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THE TWO-ROLL RUBBER MILL FRAME DEVELOPMENT SUPPORTED BY THE MCDM METHODOLOGY

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Abstract

The development process in situations when the original supplier does not exist, the equipment is obsolete and there is no technical documentation available represents a highly complicated design process with multiple confronting criteria (constraints, requests, and desires). This paper shows the MCDM (Multi-Criteria Decision-Making) methodology approach in the two-roll rubber mill frame development to support the decision-making process. Criteria weights have been calculated by SWARA (Step-wise Weight Assessment Ratio Analysis) method and TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) method has been applied for evaluation and selection of proposed alternative solutions (concepts).

Key words*: two roll rubber mill, frame, steel construction, MCDM, SWARA, TOPSIS.*

1 INTRODUCTION

Two roll mills are widely spread machines and they are usually named according to their specific application e.g.: crackers, flackers, grinders, crimpers, crumblers, etc [1].
The other source divides them into the four-high rolling mill, cluster rolling mill, continuous mill, and planetary rolling mill [2].
Two roll mills have massive applications in metal processing machinery, rubber industry, pharmaceutical industry, etc.
A two-roll rubber mill is a machine used in the rubber industry. It represents a machine with two horizontally positioned stainless steel rollers, one in front of another (often called front and back roller). Rollers rotate in opposite directions at different speeds and with different friction coefficients to mix the rubber mixture (rubber and ingredients).
Depending on the product, two roll rubber mills can either be used in a preparational phase of rubber mixture or to create different rubber compounds.
There are also more complex representations of two roll rubber mills with additional „rollers" called batch bladders which are used for better rubber mixing operations and they are, also, positioned horizontally, but above the main two rollers. Consequently, batch bladder/bladders have the same length as main rollers but have substantially smaller diameters (Figure 1).

Fig. 1 *Buzuluk's two-roll mill [3]*

Every type of two-roll mill is mounted on the top of the steel chassis or a frame. This frame ensures adequate functioning of the two-roller mills and other equipment such as engine, brake, reduction gearbox, and transmission by their proper alignment. Thus the frames must be manufactured and installed correctly.

In situations where there is no supplier available and the equipment is obsolete, where there is no technical documentation, a new frame must be designed and manufactured to satisfy all the necessary requests and constraints.
Development of the two-roll rubber mill frame represents a specifically complex problem given the fact that many confronting criteria are involved. One of the tools to overcome these problems is Multi-Criteria Decision-Making (MCDM) methodology.

The usage of the MCDM methodology is widely spread. There are no limitations in its application regarding the specificity or complexity of the decision-making processes. Those methods can help decision-makers (designers) with objective and systematic evaluation of alternatives concerning multiple conflicting criteria with different levels of importance [4].
For the presented research a hybrid MCDM method, SWARA (Step-wise Weight Assessment Ratio Analysis) + TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) has been applied for the determination of criteria weight (SWARA) and evaluation of the proposed alternative solutions (TOPSIS).

2 LITERATURE REVIEW

The MCDM method or combination of MCDM methods could be applied for any decision-making problem regarding its application to support the decision-making process. The MCDM methodology could provide decision-makers with final solutions or different approaches in the decision-making process.
The most common use of MCDM during the product development or design phase is in the material selection process. The research in which the application of MCDM methods is applied for the material selection process provides thorough research with prons and cons of a variety of methods and their applications [5]. Some researchers used those methods for pipe material selection [6] or in the material selection process of mechanical components [7]. The modern use of MCDM methodology is represented in the fuzzy application of MCDM methodology. This methodology was successfully applied to the same problem in construction management [8] and product design [9].
Probably the most popular use of MCDM methodology is in supplier selection [10] and location selection [4] problems.
This methodology could be applied for parameters optimization. Specifically in the optimization of bearing steel turning parameters [11] or in the optimization of machining parameters in turning of steel [12]. Also, the construction area is covered in the area of a concrete mix design [13].
Given the fact that a variety of researches have been conducted on the decision-making process on various subjects, the same methodology will be applied for the development of the two-roll rubber mill frame.

3 MCDM METHODOLOGY

Multi-Criteria Decision-Making (MCDM) methodology represents a mathematical tool used as support in the decision-making process when multiple criteria (or objectives) need to be considered together to rank or choose the best probable alternative solution.
Proposed MCDM methods for solving this paper's decision-making problem to support decision-makers in the development process of the two-roll rubber mill frame are SWARA (Step-wise Weight Assessment Ratio Analysis) and TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) methods.
The criteria weights for this paper's problem are calculated by the SWARA method, while, TOPSIS method is used for the evaluation of possible alternative solutions.

