МІЖНАРОДНЕ СПІВРОБІТНИЦТВО: СУСПІЛЬНО-ГЕОГРАФІЧНІ ТА ПОЛІТИКО-ПРАВОВІ АСПЕКТИ ОСВОЄННЯ АНТАРКТИКИ / INTERNATIONAL CO-OPERATION: SOCIO-ECONOMIC, POLITICAL AND LEGAL ISSUES OF ANTARCTIC EXPLORATION

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MATHEMATICAL MODELING OF PRIORITIES AND COSTS OF VERNADSKY STATION INFRASTRUCTURE MODERNISATION

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Abstract. Objective. The topical issue of Ukrainian Antarctic Akademik Vernadsky Station infrastructure system modernization was investigated to prevent accidents and failures of the infrastructure constituent elements, to Antarctica environmental conservation, and to carrying out of Ukraine' international obligations in Antarctica. **Methods.** The Antarctic Treaty Consultative Meeting (ATCM-XXXIII) adopted Resolution 3 (2010) with the Check List A to verify by the international inspections, particularly, the technical conditions of Antarctic stations infrastructures. The authors used both this Check List A and the mathematical modelling of the hierarchies study (Saaty, 2008) to obtain the quantitative characteristics of priorities and costs of Vernadsky station infrastructure modernization. Mathematical modelling was done in three stages: preparing of the two matrices (for priorities and costs) with the list of the station infrastructure elements; filling the matrices by expert estimates of successive pairwise comparison of importance (priorities and costs) of infrastructure each elements according to ranks from 0 to 9 (subject to conditions, particularly, if $a_{ij} = 1$, then $a_{ji} = 1/a_{ij}$); eigenvalues calculating of obtained matrices which after the normalization procedures gave the necessary quantitative characteristics. **Results**. Quantitative results on the priorities and cost of Vernadsky station infrastructure modernization were obtained. **Conclusions.** The obtained results will be used to the feasibility study justification of the station infrastructure modernization, to the argumentation and decision-making by the executive authorities of Ukraine, to inform the general public of Ukraine. In addition, the obtained results will contribute to the further development and implementation of other approaches to assessing the priorities and costs of Vernadsky station infrastructure modernization.

Key words: Vernadsky station infrastructure, modernization, quantitative characteristics of priorities and costs, mathematical modeling.

МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ПРІОРИТЕТІВ І ВАРТОСТІ МОДЕРНІЗАЦІЇ ІНФРАСТРУКТУРИ СТАНЦІЇ «АКАДЕМІК ВЕРНАДСЬКИЙ»

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Реферат. **Мета**. Дослідження актуального питання модернізації системи інфраструктур Української антарктичної станції «Академік Вернадський» з метою попередження аварій та виходу з ладу елементів інфраструктури, збереження навколишнього середовища в Антарктиці та виконання Україною міжнародних зобов'язань в Антарктиці. **Метод**. Консультативна нарада з Договору про Антарктику (КНДА-XXXIII) прийняла Resolution 3 (2010) з Контрольним переліком А для перевірки міжнародними інспекціями, зокрема, технічного стану інфраструктури антарктичних станцій. Автори використали як цей Контрольний перелік А, так і математичне моделювання при дослідженнях ієрархій (Saaty, 2008), щоб отримати кількісні характеристики пріоритетів та вартості модернізації інфраструктури станції. Математичне моделювання здійснювалося в три етапи: підготовка двох матриць (для пріоритетів та вартості) зі списком елементів інфраструктури станції заповнення матриць за експертними оцінками послідовного попарного порівняння важливості (пріоритетів і вартості) інфраструктури кожного елемента за рангом від 0 до 9 (за умови, зокрема, якщо $a_{ij} = 1$, то $a_{ji} = 1/a_{ij}$); розрахунку власних значень отриманих матриць, які після процедур нормалізації дали необхідні кількісні характеристики. **Результати**. Отримані кількісні результати щодо пріоритетів та вартості модернізації інфраструктури Української антарктичної станції (УАС) «Академік Вернадський». **Висновки**. Результати будуть використані для підготовки Техніко-економічного обґрунтування з модернізації інфраструктури станції, для аргументації та прийняття відповідних рішень органами виконавчої влади України, для інформування громадськості України. Крім того, отримані результати сприятимуть подальшому розвитку та впровадженню інших підходів до оцінки пріоритетів та вартості модернізації інфраструктури станції «Академік Вернадський».

