Imitation Modeling of UAV's Multi-Purpose System of Optimal Structure Based on Generalized Method of Dynamic Condensation*

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Abstract. The article presents the task of substantiating the selection of the design characteristics of a multi-purpose UAV system to simulate the optimal structure of a multi-purpose UAV system in the study of tropical cyclones, the task of justifying the choice of characteristics for building a multi-purpose UAV system, the algorithm of the generalized dynamic concentration method (GDCM) to solve a class of optimization problems using the criterion of the minimum cost of the UAV system's target tasks at a given efficiency of their implementation. The solution to the problem of substantiating the choice of characteristics for building a multi-purpose UAV system, the simulation results of the optimal multi-purpose UAV system for monitoring tropical cyclones in Vietnam are proposed**.** The results of the solution of the formulated scientific problem should be used in the future when forming the tactical and technical requirements (TTZ, TZ) of the Customer for the creation (modernization) of promising multi-purpose UAV systems when solving remote sensing problems in terms of evaluating the effectiveness of their functioning, and evaluating the resource provision, in particular, costs.

Keywords: Unmanned Aerial Vehicle (UAV), a Multi-Purpose UAV System, Imitation Modeling, Generalized Method of Dynamic Condensation (GMDC), Algorithm, Statistical Sample, Optimization, Criterion, Optimal multi-purpose, Remote sensing.

1 Introduction

Currently, many countries of the world are actively developing and using systems of unmanned aerial vehicles (UAV) that would deliver special platforms for data collection (PDC) to a certain area of the world ocean, to solve the problems of analysis, assessment, monitoring, and forecasting the formation of tropical cyclones in specific regions [1, 2]. At the same time, such special platforms should be so distributed over the area of the ocean and its height that measurements of the characteristics of the atmosphere at various points of the probed object are synchronized. This synchronization is necessary to build a General and maximally accurate model of the development of atmospheric vortices with the possibility of its practical application on a time scale close to the real one [3].

The multi-purpose feature of the UAV system is determined by the variety of tasks performed by the system, the conditions of its operation, and the set of elements that make up this system. In General, the construction of this system consists of the rational distribution of a given set of target tasks {X} between individual elements of the UAV system. Replacing the external target set of tasks {X} with some "design characteristic" in this case will be incorrect since the previously obtained "design characteristics" can lead to a significant systematic error in evaluating the effectiveness of a multi-purpose UAV system.

In General, regardless of what type of UAV should be used (operated) in the optimal structure of a multi-purpose system, the justification for the choice of characteristics to build the structure (framework) of such a system inevitably leads to the need to solve a class of optimization problems using the criterion of the minimum cost of the UAV system's target tasks at a given efficiency of their implementation.

The purpose of this work is to simulate the optimal structure of a multi-purpose UAV system using the generalized method of dynamic condensation in the study of tropical cyclones one of the most destructive and regularly recurring natural phenomena in the territories of the Earth and the world Ocean adjacent to the Socialist Republic of Vietnam.

2 The Task of Justifying the Choice of Characteristics for Building a Multi-Purpose UAV System

Find

$$C\left[W, \tilde{D}, \tilde{E}\left(\vec{\omega}\right)\right] = \min_{\vec{a} \in D} \min_{E(x)} C\left[W, D, E\left(\vec{\omega}\right)\right], \quad (1)$$

where $C[W,D,E(\omega)]$ - the cost of a multi-purpose UAV system;

W - the external target set of tasks defined by vectors

$\vec{\omega} = \left\{m_{pl}, \varphi, \lambda, H\right\} \in W$;

m_{pl} – the payload mass, latitude - φ, longitude - λ and altitude - H of a given cyclone point;

$E\left(\vec{\omega}\right)$ - the target distribution function, which is defined by elementary distribution functions e_{ij}:$e_{ij}=1$, if the i-th task is performed by the j-th type of UAV and $e_{ij}=0$, otherwise.

$$E(\vec{\omega}) = \{e(1,1), e(1,2), ..., e(i,j), ..., e(n,m)\}; i = \overline{1;n}, j = \overline{1;m},$$

Here n is the given number of target tasks, m is the given number of UAV types.