3.1. SWARA Method

The Step-wise Weight Assessment Ratio Analysis (SWARA) method was proposed in 2010 by Kersuline, Zavadskas, and Turskis.
SWARA's perspective gives the chance to decision-makers to prioritize the criteria set accordingly to the current situation in their research [14]. This method provides experts to use their knowledge, information, and experiences and to be envolved to be involved in the process of calculating criteria weights [14, 15].
SWARA method can be implemented using the following steps [16]:

Step 1. The criteria should be sorted in descending order based on their expected significance.
Step 2. Starting from the second criterion, each expert (decision-maker) marks the relative importance of criterion *j* in relation to the previous *j-1*. This process should be applied to all criteria. This ratio is called Comparative importance of average value s_j.
Step 3. Determine the coefficient k_j according to:

$$k_j = \begin{Bmatrix} 1 & j = 1 \\ s_j + 1 & j > 1 \end{Bmatrix} \tag{1}$$

Step 4. Determine the coefficient q_j:

$$q_j = \begin{Bmatrix} 1 & j = 1 \\ \frac{k_{j-1}}{k_j} & j > 1 \end{Bmatrix} \tag{2}$$

Step 5. Determine the relative weight coefficients of the criteria w_j:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{3}$$

3.2. TOPSIS Method

The Technique for the Order Preference by Similarity to Ideal Solution (TOPSIS) method was introduced by Hwang and Yoon in 1981.
The TOPSIS method is based on the concept that the best alternative solution should have the shortest Euclidian distance from the ideal solution (positive ideal solution – PIS) and at the same time that farthest from the anti-ideal alternative solution (negative ideal solution - NIS).
TOPSIS method can be implemented using the following steps [4]:
Step 1. Develop the decision matrix (*X*):

$$X = [x_{ij}]_{mxn} \tag{4}$$

Step 2. Determine the normalized decision matrix which elements are r_{ij}:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{5}$$

Step 3. Obtain the weighted normalized decision matrix which elements v_{ij} are obtained by multiplying each column *j* of the normalized decision matrix by its associated weight w_j:

$$v_{ij} = r_{ij} \cdot w_j \tag{6}$$

Step 4. Determine the positive ideal and the negative ideal solutions:

$$V^+ = (v_1^+, v_2^+, \dots, v_n^+)\{(max_i\{v_{ij}|j\epsilon B\}), (min_i\{v_{ij}|j\epsilon C\})\} \tag{7}$$

$$V^- = (v_1^-, v_2^-, \dots, v_n^-)\{(min_i\{v_{ij}|j\epsilon B\}), (max\{v_{ij}|j\epsilon C\})\} \tag{8}$$

where *B* and *C* are associated with the maximization and minimization criteria sets, respectively.
Step 5. The distance from the ideal and anti-ideal solutions are calculated for each alternatives using the two Euclidean distances as follows:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - V_j^+)^2} \tag{9}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - V_j^-\right)^2} \quad (10)$$

Step 6. Calculate the relative closeness of the *i*-th alternative A_i to the positive ideal solution:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (11)$$

The higher values of P_i indicate that the rank is better.

4 CASE STUDY – THE DEVELOPMENT OF THE TWO-ROLL RUBBER MILL FRAME SUPPORTED BY THE MCDM METHODS

The decision for the development of the frame for a two-roll rubber mill came from the problem which occurred in the rubber company.

The problem occurred when the decision had been made to relocate the two-roll mill in different position inside the workshop in order to enhance the layout properties and optimize the space for the installation of the new machines.

The relocation problem emerges because the existing frame is placed onto the concrete foundation which is beneath the floor level and concretized to equalize the levels. The frame is made of the casted plate in one piece which caries the two-roll mill as well as its engine, disk brake, and reduction gearbox. Only the connection plates of the frame, for all elements, are positioned above the floor level to ensure possible leveling and adjustments of the equipment.

The relocation problem becomes serious because the two-roll mill's frame could not be extracted out of the concrete without causing any damage to it. Thus, the new frame must be developed and manufactured in order to relocate the two-roll rubber mill (Figure 2).

