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AN ANALYTICAL APPROACH TO MULTI-CRITERIA CHOOSING TECHNOLOGICAL SCHEME FOR INFORMATION PROCESSING

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ABSTRACT

Context. Today, effective information processing is critically important for making strategic, tactical, and operational management decisions. The increasing volumes of information and the need for its rapid analysis necessitate the development and implementation of new methods for multi-criteria choosing technological schemes for information processing. The application of analytical approaches, such as the Ordered Weighted Averaging (OWA) method, allows for the improvement of the quality of final information products, which is relevant for analysis and research in various fields.

Objective. The aim of the research is to develop an analytical approach to multi-criteria choosing an information processing technological scheme using the OWA operator.

Method. The paper uses an analytical approach based on the multi-criteria decision-making method. Specifically, the Ordered Weighted Averaging (OWA) operator is applied, which allows taking into account the weight coefficients of the criteria and their ranking significance to determine the optimal information processing technological scheme.

Results. The research results show that the application of the OWA operator effectively aggregates the evaluation of alternatives and selects the technological scheme that best meets the specified criteria for the quality of the end information product. The conducted experiments confirmed the effectiveness of the proposed approach in evaluating alternative information processing schemes.

Conclusions. The proposed approach to multi-criteria selection of a technological scheme for processing intelligence data allows for improved quality of the end information product and considers the importance of various criteria. Further research could be focused on the development of automated decision support systems taking into account the metadata of intelligence data.

KEYWORDS: information processing, Technological scheme, End information product, Multi-criteria analysis, OWA operator.

ABBREVIATIONS

OWA – Ordered Weighted Aggregation;
EIP – End Information Product;
TS – Technological Scheme.

NOMENCLATURE

$A=\{a_1,...,a_n,...,a_N\}$ is a set of numbers to be aggregated;

b_j is a j-th element of a set A after ordering its constituent elements $\{a_1,...,a_n,...,a_N\}$ according to the principle of non-increasing (decreasing) their values;

$b_{m,j}$ is a j-th element of an ordered sequence levels of the criteria satisfaction for the TS_m scheme case;

$C=(c_1,...,c_n,...,c_N)$ is a set of criteria for assessing the End Information Product quality;

c_n is n-th partial criterion of End Information Product quality;

D_m is a generalized criterial level of the End Information Product quality achieved using TS_m scheme;

$F(A)$ is a resultant of the aggregation of the numbers $\{a_1,...,a_n,...,a_N\}$ by means of the OWA operator;

$l_{m,n}$ is satisfaction level of the n-th partial criterion by TS_m scheme;

M is a total number of alternative technological schemes;

N is a total number of quality assessment criteria for the EIP;

TS_m is m-th technological scheme for information processing;

$u_{m,j}$ is an importance of the criterion associated with $b_{m,j}$;

V_j is an importance of the j-th criterion;

$W=(w_1,...,w_n,...,w_N)$ is a set of weight coefficients (weights).

INTRODUCTION

As is known, one of the most important factors determining the successful functioning of virtually any organizational system is the level of its information support [1]. At the same time, taking into account the high dynamism of the modern world, special importance is payed to updating previously obtained data and replenishing it. However, the permanent increase of information volumes complicates carrying out in-depth and comprehensive analysis its and requires the use of adequate technological methods and schemes.

For conducting comprehensive, including quantitative, analysis of information, there are various TS that differ in their data analysis methods, software and instrumental

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support, level of automation, quality of created EIP, and so on [2].

Content and presentation form of the information analysis results are usually determined by the customer. In particular, as such a result can be:

– information decision;

– subjective evaluate of the object or the situation of interest state;

– in-brief report;

– thematic map, etc.

Quality of any EIP may be assessed using such criteria as relevance, reliability, completeness, timeliness, but not only [3]. However, it is namely the listed criteria are usually used when choosing a TS.

In our work, the choosing the relevant scheme TS for information processing is considered as a multi-criteria task, and to solve it an analytical approach based on the application of the OWA operator, introduced by R. Yager in [4], is proposed.

The unique properties of the OWA operator include the ability to combine (aggregate) criterion assessments taking into account their position in the rank statistics, as well as, if necessary, to help find a compromise between the assessments of alternatives across different criteria [5, 6].

The object of the study is a procedure for choosing technological scheme for information processing.

The subject of the study is a methodological approach to the multi-criteria choosing the technological scheme TS leveraging the OWA operator.

