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# APPLICATION OF THE AHP/ANP TO INVENTION PROBLEMS

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**Summary:** *The paper describes a number of computer-supported methods for invention problem solving by using the AHP/ANP. These methods are intended for creating of new mechanisms and may be useful for support of the following problems: strategic forecasting the evolution of mechanical devices having a certain functional assignment; a choice of rational analogues and prototypes from inventions databases; the synthesis and quality assessment of new conceptual solutions of mechanisms; the evaluation of novelty by examining the inventions. Application of AHP/ANP enables one to promote solving the foregoing problems through a systemic approach involving the use of multiple criteria for decision-making.*

## 1. Introduction

Diverse technical devices and technologies determine the evolution of the technosphere that provides for the satisfaction of various needs of people including the quality of their lives. The rates of the technospheric evolution depend on the speed of creating both commercial use for the inventions and new spin-off technologies.

Until recently, inventing new subjects, including technical devices, was considered the destiny of prodigies, who use in the process their intuition, personal experience, the analogies taken from nature. However, in the middle of the 20$^{th}$ century the special methods for activating abilities and a systematizing procedures for analysis and synthesis of inventions began to thrive (Altshuller G.S., 1988; Jons J.C., 1984; Zwicky F., 1948). Most of these methods do not envisage an application of a formal method for quality assessment of the solutions created. Ways of applying the AHP/ANP for creative problem solving are given in (Saaty T.L. and Vargas L.G., 1994; Saaty T.L., 2001a; Andreichicov A.V. and Andreichicova O.N., 1998).

This paper describes the outcome of applying the AHP/ANP to the solution of conceptual design problems including the following :

- Strategic forecasting the evolution of the mechanisms having a certain functional assignment;
- Choice of rational analogues and prototypes from databases;
- Synthesis and quality assessment of new conceptual solutions of the mechanisms;
- Evaluation of novelty by examining inventions.

## 2. Strategic forecasting of evolution of mechanisms

### 2.1 Forecasting challenging types of mechanisms

Such problem arises when it is necessary to determine what type of mechanism (or other device) is challenging with respect to further development and use. To answer this question a designer should have knowledge about different mechanisms with the same basic function. Databases containing information about mechanisms that have been studied are helpful in solving this problem. Making inventions databases containing the information on technical solutions of the mechanisms is one of the urgent problems in conceptual design. Descriptions of inventions often do not include parametric information. As a rule, they are represented by the text used and by graphic images. The most universal way of a representing such information in databases is the description of the technical solution by classifying the attributes, in particular the constructive and the functional ones (Andreichicov A.V. and Andreichicova O.N., 1998). In most cases, databases for storage and processing of information about the inventions are hierarchically organized. They contain thousands of descriptions of various mechanisms from different classes. Information on the inventions is represented with hierarchies of constructive and functional attributes and also by textual descriptions, graphic images, and expert estimates of different quality criteria.

There are two ways that can be used to determine the challenging types of mechanisms. First is to reveal the design directions that can lead to new solutions of the mechanisms. This task can be achieved through the use of a "discoveries matrix" that is the morphological table whose rows are the names of the basic functional attributes and whose columns include the names of basic constructive attributes. Basic attributes (functional or constructive) are those that are placed at the upper levels of the hierarchical database. Every cell of such a morphological table is a class of mechanisms that fulfils the function indicated in the row by means of the constructive mode indicated in the column. We look through the inventions in a database and put them into appropriate cells of the morphological table. After that we find out the empty cells that indicate possible directions for the "discoveries". If we wish to design a new mechanism we can select the most suitable direction using the AHP (Saaty T.L., 1994, Saaty T.L. and Vargas L.G., 1994).

The second way includes the following steps.

