executingwith the ADA match condition Y_{112};

− display the elements of ECC grid editing task solving results, which are responsible for information about the rest of the tasks for placement in the ECC grid;

− implementation of technological operations to select the "ADA tension" line for placement or editing of ECC;

− revision of selected ADA tension to locate into ECC grid.

The purposes of "The actual need of application" form elements Y_{213} forming (for ADA) are:

display the results of solving the task of editing the ECC grid elements, which are responsible for information about the ADA capabilities, actually taken into account in the ECC grid;

implementation of technological operations of selected ADA tension review, which is actually taken into account in the ECC grid.

During T_{22} phase the task of ECC elements editing, responsible for information about ADA and area of their application, is solved.

The mathematical formalization of this task(4) can be written as follows:

$$f_{22}\left(X_{22}, Y_{22}, Z_{22}\right) \to extr, \qquad (13)$$

where X_{22} – the set of input information elements (Y_{12}, Y_{211}, Y_{212}, Y_{32} – the result of solving the task of calculating the aggregate quality indicators of the ECC, X_{221} – rules of adding the information about ADA use, X_{222} – system of control checks of conditions of addition a certain number of combat missions to ECC) for task solving during T_{22} phase;

Y_{22} – the set of output information elements (Y_{221} – the matrix of combat missions distribution, Y_{222} – matrix of fire units distribution) after task solving during T_{22} phase;

$$Z_{22} = Z_{12} + Z_{cor22} + Z_{uzg22} + k_{11}C^{1}_{qc2} \to max$$ –

task solving optimalty criterionduring (T_{22}) phase, which is determined by maximizing the sum of the weighted components of the correctness Z_{cor22} (14) and harmony Z_{uzg22} (15) indicators in terms of use, processing and visual display of source and current information on all sheets of the ECC matrix.

$$Z_{cor22} = k_3C^{1}_{sq3}(k_7K^{1}_{qc11} + k_8C^{1}_{qc12} + k_{10}C^{1}_{qc13}), \qquad (14)$$

$$Z_{uzg22} = k_9C^{3}_{sq2}(k_7C^{1}_{qc11} + k_8C^{1}_{qc12} + k_{10}C^{1}_{qc13}), \qquad (15)$$

where k_{10}, k_{11} – weights of ECC formation quality indicators significance C^{1}_{qc13}, C^{1}_{qc2}.

The T_{22} phase implementation algorithm is as follows:

1. According to the information posted in the elements of the user form Y_{211} and Y_{212} about ADA quantity, which must be distributed by tasks in the ECC grid Y_{12}, editing of the elements of the current sheet is performed in order to form the ECC according to the chosen at this combat actions stage the order of interaction between the ADA X_{221}.

2. Correctness of performed operations is supported through the implementation of control checks of the possibility of a certain ADA group Y_{222} adding to the ECC gridfor certain combat mission, as well as the chosen area for its implementation, that is:

– no coincidence of the ADA number, which is assigned to a certain area with the information stored in the ECC elements corresponding to the same area of the combat mission in the grids of other ECC sheets;

– no coincidence of the ADA groups locations, which is located in the appropriate area allocated by the user for the combat mission, and the area prohibited for the combat missions of this ADA group Y_{212};

– correspondence of the number of ADA, which are distributed to a certain number of Air targets in the current sheet of ECC grid, and the number of ADA, which is exposed to the ECC grid at this phase of the operation;

– no coincidence of the combat area, which is distributed to the ADA, and determined by the way they interact, and the combat area on other sheets of ECC.

Implementation of the ECC quality analysis stage T_3 involves tasks solving during T_{31} and T_{32} phases (Figure 4).

The purpose of T_{31} phase realization is solving the task of forming on a separate sheet (sheets) the information on the actual ADA tension for an Air enemy strike and the stage of combat operations, as well as the formation of ECC cards for a certain ADA in accordance with user requests by defined report form.

