

УДК 629.7.067

DOI: 10.26467/2079-0619-2021-24-4-28-37

MULTIDIMENSIONAL ROUTING WITH THE INCREASED NAVIGATION ACCURACY WITH THE MAINTENANCE OF FLIGHT NOTIFICATIONS OF THE FLIGHT VEHICLES

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The study was conducted with the financial support of the Russian Foundation for Basic Research, grants № 19-08-00010, № 20-08-00652

The article covers the problem the multidimensional routing of flights for the transportation of cargo and mail, with the condition of the corresponding equipment presence for performing navigation of increased precision to obtain the possibility of the formation flights under any weather conditions. The given circumstances are capably essential to reduce load while using the airspace, which will make it possible to achieve transportation independent of its saturation. While planning the routes it is also necessary to consider the interests of different interested groups, which are often opposite to one another. In the view of the different directivity of the tasks in question, the solution can require the sorting as excessively as large, so the smaller quantity of possible situations (versions of the solution), the lower the level of the calculation of these versions is, and the greater their quantity is. The exact example of multidimensional routing, which is affected by the interests of operational nature and the interests of the urgency of the performance of the claims, expressed by weight coefficients, is depicted in this work. The only version in favour of the general production process, which is obtained with the help of a genetic algorithm, is a solution of this problem. It was necessary to introduce some designations and assumptions, the enumeration of which can be supplemented. Optimal solution can be obtained both by the enumeration of the solution versions and with the help of the genetic algorithm, which is allowed for a smaller number of iterations, to obtain suboptimal in real time, which corresponds to the conditions of the task solution. In that the example dynamic priorities are assigned, based on multiplicative form by expert evaluation, which form criteria for the ranking of request for each step of route planning. As a result, there are the exact versions of the solution, which correspond to the interests of different groups and the version, obtained with the help of a genetic algorithm, which satisfy the opposite interests of these groups. All versions of the solution are proved to be different, which indicates the need of applying the objective and substantiated apparatus for making the decision, which the genetic algorithm actually is. The proposed mathematical apparatus has prospects for implementation.

Key words: multidimensional routing, high-precision navigation, genetic algorithm (GA).

INTRODUCTION

The main subject of research in this work is the genetic algorithm (GA) efficiency evaluation while using multidimensional routing.

Planning of the optimal routes of the group flights of unmanned aircraft, along with the small aircraft, is the multiobjective problem. The subject of research is the GA effectiveness evaluation for multidimensional routing of the aircraft with corresponding airborne equipment for area navigation RNAV, based on the GNSS satellite system. The formation flights are not performed in commercial aviation so far. The situation may be fundamentally changed provided that high-precision navigation, enough for the execution of the formation flights under all weather conditions, is used. Such flights may be executed for cargo and mail delivery. At the same time, the solo flights of the given type may significantly overload the air traffic service, and that will have a negative impact on the passenger aircraft flights. The establishment of the aircraft flight routes multidimensional optimization mechanism considering the possibility of grouping the routes into the separate formations while considering the interests of the involved commercial service providers and air traffic security services is required at this regard [1, 2, 3].

There is a wide range of factors, influencing the efficiency evaluation while planning considering the contradictory interests of the contracting authorities and perpetrators [4, 5]. Besides that, there is the opportunity of considering rapidly the requests not only for the free aircraft, on the ground, but also for the aircraft, actually performing the delivery [6, 7]. Thus, the objective of the present study is the formation of the approach to multidimensional routing of the aircraft flights on requests, based on compatibility of GA with the allocation of request targets between the free and busy aircraft, the condition of which is known at every step of planning.

PROBLEM STATEMENT

1. It is considered, that the requests for airspace management occur randomly [7, 8] and can be divided into 3 types:

- advance (are formalized every morning before planning);
- urgency (occur after planning);
- priority (requests while performing the flight).

The number n of these requests exceeds the number N of the aircraft.

$$N \ll n < 10 \quad (1)$$

2. The destinations are located randomly corresponding to the Poisson distribution [7], or in the separate areas of high density.

3. Every request is characterized by the known parameters: the number of the request (m), the coordinates X_i ; Z_i of the i -th initial point of departure and the coordinates X_j ; Z_j of the j -th terminal point of arrival, and also the maintenance holdover time τ_m for priority provision.

4. The number N of the aircraft and their current coordinate points X_i ; Z_i either on the stand, or in flight in real time are given.

5. The increased navigation accuracy is required for flight security support in the aircraft formation. The flight of the aircraft formation is regarded as one aircraft by the air traffic control and there is no oversaturation of the airspace.

