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MODELS OF OIL WOOD COATING MATERIALS SELECTION ACCORDING TO TECHNOLOGICAL, OPERATIONAL, ECOLOGICAL AND ECONOMIC CRITERIA

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Abstract:
This article presents the use of system analysis methodology and Graph Theory for validation of the relationships among descriptive factors, which impact the selection of oil materials for wood finishing. Matrix analysis was used to determine the results of the pair wise comparisons of factor weights and optimization of the factor values. Modelling theories have been developed, which allow for construction of models of primary impacts of the factors on oil materials selection in protective and decorative wood coatings creation.

Keywords: *oil; wood; finishing; criterion; matrix; model; graph.*

INTRODUCTION

Nowadays we can observe a growing interest in environmentally friendly materials including coating materials, of which no woodworking, furniture and many other industries can do without.

Based on extensive amount of research, technologists around the world attest that protective materials (especially for interior finishing) should not restrict benefits of natural characteristics of wood. The wood should “breathe”, remain elastic in order to positively impact the interior environment. Those requirements are met by natural oil-based and wax-based coating materials. Such materials are environmentally safe, since they don’t contain synthetic materials, chlorinated carbohydrates, heavy metals, etc. (Yaremchuk 2013).

The advantage of natural coating materials, in particular plant oils, is in their renewability, while the resources for synthetic coating materials (gas, crude oil, coal) are not renewable, and their reserves are insufficient. Due to energy crisis, the issue of conserving energy resources will remain one of the most critical problems. The main growth areas in modern coating materials technology development are in high quality coating solutions based on environmentally friendly materials, thus improving aesthetics of wood block and reducing wastage of coating materials. Oils have good wetting capabilities and deeply penetrate the wood by capillary tracts. It is inconsequential, which side the oil coating is applied to, because, after making contact with wood, oil seeps through the channels in wood (Zimon 1974).

Oils, especially linseed oil, penetrate wood particularly well, additionally protecting it from blue stain, rot, harmful insects and climate impacts. Saturation of wood with linseed oil helps highlight the wood texture, giving it soft matte gloss, enhancing structural durability, providing resistance to moisture, drying out and fading (Biotechnologii, Lnyanoe maslo 2014) However, all oil materials, as opposed to other varnishes, dry slowly, have reduced resistance to abrasion and do not produce a thick hard coating even after several applications.

In order to mitigate the abovementioned drawbacks, present manufacturers of materials and products develop technologies of modified oil materials, which give very positive results towards improvements of oil properties.

Currently, such companies like Akzo Nobel, Bona, ICA, Sirca, Remmers and many others offer oil-based coating materials for woodworking manufacturers.

Wood is an eco-friendly resource. Natural oils also belong to the group of environmentally safe materials. Presently, however, in a form of a coating material, they are used rarely due to a number of reasons, but mainly because of considerable drying times.

Manufacturers and consumers have great difficulty making a rational choice in the selection of wood finishing coating materials, since currently there is a lack of scientifically reasonable methods to solve this important scientific and practical problem. Coating materials selection decisions are often made based on the choices of consumers, who have challenges taking into consideration the full spectrum of quality criteria applicable to coating materials (Yaremchuk 2013).

Presently, since most furniture and woodworking companies are small businesses, these decisions are often made by a single individual, which increases the probability of errors in coating material selection.

Considering modern ecologically progressive trends in our society (Semenyuk *et al*. 2011, Yaremchuk 2013), it is advisable to give preference to natural, sustainable and environmentally safe materials that have high technological, operational and economic indicators at a level on par with synthetic ones. Out of the total number of coating materials, which are used as protective and decorative coatings, oil coating materials (based on drying oils) have the least environmental impact.

OBJECTIVES

This research aims to confirm the hypotheses about the feasibility of usage of oil-based coating materials and to show the main selection criteria of oil coating materials that satisfy these ecological, technological and economic parameters with the methodology of graph theory and hierarchical model.