Ключові слова: інфраструктура станції «Академік Вернадський», модернізація, кількісні характеристики пріоритетів та вартості, математичне моделювання.

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРИОРИТЕТОВ И СТОИМОСТИ МОДЕРНИЗАЦИИ ИНФРАСТРУКТУРЫ СТАНЦИИ «АКАДЕМИК ВЕРНАДСКИЙ»

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Реферат. **Цель.** Исследование актуального вопроса модернизации системы инфраструктуры Украинской антарктической станции «Академик Вернадский» с целью предупреждения аварий и выхода из строя элементов инфраструктуры, сохранения окружающей среды в Антарктике и выполнения Украиной международных обязательств в Антарктике. **Метод.** Консультативное совещание по Договору об Антарктике (КСДА-XXXIII) приняло Resolution 3 (2010) с Контрольным перечнем А для проверки международными инспекциями, в частности, технического состояния инфраструктуры антарктических станций. Авторы использовали как этот Контрольный перечень А, так и математическое моделирование при исследованиях иерархий (Saaty, 2008), чтобы получить количественные характеристики приоритетов и стоимости модернизации инфраструктуры Украинской антарктической станции «Академик Вернадский». Математическое моделирование осуществлялось в три этапа: подготовка двух матриц (для приоритетов и стоимости) со списком элементов инфраструктуры станции; заполнение матриц по экспертным оценкам последовательного попарного сравнения важности (приоритетов и стоимости) инфраструктуры каждого элемента по рангу от 0 до 9 (при условии, в частности, если $a_{ij} = 1$, то $a_{ji} = 1/a_{ij}$); расчет собственных значений полученных матриц, которые после процедур нормализации дали необходимые количественные характеристики. **Результаты.** Получены количественные результаты относительно приоритетов и стоимости модернизации инфраструктуры Украинской антарктической станции (УАС) «Академик Вернадский». **Выводы.** Результаты будут использованы для подготовки Технико-экономического обоснования по модернизации инфраструктуры станции, для аргументации и принятия соответствующих решений органами исполнительной власти Украины, для информирования общественности Украины. Кроме того, полученные результаты будут способствовать дальнейшему развитию и внедрению других подходов к оценке приоритетов и стоимости модернизации инфраструктуры станции.

Ключевые слова: инфраструктура станции «Академик Вернадский», модернизация, количественные характеристики приоритетов и стоимости, математическое моделирование.

1. Introduction

Vernadsky station has been operated by Ukraine since 1996. The problem of the system modernization of the Station's infrastructure is actual taking into account:

- the condition of the station infrastructure for 2016;
- in order to prevent accidents and breakdown of infrastructure elements;
- to preserve the environment in Antarctica;
- to fulfill Ukraine's international obligations in Antarctica;
- to ensure the implementation of the State Special-Purpose Research Program in Antarctica for 2011-2020;
- in order to ensure the sustainable station development.

This study aims are to determine the quantitative characteristics of the system modernization of the Vernadsky station infrastructure, such as the priorities and the costs, which would provide the opportunities of:

- simulation of the infrastructure modernization process according to the priorities, costs, and time to optimize the modernization process;
- preparation of the Feasibility Study, Request for Proposal and Working Project for the infrastructure modernization;
- preparation of arguments and proposals for central executive authorities of Ukraine regarding financing and implementation of the station infrastructure modernization;
- informing the general public about the activities of Ukraine in Antarctica.

