Solving the problem of risk synthesis as part of infrastructure facility management

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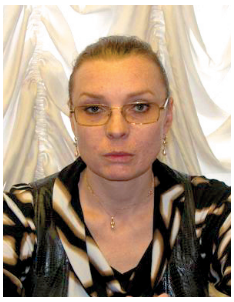

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Abstract. Aim. *Infrastructure facility management involves many decision-making problems that require estimating alternatives in the absence of clear criteria. Sufficiently common are problems that require the consideration of various numbers of factors. Those factors normally belong to different fields of knowledge and require the involvement of subject-area experts. Thus, for instance, the estimation of infrastructure facilities may involve economists, experts in land law, environment, logistics, design engineers and other specialists. The problem is often complicated by the existence of many alternatives. In such cases, it is difficult to organize even the initial expert evaluation in order to reduce the number of options for subsequent consideration. The paper primarily aims to develop a model of evaluation of the criteria that have an effect on the advisability of modernization of an infrastructure facility allowing to take into account factors from various fields of knowledge, as well as to elaborate a method of simplifying the process of evaluation of large numbers of alternative options. Therewith, such estimates can be expressed in various formats: both quantitatively and qualitatively. Such approaches have found application as part of the problem of ranking of airports as part of selection of candidates for inclusion into the Moscow air cluster (MAC). The specificity of this problem consists in the large set of various factors to be taken into account, as well as the great number of options, over 30 airports within 300 kilometers of Moscow.* **Methods.** *The risk synthesis model was used that relies on expert data that characterize the criteria that have an effect on the sought risk, as well as the values of damage for each facility by the given criteria. The criteria were estimated using a method based on pairwise comparisons allowing experts to define fuzzy and incomplete estimates of the preferability of the compared options. Damage estimation was done using the method of conversion of qualitative estimates into quantitative ones, as well as scaling of quantitative data into quantitative estimates of damage.* **Results.** *Implementing the ideas set forth in this paper allowed defining the contribution of eleven criteria that have an effect on the goals associated with relieving the MAC workload. Based on those criteria, specific risks for airports within 300 kilometers of Moscow were evaluated, and integral risks of modernization of each airport were obtained. The airports were then rated in terms of the integral risk of modernization.* **Conclusion.** *The suggested method is universal and can be used for decision-making under uncertainty in those domains where it is required to involve experts of various qualification and level of subject-matter knowledge, as well as accounting for many factors along with a great diversity of options.*

Keywords: *risk synthesis, method of incomplete pairwise comparison, estimation of damage, quantitative risk assessment.*

For citation: *Kuzmina N.M., Ridley A.N. Solving the problem of risk synthesis as part of infrastructure facility management. Dependability 2020;4: 42-49. https://doi.org/10.21683/1729-2646-2020-20-4-42-49*

Received on: *24.06.2020* / **Revised on:** *18.08.2020* / **For printing:** *18.12.2020*

Introduction

Managing infrastructure facilities is quite often associated with complex multi-aspect problems, whose solution requires the involvement of various subject-matter experts for the purpose of evaluating great numbers of factors, from economic to those related to land law or the environment. For many years, the problem of optimal decision-making in system management under the condition of poor mathematical formulation has remained of great relevance. It is characterized by, first, the uncertainty in the choice of the target function and definition of limitations associated with a large number of heteronymous and contradictory indicators of the possible system development scenarios, and second, the non-standard decision-making situation that consists in the capability to only calculate for each option only the values of individual indicators, lack of knowledge on and difficulty to implement a number of important properties of the objective function, properties of the search domain, etc. Overcoming uncertainties in the requirements for the quality of the options in non-standard situations is normally based on a more complete and correct formalization of a multi-objective decision-making problem that allows the construction of a set of regular algorithms (that is the reason such problems are normally regarded as poorly formalized). For that purpose, at the semantical level of the simulation, the concepts of goal hierarchy, resource, difficulty in achieving the objective, compensation, value equivalence function, etc. They are the foundation of the axiomatic construction of integrated indices that describe the properties of a system and its operational environment.