D is a set of strategies for building a variant of the UAV system (Dirichlet region).

$e(i,j)=1$ if the i-th task is completed by the j-th UAV type; $e(i,j)=0$, otherwise.

Thus, the task of justifying the choice of characteristics of the structure of a multi-purpose UAV system is to search for such options (scenarios) for the survey of one of N goals using various types of UAVs to obtain operational remote sensing information, in which the probability of completing the target task P_{tc} will be maximum.

In this task, not only the optimal distribution of target tasks by UAV types is selected, but also the corresponding design solutions for each of the separate UAV types. Problem (1) is solved under the following parametric constraints on design solutions [4, 5]:

$$\begin{cases} P_{0\,\min} \le P_0 \le P_{0\,\max}; \\ \mu_{\mathrm{PS}\min} \le \mu_{PS} \le \mu_{\mathrm{PS}\max}; \\ m_{\mathrm{W}\min} \le m_W \le m_{\mathrm{W}\max}; \\ M_{0\,\min} \le M_0 \le M_{0\,\max}. \end{cases} \quad (2)$$

where the vector of design parameters $\vec{a}$ defines the key characteristics of the UAV's appearance and has the following components: $\vec{a} = (P_0, \mu_{PS}, m_W, M_0)$, where P_0 is the thrust of the propulsion system (PS); μ_{PS} is the relative mass of the propulsion system; m_W is the weight of the wing; M_0 is the UAV's initial mass.

Functional restrictions have the form:

$$g_1 = D_i \cap D_j = \varnothing; \quad g_2 = \bigcup_{j=1}^{m} D_j = W, \quad (3)$$

here $D_j = \{\omega \in W \mid E(\omega) = j\}, j = \overline{1,m}$, - the Dirichlet region.

It is assumed that the solution to the problem of the functioning of a multi-purpose UAV system is related to the area of acceptable design solutions for completing UAVs with special (PDC) and service equipment, which is determined by parametric and functional restrictions of the form [6]:

$$D = \{a \in A, u \in U, a_{\min i} \le a_i \le a_{\max i}, i = \overline{1,n}, u_{\min j} \le u_j \le u_{\max j}, j = \overline{1,m}, \\ g_r(d) \ge 0, r = \overline{1,g}\}, \quad (4)$$

where A, U are the permissible regions in the parameters and control;

$$a_{\min i} \le a_i \le a_{\max i}, i = \overline{1,n}, u_{\min j} \le u_j \le u_{\max j}, j = \overline{1,m}$$

are the restrictions on the design parameters of the UAV and its motion control functions, respectively; $g_r(d) \ge 0, r = \overline{1,g}$ are the functional restrictions; $\vec{d} = [\vec{a}, \vec{u}(t)]$ is the UAV design solution vector; $\vec{\omega}$ is the vector of characteristics of the target task of a multi-purpose UAV system.

The first functional restriction in the task (1) means that the set of target tasks performed by the *i*-th type of UAV does not intersect with the set of target tasks performed by the *j*-th type of UAV.

The physical meaning of the second functional constraint in problem (1) means that the structure of the UAV system must be constructed specially. More specifically, it should be possible to redistribute a given set of target tasks to each other on a time scale that is close to real-time. At the same time, the cost of the entire UAV system for obtaining the necessary remote sensing information with the required frequency and updating it should be minimal.

The generated problem of the form (1) belongs to the class of problems of multi-criteria multiparametric multi-factor identification of indicators and characteristics of complex organizational and technical systems and their structural and parametric optimization. This problem is solved by the generalized method of dynamic condensation [7, 8, 9].

