

Application of MOORA and MEREC methods to select the best schema of scissors mechanisms

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ABSTRACT

A lift table is a very common device in the industry. To lift goods or people, this device employs a scissors mechanism. There are numerous designs for the scissors mechanism. Each schema will produce a different set of output responses when given the same set of input parameters. As a result, determining the best scheme is critical when designing an optimal lift table. The results of a study that used the multi-criteria decision-making (MCDM) technique to determine the best scheme for designing a lift table to meet two criteria at the same time: minimum lifting time and maximum lifting force, are presented in this paper. To achieve this, nine different scissor lifting mechanism diagrams were analyzed using the Multi-Objective Optimization Ratio Analysis (MOORA) method to solve the MCDM problem and the method based on the Removal Effects of Criteria (MEREC) to calculate the weights of criteria. Finally, the most effective lift table design scheme has been suggested.

Keywords: Lift table; Optimal design; MCDM; MOORA method; MEREC method.

1. INTRODUCTION

A lift table (figure 1) is a device that uses a scissors mechanism to raise and lower goods and/or people. Lift tables are commonly used in logistics warehouses, manufacturing plants, workshops, warehouses, factories, and garages, among other places. Scientists have become interested in designing and optimizing scissors mechanisms or lift tables as a result.

So far, lots of studies on scissor lifts have been conducted. Ilir Doçi et al. [1] published a study on the dynamic behavior of scissor lifts during load lifting in order to define their dynamic behavior, recognize the nature of oscillations, and regulate lifting to minimize these oscillations and optimize the work process. Tian Hongyu and Zhang Ziyi [2] used the 3D software Pro/E to carry out research on the design of a scissors lift platform. Their study platform is designed to fold away doors to save space for convenient storage. It can also be raised to a height of 8 meters. G. Arunkumar et al. [3] investigated the design, analysis, and topological optimization of hydraulic scissor lifts. In this study, topology optimization and FEA analysis techniques were used, resulting in the result, weight of the lift table was lowered by 38%. M.T. Islam et al. [4] used a bond graph modeling framework to apply general multibody system dynamics on a scissor lift mechanism. This work models and simulates the mechanism in order to evaluate several application-specific necessities such as dynamics, position accuracy, and so on. Tao Liu and Jian Sun [5] illustrated a three-dimensional model of a scissor-lifting mechanism. The kinematic and kinetic simulation analysis in this work was carried out using MATLAB/Simulink. Moreover, the mechanism's design was optimized in Pro/Mechanical based on the simulation analysis results. Ren G. Dong et al. [6] studied scissor lift stability to effectively understand the main mechanisms and factors influencing it. Both experimental and modeling approaches were used in this study. Based on the dynamic characteristics identified in the experimental results, a lumped-parameter model of the scissor lift was developed. Lukasz Stawinski et al. [7] proposed a new scissor lift drive system.

The new system employs a frequency inverter and a simple controller to control the velocity of a hydrostatic receiver, such as a hydrostatic cyreceive. Wei Zhang et al. [8] investigated the static stability of six different types of scissor lifts with a single hydraulic actuator input force applied to the scissor lifts' node lines.



Figure 1. Lift table [9].

From the above analysis, while many studies have been conducted on the scissor-lifting mechanism, no research has been conducted on selecting the most reasonable or best schema for this type of mechanism. The problem of determining the best lifting table scheme for designing was solved in this study using MCDM. Nine different lift table schemas were identified to address this issue. Furthermore, the minimum lifting time and maximum lifting force are chosen as criteria for selecting the mechanism diagram. Besides this, the MOORA method was used for solving the MCDM problem, and the MEREC method was used for finding the criteria weights. Finally, the best scissor lifting mechanism schema for optimum lift table design was proposed.

2. METHODOLOGY

2.1. Method for solving Multi-Criteria Decision Making problem

In this work, the MOORA method was used to solve the MCDM problem.

The following steps must be followed when using this method [10]:

Step 1: Making the first decision-making matrix:

$$X = \begin{bmatrix} r_{11} & \dots & r_{1j} & \dots & r_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i1} & \dots & r_{ij} & \dots & r_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{m1} & \dots & r_{mj} & \dots & r_{mn} \end{bmatrix} \quad (1)$$

Where, m is the number of options and n is the number of criteria.