The decision-making in this case is generally defined as the process of selection of the best alternative out of those available, but, in practice, achieving optimal results may be difficult, as decision-makers (DMs) and experts often have difficulties making decisions. One of the most important sections of the decision theory used for the purpose of identifying the best decision out of those available is the multi-criterial decision-making (MCDM). There are several methods that enable improved MCDM, including: T. Saaty's [1] analytic hierarchy process (AHP); superiority and inferiority ranking method [2]; Simos ranking method [3]; multiple attribute utility theory (MAUT) [4]; ELimination Et Choix Traduisant la REalité (ELECTRE) [5-7]; preference ranking and choosing by advantages (CBA) [8]. Those methods, some of which the authors examined in the Abstract above, are often used for the purpose of simplifying decision-making as part of practical activity.

Saaty's AHP is the most popular MCDM that attracted a lot of attention and gained well-earned popularity over the last two decades. AHP provides the DM with powerful tools for making substantiated strategic decisions, which allows the DM using several quantitative criteria for estimating potential alternatives and selecting the optimal one. Such widespread use is certainly due to the simplicity of its application and the structure of AHP that reflects the intuitive method of problem-solving by the DM. The hierarchical modeling of a problem, capability to use verbal assertions and conformance verification are the primary advantages of the method. Along with the conventional applications, new ones develop, e.g. those that consist in using AHP in combination with other methods: mathematical programming methods, such as linear programming, data envelopment analysis (DEA), fuzzy sets, genetic algorithms, neural networks, SWOT analysis, etc. One of the significant shortcomings of AHP is the growing computational complexity of finding proper values as the dimension of the MCDM matrix grows, however, there is no doubt that the application of AHP will be becoming more and more widespread.

As an example of its practical use, let us examine the problem of reducing the workload of the Moscow air cluster (MAC) that is the airport system of Moscow and Moscow Oblast. The airports of MAC perform 800 ths airfield operations a year as part of passenger, cargo and business flights. An overwhelming majority is passenger operations that, according to statistical data[1], ensure a passenger flow of over 100 mil a year. According to projections, by 2030, the passenger flow will be as high as 180 mil people per year [9], which will require an increased system capacity. Modernizing MAC airports is currently insufficient due to the high load on Moscow's overland transportation systems, which brings about the discussion of increasing the number of the airports.

Building a new airport is costlier that upgrading an existing one. For instance, according to preliminary estimates, constructing a passenger terminal would cost 30 bln rubles, while upgrading and existing one is about 5-7 bln rubles. As there are many airports in and around Moscow and Moscow Oblast, it is primarily required to evaluate the practicality of investment in each particular airport. Investment into the modernization of each of them bears a number of risks associated with their efficiency in terms of reducing the load on the MAC.

The difficulty to estimate the alternatives is due to the large number of factors affecting the decision-making process and non-availability of appropriate statistics. That inevitably requires the involvement of experts in various fields of knowledge. Such experts can provide a qualified assessment in their area of competence, but struggle when it comes to related fields. Due to the mutual relation and effect of decision-making factors, the problem of processing expert judgements arises, in which the estimates of some factors for the compared alternatives are missing or fuzzy. Such untrivial problem can be solved using the so-called method of risk synthesis [10].

Let us examine the problem of MAC workload in this setting.

1. Problem definition

Let K_1, K_2, …, K_n be the list of n criteria, upon which

[1] Source: https://bit.ly/MOW_stat19, statistics of the Federal Air Transport Agency of Russia (https://favt.ru/)

it is required to estimate and rank the list $A_1, A_2, \ldots, A_m$ of m airports in terms of the magnitude of the risk associated with their modernization for the purpose of relieving the load on the MAC.

The risk in this case is defined by the magnitude of possible damage caused by the realization of the alternative selected as the result of the analysis as compared to the ideal situation that is characterized by the absence (or acceptable minimum for the DM) of such damage. In this setting, the risk is understood in terms of the effect of uncertainty on the achievement of the specified objectives[1]. The uncertainty in the context of the problem under consideration is due to the uncertainty of the selected criteria and the degree of their effect, while the aim is to relieve the load on the MAC at the minimal possible cost. In this context, it is pointless talking about the frequency or probability of risk realization, as the aim of the analysis consists in selecting the MAC modernization project that is acceptable in terms of damage in case of inefficient operation.