METHODOLOGY

In the course of research and considerable amount of problem-solving related to reasonable decision-making based on the human intellect and knowledge, it turned out to be impossible to apply the well-known mathematical approaches and quantitative indices and parameters related to them.

Thankfully, solving of such kinds of problems became possible due to works of a well-known American scientist, Lotfi Zadeh, the founder of the fuzzy set theory, that is, the science of about fuzzy logic, which applies the means of fuzzy algebra (Zadeh 1976, Zaden 2001). Transition from the descriptive values of the term-set to their formalized representation is performed by reflection, which is identified with the aid of a membership function. The linguistic information, with their help, turns into numeric data.

In order to build a membership function adequately, it is reasonable to use the method of hierarchical analysis, which is a logical structural loop with the means of simple rules providing the analysis of complicated problems in all their versatility and working out solutions, the optimality of which is provided by the corresponding criteria (Saati 1993).

At the initial stage the links between factors, that is, pairwise influence between them, is defined. It is the most convenient to do it with a previously formed graph, the arcs of which represent the dependency between the nodes of graph that identify the corresponding obstacle factors. The set dependencies are recorded in a binary quadratic matrix. The graphic model of the relations between the factors is a basis for building a so called reachability matrix, where the presence or absence of possible paths between factors is formally represented. The reachability matrix serves as a basis for building the iteration tables — the tool for setting the obstacles hierarchy.

As a result of the analysis of the content and ways of impact of different factors, it is reasonable to develop the obstacles hierarchy model which, besides the ranking by the importance of the influence on the process, could enable the further division into the subordinate (inner) components in order to define the level of weakening or intensification of the causing factor.

Setting and solving of these kinds of problems call for defining the maximum complete set of the generalized factors, making the expert evaluations of the interrelation and interaction in a certain information environment (Arefieva *et al*. 2011, Lyamets 2004).

Hierarchical Model Development

The main criteria that may influence the material choices for wood finishing were selected according to the prior experimental studies, which were carried out for the evaluation of technological characteristics of oil materials and assessment of presented by manufacturers ecological and economic indicators.

The Taxonomy of selection criteria for oil coating materials is displayed in Fig. 1.

Since the presented criteria influence the coating materials selection process in a specific way, the primary assignment - considering the significance of the final result - is to designate the level and action priorities of each separate criterion. Based on this data, the solution alternatives to the problem are developed and a best alternative selection is performed.

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The impact of the determined oil coating selection criteria, despite the current analysis of properties of a given material (Yaremchuk 2011, Turlaj; Yaremchuk 2011), is of a general nature. The importance level of any criteria can be determined separately and without considering the side effects of others. Attempts to generalize this data so far formally records the result confirmed by facts.