The aim of the study is to develop a methodological approach to choosing the relevant scheme TS for information processing based on the OWA operator.

1 PROBLEM STATEMENT

We consider a situation where an analyst has obtained specific pieces of information $\{Info\}$ on the basis of which he must create the next EIP. It is assumed that to process the obtained information and to form the EIP, the analyst can use one of the M available TS $\{TS_m | m = 1,2,...,M\}$ with different capabilities.

The task for an analyst is to choose, among the available {TS}, the scheme that allows to form the EIP whose quality best meets the totality of specified criteria.

There are two or more such criteria, and they may differ in importance.

Formally, the task can be written as follows: to choose from $TS^{\cdot} \big| TS^{\cdot} \subset \{TS_m | m = 1,2,...,M\}$ one scheme $TS^{\cdot}$ which will provide the transformation $\{Info\}$ in the product $КІП^{\cdot}$ according to the rule (1):

$$\{Info\} \xrightarrow{TS^{\cdot}} КІП^{\cdot}, \tag{1}$$

at the same time the product $КІП^{\cdot}$ will satisfy the follow criterion of quality:

$$D^{\cdot} = \max\{D_m | m = 1,2,...,M\}. \tag{2}$$

An analytical approach proposed and described below allows to solve this task.

2 REVIEW OF LITERATURE

Issues of applying multi-criteria decision analysis which assists decision-making in various fields, are actively studied (see, e.g., [8–14]).

In [8], a review of approaches to multi-criteria decision analysis in the field of sustainable energy is presented. The authors examine in detail the specific features characteristic of the various stages of the decision-making process, namely: the stages of criteria selection, criteria weighting, evaluation, and final aggregation.

The experience of practical application of multi-criteria selection and decision-making methods in ecology has been analyzed by researchers from the Massachusetts Institute of Technology (USA) in [9]. The presented examples demonstrate the high effectiveness of such methods in solving various environmental problems.

Reference [10] discusses the use of a multi-criteria approach to support strategic decision-making and provides a number of proposals for adapting the approach based on the specific application area.

Reference [11] presents the results of research on the comparative evaluation of the effectiveness of modern multi-criteria methods (TOPSIS, VIKOR, COPRAS, MULTIMOORA, and PROMETHEE GAIA) in the task of selecting renewable energy sources (hydropower plants, solar photovoltaic systems) for the energy sector of Latvia. It is concluded that the choice of the most effective multi-criteria method depends on the type of energy source to which it is applied.

Based on a comprehensive content analysis of approximately 3,000 scientific articles, the authors of [12] identified a growing trend in the application of multi-criteria methods (AHP/ANP, TOPSIS, MAUT/MAVT, etc.) in the field of the environment (including water, air, energy, natural resources, and waste management), including in geospatial analysis tasks.

Researchers from the Swiss Federal Institute of Aquatic Science and Technology [13] analyzed over 300 literature sources (have been published between 2000 and 2015) that explore the potential for combining multi-criteria decision analysis methods. The study examined how extensively problem-structuring methods and multi-criteria decision analysis are used together, how they are integrated, and what advantages and challenges such an approach presents.

The study by researchers from the O. Beketov Kharkiv National University of Urban Economy [14] is devoted to solving a multi-criteria assignment problem under a categorical efficiency criterion.

At the same time, the issue of choosing and applying the most effective methods and schemes for multi-criteria analysis of information remains open.

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3 MATERIALS AND METHODS

As mentioned above, the proposed approach is based on the use of the OWA operator. Its essence is as follows. Let there be a set of N numbers $\{a_1,...,a_n,...,a_N\}$, and the task is to combine (aggregate) them into a point-valued number $F(A)$. Using the OWA operator, this number is calculated according to the following formula [4]:

$$F(A)=\sum_{j=1}^{N} w_j \cdot b_j = w_1 b_1 + ... + w_n b_n + ... + w_N b_N . \quad (3)$$

Let us now turn to the essence of the proposed approach. It is assumed that there is a set of criteria C that the EIP must meet, with each criterion having its importance V_j $(j=1,2,...,N)$. It is further assumed that there are M different data analysis schemes $\{TS_1,...,TS_m,...,TS_M\}$, where each the m-th scheme $(m=1,...,M)$ provides its level $\{l_{m,1},...,l_{m,n},...,l_{m,N}\}$ of satisfaction for the corresponding criterion c_n during data processing.

It is assumed that the levels of satisfaction of criteria c by any specific data analysis scheme TS_m are known. These levels can be obtained based on the application history of the given TS, through expert evaluations, or by statistical modeling methods.