The risk of an item (process) is the value proportional to the deviation from the item (process) quality reference [11, p. 15]. The quality of items and the risk can be measured in comparable scales. The measure of risk is the "threat of changes in the composition or properties of the item or its environment, or emergence of changes associated with possible undesirable processes that are due to anthropogenic or natural effects". At the same time, it is emphasized that the sense of the definition is probabilistic.

At the bottom level of the hierarchical structure, the compared items are described by certain sets of indicators, the particular indicators of risk (PIR). As the analysis of the states of complex items and systems used in systems research of integral estimates [12, 13, 14] has shown, generalized criteria (indices) of risk are widely used, i.e. the additive (weighted arithmetical) and multiplicative (weighted geometrical) forms.

Given the above, let us define the risk in the problem under consideration as the function of two vectors $U = (u_1, u_2, \ldots, u_{n-1}, u_n)$, i.e. the vector of damage and $W = (w_1, w_2, \ldots, w_{n-1}, w_n)$, i.e. the vector of weighted coefficient of damage (essentially, that is the expert estimate of their possibility). It may be written as follows [15]:

$$R(U,W) = 1 - \prod_{i=1}^{n} (1 - u_i)^{w_i}, \qquad (1)$$

where $w_i > 0$ is the non-zero probabilities of contributions (weight) such as

$$\sum_{i=1}^{n} w_n = 1. \qquad (2)$$

In [15], it is shown that in both cases the integrated criterion can be constructed through repetitive use of a binary associative and communicative operation and is an integer analytical function of local criteria. Also in [15], it is shown that the class of such operations is sufficiently narrow and there are only three (accurate to constant parameters) binary operations that meet the condition of commutativity, associativity and integral analyticity. They are defined by the following functions[2]: a) c; b) $\Phi_1+\Phi_2+c$; c) $a(\Phi_1 + \Phi_2) + b\Phi_1\Phi_2 + \frac{a(a-1)}{b}; a, b, c - const, b \neq 0$. Importantly, the third of the provided estimates (under certain values of the coefficients that are part of it) is to be used for the purpose of obtaining the integrated criterion of quality, provided there is interaction between subsystems and criterial limitations of the ranges of variation of local estimates.

Based on the above, the integral risk associated with the adoption of a modification option of the m-th airport for the purpose of inclusion in the air cluster is:

$$R^m = 1 - \prod_{i=1}^{n} \left(1 - u_i^m\right)^{w_i}. \qquad (3)$$

For small values of U^m, the integral risk of decision-making for option m matches the adopted definition of risk:

$$R^m \approx 1 - \prod_{i=1}^{n} \left(1 - w_i \times u_i^m\right) \approx \sum_{i=1}^{n} w_i \times u_i^m, \qquad (4)$$

where u_i^m is the value of damage for option m under criterion i, w_i is the probability of the criteria's effects.

The introduced risk (1) that is sometimes called the geometrical antirisk [16] meets the primary a priori requirements underlying the risk-based approach to the construction of the non-linear integral estimate $R_{\varnothing}$.

1) smoothness, continuous correlation between the integral estimate R and its derivatives and the partial estimates: $R(r_1, \ldots, r_M)$;

2) boundedness, the boundaries of the variation interval of the partial r_i and integral R estimates: $0 < R(r_1, \ldots, r_M) < 1$ if $0 < r_1, r_2, \ldots, r_M < 1$;

3) equality, the equal importance of partial estimates r_i and r_j;

4) hierarchical single-levelness, meaning that only those partial estimates r_i are aggregated that belong to a single level of the hierarchical structure;

5) neutrality, i.e. the integral estimate matches the partial estimate when the other assumes the minimal value: $R(r_1,0)=r_1$; $R(0,r_2)=r_2$; $R(0,0)=0$; $R(1,1)=1$.

6) uniformity $R(r_1=r, \ldots, r_M=r)=r$.