Step 2: Calculating the normalized matrix by:

$$n_{ij} = \frac{r_{ij}}{\max r_{ij}} \quad (2)$$

$$n_{ij} = \frac{\min r_{ij}}{r_{ij}} \quad (3)$$

It should be noted that equation (2) is used for lift time creation, and equation (3) is for lift force creation. This is because the lift time requires "as small as better" and the lift force requires "as large as better".

Step 3: Creating a normalized decision making matrix $[X_{ij}]_{m \times n}$:

$$X_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^m r_{ij}^2}} \quad (4)$$

Step 4: Determining the decision-making matrices after normalizing the weights by:

$$W_{ij} = w_j \times r_{ij} \quad (5)$$

Step 5: Calculating P_i and R_i by:

$$P_i = \frac{1}{|B|} \sum_{j \in B} W_{ij} \quad (6)$$

$$R_i = \frac{1}{|NB|} \sum_{j \in NB} W_{ij} \quad (7)$$

Where B and NB are the criterion number as large as better and criterion number as small as better, respectively.

Step 6: Finding Q_i by:

$$Q_i = P_i - R_i \quad (8)$$

Step 7: Rank the alternatives based on the alternative with the highest Q_i is the best.

2.2. Method for calculating the weights of criteria

In this study, the MEREC method is used to determine the weights of the criteria. The MEREC method can be applied by following the steps below. [11]:

Step 1: Making the first matrix by equation (1).

Step 2: Determining the normalized values by:

$$h_{ij} = \frac{\min r_{ij}}{r_{ij}} \quad (9)$$

$$h_{ij} = \frac{r_{ij}}{\max r_{ij}} \quad (10)$$

Where, equation (9) is used for criterion t_1 and equation (10) is used for criterion W_m .

Step 3: Calculating the alternative performance S_i by:

$$S_i = \ln \left[1 + \left(\frac{1}{n} \sum_j |\ln(h_{ij})| \right) \right] \quad (11)$$

Step 4: Determining the performance of i^{th} alternative S'_{ij} by:

$$S'_{ij} = \ln \left[1 + \left(\frac{1}{n} \sum_{k, k \neq j} |\ln(h_{ik})| \right) \right] \quad (12)$$

Step 5: Calculating the removal effect of the j^{th} criterion E_j by:

$$E_j = \sum_i |S'_{ij} - S_i| \quad (13)$$

Step 6: Finding the criterion weight by:

$$w_j = \frac{E_j}{\sum_k E_k} \quad (14)$$

2.3. Method for finding lift table schema

The problem with designing a lift table is that with the same input parameters, it is necessary to create a lifting table diagram so that the designed lifting table has the minimum lifting time and the maximum lifting force of the table. In this case, the input parameters are: the lift table's main dimensions (AC and BD); the maximum lift height h_m , the piston force F_p , and the piston speed V_p . In a real sense, there are numerous lifting table schema options. Figure 2 depicts nine different lift table design schemas. Each schema will produce different results.

The calculation process for determining the best option for the lift table is as follows:

Calculate the output parameters for the lift table's nine options. Following that, use the MOORA method to find the best solution - the one that meets both the minimum lifting time and the maximum lifting force criteria.

3. DETERMINING OUTPUT RESPONSES OF THE LIFT TABLE

Figure 3a depicts lift table solution 1 (as in figure 2). The input data are: The force on the piston $F_p=2000$ (N), the velocity of the piston $V_p=10$ (mm/s), the maximum lifting height $h_m=866$ (mm), and the length of the link AC and BD $L=1000$ (mm). The maximum lifting force W_m (N) and the time of lift t_l are the output responses (s). The force balance equation is given in figures 3a and figure 3b as follows:

$$F_A = F_B = F_C = F_D = W/2 \quad (15)$$

From figure 3d it is found that $F_{Gx} = 0$; $F_{Gy} = 0$. Also, from figure 3c: $\sum M_A = 0$. As a result, the following equation can be proposed:

$$\sum M_A = -F_C \cdot L_x + F_{Gx} \cdot \cos\beta \cdot \frac{L_y}{2} + F_{Gx} \cdot \sin\beta \cdot \frac{L_x}{2} = 0 \quad (16)$$

With $L_x = L \cdot \cos\alpha$, $L_y = L \cdot \sin\alpha$.