6. It is necessary to:

- form the efficient approach to the multidimensional routing, based on the combination of the genetic algorithm (GA) with the operation of allocation of targets between the free and busy aircraft at each step of the priority requests;
- estimate the efficiency of the suggested approach in comparison with the known routing algorithms.

THE SUGGESTED APPROACH TO THE SOLUTION OF THE PROBLEM

Planning of the optimal routes is performed in two steps:

1. Forming of the initial "elite" of the multidimensional routes, chosen from the variants, predetermined while performing the multiple calculation with the different priority request criteria of performing the application at each step of planning. The criteria may consider the contradicting interests of the air traffic control services in terms of the exclusion of overloading the airspace [9], and also the commercial interests.

2. At the first step of managing the requests the calculation of the dynamic priority Π_j is carried out on a formula:

$$\Pi_j = \max_{j=1 \dots N} \left[\frac{r_{min}}{r_{ij}} + \eta_1 \right] \left[\frac{\tau_j}{\tau_{max}} + \eta_2 \right], \quad (2)$$

where: r_{ij} – the distance between the beginning of the route by the j -th application and the estimated staging point of the i -th route;

r_{min} – minimal distance between the points;

τ_j – the holdover time of the application in the lineup;

τ_{max} – the maximum allowed holdover time;

η_1 и η_2 – weighting coefficients of the term signification (the less the η_1 , the more significant the first term is, provided that $\eta_1 + \eta_2 = 1$).

Thus, the normed parameter valuations are included into the formula (2) terms. It is necessary to notice, that the allocation of the route requests is performed at a single step of the planning simultaneously. Here it is necessary to distinguish the two cases:

– the number $\psi > 1$ of the free aircraft is large, which always happens before the beginning of planning [10, 11, 12];

– the number $\psi = 1$ which corresponds to the request on one aircraft. In this case the choice of the request for each route is made from the complete set of requests. Whether the results of the choice on different routes do not correspond to each other, the choice will be considered to be successful, otherwise – the request is performed by the aircraft, which is closer to the starting point. As a result each request is performed by the only aircraft. In the second case the aircraft is chosen on a formula (2), on a competitive basis.

Thus, whether the number of variants of the weighting coefficients η_1 and η_2 appointment on the criterion (2) is M , $M N$ of routes forming the initial elite for the next step of calculations [13]. There are two subjective variants of the weighting coefficients $\eta_1 = 0.2$ и $\eta_2 = 0.8$ used in this work.

At the second step M the formed routes for each aircraft are used in the GA, in which each route is divided into the set of blocks (legs), consisting of two and more points of destination. This allows us to perform breeding of the blocks, taken from the different variants, along with the "mutation" due to partial rearrangement, changing their order. As a result, the expanded set of the "descendants" of the initial "elite" is formed. After that they perform the operation of the "genetic breeding", there is the integral criterion of planning efficiency J_0 considering the interests of the groups which is necessary for the criterion. It is suggested to use the minimizing penalty function, estimating the degree of imperfection of the system both for the contracting authorities and perpetrators, and the principle of demand (the quantity of the requests) and proposal (the number of the free aircraft) balance. We set the normed valuations of holdover time and route length, along with the matched weighting coefficients $m_3 = m_4$.

$$J_v = \min_{v=1 \dots MN} \left[\left(\max_{i=1 \dots N} \frac{\eta_i}{T_{max}}(v) + m_3 \right) \left(\frac{\sum_{i=1}^N L_i(v)}{L_{max}} + m_4 \right) \right], \quad (3)$$

where: J_0 – the integral penalty function;

v – the number of the variant after breeding and mutation;

T_{max} – the maximum holdover time of performing the request;

L_{max} – the maximum integrated route length of all the aircraft;

$L_i(v)$ – the length of every route in the i -th variant;

$\max \eta_i(v)$ – the maximum equipment downtime of the application in line in the v -th variant.

The multiplicative form (3) corresponds to the minimum assured penalty result principle. The calculation shows us that the number of evolution steps by (3) is not large.

Example: let us consider the following problem of routing of formation of the three aircraft flight from departure point to the arrival point (24 all together) corresponding to the requests for the area of 250 square kilometers as it is shown in (fig. 1).