The geometrical antirisk is the upper-bound estimate for the weighted arithmetical and weighted geometrical. Let us also emphasize that the geometrical antirisk meets the theorem on the "fragility of good things" in the catastrophe theory, according to which "… in case of small variation of the parameters, a system belonging to a special part of the stability limit is more likely to fall within the instability zone rather than the stability zone. That is a manifestation of the general principle, according to which all good things (e.g. stability) are more fragile that bad things" [17, p. 31-32]. Risk analysis uses a similar principle of the limiting factor

[1] GOST R ISO 31000-2019. Risk management. Principles and guidelines

[2] Ibidem

of risk.

Thus, any system can be considered to be “good”, if it meets a certain set of requirements, but must be recognized as “bad”, if does not fulfill at least one of them. At the same time, all the “good things”, e.g. the environmental safety of a territory, is more fragile. It can be easily lost, but difficult to recover.

In [18], it is suggested to perform substantial interpretation using the Harrington verbal and numerical scale that is sufficiently universal in its nature.

For the purpose of solving the problem at hand, it is required to successively solve the following sub-problems:

1. Selecting the criteria that affect the risk magnitude.
2. Identifying the contribution of the criteria into the risk magnitude.
3. Making the list of the considered alternatives.
4. Identifying the magnitude of the particular risks of each alternative per each criterion.
5. Evaluating the integral risk in accordance with the selected model for each alternative and rank them.

2. Expert data and processing results

2.1. Criteria and estimation of their contribution to the integral risk

In order to identify the list of criteria that have an effect on the risk caused by an airport’s modernization, experts were questioned according to the method that was generally described in [10] and that includes two stages:

Stage 1. Based on their personal experience and preference, the experts use a certain numerical scale to rate the value of damage that may be caused by a certain parameter value. At the same time, if the parameters are discrete, an expert rates each one of them. For continuous values, ranges of adopted values are selected, for which the experts give an estimate. The higher is the estimated damage, the higher is, in the experts’ opinion, the probability of a negative outcome.

Stage 2. The weights are identified, which can be done both by means of direct calculation (experts’ opinions regarding other experts’ estimates are collected, rating coefficients are specified and the weights are calculated), and by calculating weights through coefficients. In the latter case the weights are defined in accordance with a procedure of the hierarchy analysis method through the normalized vector under the maximum own value of the matrix of pairwise comparisons [1]. For each pair of compared items, a coefficient is defined based on all obtained expert estimates. In case of a significant range of opinions regarding such coefficient, it would be reasonable to choose not to make any estimate, i.e. leave the cell undefined.

As the result, the following list of criteria was made:

1. Optimal distance from downtown Moscow (COD).
2. Airport capacity (CAC).
3. Quality and number of runways (CRW).
4. Airfield infrastructure (CAFI).
5. Airport infrastructure (CAPI).
6. Other transportation infrastructure (COTI).
7. Land resources (CLR).
8. Availability of cargo terminal (CCT).
9. International status (CIS).
10. Joint deployment (CJD).
11. Form of ownership (CFO).

As it was noted above, as such criteria deal with various domains, their comparison requires the involvement of experts with different professional experience that might have difficulties comparing criteria outside the scope of their expertise. In this context, the method of incomplete pairwise comparisons was used [19] with interval-based preference judgement on the Saaty scale [1]. Thanks to its flexibility, this method allows experts to provide accurate estimates in domains of their respective most solid expertise, and, additionally, to specify a wide range of preference judgement regarding those pairs of alternatives that the expert cannot provide an unambiguous opinion for due to the above reasons. This approach, among other things, allows improving the concordance of the matrix of pairwise comparisons by removing such preference judgements that disrupts the concordance due to the insufficiency of the grading scale [20].

The data obtained using the weight method are shown in Table 1.