4.1. Two-Roll Mil Frame Concepts

In order to apply MCDM methods, possible alternative solutions must be defined. Possible alternative solutions match proposed concepts for the development of the two-roll rubber mill frame.

The main reason for the definition of a bigger number of concepts (alternatives) is that there is no technical documentation of the two-roll rubber mill and the two-roll rubber mill frame. The machine is an obsolete piece of equipment. The original manufacturer does not exist, and the specification and the documentation were lost for years.

A1 – Concept 1. One-piece casted plate frame. The concept basically represents the existing frame–casted plate which is placed on the foundation and then concretized with only connection plates for equipment above the floor level.

A2 – Concept 2. One-piece casted plate frame with vibration absorbers and leveling mechanisms. The modern version of the existing solution without any concreting. A two-roll mill frame is placed on the foundation which is in level with the floor and vibration absorbers and leveling mechanisms are placed beneath the frame.

A3 – Concept 3. „One-piece" welded steel construction with vibration absorbers and leveling mechanism. The concept is described as the existing frame, but it is made of steel plates welded together to create the one-piece frame. The installation is the same as in Concept 2.

A4 – Concept 4. Multiple plates welded steel construction with vibration absorbers and leveling mechanism. This concept is proposed to have two frames, one for the two-roll rubber mill and the other for the drive equipment. Installation of frames is independent. Frames are positioned on the vibration absorbers and leveling mechanisms. The main problem is to perfectly level both parts of the equipment.

A5 – Concept 5. Steel construction frame with vibration absorbers and leveling mechanism. The concept is described as the combination of steel plates and UPN steel profiles. The idea is to have two levels of steel plates and UPN profiles between them. Installation is the same as described in previous Concepts with absorbers and leveling mechanisms.

A6 – Concept 6. Multiple steel construction frames with vibration absorbers and leveling mechanism. The concept is to divide Concept 5 as described in Concept 4 – two frames, one for the two-roll rubber mill and the other for the drive.

4.2. Criteria Set Definition

The other part of the process is to define the criteria set upon which the alternative solutions (concepts) would be evaluated. Criteria are defined as specific requests, constraints, and desires which designers take into account while developing solutions (concepts).

The selected criteria set for this research consist of 7 criteria such as cost, manufacturing time, construction complexity, load capacity, overall construction weight, installation time, and safety.

C1 – Costs (minimization criterion). The core principle of product development is to produce products at minimal costs for minimal time and with maximum performance. This criterion includes design, material, production, installation costs.

C2 – Manufacturing time (minimization criterion). Manufacturing time is pre-defined by the users because of the urgency of the two-roll rubber mill relocation. Thus, manufacturing time should be shortened as possible. This criterion depends on the type of construction.

C3 – Construction complexity (minimization criterion). More complex construction enhances costs, design, manufacturing, and installation time.

C4 – Load capacity (maximization criterion). The two-roll rubber mill weights approximately 34.8t and its engine and gearbox are around 6.5t combined. The frame must be designed to carry all the weight and not to cause inconveniences in two-roll mill operating conditions.

C5 – Overall construction weight (minimization criterion). The new two-roll mill frame construction must not exceed the weight of the existing two-roll mill frame, because of the same foundation construction.

C6 – Installation time (minimization criterion). Installation time depends also on the type of the two-roll rubber mill frame and its complexity of construction. The frames manufactured individually, in two separate parts, will take more time to mount, and vice versa.

C7 – Safety (maximization criterion). The existing solution represents the old type of two-roll mill frames and because it is covered with a huge amount of concrete the vibrations generated in the production conditions are sensed in the large area in the workshop. Thus, constant exposure to vibrations could negatively affect human health.