1) Cluster analysis of inventions from a database with the purpose to reveal the classes of mechanisms similar in constructive and functional attributes. Here we use the sets of attributes from the lower levels of a hierarchical database and classify the mechanisms, using appropriate similarity measures for comparing the attributes.
2) Revealing significant differences between the classes obtained by means of ANOVA/MANOVA. Here we try to find out the differences between classes with respect to various quality criteria, analyzing experts estimates of mechanisms from a database. Following that one can form a binary relation for the classes considered to discover what classes are better than others according to each criterion.
3) A choice of the challenging classes of mechanisms with use of AHP/ANP (Andreichicov A.V. and Andreichicova O.N., 2001). Thus we determine the direction for designing mechanisms with desirable properties and novelty.

We can use one of these ways or both to forecast the challenging mechanism types.

### 2.2 Forecasting change of requirements for inventions

The requirements for technical devices (mechanisms) change with time. This arises from appearance of new needs of people and also because of constant modification of the human values system. These reasons give rise to a changing of relative priorities of criteria used for quality assessment of the mechanisms and also an appearance of new criteria. The new inventions should be created taking into account the trends of the requirements changes if such trends are known. AHP can help to reveal trends of changing the requirements to the class of technical solutions under study (Andreichicov A.V. and Andreichicova O.N., 2003). For this purpose one can construct a hierarchy containing all the important criteria and then use it to evaluate an evolutionary set of alternatives, which includes the mechanisms created at different times with the same basic function. After evaluating the alternatives we can observe changes of their priorities with respect to the criteria. Usually the improvements by some criteria are accompanied by the deteriorations by other criteria. Thus the analysis of an evolutionary set of mechanisms helps to find out the trends of the criteria importance. These trends can change in future, therefore we carry out a marginal analysis of criteria by means of AHP.

Marginal analysis helps to reveal criteria that are most desirable for future improvements. By pairwise comparing the criteria, experts should answer the question: "Is an improvement through one criterion more preferred than a commensurate improvement by another, and how much more preferred?" If some important parameters deteriorate during the evolution it may be desirable to improve them in future. Thus we can determine the direction for perfecting the mechanisms.

The ANP is another mathematical method that can help to forecast changes in the requirements (Saaty T.L., 2001b; Andreichicov A.V. and Andreichicova O.N., 2001). Analysis of the interdependence of various factors that influence the choice a challenging mechanism type by means of ANP enables us to find the type and the most important criteria (requirements).

## 3. Morphological synthesis and quality assessment of new conceptual solutions of mechanisms

The synthesis of new mechanisms is needed when we cannot find required technical solution in the inventions database, or it is necessary to improve the properties of the existing prototypes. Let's notice that the search of rational analogues and prototypes in the inventions databases is carried out with use AHP for prioritization of selected attributes and criteria of quality.

### 3.1 Method of labyrinth synthesis

The method is meant for the invention problems with incomplete information on compatibility of the separate elements, which are included in a mechanism. The synthesis begins at a choice of the mechanism prototype, which is decomposed to the generalized functional subsystems ($GFSS_i$). After that one should form a morphological table whose rows names correspond to $GFSS_i$. The elements of each row are the alternative constructive embodiments of $GFSS_i$ indicated at the left.

Let us consider the example. Suppose it is necessary to design a vibroprotective mechanism for a car. This mechanism should satisfy the requirements of car users (drivers and passengers), manufacturers, and customers. The most important requirements of the drivers are: effective vibration isolation; safety; adjustment for different weight. The manufacturers require a high manufacturability, patentability, components availability and standardization. The customers requirements are: low cost; high reliability; compactness; low repair costs. Experienced designer has defined, what type of vibroprotective mechanism can fulfil these requirements. Such mechanism includes four functional subsystems: springing element ($GFSS_1$); guide mechanism ($GFSS_2$); vibration damper ($GFSS_3$); inertial vibration suppressor ($GFSS_4$). There are various constructive embodiments of these subsystems, which have different characteristics. We have selected the constructive embodiments shown in Figure 1 because of their off-the-shelf availability. The impact of each $GFSS_i$ into the quality (efficiency) of a whole mechanism was determined with use of AHP, therefore the rows of the morphological table are arranged according to decreasing of priorities of $GFSS_i$. We took into account two main criteria for $GFSS_i$: importance and effectiveness.