Each element c_n from the C set can be considered a partial criterion (n=1,2,…,N). The level of satisfaction of partial criteria is measured in relative units. For example, the partial criterion c_n is defined as the maximum time resource allocated for the production of the EIP, which should not exceed two hours.

Let us assume that when applying the m-th data analysis scheme TS, this criterion is fully satisfied at 100%, which means $l_{m,n}=1.0$. At the same time, the $(m+1)$-th TS requires 2.5 hours to complete the same task, exceeding the allocated resource by 20%; this means that $l_{m,n}=0.8$.

According to the proposed approach, all partial criteria are combined (aggregated) into a generalized criterion. The task then is to analytically and justifiably select, among the M available {TS} the scheme that will ensure the formation of the EIP with the biggest value of the generalized criterion.

Let us denote by D_m the generalized criterion level corresponding to the EIP formed using the m-th TS during the processing of the given information. Applying the OWA operator, the generalized criterion level is calculated using formula (4):

$$\begin{aligned} D_m &= \sum_{j=1}^{N} w_{m,j} \cdot b_{m,j} = \\ &= w_{m,1}b_{m,1} + ... + w_{m,n}b_{m,n} + ... + w_{m,N}b_{m,N}, \\ &(m=1,2,...,M). \end{aligned} \quad (4)$$

To perform calculations according to formula (4), certain logical and computational procedures need to be carried out.

First, from the known elements of the sequence L_m, the sequence (5) is constructed:

$$b_{m,j} = \{b_{m,1},...,b_{m,n},...,b_{m,N}\}, \quad (5)$$

whose elements are related to each other as
$b_{m,1} \ge b_{m,2} ... \ge b_{m,N}$, at what:
$b_{m,1} = \max\{l_{m,1},...,l_{m,n},...,l_{m,N}\}$;
$b_{m,N} = \min\{l_{m,1},...,l_{m,n},...,l_{m,N}\}$.

Second, a correspondence table is compiled:

$w_{m,j}$	$b_{m,j}$	$u_{m,j}$
$w_{m,1}$	$b_{m,1}$	$u_{m,1}$
$\vdots$	$\vdots$	$\vdots$
$w_{m,n}$	$b_{m,n}$	$u_{m,n}$
$\vdots$	$\vdots$	$\vdots$
$w_{m,N}$	$b_{m,N}$	$u_{m,N}$

which reflects the fact that the weight values $w_{m,j}$ are functions of two arguments, namely $b_{m,j}$ and $u_{m,j}$. Note that the values of the argument $b_{m,j}$ are defined by sequence (3), and thus are known.

Regarding the elements of column $u_{m,j}$: according to the construction rule of sequence $b_{m,j}$, each of its elements $b_{m,n}$ is associated with a corresponding partial criterion from the set $\{c_1,...,c_n,...,c_N\}$. The column $u_{m,j}$ consists of the importance values V_j assigned to the partial criteria associated with the respective elements of sequence $b_{m,j}$.

Third, the construction of sequence $u_{m,j} = \{u_{m,1},...,u_{m,1},...,u_{m,1}\}$ allows proceeding to the calculation of weights $w_{m,j} = \{w_{m,1},...,w_{m,1},...,w_{m,1}\}$, for which formula (6) is proposed in [7]:

$$w_{m,j} = \left(\frac{\sum_{k=1}^{j} u_{m,k}}{\sum_{k=1}^{N} u_{m,k}} \right)^2 - \left(\frac{\sum_{k=1}^{j-1} u_{m,k}}{\sum_{k=1}^{N} u_{m,k}} \right)^2 , \quad (6)$$

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$(m = 1,2,...,M)$.

Having the results of the logical and computational procedures, the criterion level $\left(D_m \middle| m = 1,2,...,M\right)$ that can be achieved by the EIP formed using each available TS is determined according to formula (4).

Finally, comparing the calculated criterion levels from D_1 to D_M provides the analyst with the opportunity to select the relevant and most effective scheme TS for information processing according to criterion c_n.

4 EXPERIMENTS

Assume the EIP quality is evaluated by three criteria: reliability (c_1), completeness (c_2) and timeliness (c_3). The importance of these criteria is given respectively as: $V_1 = 1.0$; $V_2 = 0.60$; $V_3 = 0.80$.