2. Materials and methods

Antarctic Treaty Consultative Meeting (ATCM-XXXIII) adopted Resolution 3 (2010) with the Check List A to verify by international inspections, particularly, technical condition of such compositions of Antarctic stations infrastructure in that List:

1. Living quarters, warehouses and scientific-technical buildings;
2. Equipment and the scientific-technical research means;
3. Communication means;
4. Transport means;
5. Fuel handling and storage means;
6. Electricity supply means;
7. Means of providing with the fresh and technical water;
8. Means for the emergency situations;
9. Means of the waste management.

In this study authors used the above-mentioned Check List A (Resolution 3, 2010) and the analytical mathematical method of hierarchies investigation (Saaty T.L., 2008) to obtain quantitative characteristics of the priorities and the costs of the Vernadsky Station infrastructure modernization.

It should be noted that the mentioned mathematical method was successfully used, particularly, for:

- the arms race study and for the disarmament control in the XX century (Saaty, 1968);

• the quantitative analysis of the Antarctica values and the threats to Antarctica (Fedchuk et al., 2012), (Kuzko et al., 2012);

• and the quantitative analysis of the Ukraine' national interests in Antarctica (Kuzko et al., 2013);

According to the Saaty (2008) method in the first stage of study two special matrices were prepared for experts judgments (both priorities and costs) with the list of station infrastructure components (means) conformity with the Check List A (Table 1):

Table 1

Model of matrices for experts judgments (both priorities and costs)

	Buil-dings	Research	Communi-cation	Trans-port	Fuel	Electri-city	Water	Emer-gency	Waste
Buildings	1								
Research		1							
Communi-cation			1						
Transport				1					
Fuel					1				
Electricity						1			
Water							1		
Emergency								1	
Waste									1

In the second stage of study the successive pairwise comparison of the values was carried out by importance ranking (Table 2) and the filling the matrices elements by the appropriate expert's judgements was carried out (Table 3, Table 4) under circumstances that the matrixes are consistent, namely $a_{ii}=1$ and $a_{ji}=1/a_{ij.}$

Table 2

Ranks of objects importance

Rating	Determination of importance ranking
0	The values are not comparable
1	The values are equally important
3	One value is a little bit more important than another one (weak superiority)
5	One value is considerably more important than another one (strong superiority)
7	One value is evidently more important than another one
9	One value is absolutely more important than another one
2, 4, 6, 8	Meanings which are appointed for intermediate judgements

Table 3

Experts matrix of the modernization priorities

	Buil-dings	Research	Communi-cation	Trans-port	Fuel	Electri-city	Water	Emer-gency	Waste
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Buildings	**1**	2	3	1/4	1/5	1/3	4	2	4
Research	1/2	**1**	1/3	1/3	1/5	1/4	3	3	4
Communi-cation	1/3	3	**1**	1/5	1/5	1/3	5	3	5
Transport	4	3	5	**1**	1/5	1/3	5	3	5
Fuel	5	5	5	5	**1**	3	5	5	6
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Electricity	3	4	3	3	1/3	**1**	4	4	5
Water	1/4	1/3	1/5	1/5	1/5	1/4	**1**	3	3
Emergency	1/2	1/3	1/3	1/3	1/5	1/4	1/3	**1**	3
Waste	1/4	1/4	1/5	1/6	1/6	1/5	1/3	1/3	**1**

Table 4

Experts matrix of the modernization costs

	Buildings	**Research**	**Communication**	**Transport**	**Fuel**	**Electricity**	**Water**	**Emergency**	**Waste**
Buildings	**1**	4	5	5	1/5	1	7	5	5
Research	1/4	**1**	3	4	1/4	1	5	1	2
Communication	1/5	1/3	**1**	4	1/5	1	2	1/2	3
Transport	1/5	1/4	1/4	**1**	1/7	1/5	1/5	1/2	1/2
Fuel	5	4	5	7	**1**	4	5	5	6
Electricity	1	1	1	5	1/4	**1**	3	1	3
Water	1/7	1/5	1/2	5	1/5	1/3	**1**	1/3	1/2
Emergency	1/5	1	2	2	1/5	1	3	**1**	2
Waste	1/5	1/2	1/3	2	1/6	1/3	2	1/2	**1**