Table 1. Probability of criteria effect

№	Criterion	Abbreviation	Criterion’s effect
1	Optimal distance from Moscow	COD	0.1624
2	Airport capacity	CAPC	0.0673
3	Quality and number of runways	CRW	0.1301
4	Airfield infrastructure	CAFI	0.1390
5	Airport infrastructure	CAPI	0.1330
6	Land resources	CLR	0.1282
7	Other transportation infrastructure	COTI	0.1570
8	Availability of cargo terminal	CCT	0.0233
9	International status	CIS	0.0201
10	Joint deployment	CJD	0.0219
11	Form of ownership	CFO	0.0178

2.2. Estimation of the magnitude of damage by criteria

So, 11 criteria were selected for the purpose of assessing the options. Given that the group of the significant criteria includes the criterion of optimal distance from Moscow (see Table 1), as well as that airports outside the 300-km zone of Moscow will not appeal to passengers [21], only airports within this range were considered. Besides Vnukovo, Domodedovo and Sheremetyevo, 31 airports are within 300 km of Moscow (Table 2). Thus, if we attempt to estimate each airport per each criterion directly (i.e. asking an expert to specify the value of risk), due to the dimension of the problem, a great number of errors might occur. Additionally, it was observed that many criteria could be characterized by

Table 2. The list of options under consideration

№	List of airports	№	List of airports
1	Klin-5 – Klin, Moscow Oblast (MO)	17	Turlatovo – Ryazan
2	Semyazino – Vladimir	18	Krutyshki – Stupinio, MO
3	Dobrynskoye – Vladimir	19	Zmeyovo – Tver
4	Miachkovo – Ramenskoye District, MO	20	Tretiakovo – Lukhovitsy, MO
5	Tunoshna – Yaroslavl	21	Mozhaysky – Mozhaysk, MO
6	Klokovo – Tula	22	Alferievo – Volokolamsk, MO
7	Migalovo – Tver	23	Volosovo – Chekhov, MO
8	Ramenskoye – Zhukovsky, MO	24	Monino – Monino, MO
9	Ivanovo South – Ivanovo	25	Chiornoye – Balashikha, MO
10	Yefremov East – Tula Oblast	26	Vikhrevo – Sergiyev-Posad District, MO
11	Chkalovsky – Shchyolkovo, MO	27	Vatulino – Ruza, MO
12	Grabtsevo – Kaluga	28	Severka – Kolomna, MO
13	Bykovo – Moscow	29	Korobcheyevo – Kolomna, MO
14	Ostafyevo – Moscow	30	Borki – Kimry, Tver Oblast
15	Protasovo – Ryazan	31	Yermolino – Balabanovo, Kaluga Oblast
16	Dyagilevo – Ryazan		

additional unambiguously objective parameters that can be found in technical documentation: distance, length, number. In this context, a simplified expert evaluation process was implemented, according to which experts were to estimate not the value of risk for each specific airport, but its characteristics. Where such characteristics were not defined in official sources (e.g. the quality of the infrastructure), expert evaluation was conducted for each specific airport.

Jointly with the experts, for each criterion, airport evaluation scales were made. For instance, it was suggested evaluating runways (RW) using a two-dimensional scale proceeding from the number of strips and the length of the longest of them. Additionally, it was established that in terms of the number there is a difference for airports with 1 RW, 2 RWs, while if an airport has 3 and more RWs they fall into a single category. In terms of length, for instance, intervals were defined such that, within a group, the difference between RWs is insignificant (on each such interval there is no significant diversity of aircraft able to safety take off/land).

According to those scales, the following parameters were calculated: C_i, the risk coefficient for the i-th value of the scale expressed in any nonnegative number, and γ, the maximum value of damage (on the scale from 0 to 1) by the selected criterion. Based on those parameters, the value of risk R_i is calculated based on the respective parameter value on the scale, as well as the amount of damage U_i according to the following formulas:

$$R_i = \frac{C_i}{\max_i C_i}, \quad (5)$$

$$U_i = \gamma \times R_i. \quad (6)$$

The formulas and value characteristics show that $0 \le U_i \le R_i \le 1$. Thus, for instance, let us examine the estimates assessment by criterion of CCT (see Table 1) shown in Table 3. Those estimates provide a qualitative characteristic of the airport's cargo terminal (CT).