**Morphological table**

| | Embodiments | | |
|---|---|---|---|
| $GFSS_1$ Springing element | $A_1$ Air damper | $A_2$ Rubber | |
| $GFSS_2$ Guide mechanism | $B_1$ Framework | $B_2$ Bracket-swing | $B_3$ Coaxial inserting |
| $GFSS_3$ Vibration damper | $C_1$ Friction | $C_2$ Hydraulic | $C_3$ Air |
| $GFSS_4$ Inertial vibration suppressor | $D_1$ Oscillation weight | $D_2$ Balance bob | |

*Priorities*

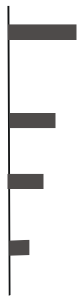


**Figure 1 Morphological table for the synthesis of vibroprotective mechanism**

An assemblage of new invention begins from joining $GFSS_2$ to $GFSS_1$, at that all pairwise combinations of alternative embodiments are generated. Then we make a choice of the best alternative, using AHP. In the Figure 2 the best alternative is the combination $A_1B_2$, which is combined with all elements from the third row of the morphological table at the next step. A choice of the best ternary combination is made with use of a new hierarchy (see Figure 3); such combination is $A_1B_2C_3$. The last step of labyrinth synthesis is shown in a Figure 4, where we can see the hierarchy for a choice of the best vibroprotective mechanism composed of four functional subsystems.