In the third stage of study the task solution was carried out of the eigenvalues obtaining of the prepared matrices (Table 5):

Table 5

Normalized values of the eigenvalues of the prepared matrices

Components of Infrastructure (means)	**Quantitative characteristics of modernization priorities**	**Quantitative characteristics of modernization costs**
Buildings	0.0908	0.2075
Research	0.0578	0.0982
Communication	0.0831	0.0645
Transport	0.1597	0.0243
Fuel	0.3238	0.3495
Electricity	0.1873	0.0996
Water	0.0399	0.0391
Emergency	0.0357	0.0763
Waste	0.0211	0.0410

3. Results and discussion

For convenience in Table 6 the quantitative characteristics of the modernization priorities from Table 5 are given in descending order:

Table 6

Quantitative characteristics of modernization priorities in descending order

Components of infrastructure (means)	Quantitative characteristics of modernization priorities
Fuel	0.3238
Electricity	0.1873
Transport	0.1597
Buildings	0.0908
Communication	0.0831
Research	0.0578
Water	0.0399
Emergency	0.0357
Waste	0.0211

For convenience in Table 7 the quantitative characteristics of modernization costs from Table 5 are given in descending order:

Table 7

Quantitative characteristics of modernization costs in descending order

Components of infrastructure (means)	Quantitative characteristics of modernization costs
Fuel	0.3495
Buildings	0.2075
Electricity	0.0996
Research	0.0982
Emergency	0.0763
Communication	0.0645
Waste	0.0410
Water	0.0391
Transport	0.0243

To begin the costs are considered of the modernization of both individual components of the infrastructure and the entire station infrastructure. For simplicity the option is considered, for example, when the cost of communication means modernizing (in particular, providing the station with the internet modern means) can be estimated at $ US 150,000 (which in the normalized form of the quantitative characteristics of the costs in Table 7 corresponds to 0.0645).

Then calculated from the Table 7 data the costs of the other components modernization of the station infrastructure will have the values which are given in Table 8:

Table 8

Modernization costs of station infrastructure components

Components of station infrastructure (means)	Modernization costs (in $ USA)
1	**2**
Fuel	812 791
Buildings	482 558
Electricity	231 628
Research	228 372
Emergency	177 442

Table 8

1	2
Communication	150 000
Waste	95 349
Water	90 930
Transport	56 512

Then from Table 8 the total cost of modernization of the all infrastructure components of the Station is 2 325 581 US $ or 62 790 698 UAH (by 1 US $ = 27 UAH).

It should be noted that the value shown in Table 8 can be specified by other methods, if the cost of modernization of another (other) component of the Station infrastructure will be obtained by other methods, and using Table 7 to recalculate the costs of modernization of the rest of the infrastructure components.

Using data from Tables 6 and 8 the possible options can be simulated for both the Station modernization funding and the possible schedules for modernization of the Station infrastructure.

The option was considered for the modernization of the all Station infrastructure components one by one within one year for each component in accordance with Table 6. The appropriate schedule for the modernization of the Station's infrastructure components by years and the corresponding costs of modernization by years are given in Table 9:

Table 9

Option of station infrastructure modernization within 9 years

Components of Station infrastructure (means)	Quantitative characteristics of modernization priorities	Number order of modernization years	Modernization costs (in $ USA)
Fuel	0.3238	1	812 791
Electricity	0.1873	2	231 628
Transport	0.1597	3	56 512
Buildings	0.0908	4	482 558
Communication	0.0831	5	150 000
Research	0.0578	6	228 372
Water	0.0399	7	90 930
Emergency	0.0357	8	177 442
Waste	0.0211	9	95 349

The disadvantage of such modernization option is the long interval of modernization time during which at the station both priorities and the cost of the infrastructure components modernization can change.