As the concepts used in this scale are evaluative (except the latter one, for which information can be found), the

Table 3. Assessment of airport evaluation scale in terms of the CCT criterion

Parameter	Perfect CT condition	Good CT condition	Limited CT activities	No cargo activities
Assessment, C_i	1	2	4	8
Max damage, γ	0.4			
Risks, R_i	0.125	0.25	0.5	1
Damage, U_i	0.05	0.1	0.2	0.4

Table 4. Values of damage per airport evaluation scale in terms of the CCT criterion

Capacity, ths pass./year as of 2019	10000 and more	2000	1000	200	100	40	10 and less
Damage, U_i	0.01	0.02	0.04	0.1	0.2	0.4	1

Table 5. Processing of expert assessments of the suggested options for the MAC modernization

№	Expert assessments												№	Calculated utility components										
	COD	CAPC	CRW	CAFI	CAPI	CLR	COTI	CCT	CIS	CJD	CFO			COD	CAPC	CRW	CAFI	CAPI	CLR	COTI	CCT	CIS	CJD	CFO
1	0.04	0.99	0.16	0.8	0.8	0.2	0.1	0.4	0.2	0.1	0.05		1	0.99272	0.77543	0.97412	0.81421	0.83564	0.96997	0.98319	0.98746	0.99544	0.99819	0.99917
2	0.08	0.8	0.28	0.8	0.8	0.99	0.8	0.4	0.2	0	0.05		2	0.98520	0.91495	0.95180	0.81421	0.83564	0.53299	0.77185	0.98746	0.99544	1.00000	0.99917
3	0.05	0.35	0.13	0.4	0.8	0.01	0.4	0.4	0.2	0.1	0.05		3	0.99087	0.97649	0.97927	0.93684	0.83564	0.99863	0.92109	0.98746	0.99544	0.99819	0.99917
4	0.01	0.99	0.62	0.8	0.8	0.99	0.1	0.4	0.2	0.1	0.05		4	0.99820	0.77543	0.86458	0.81421	0.83564	0.53299	0.98319	0.98746	0.99544	0.99819	0.99917
5	0.38	0.3	0.07	0.1	0.1	0.2	0.4	0.05	0	0	0.02		5	0.91805	0.98049	0.98915	0.98663	0.98831	0.96997	0.92109	0.99873	1.00000	1.00000	0.99967
6	0.1	0.99	0.3	0.8	0.8	0.99	0.4	0.4	0.2	0.1	0.05		6	0.98133	0.77543	0.94777	0.81421	0.83564	0.53299	0.92109	0.98746	0.99544	0.99819	0.99917
7	0.95	0.99	0.13	0.8	0.4	0.5	0.2	0.4	0	0	0.03		7	0.58517	0.77543	0.97927	0.81421	0.94460	0.90964	0.96473	0.98746	1.00000	1.00000	0.99950
8	0.01	0.01	0	0.1	0.1	0.2	0.1	0.05	0	0	0.02		8	0.99820	0.99945	1.00000	0.98663	0.98831	0.96997	0.98319	0.99873	1.00000	1.00000	0.99967
9	0.37	0.38	0.13	0.1	0.1	0.2	0.4	0.2	0	0	0.03		9	0.92068	0.97394	0.97927	0.98663	0.98831	0.96997	0.92109	0.99450	1.00000	1.00000	0.99950
10	0.38	0.8	0.13	0.4	0.8	0.5	0.8	0.01	0	0	0.02		10	0.91805	0.91495	0.97927	0.93684	0.83564	0.90964	0.77185	0.99975	1.00000	1.00000	0.99967
11	0.01	0.8	0.02	0.8	0.4	0.2	0.1	0.01	0	0	0.05		11	0.99820	0.91495	0.99697	0.81421	0.94460	0.96997	0.98319	0.99975	1.00000	1.00000	0.99917
12	0.055	0.4	0.2	0.4	0.4	0.5	0.4	0.4	0	0	0.02		12	0.98993	0.97218	0.96700	0.93684	0.94460	0.90964	0.92109	0.98746	1.00000	1.00000	0.99967
13	0.01	0.5	0.23	0.2	0.8	0.99	0.1	0.1	0.2	0.1	0.05		13	0.99820	0.96244	0.96146	0.97190	0.83564	0.53299	0.98319	0.99740	0.99544	0.99819	0.99917
14	0.01	0.8	0.23	0.2	0.4	0.8	0.1	0.4	0	0	0.01		14	0.99820	0.91495	0.96146	0.97190	0.94460	0.80259	0.98319	0.98746	1.00000	1.00000	0.99984