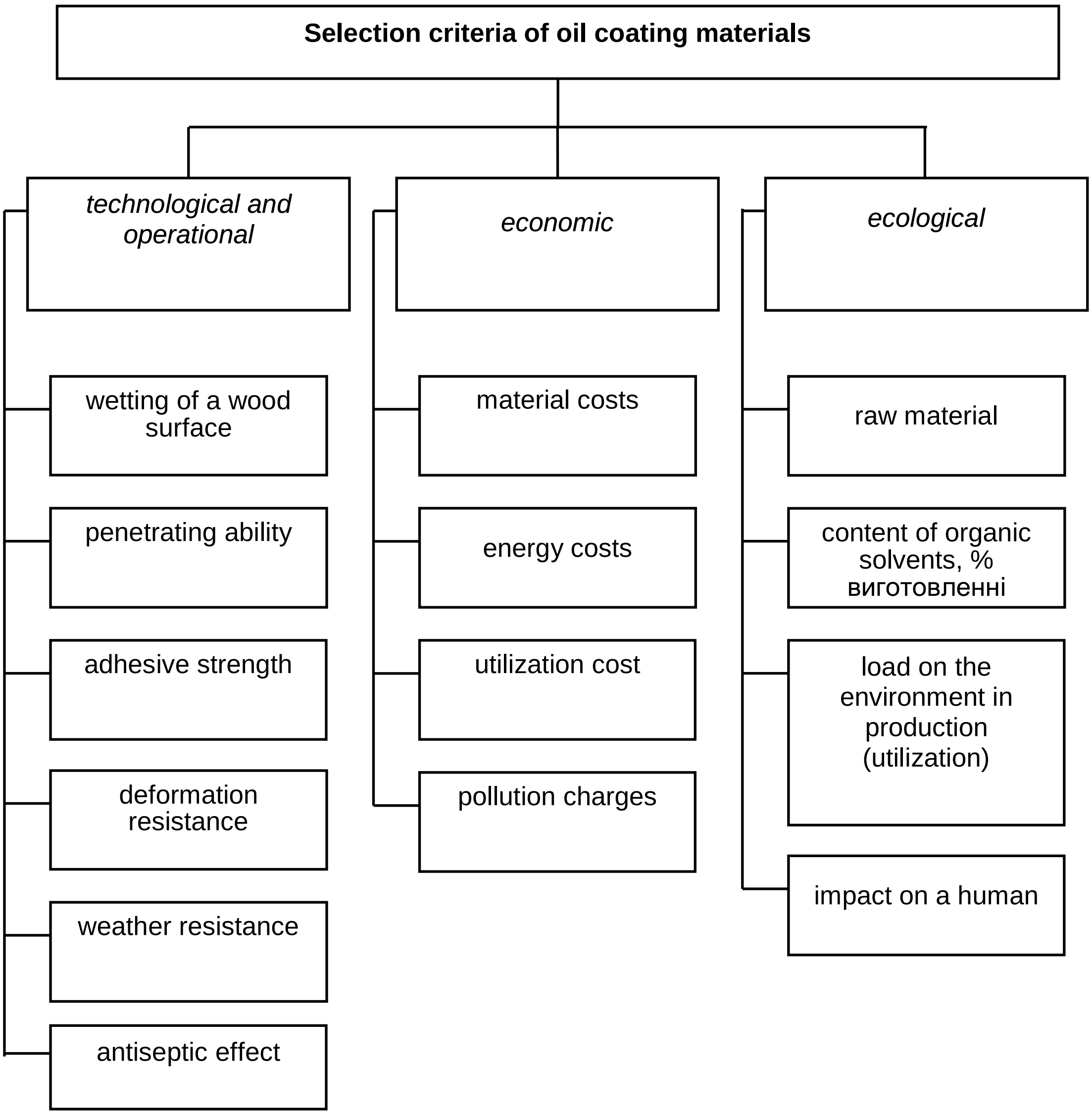

Fig. 1.
***Taxonomy of oil coating selection criteria*.**

The formulation and solution of such problems requires: identifying the most complete set of generalized criteria and establishment of expert opinions about the correlations and mutual influences in the selected information environment. The basis for determining the significance of such effects is their pairwise comparisons. During the initial phase, the relationships or pairwise influences between criteria are established. It is best to build the relationships with an established graph, edges of which represent the dependency among the vertices (nodes) of the graph which identify specific criteria. The established dependencies are recorded in a binary square matrix. The algorithm for this matrix construction is presented below. The graphical model of relationships among the criteria becomes the basis for building a reachability matrix, structurally similar to the previous one, where the presence or absence of the possible connections among them is reproduced in a formal way. A reachability matrix is the basis for the construction of iterative tables – instrument of establishment of the hierarchy of criteria (Katrenko 2007, Lyametc 2004, Semenyuk *et al*. 2012).

The names of the determined oil coating selection criteria and their mathematical representations are shown in the tables 1-3 below for visual convenience.

