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**ПРИРОДНИ РЕСУРСИ И ТЕХНОЛОГИИ**
**NATURAL RESOURCES AND TECHNOLOGIES**

**За издавачот**
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# APPLICATION OF THE METHODS OF MULTI CRITERIA DECISION MAKING IN INDUSTRIAL ENGINEERING AND MANUFACTURING

**Jane Tomov[1], Zoran Despodov[1]**

[1] Faculty of Natural and Technical Sciences, Goce Delchev University, Stip
jane.132052@student.ugd.edu.mk

**Abstract**. Today, a number of data are constantly being generated that require proper processing and access to them. Standard processing techniques could not meet these requirements. The development of information technology and decision theory has contributed to the emergence of the application of modern-applicable methods and approaches for data processing and analysis. The method of data processing from traditional data processing tools is adapted for data processing and with the help of tools and mathematical methods that enable processing and analysis of large data that depend on multiple criteria. This data processing can locate certain problems or shortcomings during the operation, production and management of a company that could not be determined in any other way. Identification and analysis of the problem to be solved, determining the possible solutions to the problem, the criteria according to which the possible solutions are evaluated, i.e. alternatives and the choice of the best possible solution is a decision-making process - (Decision Making - DM), i.e. decision-making process, and as a result of the decision-making process, the decision arises. It is, in fact, the choice of the best of the best possible alternatives to the problem.

**Keywords**: Data, decision making, multi-criteria decision making, analysis, mathematical methods, data processing.

# ПРИМЕНА НА МЕТОДИТЕ ЗА ПОВЕЌЕ КРИТЕРИУМСКО ОДЛУЧУВАЊЕ ПРИ ДОНЕСУВАЊЕ НА ОДЛУКИ ВО ИНДУСТРИСКОТО ИНЖЕНЕРСТВО И ПРОИЗВОДСТВО

**Јане Томов[1], Зоран Десподов[1]**

[1] Факултет за природни и технички науки, Универзитет „Гоце Делчев“, Штип
jane.132052@student.ugd.edu.mk

**Апстракт.** Денес постојано се генерира голем број на податоци кои бараат соодветна обработка и пристап кон истите. Стандардните техники за обработка не можеа да одговорат на овие барања. Развојот на информатичката технологија и теоријата на одлучување допринесе за појава на примена на модерно-применливи методи и пристапи за обработка и анализа на податоците. Начинот на обработка на податоците од традиционалните алатки за обработка на податоци се адаптираат за процесирањето на податоци и со помош на алатки и математички методи кои овозможуваат обработка и анализа на големи податоци кои зависат од повеќе критериуми. Со ваква обработка на податоците може да се лоцираат одредени проблеми или недостатоци во текот на работењето, производството и менаџирањето на една компанија кои не би можеле да се утврдат на друг начин. Идентификацијата и анализата на проблемот кој треба да се реши, одредувањето на можните решенија на проблемот, критериумите според кои се оценуваат можните решенија, т.е. алтернативите и изборот на најдоброто можно решение претставува процес на донесување на одлука – ДО (анг. Decision Making – DM), т.е. процес на одлучување, а како резултат од процесот на одлучување, произлегува одлуката. Таа всушност претставува самиот избор на најдоброто, од повеќето можни алтернативни решенија на проблемот.

**Клучни зборови:** податоци, донесување на одлука, повеќе критериумско одлучување, анализа, математички методи, процесирање на податоци.

## 1. Introduction

In modern business, the main bearers of the success and development of an organization or system are the decision makers. Decision makers need to see the problem, analyze it and decide how to solve it. The main task of decision makers is to make a decision that will achieve the organization's predetermined goals, i.e. business system, with as little cost as possible for material, human and other resources. This means that the decision maker should strive to maximize the organization's goals within a certain system of constraints.

Over time, as everyday life and business become more complex, decision-making itself becomes more complex. Because of modern life and way of working, decision makers who participate in the management process in modern business organizations, i.e. business systems are increasingly making important decisions in the face of constant changes in the environment, in terms of risk, and in situations where inaccurate data cannot be obtained on all parameters that affect a decision [5].