3 The Algorithm of the Generalized Method of Dynamic Condensation (GMDC)

The generalized method of dynamic condensation consists of using a combination of the possibilities of the optimization method in the space of inverse functions and the possibilities of the dynamic condensation method. Based on the method of dynamic condensation, a certain verification function is formed that allows you to build the final distribution of target tasks between individual types of UAVs based on the distances between the design parameters of the UAV.

To apply the inverse function method, you must set parametric restrictions on the variable parameters of the UAV type (2) and the corresponding functional restrictions.

The measure of adequacy between a subset $A^{'} \subset A$ and an object *y* is defined as follows [10]:

$$D\left(A^{'},y\right)=\sum_{a\in A^{'}}\mu\left(a\right)d^{-1}\left(a,y\right)=\sum_{a\in A^{'}}\mu\left(a\right)\rho^{2}\left(a,y\right), \qquad (5)$$

where $\mu(a)$ is " the weight" coefficient in the context of task (1), i.e. the required number of modules required to justify the configuration of all types of UAV multi-purpose system.

The function of representation (selection) of UAV parameters for a set of target tasks $g(P)=L$ matches each cluster P_k with its representative l_k by the condition:

$$l_k = g\left(P_k\right)=\left[a_j \in P_k \middle| \max_j d\left(a_j, y\right)\right], \qquad (6)$$

where $y \in R^p$ - cluster center of gravity P_k.

$$y = \frac{\sum\limits_{a_j \in P_k} \mu\left(a_j\right)\rho\left(0, a_j\right)}{\sum\limits_{a_j \in P_k} \mu\left(a_j\right)}, \qquad (7)$$

Thus, the object *y* that is closest to the center of gravity of the cluster with P_k is selected as the cluster representative.

The assignment function (distributing targets by UAV type) *f(L)=P* takes integer values *1,2,…,k* and distributes objects to clusters:

$$P_i = \left\{ a \in A \middle| d\left(a, l_i\right) > d\left(a, l_j\right) \right\}, \qquad (8)$$

In the case, if $d(a,l_i)=d(a,l_j)$, then $a \in P_i$ when $i<j$.

Indicator of optimal splitting of a set of modules *A* into clusters

$$P_k, A = \left\{P_k\right\}; P_i \cap P_j = \varnothing$$

has the form:

$$Arg \min W\left(P, L\right) = \sum_{i=1}^{K} D\left(P_i, l_i\right) = \sum_{i=1}^{K} \sum_{a \in P_i} \mu\left(a\right) d^{-1}\left(a, l_i\right), \qquad (9)$$

Where l_i is representative of the *i*-th cluster, selected based on the results of an assessment of proximity to the center of gravity of this cluster.

It is obvious that the criterion *W*expresses the average intra-cluster dispersion of the UAV's set of parameters *{P}* splitting into corresponding clusters P_i.

The optimization problem of splitting a set of homogeneous modules *A* into an optimal number of clusters is solved as follows.

The pair $<P^*, L^*>$, that characterizes the set of UAV design parameters and the target tasks to be solved is formed as a set of partitions by UAV types and its corresponding set of representatives so that the condition is met:

$$W\left(P^*, L^*\right) = \min_k \sum_{i=1}^{K} \sum_{a \in P_i} \mu\left(a\right) d^{-1}\left(a, L_i\right), \qquad (10)$$

The algorithm for finding the optimal pair formation $<P^*, L^*>$ and partition of sets $\{P_k^*, L^*\}$ consists of the following iterative steps [8, 11]:

Step1. Search for the optimal partition of the set P_k at *k=const*.

Step2. Selecting a candidate object $a' \in A$ for the *(k+1)*-th cluster representatives P_k.

Step3. Checking for convergence to the desired solution.

The rule for selecting object *y* as a representative of the new *(k+1)* -th cluster P_{k+1} has the form:

$$l_{k+1} = \left(a_j \in A \middle| \min_k \min_{a_j \in P_k} d(a_j, l_k) \right), \qquad (11)$$

that is, the object y with the minimum similarity measure to its cluster P_{k+1} is selected as a candidate for representatives, or, in other words, the most remote object in metrics $\rho(a,y)$.