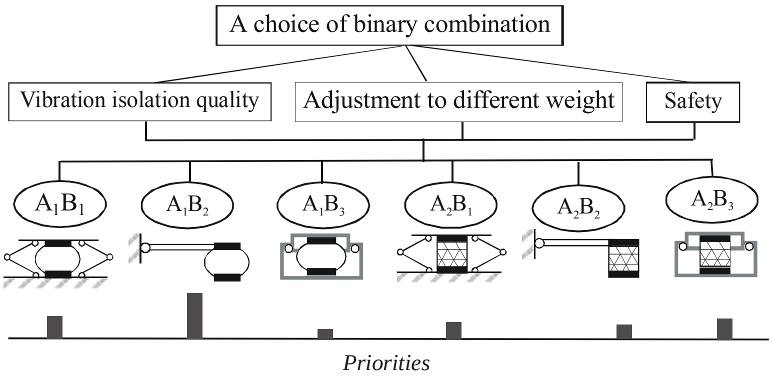



**Figure 2 The first step of labyrinth synthesis**

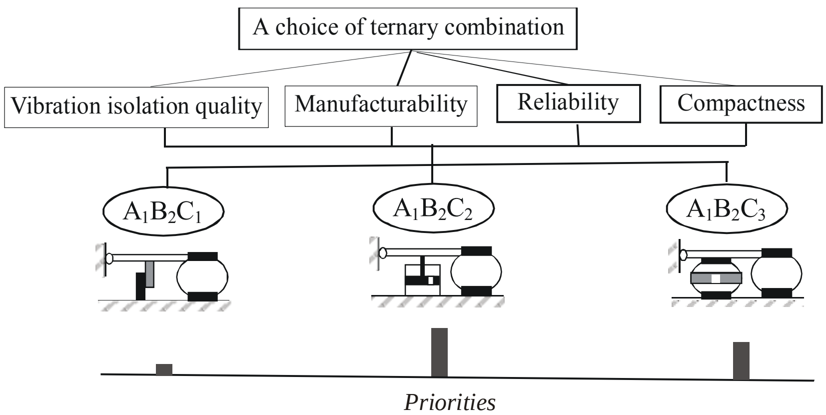



**Figure 3 The second step of labyrinth synthesis**

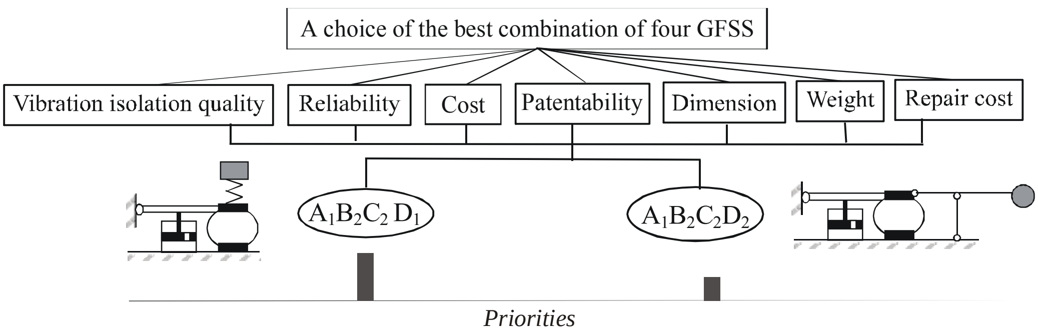



**Figure 4 The last step of labyrinth synthesis**

The synthesis procedure continues until all the rows of the morphological table would be handled. The mechanism synthesized is examined for a satisfaction to the designing requirements. If these requirements are not fulfilled we can come back to the previous stages of the synthesis to take another alternatives.

### 3.2 Method of exhaustive treatment

An exhaustive treatment of all possible combinations, which can be synthesized in the morphological table, is reasonable at the invention problems with complete information. This implies the designer knows, what constructive elements embody each function by the best way and what of these elements can be combined together.

In this case the morphological table contains only compatible embodiments of $GFSS_i$. Every mechanism synthesized includes the only element from each row of the morphological table. The totality of mechanisms synthesized is called a morphological set; every element of this set differs from others at least by one constructive embodiment. We apply AHP to the analysis of a source information, using a proper hierarchy for each $GFSS_i$. Such hierarchies include the following levels:

1) Focus that is the main goal, namely: to find out the best embodiments for the $GFSS_i$;
2) Quality criteria level;
3) Alternatives level containing the embodiments of $GFSS_i$.

After pairwise comparing the criteria and alternatives we compute the priorities vectors and obtain priorities of alternatives concerning the hierarchy focus. Then we can find the best alternative embodiments for each $GFSS_i$. Since the embodiments of different $GFSS_i$ are compatible, then we can synthesize the best mechanism consisting of the best alternatives for each $GFSS_i$. Let's notice, that sometimes we can obtain several combinations if there is non-unique the best embodiment for some of $GFSS_i$. The alternatives with high and very close priorities values are supposed to consider as the best ones. Tendency to a high accuracy in this case can lead to a loss of challenging mechanisms. The mechanisms selected are developed at the further stages of designing.

Let's consider the example of synthesis with use of the morphological table shown in Figure 1. Suppose that all embodiments are compatible to a variable degree. We build the hierarchies for each $GFSS_i$ and choose the best alternative from the set of possible embodiments (see Figure 5). The outcome is the mechanism that consists of the best alternatives. It is the same vibroprotective mechanism as in the previous example.