Therefore, to make the right decisions and their successful implementation that entails positive results, experts with appropriate education and knowledge from various scientific fields are needed, such as mathematics, statistics, probability theory, economics, business administration, computer skills, engineering, physics. , social sciences and social sciences, etc. They should also be well acquainted with the techniques of the decision-making process, i.e. decision-making and have appropriate work experience. That is why a whole science must be developed for decision making [3] [4].

## 2. Research methodology

The emergence of Operations Research (OR) dates to World War II, when the first attempt at a scientific approach to solving real decision-making problems was made. After the great success of the war, Operations Research gradually began to be applied in many other areas, such as business, economics, engineering, natural and social sciences, industry, government, military, construction, hospitals, and so on.

Operations research consists of scientific quantitative techniques and methods for mathematical modeling of real problems that need to be solved in the decision-making process, in order to find the best or optimal solution.

This aspect of decision-making, which focuses on quantitative techniques and methods of decision-making, is called the quantitative aspect of decision-making and covers economics, statistics, and mathematics.

Most advocates of the quantitative aspect of decision-making almost completely ignore all other aspects, but research in the field of decision-making theory suggests that the behavioral aspect of decision-making is significantly more present in what can be called real decision-making.

### 2.1 Methods of decision making and their application

Although studying the decision-making process can be approached using the behaviorist or quantitative aspect of decision-making, according to modern twentieth-century decision theory, it is necessary to integrate the two approaches in order to achieve the best results, at least when in question theory. To understand how decision-making works, you need knowledge developed by experts in both psychology and management, i.e. management. Thus, according to modern decision-making theory, the scientific basis of decision-making is the unity between decision-making theory and management science, i.e. Operations Research.

The modern theory of decision-making has an interdisciplinary character and is an area in which we meet and intertwine economics, statistics, mathematics, philosophy, psychology, sociology, law, anthropology, and political science.

Regarding the definition and clarification of the terms and stages of the problem-solving process and the decision-making process, i.e. the decision-making process, there are no clear boundaries.

Solving the problem is a process of identifying the differences between the current state of the system and the desired state, as well as undertaking activities to eliminate the perceived differences. In *Fig.1*, the problem-solving process is presented in a very simple way, as a model consisting of three components:

- current situation (available resources);
- transformation process, (alternatives, operators); and
- desired (final) condition, (defined goals).

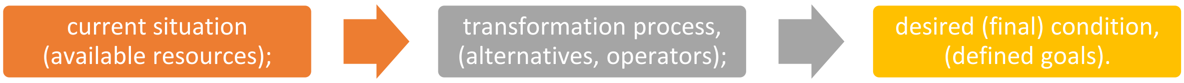


Figure 1. Basic components of the problem-solving process

Therefore, for a decision to be made, the following conditions must be met:

- the decision maker should be aware that there is a discrepancy, i.e., disharmony between the current and desired state of the system;
- The decision maker should be motivated to act in order to eliminate that inconsistency, i.e. to achieve the defined goals;
- The decision maker should have the appropriate resources, which are needed to remove the inconsistency, i.e. to achieve the defined goals.

In the scientific world, there is inconsistency and contradiction in determining the stages of the problem-solving process. [2] In this material, it is adopted that the problem-solving process consists of the following seven stages:

- identification and definition of the problem;

- determining possible solutions to the problem;
- determining the criteria for evaluating possible solutions to the problem;
- assessment of all possible alternative solutions to the problem;
- choice of solution, i.e. making a decision;
- implementation of the selected solution, i.e. implementation of the decision; and
- analysis and evaluation of the results of the implementation of the solution, i.e. from the implementation of the decision.

Figure 2, shows the relationship between the problem-solving process and the decision-making process, at all stages.