Indicator of optimal splitting of a set of modules A into clusters

$$P_k, A = \{P_k\}; P_i \cap P_j = \varnothing$$

has the form:

$$Arg\ \min W(P,L) = \sum_{i=1}^{K} D(P_i, l_i) = \sum_{i=1}^{K} \sum_{a \in P_i} \mu(a) d^{-1}(a, l_i), \quad (12)$$

where l_i- the representative of the *i*-th cluster, selected based on the results of an assessment of proximity to the center of gravity of this cluster.

To estimate the end of the iterative process, use the condition:

$$\max_{a_j \in P_k} \rho(a_j, l_k) \le \varepsilon, P_k \subset A \quad (13)$$

where ε - the given accuracy of the target function.

The algorithm of the generalized method of dynamic condensation (GMDC) is shown in figure 1 (see fig. 1). [5, 6].

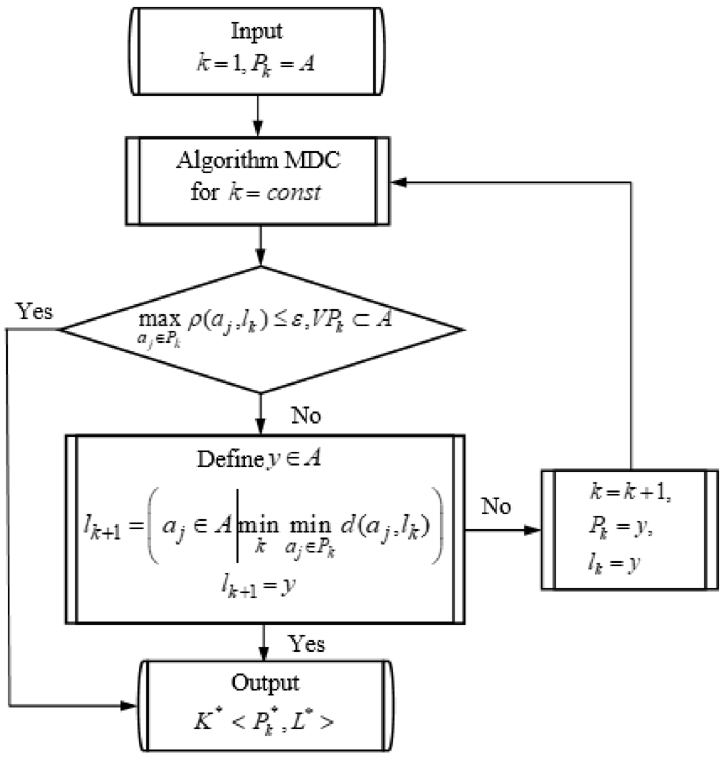

Fig. 1. Algorithm of the generalized method of dynamic condensation (GMDC).

Figure 2 shows the algorithm of the generalized method of dynamic condensation (GMDC). In its final form the GMDC algorithm consists of the following sequence of iterative steps [9, 11]:

Step 1. Put $k=1$, $P_k=A$ (l_i can be selected at random).

Step 2. Execute the GMDC algorithm for the current value $k=const$.

Step 3. For the given accuracy ε check whether the condition (9) is met.

a. If this condition is met, the algorithm is complete, and the division of the set of design parameters by UAV P_k type and representation L_k by UAV target tasks are considered final.

b. If this condition is not met, then you need to go to step 4.

Step 4. Define the object $y \in A$ that meets the condition (11).

Step 5. Put $k=k+1$, $P_k=y$, $l_k=y$ you can go to step 2 of the algorithm by excluding the object from the cluster that it belonged to in the previous step.

Thus, the generalized method of dynamic condensation consists of using a combination of the possibilities of the optimization method in the space of inverse functions and the possibilities of the dynamic condensation method. Based on the method of dynamic condensation, a certain verification function is formed that allows you to build the final distribution of target tasks between individual types of UAVs based on the distances between the design parameters of the UAV.