Table 1

List of ecological criteria

Selection criteria	Variable names
raw material for coating material production	a_1
content of organic solvents, %	a_2
load on the environment in production (utilization)	a_3
impact on a human	a_4

Table 2

List of technological and operational criteria

Selection criteria	Variable names
wetting of a wood surface	b_1
penetrating ability	b_2
adhesive strength	b_3
deformation resistance	b_4
weather resistance (water resistance, resistance to changes in temperature)	b_5
antiseptic effect on wood	b_6

Table 3

List of economic criteria

Selection criteria	Variable names
material costs	c_1
energy costs	c_2
utilization cost	c_3
environmental pollution charges	c_4

An array of ecological oil coating selection criteria $a = \{a_{1,}\ a_1 \ldots\ a_n\}$ and the possible relationships between them is displayed as an oriented graph in Fig. 2.

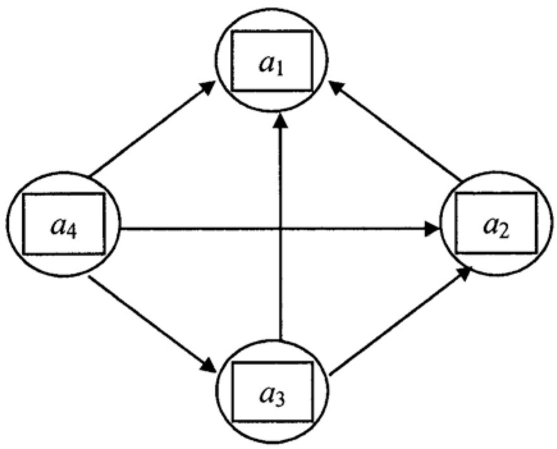

Fig. 2.
Graph of relationships among ecological oil coating selection criteria.

Based on this graph (Fig. 2), binary dependency and reachability matrices M_a for the determined vertices are constructed.

Table 4

Dependency matrix M_a

		a_1	a_2	a_3	a_4
a_1	b_1	0			
a_2	b_2		0		
a_3	b_3			0	
a_4	b_4				0

Table 5

Reachability matrix M_a

	a_1	a_2	a_3	a_4	
a_1	1	0	0	0	a_1
a_2	1	1	0	0	a_2
a_3	1	1	1	0	a_3
a_4	1	1	1	1	a_4

Hierarchical levels of oil coating selection criteria (Fig. 3) are established as a result of iterative procedures (Tables 6-8) using the dependency matrix M_a (Table 5).

Table 6

Iterative table for generating the first (the lowest) hierarchical level of the matrix M_a

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1, 2, 3, 4	1
2	1, 2	2, 3, 4	2
3	1, 2, 3	3, 4	3
4	1, 2, 3, 4	4	4

As we can see from Table 6, the equation $A(h_i) = R(h_i) \cap A(h_i)$ is solved for the 4th element, that forms the lowest hierarchical level. By taking out row 4 from the table 6, and a number 4 from the rows 1,2,3, we can obtain Table 7, that is a basis of the second iteration calculation.

Table 7

Iterative table for generating the second hierarchical level of the matrix M_a

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1,2,3	1
2	1,2	2,3	2
3	1,2,3	3	3

Table 8 is built according to the above-described method and serves as a basis of the third hierarchical level of the model establishment.

Table 8

Iterative table for generating the second hierarchical level of the matrix M_a

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1,2	1
2	1,2	2	2

According to Table 4, the hierarchical next-to last level is solved for the 2nd element. Therefore, the highest level of hierarchy is established by the 1st element. After the elements were distributed according to the determined levels, we get our hierarchical structural model (Fig. 3).

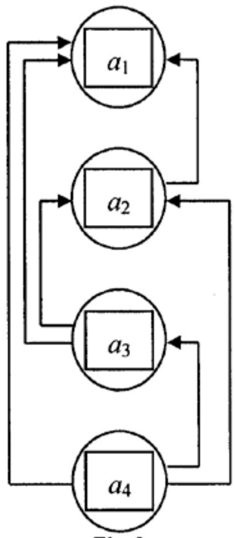

Fig. 3.
Hierarchical model of ecological oil coating selection criteria.