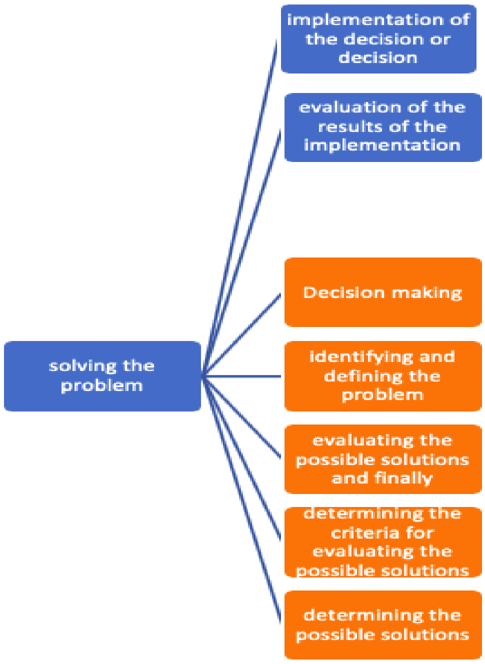


Figure 2. The relationship between the problem-solving process and the decision-making process

The decision-making process covers the first five stages in solving the problem: identifying and defining the problem, determining the possible solutions, determining the criteria for evaluating the possible solutions, evaluating the possible solutions and finally, this process ends with choosing the best possible solution, i.e. by making the decision.

Problem solving differs from decision making in that it contains two additional stages: the implementation stage, i.e. implementation of the decision or decision and evaluation of the results of the implementation, i.e. from the implementation of the decision or decision.

Therefore, problem solving is a complex process in which, in addition to identifying and formulating the problem, determining possible solutions and evaluation criteria, selection and evaluation of solutions, i.e. decisions, the decision maker must implement the decision, evaluate the results of the implemented decision and re-examine all alternative directions of action, until he receives an optimal or satisfactory solution. The problem-solving process can only be considered complete when the problem is eliminated.

## 2.2 Material and method of operation

The decision-making process is often extremely complex due to the presence of competitive and conflicting goals among the available criteria or alternatives. Decision-making practices often deal with weighted alternatives, all of which meet the set of desired goals. The problem is to choose the alternatives that will best meet the overall package of goals.

Analytical hierarchical process (AHP) is based on the concept of balance used to determine the overall relative importance of a set of attributes, activities or criteria and refers to the analyzed problem with the decision. This can be achieved by structuring any complex decision-making problem, involving multiple individuals, multiple criteria and multiple periods at several hierarchical levels, assigning weights in the form of a series of double-piece matrices, and then using Expert decision support system to determine normalized weight. These weights are used to estimate the attributes at the lowest level of the entire hierarchy. The thus understood process of modeling includes four stages:

- Problem structuring,
- Data collection,
- Relative weight assessment and
- Determining the solution to the problem.

The problem structuring stage consists of breaking down a complex problem of decision-making into a series of hierarchies where each level represents a smaller number of managed attributes. Then, they break down into another set of elements that correspond to the next level and in the same order as *Figure 3*. This hierarchical structuring of any problem-solving problem in this way is an effective way to deal with the complexity of real problems and identify significant ones attributes in order to achieve the overall goal of the problem. Therefore, the method (AHP) possesses and provides exceptional flexibility in assisting decision-making processes. The method (AHP) allows the realization of independence - independence between attributes to disintegrate at different hierarchical levels.