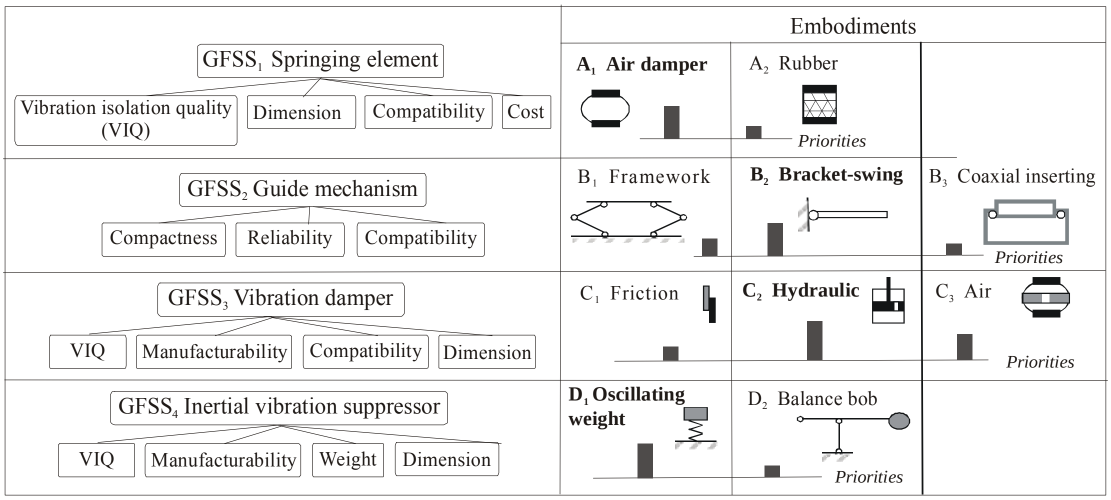



**Figure 5 Choice of the best embodiments for each GFSS**

Let us notice that the exhaustive treatment of all possible variants, as well as the estimating them by the experts is not executed here. Application of AHP helps us to make simpler the problem of evaluating the synthesized (non-existent) mechanisms, reducing it to the estimation of existent constructive embodiments. Furthermore, this approach saves the experts from the time-consuming evaluation of a huge set of synthesized variants.

## 4. Synthesis method based on invention algorithm and AHP

Invention algorithm (Altshuller G.S., 1988) includes the following main steps:

1) A choice of the subject researched (for example, a choice of a mechanism prototype from inventions database);
2) A revelation of shortcomings and engineering contradictions of the prototype;
3) Making up of requirements specification for the prototype improvement that is aimed at the shortcomings and contradictions elimination;
4) Determining the levels of requirements specification, i.e. desirable quantitative ratings for criteria characterizing a mechanism efficiency;
5) A choice of appropriate heuristic rules for the prototype improvement;
6) A transformation of the prototype with use of heuristic rules and then a forming a new set of inventions;
7) Analysis of new inventions and a choice the best of them.

Invention algorithm needs in information support in the form of a set of heuristic rules. The heuristic rule is a brief suggestion concerning a transformation of the prototype in order to improve its. In most cases the heuristic rule is not a well-defined instruction for a univocal transformation of the prototype, but a prompting, which can help to find a good solution without a guarantee. Any heuristic rule contains an advice for an improvement of certain properties of a mechanism and can be characterized by some estimate of its worth. The set of heuristic rules should be organized in some way for further using. This may be done by a generalization of the experience that the designers and inventors possess. We study inventors experience in the field of vibroprotective mechanisms, and the result of this study is the sets of relevant heuristic rules and important properties of these mechanisms. It was obtained by the following way. Vibroprotective mechanisms in the database were ordered in the form of some evolutionary chains (schemes) that demonstrate their historic development. The mechanisms in the evolutionary schemes were arranged so that each previous mechanism was a prototype for the next more perfect mechanism. Then the analysis of prototypes transformation in the evolutionary schemes was carried out. As a result of such analysis, the relations between the heuristic rules and the properties being improved were discovered. Besides, the expert estimates of a worth were assigned to each heuristic rule with respect to the improvements of certain properties. After that we could form the set of 150 heuristic rules, the set of 55 properties being improved, and the set of expert estimations of the worth of heuristic rules for an improvement of various properties of vibroprotevtive mechanisms.

Then heuristic rules and the mechanisms properties were systemized in the form of the general hierarchy shown in a Figure 6. This hierarchy includes the following levels:

1 - Focus that defines the worth of heuristic rules for the improvement of mechanisms properties;
2 - Criteria level (criteria correspond to the mechanisms properties);
3 - Level of the linguistic standards, which are used for estimating alternatives;
4 - Alternatives level (heuristic rules).

At the solving of a specific invention problem we use a part of general hierarchy that includes only those criteria (properties), which should be improved for the mechanism researched.