When planning the data analysis process, the analyst has two alternative technological schemes – TS_1 and TS_2. Using one of the methods mentioned above, it was established that the TS_1 scheme can generate the EIP that satisfies the accepted criteria to the following extent: criterion (c_1) – 100%, criterion (c_2) – 70%, and criterion (c_3) – 80%. The TS_2 scheme allows for the formation of an EIP that satisfies the accepted criteria as follows: criterion (c_1) – 90%, criterion (c_2) – 80%, and criterion (c_3) – 100%.

The question arises: which TS should be preferred? According to the proposed approach, preference is given to the one of the two that can generate the EIP with a higher value of the generalized criterion.

Let us perform the necessary calculations for the schemes TS_1 and TS_2, and then compare their results.

5 RESULTS

For the scheme TS_1, the correspondence table will be as follows:

c	$w_{1,j}$	$b_{1,j}$	$u_{1,j}$
c_1	$w_{1,1}$	1.0	1.0
c_2	$w_{1,2}$	0.8	0.8
c_3	$w_{1,3}$	0.7	0.6

$$w_{1,1} = \left(\frac{u_{1,1}}{\sum_{k=1}^{3} u_{1,k}} \right)^2 = \left(\frac{1.0}{1.0+0.8+0.6} \right)^2 = 0.174;$$

$$w_{1,2} = \left(\frac{\sum_{k=1}^{2} u_{1,k}}{\sum_{k=1}^{3} u_{1,k}} \right)^2 - \left(\frac{u_{1,1}}{\sum_{k=1}^{3} u_{1,k}} \right)^2 =$$

$$= \left(\frac{1.0+0.8}{1.0+0.8+0.6} \right)^2 - 0.174 = 0.388;$$

$$w_{1,3} = \left(\frac{\sum_{k=1}^{3} u_{1,k}}{\sum_{k=1}^{3} u_{1,k}} \right)^2 - \left(\frac{\sum_{k=1}^{2} u_{1,k}}{\sum_{k=1}^{3} u_{1,k}} \right)^2 =$$

$$= 1 - \left(\frac{1.0+0.8}{1.0+0.8+0.6} \right)^2 - 0.5625 = 0.438.$$

Substituting the calculated weight values, as well as the data from the correspondence table into formula (4), we obtain:

$$D_1 = \sum_{j=1}^{3} w_{1,j} \cdot b_{1,j} =$$

$$= 0.174 \cdot 1.0 - 0.388 \cdot 0.8 + 0.438 \cdot 0.7 = 0.791.$$

For the TS_2 scheme, the correspondence table will be as follows:

c	$w_{2,j}$	$b_{2,j}$	$u_{2,j}$
c_3	$w_{2,1}$	1.0	0.8
c_1	$w_{2,2}$	0.9	1.0
c_2	$w_{2,3}$	0.8	0.6

The weights are calculated using formula (6):

$$w_{2,1} = \left(\frac{u_{2,1}}{\sum_{k=1}^{3} u_{2,k}} \right)^2 = \left(\frac{0.8}{1.0+0.8+0.6} \right)^2 = 0.111;$$

$$w_{2,2} = \left(\frac{\sum_{k=1}^{2} u_{2,k}}{\sum_{k=1}^{3} u_{2,k}} \right)^2 - \left(\frac{u_{2,1}}{\sum_{k=1}^{3} u_{2,k}} \right)^2 =$$

$$= \left(\frac{0.8+1.0}{1.0+0.8+0.6} \right)^2 - \left(\frac{0.8}{1.0+0.8+0.6} \right)^2 = 0.451;$$

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$$w_{2,3} = \left(\frac{\sum_{k=1}^{3} u_{2,k}}{\sum_{k=1}^{3} u_{2,k}} \right)^2 - \left(\frac{\sum_{k=1}^{2} u_{2,k}}{\sum_{k=1}^{3} u_{2,k}} \right)^2 =$$

$$= 1 - \left(\frac{0.8 + 1.0}{1.0 + 0.8 + 0.6} \right)^2 = 0.438.$$

Substituting the calculated weight values and the data from the correspondence table into formula (4), we obtain:

$$D_2 = \sum_{j=1}^{3} w_{2,j} \cdot b_{2,j} =$$

$$= 0.111 \cdot 1.0 + 0.451 \cdot 0.9 + 0.438 \cdot 0.8 = 0.867.$$

A comparison of the criterion values D_1 and D_2 shows that, under the given conditions, the TS_2 scheme is capable of providing higher the EIP quality.