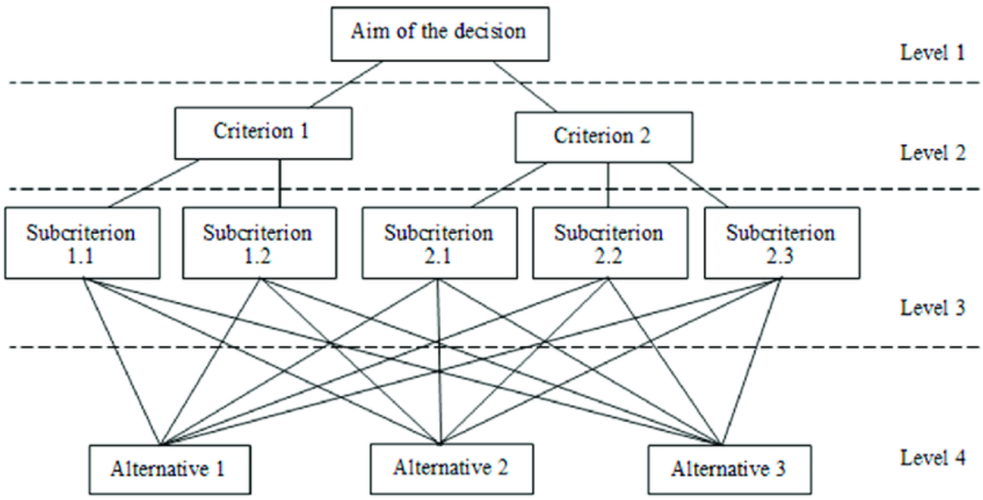


Figure 3. Structuring the problem

The second stage of the method (AHP) begins with data collection and measurement. It is then necessary to assign a relative estimate of pairs of attributes to one hierarchical level, then to the next level, and so on, to the last level. A nine-point scale for weight distribution in *Table 1*, has proven to be extremely reliable in solving real-world problems [1].

*Table 1. Nine-point scale according to Saaty*

| AHP Scale of Importance for comparison pair ($a_{ij}$) | Numeric Rating | Reciprocal (decimal) |
|---|---|---|
| **Extreme Importance** | 9 | 1/9 (0.111) |
| **Very strong to extremely** | 8 | 1/8 (0.125) |
| **Very strong Importance** | 7 | 1/7 (0.143) |
| **Strongly to very strong** | 6 | 1/6 (0.167) |
| **Strong Importance** | 5 | 1/5 (0.200) |
| **Moderately to Strong** | 4 | 1/4 (0.250) |
| **Moderate Importance** | 3 | 1/3 (0.333) |
| **Equally to Moderately** | 2 | 1/2 (0.500) |
| **Equal Importance** | 1 | 1 (1.000) |

The third stage of the method (AHP) involves the assessment of relative weights. Pair comparison matrices will turn into problems with important values to obtain normalized and unique weight agitators for all attributes at each level of the hierarchy. The assumption is that there are n levels of the hierarchy of attributes $A_1, A_2, \ldots, A_n$ with vector weight $t = (t_1, t_2, \ldots, t_n)$. It is necessary to find t to determine the relative importance of $A_1, A_2, \ldots, A_n$. Approaching the comparison of pairs $A_i$ and $A_j$ of all attributes, as the degree to which $A_i$ dominates over $A_j$, i.e. we are, i.e., to be able to form a matrix for comparing pairs.

$$A = (a_{ij}) = \begin{pmatrix} t_1/t_1 & t_1/t_2 & \dots & t_1/t_n \\ \vdots & \vdots & \vdots & \vdots \\ t_n/t_1 & t_n/t_2 & \dots & t_n/t_n \end{pmatrix}$$

The last stage of the method (AHP) involves finding a composite normalized vector. Because successive hierarchical levels are interconnected, the single composite vector of unique and normalized weight vectors for the entire hierarchy will be determined by multiplying the weight vectors by all subsequent levels. This composite vector will then be used to find the relative priorities of all subjects at the lowest hierarchical level, which allows to achieve the set goals of the overall problem.

The method (AHP) is very successfully used to solve several real-world problems: when choosing an operating system for a local computer network, to study a product / market / distribution when generating and evaluating new production concepts, to predict the real price of products.

## 3. Research study using the method of Analytical Hierarchical Process (AHP)

The main purpose of this paper is to propose a modern scientific methodology such as (AHP) that will be used in selecting the most favorable producers and supplier of material for a company, using the methods for multicriteria decision making as a modern approach uses:

- analyze the problem;
- to identify alternatives (variant solutions);
- selection of criteria and definition of their weights;
- to transform the qualities of the attributes (criteria);
- making a multi-criteria model;
- solving the model and
- Determining the optimal solution.