15	0.09	0.4	0.23	0.2	0.4	0.99	0.4	0.4	0.2	0.1	0.05		15	0.98327	0.97218	0.96146	0.97190	0.94460	0.53299	0.92109	0.98746	0.99544	0.99819	0.99917
16	0.09	0.8	0.07	0.2	0.8	0.8	0.2	0.4	0	0	0.03		16	0.98327	0.91495	0.98915	0.97190	0.83564	0.80259	0.96473	0.98746	1.00000	1.00000	0.99950
17	0.09	0.99	0.76	0.8	0.8	0.8	0.8	0.4	0.2	0.1	0.05		17	0.98327	0.77543	0.80684	0.81421	0.83564	0.80259	0.77185	0.98746	0.99544	0.99819	0.99917
18	0.05	0.8	0.2	0.4	0.8	0.2	0.2	0.01	0	0	0.05		18	0.99087	0.91495	0.96700	0.93684	0.83564	0.96997	0.96473	0.99975	1.00000	1.00000	0.99917
19	0.08	0.99	0.93	0.4	0.8	0.99	0.8	0.4	0.2	0.1	0.05		19	0.98520	0.77543	0.67037	0.93684	0.83564	0.53299	0.77185	0.98746	0.99544	0.99819	0.99917
20	0.065	0.99	0.07	0.2	0.8	0.5	0.4	0.4	0.2	0.1	0.05		20	0.98805	0.77543	0.98915	0.97190	0.83564	0.90964	0.92109	0.98746	0.99544	0.99819	0.99917
21	0.05	0.99	0.54	0.8	0.8	0.99	0.8	0.4	0.2	0.1	0.05		21	0.99087	0.77543	0.88978	0.81421	0.83564	0.53299	0.77185	0.98746	0.99544	0.99819	0.99917
22	0.75	0.99	0.92	0.8	0.8	0.99	0.8	0.4	0.2	0.1	0.05		22	0.78038	0.77543	0.68397	0.81421	0.83564	0.53299	0.77185	0.98746	0.99544	0.99819	0.99917
23	0.03	0.99	0.98	0.4	0.4	0.99	0.1	0.4	0.2	0.1	0.05		23	0.99457	0.77543	0.55525	0.93684	0.94460	0.53299	0.98319	0.98746	0.99544	0.99819	0.99917
24	0.01	0.99	0.7	0.8	0.8	0.99	0.1	0.4	0.2	0.1	0.05		24	0.99820	0.77543	0.83438	0.81421	0.83564	0.53299	0.98319	0.98746	0.99544	0.99819	0.99917
25	0.01	0.99	0.92	0.4	0.4	0.99	0.1	0.4	0.2	0.1	0.05		25	0.99820	0.77543	0.68397	0.93684	0.94460	0.53299	0.98319	0.98746	0.99544	0.99819	0.99917
26	0.03	0.99	0.62	0.4	0.8	0.99	0.1	0.4	0.2	0.1	0.05		26	0.99457	0.77543	0.86458	0.93684	0.83564	0.53299	0.98319	0.98746	0.99544	0.99819	0.99917
27	0.04	0.99	0.95	0.4	0.4	0.99	0.2	0.4	0.2	0.1	0.05		27	0.99272	0.77543	0.63729	0.93684	0.94460	0.53299	0.96473	0.98746	0.99544	0.99819	0.99917
28	0.05	0.99	0.99	0.4	0.4	0.8	0.2	0.4	0.2	0.1	0.05		28	0.99087	0.77543	0.50029	0.93684	0.94460	0.80259	0.96473	0.98746	0.99544	0.99819	0.99917
29	0.05	0.99	0.76	0.8	0.4	0.99	0.2	0.4	0.2	0.1	0.05		29	0.99087	0.77543	0.80684	0.81421	0.94460	0.53299	0.96473	0.98746	0.99544	0.99819	0.99917
30	0.06	0.99	0.62	0.8	0.4	0.99	0.8	0.4	0.2	0.1	0.05		30	0.98899	0.77543	0.86458	0.81421	0.94460	0.53299	0.77185	0.98746	0.99544	0.99819	0.99917
31	0.05	0.02	0.07	0.1	0.15	0.2	0.2	0.2	0	0	0.03		31	0.99087	0.99888	0.98915	0.98663	0.98203	0.96997	0.96473	0.99450	1.00000	1.00000	0.99950

airports were assessed by experts, and the most popular assessment was taken into account. However, for instance, there is the CAPC criterion (see Table 1) that characterizes an airport's capacity (number of passengers per year). For this criterion, the damage values were evaluated per the scale shown in Table 4.