According to the hierarchical model of ecological criteria, we can conclude that one of the most important ecological oil coating criteria is criterion a_1, which represents raw materials for production of coating paints and varnishes. Out of the above mentioned ecological criteria, the raw material is really the main criterion that characterizes the environmental impact of the given material. The present model confirms the hierarchical level of selected criteria. (Katrenko 2007, Olyanyshyn *et al*. 2011).

Similarly, the relationships among elements of the array $b = \{b_1, b_2 \ldots b_3\}$ consisting of technological and operational oil coating selection criteria are displayed as an oriented graph (Fig. 4) below. The dependency and reachability matrices M_b (Tables 9, 10) are constructed according to the relationships among the vertices of the graph.

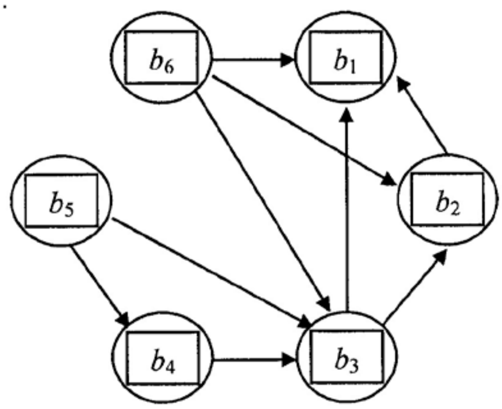

Fig. 4.
Graph of relationships among technological and operational oil coating selection criteria.

Table 9

Dependency matrix M_b

	b_1	b_2	b_3	b_4	b_5	b_6
b_1	0					
b_2		0				
b_3			0			
b_4				0		
b_5					0	
b_6						0

Table 10

Reachability matrix M_b

	b_1	b_2	b_3	b_4	b_5	b_6
b_1	1	0	0	0	0	0
b_2	1	1	0	0	0	0
b_3	1	1	1	0	0	0
b_4	1	1	1	1	0	0
b_5	1	1	1	1	1	0
b_6	1	1	1	0	0	1

The following tables (Tables 11-14) represent the steps of iterative procedures using the reachability matrix M_b.

Table 11

Iterative table for generating the first (the lowest) hierarchical level of the matrix M_b

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1, 2, 3, 4, 5, 6	1
2	1, 2	2, 3, 4, 5, 6	2
3	1, 2, 3	3, 4, 5, 6	3
4	1, 2, 3, 4	4,5	4
5	1, 2, 3, 4, 5	5	5
6	1, 2, 3, 6	6	6

Table 12

Iterative table for generating the second hierarchical level of the matrix M_b

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1, 2, 3, 4	1
2	1, 2	2, 3, 4	2
3	1, 2, 3	3, 4	3
4	1, 2, 3, 4	4	4

Table 13

Iterative table for generating the third hierarchical level of the matrix M_b

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1, 2, 3	1
2	1, 2	2, 3	2
3	1, 2, 3	3	3

Table 14

Iterative table for generating the fourth hierarchical level of the matrix M_b

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1, 2	1
2	1, 2	2	2

Similarly, after the elements were distributed according to the determined levels, we get our hierarchical structural oil coating selection model according to the technological and operational criteria (Fig. 5).

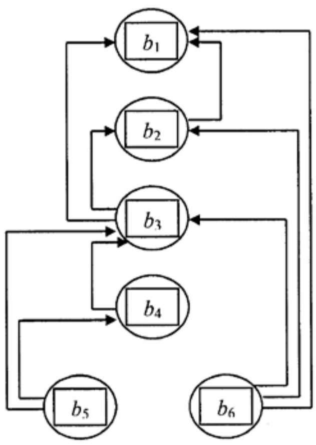

Fig. 5.
Hierarchical model of technological and operational oil coating selection criteria.

As we can see from the obtained model, the indicator of wetting of the wood surface is at the top of the hierarchy of technological and operational criteria. The main technological and operational properties of protective and decorative coating, particularly the smoothness of the film, the depth of penetration into wood pits, the thickness of the film and its adhesive strength to the wood base, depend on the wetting ability of an oil coating material. Therefore we can conclude that adhesive strength, according to the constructed model provides the largest number of the relationships among the operational criteria of coating materials and states its reasonably satisfactory technological properties.