When making orders, it is necessary to develop a production plan that requires knowledge of the procurement and operation of a production company as well as appropriate material resources in order to most efficiently and cheaply perform an activity in production and orders "from-to" a certain place and distance. The process of correct selection of material according to the offer from a given bidder where the factor-criterion that has been taken is both the transport and the price of the material which is an important factor in the optimization. This problem is recorded in the routing and planning of routes using various optimization techniques such as network planning, transport problem and linear programming in order to optimize an activity that in this case requires the most efficient supplier of materials and orders from the place of production. To solve the problem, it is necessary to analyze the technical-economic parameters by making a model for selection of an appropriate manufacturer and supplier of material for production of secondary raw materials, according to a multi-criteria decision-making method [3].

In our case, four alternative hypothetical models of material manufacturers are given, which should be used for an industrial process in which chemical preparations with their basic characteristics are used:

Table 2. Nine-point scale according to Saaty

| No. | Alternative | Mark |
|---|---|---|
| **1** | **DowDuPont** | A1 |
| **2** | **BASF** | A2 |
| **3** | **Sinopec** | A3 |
| **4** | **Sabic** | A4 |

Defining criteria for multi-criteria decision making:

**Criteria 1** - Price of chemical material by appropriate quantity (material required for production),

**Criteria 2** - Material performance ("positive" chemical properties),

**Criteria 3** - Delivery time,

**Criteria 4** - Location (distance from production site to industrial plant) for transport of chemical material (km),

**Criteria 5** - "Material quality" according to the method / ratio used in the industrial plant.

### 3.1 Solving a multi-criteria model in selecting the best manufacturer and bidder according to the requirements of a company

The calculation methodology uses the AHP method for multi-criteria decision making described in the previous chapters. The data used for this illustration of problem solving are hypothetical. At the beginning, a decision matrix is formed with quantitative and qualitative assessments of the criteria that were considered as input data of the model, during processing the following matrix is obtained [4].

Table 3. Real data from the bidders

| Alternatives | Criteria | | | | |
|---|---|---|---|---|---|
| | К1 | К2 | К3 | К4 | К5 |
| **Goal** | min | max | min | min | max |
| **A1** | 9800 | 1,4 | 4,5 | 230 | Average |
| **A2** | 7890 | 1,5 | 5,6 | 180 | High |
| **A3** | 6500 | 1,0 | 4,7 | 200 | Very low |
| **A4** | 7000 | 1,2 | 5,5 | 170 | Average |

The transformation of qualitative attributes, i.e. in numerical values and they are ranked for each alternative in numerical scale that are presented in the matrix form of the AHP algorithm method that provides means for decomposing parts of the problem in a hierarchy of subproblems that can be more easily understood and subjectively evaluated. Subjective assessments i.e. evaluations are converted to numerical values and they are ranked for each alternative with numerical values from the Saaty scale., which is called a quantified decision matrix represented by the following appearance [1]:

Table 4. Nine-point scale according to Saaty with numerical values

| Qualitative assessment | Very low | Low | Average | High | Very High | Type of criteria |
|---|---|---|---|---|---|---|
| **Quantitative assessment** | 1 | 3 | 5 | 7 | 9 | max |
| | 9 | 7 | 5 | 3 | 1 | min |

Table 5. Nine-point scale according to Saaty with numerical values presented in the real data from the bidders

| Alternatives | Criteria | | | | |
|---|---|---|---|---|---|
| | К1 | К2 | К3 | К4 | К5 |
| **Goal** | min | max | min | min | max |
| **A1** | 9800 | 1,4 | 4,5 | 230 | 5 |
| **A2** | 7890 | 1,5 | 5,6 | 180 | 7 |
| **A3** | 6500 | 1,0 | 4,7 | 200 | 1 |
| **A4** | 7000 | 1,2 | 5,5 | 170 | 5 |