It is obvious that, such airport parameters are predominantly between scale values. For such airports, piecewise line approximation was used. For value *c* from the value range of criterion [*a*, *b*] and corresponding risk range [U_a, U_b] the formula for calculating the risk is written as:

$$U_c = U_a + (c-a)\frac{U_b - U_a}{b-a}. \quad (7)$$

The experts' estimates for each considered option and calculated components of usefulness for all previously selected criteria are shown in Table 5.

3. Ranking of airports by value of integral risk

The integral risk was calculated according to formula (1) using the data obtained per the above principles (see Table 5). As the result, a list of alternative airports was made, the first ten of which are shown in Table 6. The following airports in the rating have the risk value above 0.5 and are not considered due to unacceptable risk associated with modernization.

Table 6. Rating of airports in terms of the integral risk of modernization

№	Airport	City/Town	Region	Integral risk
1	Ramenskoye	Zhukovsky	Moscow Oblast	0.0747
2	Yermolino	Balabanovo	Kaluga Oblast	0.1173
3	Tunoshna	Yaroslavl	Yaroslavl Oblast	0.2293
4	Yuzhny	Ivanovo	Ivanovo Oblast	0.2380
5	Grabtsevo	Kaluga	Kaluga Oblast	0.3105
6	Chkalovsky	Shchelkovo	Moscow Oblast	0.3627
7	Dobrynskoye	Vladimir	Vladimir Oblast	0.3777
8	Ostafievo	Moscow	Moscow	0.3799
9	Krutyshki	Stupino	Moscow Oblast	0.3907
10	Dyagilevo	Ryazan	Ryazan Oblast	0.4684

As it can be seen from Table 6, the projects numbered 1, 2, 3 and 4 have the minimal risk. Those options should be considered as preferable when taking the final decision regarding the funding of the MAC modernization.

Conclusion

Obviously, the presented algorithm of risk synthesis for ranking infrastructure facilities cannot be recommended as the one and only in situations of decision-making regarding investment in certain projects. However, such algorithms allow significantly reducing the number of compared options and enable DMs to carefully examine the remaining options for the purpose of finding the best one.

The above approach to risk synthesis may find application in many domains, both by major companies, for instance, for the purpose of investment project estimation, infrastructure facilities construction, and small business, e.g. for estimating the risk associated with warehouse or new client office leasing. The latter problems are interesting due to the fact that there are many property units, whose descriptions are available at various online aggregators. Manual analytical data processing as regards such units is impossible, as it often limits the selection of options that (in the experts' opinion) best comply with the DM's preferences, and eliminates a great number of equally valid options. The suggested algorithm of risk synthesis simplifies the problem faced by a DM and allows easily automating the process of multicriteria selection out of a large number of options.

Acknowledgements

We express our gratitude to Mr. Dmitry Sivenia, Deputy Head of the Department for Economy and Development Programs, Federal Air Transport Agency of Russia, and Ms. Alexandra Pashetnykh, Advisor of the Division for Reporting on the Federal Target Programs, Department for Economy and Development Programs, Federal Air Transport Agency of Russia, for their assistance in the organization of the collection and processing of the data used in the research.

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The authors' contribution

Kuzmina N.M. supported the collection of expert data, selection and verification of statistical data and characteristics of airports, provided the information and selected sources associated with commercial operation.

Ridley A.N. used the above model of risk synthesis for the purpose of solving the problem at hand, presented ideas regarding the management of obtained data, set forward the results of the research and possible applications of the involved ideas, models and methods for solving complex problems.

Conflict of interests

The authors declare the absence of a conflict of interests.