It was noted from equation (15) that:

$$W = F_p \cdot \sin(\alpha + \beta) / \cos\alpha \quad (17)$$

Where, F_p is the force acting on the piston tip. F_{Gx} and F_{Gy} are the component forces of the force F_G of joint G acting on rod BD.

Setting $L_{AE} = a$, $L_{AF} = b$, $L_{EF} = c$ and from ΔAFE have:

$$c = \sqrt{a^2 + b^2 - 2 \cdot a \cdot b \cdot \cos\alpha} \quad (18)$$

We get:

$$H = c_{\alpha_{max}} - c_{\alpha_{min}} \quad (19)$$

From ΔAFE , it is found that:

$$b^2 = a^2 + c^2 - 2 \cdot a \cdot c \cdot \cos\beta \quad (20)$$

From (18):

$$\beta = \arccos\left(\frac{a^2 + c^2 - b^2}{2 \cdot a \cdot c}\right) \quad (21)$$

The piston stroke which was denoted as H is calculated by:

$$H = c_{max} - c_{min} \quad (22)$$

In which c_{max} and c_{min} are the maximum and minimum positions of piston, respectively. They are calculated from equation (17).

The lifting time t_l is found by:

$$t_l = H/V_p \quad (23)$$

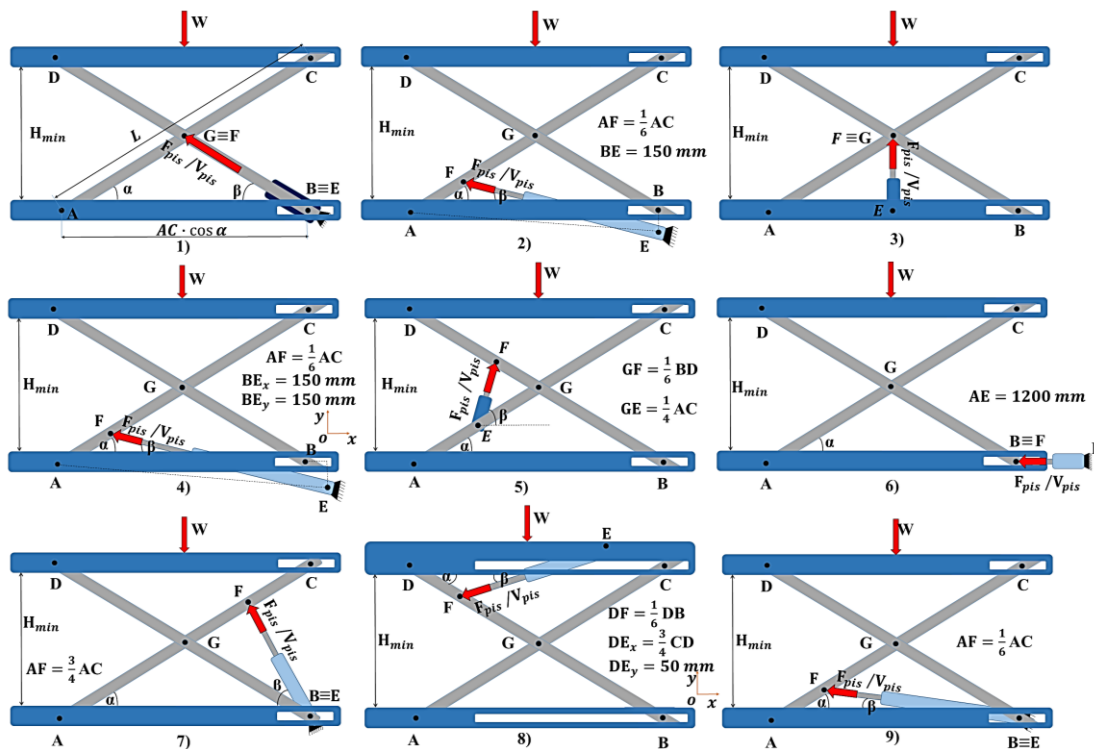


Figure 2. Different schemas for lift table design.