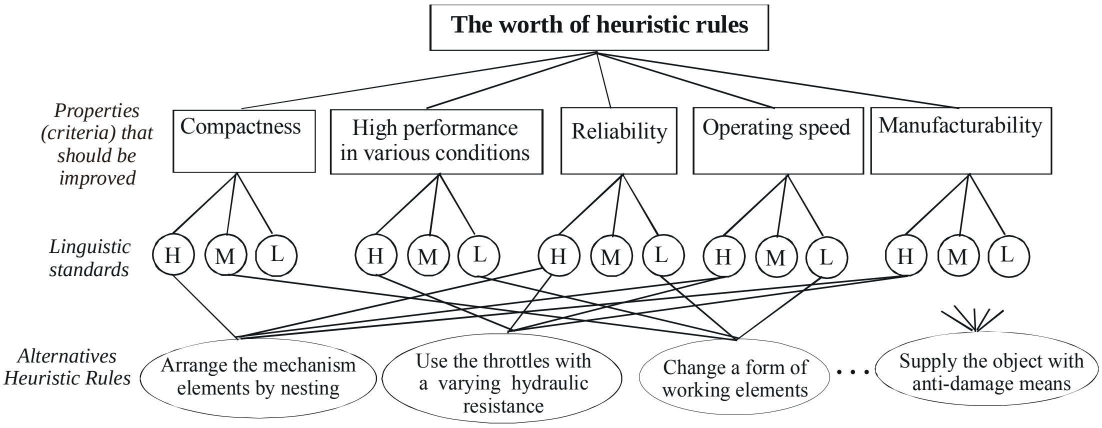
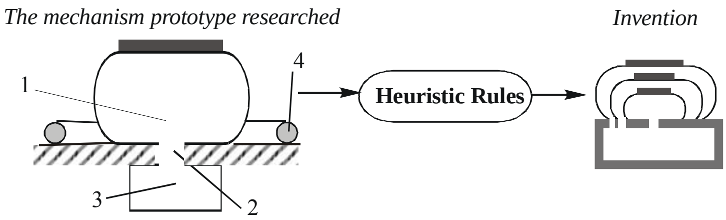



**Figure 6 General hierarchy for estimation of heuristic rules**

Let us consider the example of invention problem. Suppose we wish to improve the competitiveness of the air damper (pneumatic vibroprotective mechanism) shown in a Figure 7. Main shortcomings of this mechanism are a large overall dimension and low reliability. Our goal is the improvement of such properties (criteria) as a compactness, a reliability, and high performance at various conditions. For a solving of this problem we have used the part of general hierarchy that includes mentioned criteria and heuristic rules, which are connected with them.




1 - Compressed-air flask; 2 - Throttle; 3 - Auxiliary flask; 4 - Buffer.

**Figure 7 Example of inventing the air damper**

For this problem the alternatives level includes the following heuristic rules:
1) Arrange the mechanism elements by nesting
2) Use the throttles with a varying hydraulic resistance
3) Replace a single object by a set of elements of the same type, but with various quantitative characteristics
4) Use the other mode of functioning
5) Replace a single-stage system by many-stage one
6) Use hydraulic fluids with electromagnetic properties
7) Change a form of working elements
8) Divide the object into two parts with different sizes, to place the part with large dimension outside the object workspace
9) Replace a reciprocation by a swinging movement
10) Use the materials having self-repair properties
11) Replace a monofunctional element by multifunctional one
12) Supply the object with anti-damage means

At first we determine the relative importance of criteria and then compute the priority vectors for heuristic rules. As a result we have found two heuristic rules: 1 - Arrange the mechanism elements by nesting; 2 - Use the throttles with a varying hydraulic resistance.

These rules help us to design a new air damper (see Figure 7) that includes the set of nesting flasks and some throttles with various hydraulic resistances.

## 5. Conclusion

Application of AHP to inventions problem gives an opportunity to analyse decisions researched with respect to multiple criteria. AHP/ANP are the effective mathematical method for systemic analysis and a formalization of poorly structured problems. Except decision-making support it can be used for a strategic forecasting, a searching of a relevant information in databases, and the analysis of mutual influences in complex systems.

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