4 The solution to the Problem of Substantiating the Choice of Characteristics for Building a Multi-Purpose UAV System

The solution of a set of tasks for modeling the optimal structure of a multi-purpose UAV system for sensing the Earth's atmosphere is carried out in the following sequence.

Step 1. For each payload using a UAV, a statistical sample of the form is constructed (see Table 1) [7]:

Table 1. The statistical sample of UAV design parameters.

$\vec{a}$	c_{Σ_i}	N

where N - the volume of the statistical sample, $\vec{a}$ - the vector of UAV design parameters, $c_{\Sigma i}$ - the total cost of i-th acceptable variant of building a multi-purpose UAV system.

Step 2. Based on the obtained statistical samples, in the class of power polynomials, for each payload using UAVs, dependencies $C_i = C_i\left(\vec{a}\right), i=\overline{1,8}$ are constructed, and optimization problems $C_i = \min_{\vec{a} \in D} C_i\left(\vec{a}\right), i=\overline{1,8}$ are solved by the generalized method of dynamic condensation, which determines the optimal vectors of UAV design parameters $\vec{a}_{opt}, i=\overline{1,8}$ and the minimum cost of a multi-purpose UAV system.

Step 3. To implement strategies for structural selection of optimal variants of a multi-purpose UAV system, all design parameters $\vec{a}$ are converted to a dimensionless form, and new variants of the structure of UAV systems are formed for different accuracy $\varepsilon^{opt}(i,j)$ of building a multi-purpose UAV system.

Step 4. The total cost of a multi-purpose UAV system was calculated using the formula [10, 12]:

$$C_{\Sigma} = \sum_{i=1}^{s}\sum_{j=1}^{p} n_j c_j, \qquad (14)$$

where s is the number of UAV types in a multi-purpose UAV system, p is the number of payloads (PDC) delivered by the i-th type of UAV, n_j is the number of UAVs required to service the j-th payload (PDC).

The matrix of configuration options for a multi-purpose UAV system has the form (Table 2).

Table 2. Matrix of options for completing a multi-purpose UAV system.

x_1	x_2	…	$x_{nц}$	$J(X,A,E(x))$
$(a_1)_{1,j1}$	$(a_1)_{2,j2}$	…	$(a_1)_{nц,jnц}$	$J_1(X,A,E(x))$
$(a_2)_{1,j1}$	$(a_2)_{2,j2}$	…	$(a_2)_{nц,jnц}$	$J_2(X,A,E(x))$
…	…	…	…	…
$(a_n)_{1,j1}$	$(a_n)_{2,j2}$	…	$(a_n)_{nц,jnц}$	$J_{nц}(X,A,E(x))$

Here, J_i^{opt} is the optimality criterion of the i-th target task, $\overrightarrow{\omega_i}\left(e(i,j)\right)$ is a vector of characteristics of i-th target task, $\overrightarrow{a_j}$ is the vector of design parameters characterizing the j-th type of UAV [10, 13].

$$J_i^{opt} = \min_{\vec{a}_j \in A}\left[\overrightarrow{a_j}, \overrightarrow{\omega_i}\left(e(i,j)\right)\right], \qquad (15)$$

The vector of characteristics of the i-th target problem for the j-th type of UAV $\omega_i(e(i,j))$ characterizes the dependence of the optimality criterion J_i^{opt} on which type of UAV the i-th target problem is performed in the interests of the UAV system. Besides, for each target, you must generate the corresponding optimality criterion, in particular, these criteria may coincide. Based on the values of partial optimality criteria, a generalized integral criterion for structural and parametric selection of a multi-purpose UAV system is formed [14]:

$$J_{\Sigma}^{opt} = F\left(J_1, J_2, ..., J_i, ..., J_{n_ц}\right). \qquad (16)$$

Here *F(…)* is a convolution of partial criteria of optimality $J_1, J_2, \ldots, J_i, \ldots, J_{nij}$. In particular, when solving special problems, the most common convolution is the additive convolution of particular criteria, which is typical for evaluating technical, economic, and cost criteria [17,22].