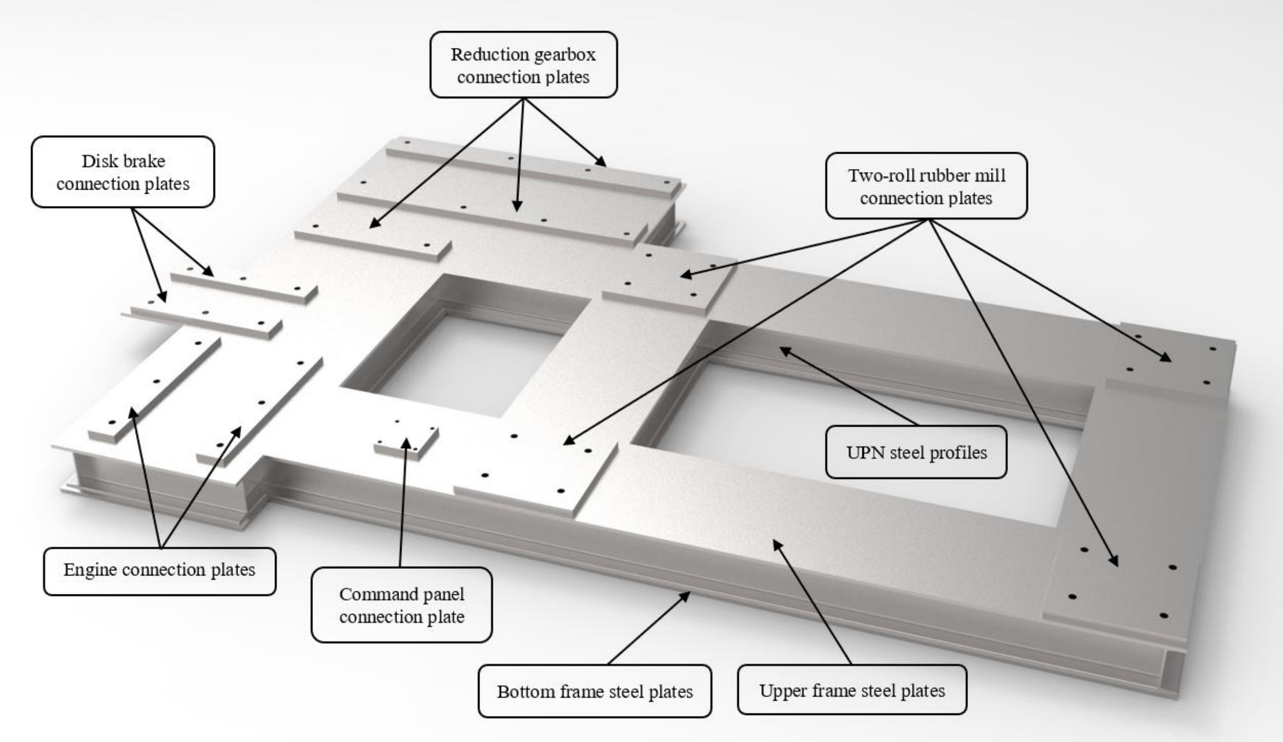

Fig. 2 *Concept 5 in development with connection plates on the upper side of the two-roll rubber mill frame*