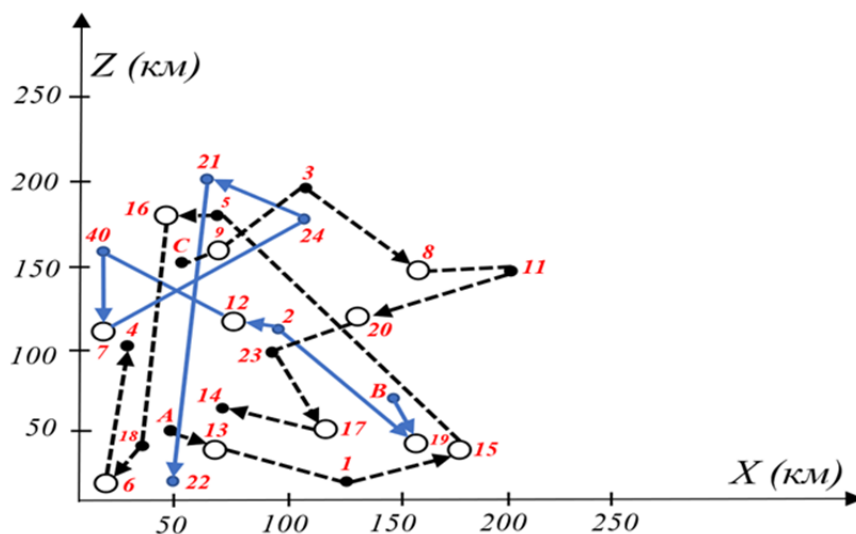


Fig. 1. A picture of the location of the serviced points on a given territory.
Sign O – departure point according to the application

Initially there were 12 requests, there are the coordinates of the departure point $X_i; Z_i$ in each of them and the corresponding arrival point $X_j; Z_j$, as it is shown in Table 1. Setting of all the 24 points on the territory corresponds to the poisson appointment of the random variable and is of irregular character [14]. Initially, the aircraft are located in the points with the coordinates $X_A = 50; Z_A = 50; X_B = 150; Z_B = 50; X_C = 50; Z_C = 150$.

Table 1

Original departure and departure points data

№ of application	1	2	3	4	5	6	7	8	9	10	11	12
№ of the departure point	6	7	8	9	12	13	15	16	17	19	20	21
$X_{i(km)}$	10	20	170	70	80	70	190	50	120	160	130	70
$Z_{i(km)}$	10	110	130	150	120	20	30	170	50	30	120	200
№ of the arrival point	4	24	11	3	10	1	5	18	14	2	23	22
$X_{j(km)}$	30	90	200	150	10	130	70	50	70	100	120	60
$Z_{j(km)}$	120	170	140	180	160	10	170	0	70	120	150	10

Let us consider that receipt of requests is the subject of the poisson appointment, and the hold-over time in general queue is not identical [15, 16], but is known (τ_j) (Table 2).

Table 2

Holding time for requests

J	6	7	8	9	12	13	15	16	17	19	20	21
τ_j min	152	150	149	148	146	130	120	90	87	84	80	68

Let us use formula (2) for solving the routing problem for the two variants of requests of the dynamic priorities $\eta_1 = 0.2$ and $\eta_2 = 0.8$. There are three aircraft and 12 requests with corresponding

characteristics (see Table 1) at the first step $k = 1$. We choose the requests of the largest holdover time and the least distance, and receive the requests 6 and 13 for the first Aircraft₁(6;13), and, respectively, for Aircraft₂(13;15;19), Aircraft₃(5;9;16). The calculations show us, that the requests 13; 19; 9 are in the "elite", respectively, for the points 1, 2, 3 (see Table 1). At the second and subsequent steps one of the three aircraft is vacated before the other ones, and the calculations are performed considering this circumstance. For one, at $k = 2$ Aircraft₁ is the first one to be vacated, 7 is the following request for it – (Aircraft₁²-7). The requests for (Aircraft₂³-12), (Aircraft₃⁴-8) are determined in the similar way. There is a variant of the chosen routes at $\eta_1 = 0.2$ (see Figure 1) in Table 3.

Table 3

Optimal route configuration at $\eta_1 = 0.2$

Aircraft ₁	A	13	1	15	5	16	18	6	4
Aircraft ₂	B	19	2	12	10	17	24	21	22
Aircraft ₃	C	9	3	8	11	20	23	17	14

Let us perform the calculations while $\eta_2 = 0.8$ in the similar way, and summarize the results in Table 4.

Table 4

Optimal route configuration at $\eta_1 = 0.8$

Aircraft ₁	A	6	4	7	24	12	10	21	22
Aircraft ₂	B	17	14	16	18	13	1	19	2
Aircraft ₃	C	9	3	8	11	20	23	15	5

Significant differences in the results in Tables 3 and 4 show us the principal opportunity of using the GA for solving such problems, due to the fact that the initial "elite" consists of the "different ancestors" which do not have the same features. In order to carry out the genetic selection let us divide each route into two blocks – (the beginning and the end) belonging to the two requests. Then let us breed the four blocks by the principle "every block is merged with each of the rest ones" for each of the aircraft, as a result the total amount of rearrangements forms 9 variants. Let us choose one variant out of 9 of a minimal penalty function with the criterion (3), while considering the valuations of $T_0 = \tau_0 = 30$ min, approximately corresponding to the minimal holdover time of performing the request while the equality of demand and proposal interests. Considering the measures of the maximum holdover time and the total length of the routes T_{max} and L_{max} let us make the calculations for each of the 9 variations. As a result there are the new routes for all the Aircraft₁, Aircraft₂, Aircraft₃, different from the valuations in Tables 3 and 4.