The interrelationships among elements of the array $c = \{c_1, c_2 \ldots c_n\}$ consisting of economic oil coating selection criteria are displayed as oriented graph (Fig. 6) and the dependency and reachability matrices M_c (Tables 15, 16) based on it.

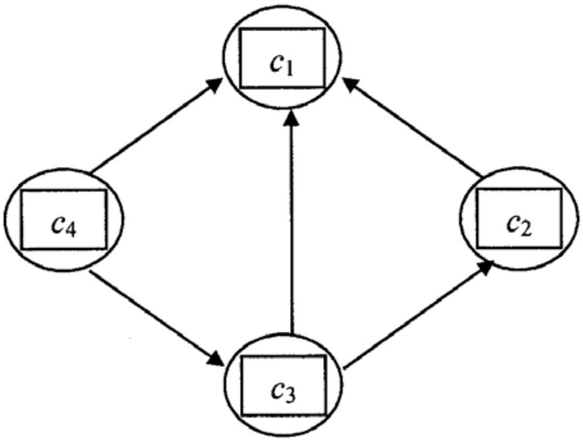

Fig. 6.
Graph of relationships among economic oil coating selection criteria.

Table 15
Dependency matrix M_c

	c_1	c_2	c_3	c_4
c_1	0			
c_2		0		
c_3			0	
c_4				0

Table 16
Reachability matrix M_c

	c_1	c_2	c_3	c_4
c_1	1	0	0	0
c_2	1	1	0	0
c_3	1	1	1	0
c_4	1	0	1	1

Iterative tables 17–19 and hierarchical structural model of economic oil coating selection criteria (Fig. 7) obtained from the reachability matrix M_c (Table 16) are presented below.

Table 17
Iterative table for generating the first (the lowest) hierarchical level of the matrix M_c

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1, 2, 3, 4	1
2	1, 2	2, 3	2
3	1, 2, 3	3, 4	3
4	1, 3, 4	4	4

Table 18
Iterative table for generating the second hierarchical level of the matrix M_c

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1, 2, 3	1
2	1, 2	2, 3	2
3	1, 2, 3	3	3

Table 19

Iterative table for generating the third hierarchical level of the matrix M_c

h_i	$R(h_i)$	$A(h_i)$	$R(h_i) \cap A(h_i)$
1	1	1, 2	1
2	1, 2	2	2

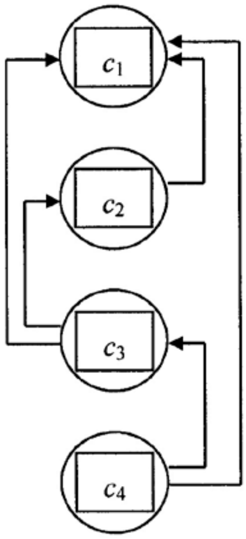

Fig. 7.
Hierarchical model of economic oil coating selection criteria.

Determination of the main economic criteria of the material also is a very important characteristic of appropriate production and usage of the product. The construction of the hierarchical model of the economic selection criteria, therefore, allows us to make certain conclusions that material costs, which are in the top level of our hierarchy, in comparison with the material costs associated with synthetic coatings, are more attractive since they have lower energy costs, lower utilization costs and environmental pollution charges.

CONCLUSIONS

The construction of models of oil coatings selection according to the ecological, technological and economic criteria confirms the appropriateness of production and usage of oil compositions for wood finishing as safe for the environment with adequate operational properties while attractive from the economic and competitive point of view. However, the results of selected barriers to the appropriate hierarchical level are objective in so far as its validity is provided using known principles of the theory of systems analysis, modeling theory, research methodology and problem solving. The appearance of a specific obstacle/ barrier at a given level significantly depends on the established relations between them given in the original graph. Any change in their number and content will result in modification of the model. The obtained results can be corrected in the process of further future studies.

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