The second hypothetical option of all components modernization of station infrastructure within one year was considered. The appropriate schedule for modernization of the station infrastructure and the corresponding cost of modernization are given in Table 10:

Table 10

Option of station infrastructure modernization within 1 year

Components of station infrastructure (means)	Quantitative characteristics of modernization priorities	Number order of modernization years	Modernization costs (in $ USA)
Fuel+Electricity+ +Transport+Buildings+ +Communication+ +Research + +Water+Emergency+ Waste	1	1	2 325 581

This version of the modernization of all components of the infrastructure physically impossible to implement due to a limited time of modernization.

The third intermediate option of the modernization of the station infrastructure was considered where the period of modernization was defined within 5 years and the conditions for more even funding for modernization by years were created due to the merger of the modernization of the relevant infrastructure components.

This option is presented in Table 11 with the corresponding changes in the priorities of modernization and changes in the financing of modernization by years.

Table 11

Option of station infrastructure modernization within 5 years

Components of Station infrastructure (means)	Quantitative characteristics of modernization priorities	Number order of modernization years	Modernization costs (in $ USA)
Electricity + Transport	0.1873 + 0.1597 = ***0,3470***	1	231 628 + 56 512 = ***288 140***
Fuel	0.3238	2	812 791
Communication + + Research	0.0831 + 0.0578 = ***0,1409***	3	150 000 + 228 372 = ***378 372***
Water + Emergency + + Waste	0.0399 + 0.0357 + + 0.0211 = ***0,0967***	4	90 930 + 177 442 + + 95 349 = ***363 721***
Buildings	0.0908	5	482 558

It should be emphasized that this option of modernization changes the priorities of modernization, which are given in Table 6.

One more, the fourth option of the modernization of the station infrastructure was simulated in which the period of modernization was reduced up to 3 years at the expense of combining the modernization of the infrastructure components in their order in Table 7.

Such possible option is given in Table 12 with the corresponding changes in financing modernization by years

Table 12

Option of station infrastructure modernization within 3 years

Components of Station infrastructure (means)	Quantitative characteristics of modernization priorities	Number order of modernization years	Modernization costs (в $ USA)
Fuel + Electricity + + Transport	0.3238 + 0.1873 + + 0.1597 = ***0,6708***	1	812 791 + 231 628 + + 56 512 = ***1 100 931***
Buildings + Communication + + Research	0.0908 + 0.0831 + + 0.0578 = ***0,2317***	2	482 558 + 150 000 + + 228 372 = ***860 930***
Water + Emergency + + Waste	0.0399 + 0.0357 + + 0.0211 = ***0,0967***	3	90 930 + 177 442 + + 95 349 = ***363 721***

The given option of the modernization seems more optimal as a result of both the implementation period and the preservation of the modernization priorities which are given in Table 6. The disadvantage of this option is the uneven modernization funding within the years which can be achieved only with the violation of modernization priorities which are given in Table 6.

4. Conclusions

The method of quantitative characteristics of priorities and cost of modernization of infrastructure of the Ukrainian Antarctic Akademik Vernadsky station infrastructure was applied the first time. The quantitative characteristics obtained in the study provide the opportunities of:

- simulation of the infrastructure modernization process according to the priorities, costs, and time to optimize the modernization process in conditions both of the limited funding and the limited time for the modernization of Vernadsky station infrastructure;
- preparation of the Feasibility Study, Request for Proposal and Working Project for the infrastructure modernization;
- preparation of arguments and proposals for central executive authorities of Ukraine regarding financing and implementation of the station infrastructure modernization;
- informing the general public about the Ukraine activities in Antarctica.

Based on the obtained quantitative characteristics, in the study for example four specific options have been simulated of the modernization of Vernadsky station infrastructure which provide a solid foundation for choosing, maneuvering and making decisions with limited resources in funding and in time.

The proposed method does not require a large number of experts, effectively utilizes the experience of the involved specialists, and can be used to specify the cost and priorities of the modernization at any stage of the modernization.

The quantitative characteristics obtained in the study can be made more exact by attracting other experts and specialists, and by clarifying the cost and priorities of modernizing the individual components of the Station infrastructure by other methods.

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