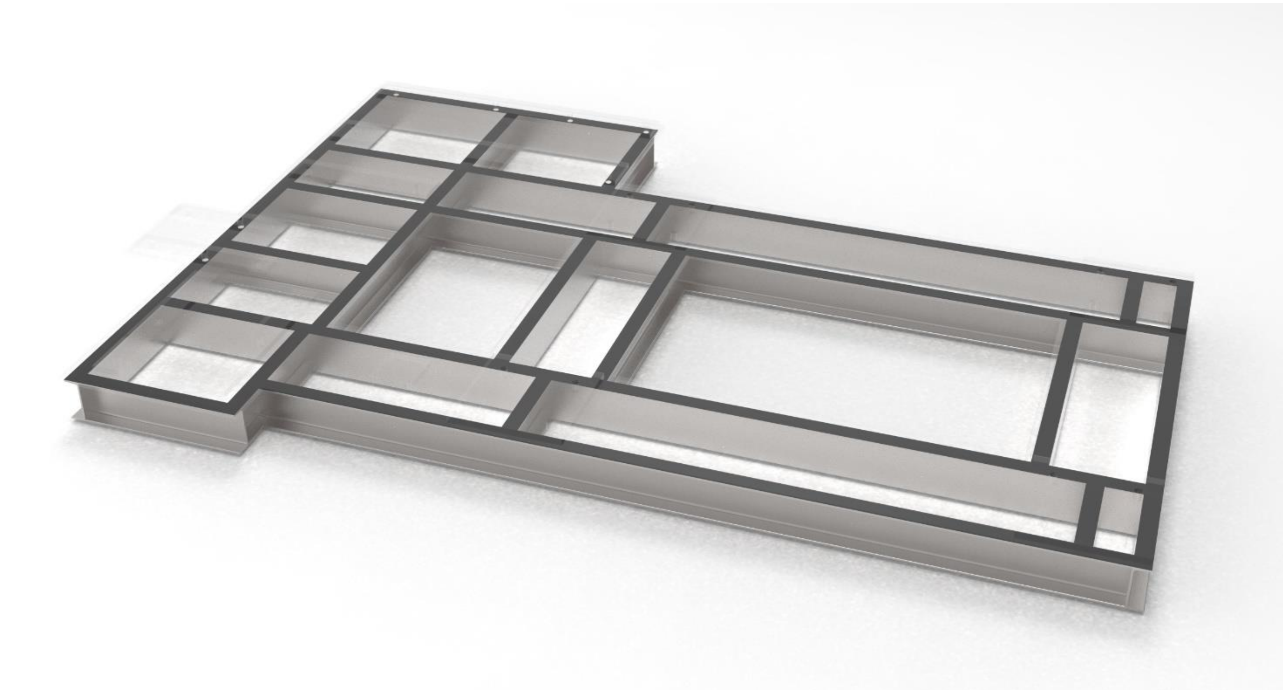

Fig. 3 *Concept 5 in development with UPN steel profiles layout inside of the two-roll rubber mill frame*

4.3. Application of the MCDM Methodology

The team of designers and MCDM experts was responsible for the evaluation and selection of the proposed concepts. Thus the decision matrix was formed. The criteria set is evaluated in comparison with concept solutions with numerical values 1-9 from the basic Satty scale and presented in Table 1.

Criteria C_1, C_2, C_3, C_5, and C_6 are minimization criteria where lower attribute values are preferred.

Table 1 Decision matrix

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Concept	min	min	min	max	min	min	max
A_1	7	8	2	9	1	8	1
A_2	6	8	2	6	1	4	7
A_3	4	4	3	7	3	4	8
A_4	3	4	3	7	3	5	8
A_5	4	3	4	9	4	2	9
A_6	3	3	4	9	4	4	8

Criteria C_4 and C_7 are maximization criteria where the higher attribute values are preferable.
The SWARA method was applied for criteria weight calculation. According to step 1 (section 3.1) the criteria are sorted in descending order based on their importance $C_7 > C_4 > C_2 > C_6 > C_1 > C_3 > C_5$. Then the relative importance of each criterion in the relation to the previous is defined as s_j. Furthermore, the calculation of the criteria weights is performed and the results are presented in Table 2.

Table 2 Criteria weights obtained by the SWARA method

	s_j	k_j	q_j	w_j
C_7	0.00	1.00	1.000	0.236
C_4	0.30	1.30	0.769	0.182
C_2	0.20	1.20	0.641	0.151
C_6	0.20	1.20	0.534	0.126
C_1	0.15	1.15	0.465	0.110
C_3	0.10	1.10	0.422	0.100
C_5	0.05	1.05	0.402	0.095
		$\sum$	4.233	1.000

Complete alternative (concept) evaluation and ranking are obtained with the TOPSIS method as described in Section 3.2. and the assessment results are given in Table 3.

Table 3 Complete rankings obtained by the TOPSIS method

Concepts	A_1	A_2	A_3	A_4	A_5	A_6
TOPSIS	0.282	0.569	0.720	0.697	0.745	0.700
Rank	6	5	2	4	1	3

Accourding to presented table, the preference is given in the following order: Concept A_5 > Concept A_3 > Concept A_6 > Concept A_4 > Concept A_2 > Concept A_1.
Concept A5 represents a proposed solution which is a steel construction frame with vibration absorbers and leveling mechanism. This variant has steel plates on the upper and bottom level of the frame and inside there is a UPN steel profile creating a welded steel construction. This way material acquisition would be simpler. The construction would be completely welded and the only surfaces which need to be processed are the connection plates (represented in Figure 1) which come in contact with the machine and other equipment. This concept represents a safe and reliable solution for the two-roll rubber mill frame.

5 CONCLUSIONS

This research has introduced the MCDM methodology (SWARA+TOPSIS) in the mechanical construction development process. Specifically, for the development of the two-roll rubber mill frame. The MCDM methods applied on the specific criteria set (constraints and requests) and alternative possible solutions (concepts) provided the designers with a better view in which the development process should continue.
The next step is to design the fully defined 3D CAD model of the frame and to generate the proper technical documentation.
Before the manufacturing process of the frame, an FEA (Finite Element Analysis) should be conducted to confirm the concept. The statical structural analysis should confirm the load capacity and strength of the construction, while dynamic analysis should confirm the use of the vibration absorbers and construction integrity.
After the frame is manufactured and installed, the real confirmation test would be applied.

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