The mathematical formalization of this task(5) can be written as follows:

$$f_{31}\left(X_{31}, Y_{31}, Z_{31}\right) \to extr, \qquad (16)$$

where X_{31} – the set of input information elements (X_{311} –report request parameters, Y_{221}, Y_{222}) for task solving during T_{31} phase;

Y_{31} – the set of output information elements (Y_{311} –a report on the ADA actual tension per strike or combat phase, Y_{312} – a report on the actual filling of the area per a strike or combat phase)after task solving during T_{31} phase;

$$Z_{31} = k_2C^{1}_{sq2} + k_3C^{1}_{sq3} + k_{12}C^{3}_{sq1} + k_{13}C^{3}_{sq3} + k_{14}C^{1}_{qc3} \to max$$

– task solving optimalty criterion during (T_{31}) phase, which ensures the formation of the ECC and is determined by maximizing the quality of the formed reporting system, or rather the sum of its weighted components: information completeness C^{1}_{sq2}; correctness C^{1}_{sq3}, relevance C^{3}_{sq1}; adjustability C^{3}_{sq3} andreporting quality C^{1}_{qc3} with the corresponding weights of their significance k_{12}, k_{13}, k_{14}.

During T_{32} phase the solution of the ECC quality assessment task is provided, which is formed by comparing the ADA combat capabilities with the Air targets characteristics at each combat phase and for each strike, taking into account the indicators of rationality.

The mathematical formalization of this task(6) can be written as follows:

$$f_{32}\left(X_{32}, Y_{32}, Z_{32}\right) \to extr, \qquad (17)$$

where X_{32} – the set of input information elements (X_{321} –report request parameters, Y_{221}, Y_{222}) for task solving during T_{32} phase;

Y_{32} − the set of output information elements (Y_{321} −quality indicators of the distribution matrix of each ADA, Y_{322} − quality indicators of Air targets distribution, Y_{323} − indicators of interaction efficiency, Y_{324} − AD quality indicators in general) after task solving during T_{32} phase;

$Z_{32} = k_7 C^2_{qc11} + k_8 C^2_{qc12} + k_{14} C^2_{qc2} \to opt$ − task solving optimalty criterion during (T_{32}) phase, which determines the optimization the ADA tension uniformity criteria.

Thus, partial criteria for solving tasks (8-10, 13, 16, 17), used in solving set of tasks $T = \{T_{11}, T_{12}, T_{21}, T_{22}, T_{31}, T_{32}\}$ are the results of the decomposition of the general problem at set of local objects of the ECC formation process, their optimization ensures the achievement of the extremum of the main criterion of the ECC formation problem Z_{IPT}:

maximum quality of the ECC form (Z_{sq});

maximum quality of ECC content (Z_{qc}).

$$Z_{IPT} = v_1 Z_{sq} + v_2 Z_{qc} \to max, \quad (18)$$

where v_1 i v_2 − weights of significance of indicators (Z_{sq}) and (Z_{qc}).

After the implementation of the ECC formation main stages, it is finalized in order to take into account the factors and to coordinate the conflicting criteria, namely: taking into account the commander main idea; restrictions on the interaction between GBAD and AD Aircraft; features of the organization of AD in the operation, etc.

3. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

Thus, the proposed methodics using the methods of decomposition of the multicriteria problem of ADA ECC forming allows:

1. Due to the application of the system approach principles – taking to account of optimality criteria and the limitation of two interrelated tasks: the task of optimizing the main indicators of interaction between GBAD and AD Aircraft and the task of ECC forming;

2. Due to decomposing a complex problem – to simplify the solution of a multicriteria problem by forming a hierarchical structure of coordinated by criteria tasks of “acceptable” complexity;

3. Due to the ADA ECC forming methodics implementation in the decision support system - reducing the complexity of manual operations for its formation, implement an effective system of error and logical inconsistencies in the received ECC, taking into account the features, main limitations of interaction between GBAD and AD Aircraft in specific conditions of combat operations.

4. Due to the introduction of ECC quality assessment, it is pissible to take into account the ADA combat capabilities, and the level of missions complexity to ensure the uniformity of the ADA tension with full realization of their combat capabilities.

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