Table 5

Optimal route configuration in genetic selection

Aircraft ₁	A	6	4	7	24	17	14	15	5
Aircraft ₂	B	12	10	21	22	13	17	19	2
Aircraft ₃	C	9	3	8	11	20	23	15	18

Using the GA in this problem showed us that:

- for variant 1 – the maximum holdover time took $T_{max} = 187$ out of all the 12 valuations for all the three routes, and the path length was $L_1 = 27$, $L_2 = 29$, $L_3 = 30$ respectively. The mean observation of the operational costs $T_{avg.} = 29$, and integral penalty function $J_v = 13020$;
- for variant 2 – $T_{max} = 165$, $T_{avg.} = 34$, $J_v = 12500$;
- while genetical selection – $T_{max} = 155$, $T_{avg.} = 36$, $J_v = 11470$.

CONCLUSIONS

In case of the small number of requests and managing the aircraft at their full search (corresponding to the setting of the given problem) the total amount of combinations exceeds 1500 variants. In the suggested approach to solving the problem with the help of the GA the number of variants does not exceed 100.

Using the GA provides us with the opportunity to choose the optimal variant of reducing the time of delay while insignificantly enlarging the operational costs considering both free and busy aircraft.

The total positive effect of formation flight planning optimization is not high enough due to the random way of locating the points on the territory. In case the part of the routes overlaps the ones published in the AIP, the probability of the formation flights will significantly rise.

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МНОГОМЕРНАЯ МАРШРУТИЗАЦИЯ С ПОВЫШЕННОЙ НАВИГАЦИОННОЙ ТОЧНОСТЬЮ ПРИ ОБСЛУЖИВАНИИ ЗАЯВОК НА ПОЛЕТЫ ЛЕТАТЕЛЬНЫХ АППАРАТОВ

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Работа выполнена при материальной поддержке РФФИ
(гранты № 19-08-00010, № 20-08-00652)

В статье решается задача многомерной маршрутизации полетов летательных аппаратов для перевозки грузов и почты, которые при условии наличия соответствующего оборудования для выполнения навигации повышенной точности получают возможность выполнения групповых полетов в любых погодных условиях. Данное обстоятельство способно существенно снизить нагрузку при использовании воздушного пространства, что позволит осуществлять перевозки независимо от его загруженности. В то же время при планировании маршрутов требуется учитывать интересы различных заинтересованных групп, зачастую имеющих противоположные интересы. В силу разной направленности решаемых задач решение может потребовать перебора как непомерно большого, так и малого количества возможных ситуаций (вариантов решения), чем ниже уровень учета этих вариантов, тем больше их количество. В работе представлен конкретный пример многомерной маршрутизации, на которую оказывают влияние интересы эксплуатационного характера и интересы срочности исполнения заявок, которые выражены весовыми коэффициентами. Решением такой задачи является единственный вариант в пользу общего производственного процесса, который получен с помощью использования генетического алгоритма. Для этого потребовалось ввести ряд обозначений и допущений, перечень которых может дополняться. Оптимальное решение может быть получено как простым перебором вариантов решения, так и при помощи генетического алгоритма, который позволяет за меньшее число итераций, в реальном масштабе времени получить субоптимальное, отвечающее условиям задачи решение. В приведенном примере экспертным путем назначаются динамические приоритеты на основе мультипликативной формы, которые формируют частные критерии для ранжирования заявок на каждом шаге планирования маршрутов. В результате получены конкретные варианты решения, отвечающие интересам разных групп, и вариант, полученный при помощи применения генетического алгоритма, удовлетворяющий противоположным интересам этих групп. Все варианты решения оказались различными, что говорит о необходимости применения объективного и обоснованного аппарата принятия решения, которым является генетический алгоритм. Предлагаемый математический аппарат имеет перспективы внедрения.

Ключевые слова: многомерная маршрутизация, навигация повышенной точности, генетический алгоритм (ГА).

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Поступила в редакцию
Принята в печать

15.05.2021
22.07.2021

Received
Accepted for publication

15.05.2021
22.07.2021