Optimal accuracy of building a multi-purpose UAV system is achieved by formalizing algorithmic procedures that exclude subjectivism when justifying the structure of a multi-purpose UAV system. Previously, the corresponding cost of the structure of a multi-purpose UAV system is determined for various specified values and a statistical sample of the type is formed (Table 3)

Table 3. The statistical sample of the cost of a multi-purpose UAV system structure.

ε	J(A,W,E(ω))
ε_1	J_1(A,W,E(ω))
ε_2	J_2(A,W,E(ω))
…	J(A,W,E(ω))
ε_N	J_N(A,W,E(ω))

Based on the data from a statistical sample, a dependency of the following type is formed [15]:

$$J\left(A, W, E(\omega)\right) = c_1\varepsilon^{\alpha_1} + c_2\varepsilon^{\alpha_2} + \ldots + c_n\varepsilon^{\alpha_n}, \qquad (17)$$

Linear and nonlinear parameters $c_1, c_2, \ldots, c_n, \alpha_1, \alpha_2, \ldots, \alpha_n$ are determined from the minimum condition of the regularity criterion, and the optimal accuracy of the structure of a multi-purpose UAV system is determined from the condition:

$$\frac{\partial J\left(A, W, E(\omega)\right)}{\partial(\varepsilon)} = 0 \Rightarrow \varepsilon^{opt}, \qquad (18)$$

A special case of building a multi-purpose UAV system is a scenario where the j-th target task is characterized by the delivered payload mass mplj with the launch frequency nj, where $j = \overline{1, n}$. The cost criterion CΣ for a multi-purpose UAV system is used as an optimality criterion. It is assumed that if at a given value P(mplj) is the thrust of the UAV propulsion system, the design solution allows you to deliver a payload of mass mplj to a given height Hgv, then the same type of UAV can deliver payloads of a smaller mass mplj-1, mplj-2,…, mpl1 to the same height.

Based on statistical samples from table 4, for each target problem, polynomials in the power function class are restored from a given external set of targets [15]:

$$\begin{cases} C_1 = C_1^{(1)} d_1^{\alpha_1^{(1)}} + C_2^{(1)} d_2^{\alpha_2^{(1)}} + \ldots + C_n^{(1)} d_n^{\alpha_n^{(1)}}, \\ C_2 = C_1^{(2)} d_1^{\alpha_1^{(2)}} + C_2^{(2)} d_2^{\alpha_2^{(2)}} + \ldots + C_n^{(2)} d_n^{\alpha_n^{(2)}}, \\ \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \\ C_n = C_1^{(n)} d_1^{\alpha_1^{(n)}} + C_2^{(n)} d_2^{\alpha_2^{(n)}} + \ldots + C_n^{(n)} d_n^{\alpha_n^{(n)}}. \end{cases} \qquad (19)$$

A generalized criterion for the cost of creating a multi-purpose UAV system of optimal structure can be presented in the following form [10]:

$$C_{\Sigma} = J\left(X, A, E(x)\right), \quad (20)$$

which characterizes, in General, the total cost of creating a multi-purpose UAV system of the optimal structure taking into account the features of its design technical characteristics and the diversity of the target tasks to be solved.

The cost of a multi-purpose UAV system is defined as the sum of the costs of the *i*-th UAV structure, which are necessary for the formation of this variant of a multi-purpose system, and the cost of R & d in the development of appropriate types of UAVs. R & d costs for the development of *i*-th type UAVs are defined as:

$$C_{i\ R\&d} = C_{\text{yd}} M_{0i}, \quad (21)$$

where C_{yd} is specific R & d costs, M_{0i} is the starting mass of the *i*-th type of UAV.