6 DISCUSSION

The proposed approach to choose relevant TS for information processing based on the OWA operator demonstrates advantages compared to traditional methods, particularly due to its ability to account for the ranked importance of partial criteria. This enables a more flexible and adaptive decision-making process, especially in cases where different criteria have varying weights and impotance.

The results of the numerical example indicate that even minor differences in the values of partial criteria can significantly influence the choice of TS when using the OWA operator.

A comparison with similar studies [8–14] shows that most existing multi-criteria decision analysis methods rely on rigid ranking rules and do not always consider the relative importance of criteria. In this context, the proposed approach offers greater flexibility, especially when integrating expert assessments or fuzzy data.

The application of the OWA operator requires the prior determination of weighting coefficients, which may necessitate involving experienced experts or additional normalization procedures. This aspect defines the dependence of result accuracy on the quality of input data and the justification of the weights.

Further improvement of the approach may involve the use of machine learning methods for the automatic determination of weights based on historical data or predictive models.

Practical significance of the obtained results: the analytical approach can be effectively used in decision support systems under conditions of limited time or incomplete information.

The proposed approach is not only theoretically justified but also demonstrates high effectiveness in the numerical example. This opens prospects for further research in the direction of automating TS evaluation processes, integrating with intelligent agents, and developing dynamic models for adapting criteria to changing environments.

CONCLUSIONS

The paper proposes the analytical approach to multi-criteria choosing TS for information processing based on the OWA operator leveraging. The content of the approach is described in detail, and the numerical example of its application is provided.

The scientific novelty of the study is that the proposed approach to multi-criteria choosing TS for information processing makes it possible to adapt the weighting coefficients of criteria and their ranking structure considering the properties of available TS, thereby helping to find a compromise between the evaluations of alternatives across different criteria.

The practical significance lies in the possibility of applying the proposed approach in decision support systems for information processing, which will improve the quality of the EIP. The methodology can be used in information-analytical structures engaged in the evaluation of strategic information, as well as in military and intelligence units.

For future research, it is important to expand the proposed methodology by integrating machine learning and neural network approaches to automate the process of choosing the relevant TS. Additionally, a promising direction is the development of algorithms for predicting the quality of the EIP based on the analysis of metadata of the input information.

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АНАЛІТИЧНИЙ ПІДХІД ДО БАГАТОКРИТЕРІАЛЬНОГО ВИБОРУ ТЕХНОЛОГІЧНОЇ СХЕМИ ОПРАЦЮВАННЯ ІНФОРМАЦІЇ

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АНОТАЦІЯ

Актуальність. Сьогодні ефективне опрацювання інформації є критично важливим для прийняття стратегічних, тактичних та оперативних управлінських рішень. Зростаючий обсяг інформації та необхідність її швидкого аналізу вимагають розробки та впровадження нових методів багатокритеріального вибору технологічних схем обробки інформації. Застосування аналітичних підходів, таких, як метод упорядкованого зваженого агрегування (OWA), дозволяє покращити якість кінцевих інформаційних продуктів, що є актуальним для аналізу та досліджень у різних сферах людської діяльності.

Мета. Метою дослідження є розробка аналітичного підходу до багатокритеріального вибору технологічної схеми опрацювання інформації із застосуванням оператора упорядкованого зваженого агрегування (OWA-оператора).

Метод. В роботі використано аналітичний підхід, заснований на методі багатокритеріального прийняття рішень. Зокрема, застосовується OWA-оператор, що дозволяє враховувати вагові коефіцієнти критеріїв та їх рангову значущість для визначення найбільш ефективної технологічної схеми опрацювання інформації.

Результати. Результати досліджень показують, що застосування OWA-оператора дозволяє ефективно агрегувати оцінки альтернатив та обрати технологічну схему, яка найбільше серед тих, що є в наявності, відповідає заданим критеріям якості кінцевого інформаційного продукту. Проведені експерименти підтвердили ефективність запропонованого підходу при оцінюванні альтернативних схем опрацювання інформації.

Висновки. Запропонований підхід до багатокритеріального вибору технологічної схеми опрацювання розвідувальних даних дозволяє підвищити якість кінцевого інформаційного продукту та враховувати при цьому важливість розглядуваних критеріїв. Подальші дослідження планується спрямувати на розробку автоматизованої системи підтримки прийняття рішень з урахуванням результатів аналізу метаданих вхідних даних.

КЛЮЧОВІ СЛОВА: опрацювання інформації, технологічна схема, кінцевий інформаційний продукт, багатокритеріальний аналіз, OWA-оператор.

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