The calculation of the output responses in the remaining schema in figure 2 is similar to the above. The calculated results of ten schemas using the above-mentioned input data are shown in table 1.

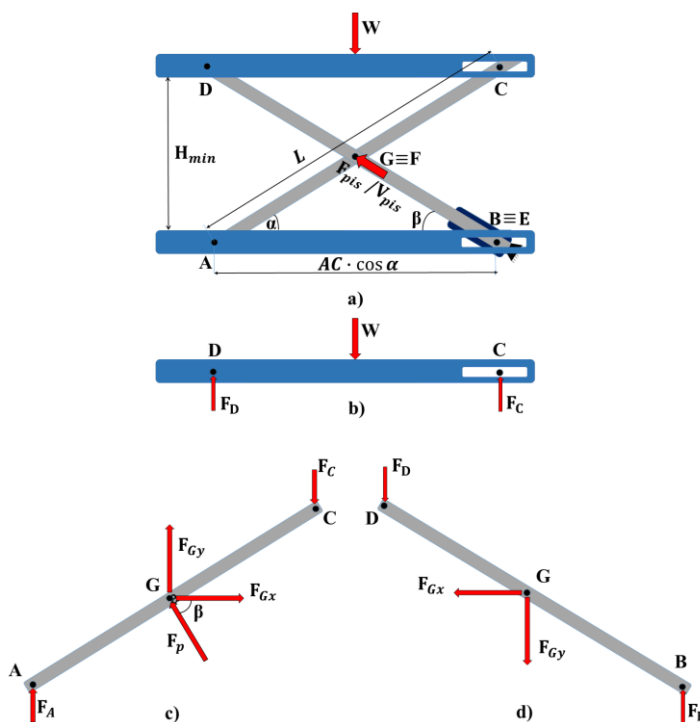


Figure 3. Schema for determining output responses of a lift table.

Table 1. Output results of different solutions of lift table.

Solution	t_l (s)	W_m (N)
1	36.27	348.62
2	45.55	2000.00
3	27.26	320.62
4	64.13	1015.47
5	9.39	69.98
6	11.28	186.82
7	10.90	167.88
8	49.62	174.98
9	10.70	770.07

4. DETERMINING THE BEST SCHEMA FOR THE SCISSORS MECHANISM

This section shows the results of using the MOORA method to solve the MCDM problem and the MEREC method to calculate the weights of the criteria.

4.1. Determining the weights of criteria

To quantify the weights for the criteria using the MEREC method, follow the steps outlined (see section 2.2): Determine the normalized values h_j using equations (9) and (10); Calculate S_i and S'_{ij} using equations (11 and (12); Find the criterion removal effect using equation (13); and determine the weight of the criteria w_j using equation (14). Moreover, t_l and W_m were found to have weights of 0.6142 and 0.3858, respectively.

4.2. Determining the best schema of scissors mechanism using MOORA method

The following are the steps for MCDM using the MOORA method (see section 2.1):

Using equations (2) or (3), compute the normalized matrix (3). The normalized decision-making matrix is then computed using equation (4). The decision-making matrices are then computed using equation (5). Then, using equations (6) and (7), calculate P_i and R_i . Then, using the formula (8), determine Q_i . Finally, arrange the options so that the one with the lowest Q_i is the best. Table 3 displays the results of various parameters as well as alternative rankings.

Table 2. Several calculated results and ranking of solutions.

Solution	X_{ij}		W_{ij}		R_i	P_i	Q_i	Rank
	t_l	W_m	t_l	W_m				
1	1315.75	121537.98	0.614	0.386	0.2109	0.0552	-0.1558	7
2	2074.56	4000000.00	0.614	0.386	0.2648	0.3164	0.0516	2
3	743.27	102797.31	0.614	0.386	0.1585	0.0507	-0.1078	6
4	4112.26	1031178.13	0.614	0.386	0.3729	0.1607	-0.2122	8
5	88.20	4897.23	0.614	0.386	0.0546	0.0111	-0.0435	5
6	127.31	34900.15	0.614	0.386	0.0656	0.0296	-0.0361	3
7	118.79	28184.04	0.614	0.386	0.0634	0.0266	-0.0368	4
8	2462.09	30617.06	0.614	0.386	0.2885	0.0277	-0.2608	9
9	114.47	593008.45	0.614	0.386	0.0622	0.1218	0.0596	1