Table 4. The statistical sample of options for completing a multi-purpose UAV system.

m_{pl1}	m_{pl2}	...	m_{plj}	...	m_{pln}	C_{Σ}
$P(m_{pl1})_1$	$P(m_{pl2})_1$	...	$P(m_{plj})_1$	...	$P(m_{pln})_1$	$C_{\Sigma 1}$
$P(m_{pl1})_2$	$P(m_{pl2})_2$	...	$P(m_{plj})_2$	...	$P(m_{pln})_2$	$C_{\Sigma 2}$
...	...	...	...	...	...	...
$P(m_{pl1})_i$	$P(m_{pl2})_i$	...	$P(m_{plj})_i$	...	$P(m_{pln})_i$	$C_{\Sigma i}$
...	...	...	...	...	...	...
$P(m_{pl1})_N$	$P(m_{pl2})_N$	...	$P(m_{plj})_i$	...	$P(m_{pln})_N$	$C_{\Sigma N}$

The total cost of a multi-purpose UAV system is as follows:

$$C_{\Sigma} = \sum_{j=1}^{n} C_j + \sum_{j=1}^{n} C_{j\ R\&d}, \quad (22)$$

The obtained value of the optimality criterion $Arg \min C_{\Sigma}^{(1)} = C_{\Sigma}\left(\varepsilon_1^{opt}\right)$ is compared with the best extreme value of the target function:

$$\left|C_{\Sigma} - C_{\Sigma}^{(1)}\right| \le \delta, \quad (23)$$

where δ - the given accuracy of cost estimates of variants of the structure of a multi-purpose UAV system.

For the *k*-th step we have: $\tilde{C}_{\Sigma}^{(k)} = C_{\Sigma}^{(k-1)} - \Delta C_{\Sigma}$, and local optimization is performed according to the criterion [10]:

$$J = \min_{\varepsilon}\left|\tilde{C}_{\Sigma}^{(k)} - C_{\Sigma}^{(k)}\right|, \quad \varepsilon = x_1 \cos\left(\frac{2\pi \tilde{C}_{\Sigma}^{(k)}}{x_3}\right) + x_2 \sin\left(\frac{2\pi \tilde{C}_{\Sigma}^{(k)}}{x_3}\right), \quad C_{\Sigma}^{(k)} = C_{\Sigma}^{(k)}(\varepsilon), \quad (24)$$

The condition for the end of the process of optimizing the accuracy of the structure of a multi-purpose UAV system is the output of the variable parameter ε to the given constraints.

The optimal multi-purpose UAV system was built from the condition of delivery of eight target remote sensing data collection platforms (PDC) remote sensing of the Earth (RSE) to various points (targets) in the South China sea. The origin of the coordinates was located at the start point of the UAV in the area of da Nang, Vietnam. Target remote sensing data collection platforms (PDC RSE) for monitoring tropical cyclones were located at points with coordinates (figure 2) (in meters):

1. p. A (350 000; 50 000)
2. p. B (300 000; 80 000)
3. p. C (35 000; 20 000)
4. p. D (280 000; 70 000)
5. p. E (250 000; 40 000)
6. p. F (310 000; 10 000)
7. p. G (360 000; 90 000)
8. p. H (250 000; 10 000)

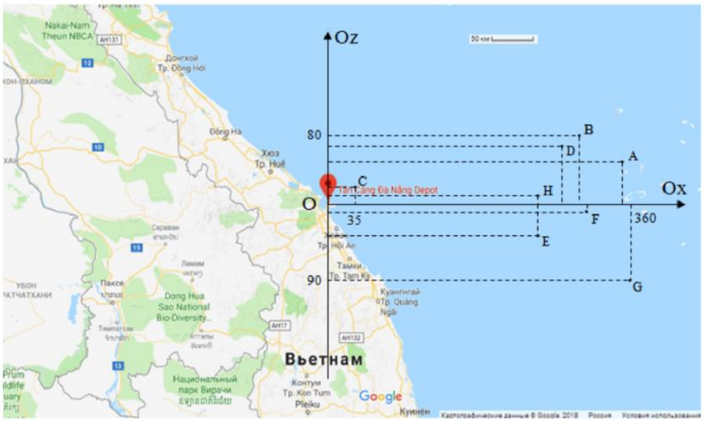

Fig. 2. Point of delivery platforms to collect remote sensing data RSE using a UAV (in km).