The development of a multi-criteria model with the AHP method is structured in four stages and is processed as follows:

- Stage 1. Structuring the problem
- Stage 2. Data collection
- Stage 3. Assessment of relative weights
- Stage 4. Determining the solution to the problem

After performing all stages, it is obtained from the given parameters that as the best bidder regardless of who the manufacturer is but who meets the important criteria such as price of material by purchase quantity and price for delivery or transport as primary, and as secondary important parameters quality of purchased material for production taking into account that it is the same chemical material that is obtained by a specific production method regardless of the industrial plant that will be used by all manufacturers and suppliers, it is obtained that:

„In the last and final stage for determining the solution of the problem, the overall synthesis of the problem for optimal selection of material procurement from certain products of a specific order has been performed in this case chemical material used in a certain industrial plant. "

Table 6. Data before interaction and Criteria weight

| **Criteria** | **Criteria weight** | **A1** | **KxA1** | **A2** | **KxA2** | **A3** | **KxA3** | **A4** | **KxA4** |
|---|---|---|---|---|---|---|---|---|---|
| **K1** | 0,322 | 0,395 | | 0,422 | | 0,112 | | 0,071 | |
| **K2** | 0,389 | 0,502 | | 0,261 | | 0,193 | | 0,044 | |
| **K3** | 0,134 | 0,292 | | 0,408 | | 0,203 | | 0,097 | |
| **K4** | 0,070 | 0,128 | | 0,677 | | 0,134 | | 0,061 | |
| **K5** | 0,086 | 0,673 | | 0,198 | | 0,079 | | 0,049 | |

Table 7. Data interaction and Criteria weight

| **Criteria** | **Criteria weight** | **A1** | **KxA1** | **A2** | **KxA2** | **A3** | **KxA3** | **A4** | **KxA4** |
|---|---|---|---|---|---|---|---|---|---|
| **K1** | 0,322 | 0,395 | 0,127 | 0,422 | 0,136 | 0,112 | 0,036 | 0,071 | 0,023 |
| **K2** | 0,389 | 0,502 | 0,195 | 0,261 | 0,102 | 0,193 | 0,075 | 0,044 | 0,017 |
| **K3** | 0,134 | 0,292 | 0,039 | 0,408 | 0,055 | 0,203 | 0,027 | 0,097 | 0,013 |
| **K4** | 0,070 | 0,128 | 0,009 | 0,677 | 0,047 | 0,134 | 0,009 | 0,061 | 0,004 |
| **K5** | 0,086 | 0,673 | 0,058 | 0,198 | 0,017 | 0,079 | 0,007 | 0,049 | 0,004 |
| **Total** | | | **0,428** | | **0,357** | | **0,155** | | **0,061** |

Table 8. Final ranking of the alternatives

| | **Total** | **Rank** |
|---|---|---|
| **A1** | 0,428 | 1 |
| **A2** | 0,357 | 2 |
| **A3** | 0,155 | 3 |
| **A4** | 0,061 | 4 |

## 4. Conclusion

This paper presents a process of optimal selection of procurement of chemical material / raw material for the needs of an industrial plant / enterprise dealing with secondary production using appropriate chemical reagents / preparations. The AHP method as a method for multi-criteria evaluation and selection has been used for the research conducted in this paper. The method is first explained theoretically, all the procedures by which it is used in everyday decision-making in the logistics process. In the research for solving the problem in the optimal choice of raw material, the criteria and evaluation of the values of their relative weights were performed based on their own experiences and laboratory research. The main problem with the application of this method is the definition of decision-making attributes in the second level of the hierarchical structure for the selection of criteria and the assessment of their relative weights. The definition of alternatives is based on the budget and the basic requirements of the end user that would meet the basic criteria for production and environmental protection because it is a product that uses certain chemical reagents and forward which is important to be taken into account when choosing a suitable supplier of suitable material.

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