Table 2 displays several calculated results as well as the ranking of scissors mechanism solutions when using the MOORA method to solve MCDM problem and the MEREC method to find the weight of criteria. Figure 4 also depicts the relationship between the solutions and the Q_i values. According to table 2 and figure 4, the best schema for the scissors mechanism is solution 9 because it has the highest value of Q_i (0.0596). Table 1 shows that this solution has a lift time of 10.7 seconds and a maximum lift force of 770.07 pounds (N).

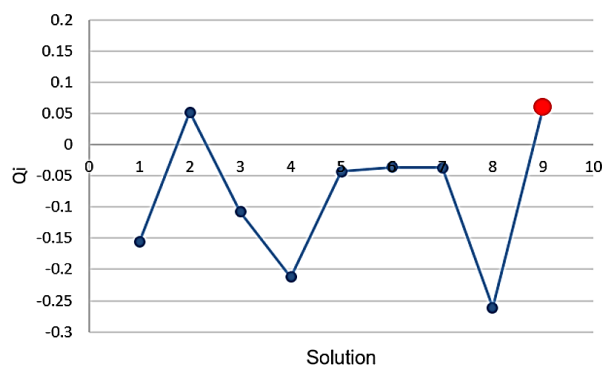


Figure 4. Relation between solution and the value of Q_i .

5. CONCLUSIONS

The results of a study to determine the best schema for scissors mechanism for lift tables to achieve both the minimum lift time and the maximum lift force simultaneously are presented in this paper. The MOORA method was used to solve the MCDM problem in this study, and the MEREC method was also used to determine the weight of the criteria. The results of the research lead to the following conclusions:

- In this work, the MOORA method was used to find the best schema for the scissors mechanism for lift tables that met two competing criteria at the same time: minimum lift time and maximum lift force.
- Solution 9 is the best schema for the scissors mechanism as it has the maximum value of Q_i (0.0596);
- Solution 9 can provide a lift time of 10.7 (s) and a lift force of 770.07 (N).

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TÓM TẮT

Ứng dụng các phương pháp MOORA và MEREC để chọn giải đồ tốt nhất cho cơ cấu nâng kiểu kéo

Bàn nâng là thiết bị rất thông dụng trong công nghiệp. Nó dùng để nâng hàng hóa hoặc người, thiết bị này sử dụng cơ cấu nâng dạng kéo cắt. Có rất nhiều thiết kế cho cơ chế kéo. Mỗi lược đồ sẽ tạo ra một tập hợp các phản hồi đầu ra khác nhau khi được cung cấp cùng một tập hợp các tham số đầu vào. Do đó, việc xác định sơ đồ tốt nhất là rất quan trọng khi thiết kế một bàn nâng tối ưu. Kết quả của một nghiên cứu sử dụng kỹ thuật ra quyết định đa tiêu chí (MCDM) để xác định phương án thiết kế bàn nâng tốt nhất đáp ứng đồng thời hai tiêu chí: thời gian nâng tối thiểu và lực nâng tối đa được trình bày trong bài báo này. Để đạt được điều này, chín sơ đồ cơ cấu nâng dạng kéo cắt khác nhau đã được phân tích bằng cách sử dụng phương pháp Phân tích tỷ lệ tối ưu hóa đa mục tiêu (MOORA) để giải quyết bài toán MCDM và Phương pháp dựa trên tác động loại bỏ của tiêu chí (MEREC) để tính trọng số của các tiêu chí. Cuối cùng, phương án thiết kế bàn nâng hiệu quả nhất đã được đề xuất.

Từ khóa: Bàn nâng; Thiết kế tối ưu hóa; Bài toán ra quyết định đa tiêu chí (MCDM); Phương pháp phân tích tỷ lệ tối ưu hóa đa mục tiêu (MOORA); Phương pháp dựa trên tác động loại bỏ của tiêu chí (MEREC).