5 Simulation Result

The probabilities of completing the target tasks $P_1, P_2, \ldots, P_8$ and the number of UAV launches $n_1, n_2, \ldots n_8$ are shown in Table 5.

The required number of UAVs for a multi-purpose system with the required target payloads (PDC) $m_{pl\,i}, i=\overline{1,8}$ is determined based on the given efficiency P_i of the delivery of the i-th PDC to the specified area.

Table 5. Structural-parametric synthesis of a multi-purpose UAV system.

P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
0,6	0,7	0,65	0,5	0,8	0,75	0,8	0,8
n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
4	3	3	5	2	3	2	2

Probability of covering the *i*-th point of the goal [4, 5]:

$$P_{\mathrm{cov}_i} = \frac{n_{y0}}{n_{\Sigma}}.e(i,j), \qquad (25)$$

where n_{y0} is the number of successful realizations (when there is a convergence with the *i*-th goal); n_{Σ} is a total number of realizations.

The required number of UAVs of the *i*-th type is defined as [6]:

$$n_i = \frac{\lg(1-P_{\Sigma})}{\lg(1-P_i)}, \qquad (26)$$

where P_{Σ} is the total efficiency of a multi-purpose UAV system, which in this task is assumed to be equal to $P_{\Sigma} = 0.7$.

The following numerical results are obtained:

Parameters	The distribution of the targets according to the types of UAV
X(1) = 1,367	e(1,1) =1- the first target task is solved by 1-th type of UAV;
X(2) = 2,892	e(2,2) =1- the second target task is solved by 2-th type of UAV;
X(3) =1,245	e(3,1) =1- the 3-th target task is solved by 1-th type of UAV;
X(4) =2,080	e(4,2) =1- the 4-th target task is solved by 2-th type of UAV;
X(5) =2,591	e(5,2) =1- the 5-th target task is solved by 2-th type of UAV;
X(6) =3,969	e(6,3) =1- the 6-th target task is solved by 3-th type of UAV;
X(7) =3,003	e(7,3) =1- the 7-th target task is solved by 3-th type of UAV;
X(8) =3,479	e(8,3) =1- the 8-th target task is solved by 3-th type of UAV.

Thus, the obtained multi-purpose UAV system of an optimal structure consists of three types: the first type of UAV serves target platforms with masses $m_{pl}=150kg$ and $m_{pl}=250kg$; the second type of UAV serves platforms with masses $m_{pl}=200kg$, $m_{pl}=300kg$, and $m_{pl}=350kg$; the third type of UAV serves platforms with masses $m_{pl}=400kg$, $m_{pl}=450kg$ and $m_{pl}=500kg$.

The total cost of the optimal structure of a multi-purpose optimal UAV system is: $C_{\Sigma}^{opt} = 0,86 \times 10^{6}\, y.e.$, which gives a cost-benefit of about 4-5% less than using a UAV system with the same type of specialized UAVs.

6 Conclusions

The developed generalized method of dynamic condensation (GMDC) consists in comprehensive use of the possibilities of solving a class of optimization problems in terms of justification and selection of structures of multi-purpose UAV systems of a given accuracy both in the space of its inverse characteristics and taking into account the possibilities of final prioritization of the distribution of target tasks by types of UAVs and restrictions on their design parameters.

As a result of solving the problem of finding the optimal design solution, the structure of a multi-purpose UAV system costs about 4-5% less than the use of a system with the same type of specialized UAVs is obtained.

The results of the solution of the formulated scientific problem should be used in the future when forming the tactical and technical requirements (TTZ, TZ) of the Customer for the creation (modernization) of promising multi-purpose UAV systems when solving remote sensing problems in terms of evaluating the effectiveness of their functioning, and evaluating the resource provision, in particular, costs.

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