The optimization of the loading ramp mechanism of a heavy-weight trailer

Predrag Z. Mladenović[1*], Radovan R. Bulatović[1], Nebojša B. Zdravković[1], Mile M. Savković[1], Goran Đ. Marković[1], Goran V. Pavlović[2]

[1]Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Serbia
[2]Faculty of Electronic Engineering, University of Niš, Niš, Serbia

This research optimized the loading ramp mechanism of the trailer for transporting heavy construction machinery to minimize the force in the hydro-cylinder. Firstly, a mathematical model for the mechanism transition between the loading and unloading position was established. Then, it was used to optimize the lengths of the mechanism members using the metaheuristic method to achieve the operational function of the ramp. Besides the lengths of the members, the positions of the lever, which transfers the action of the hydro-cylinder to the ramp and the hydro-cylinder, were also considered during the optimization process. Finally, the optimized positions were determined by their coordinates in the vertical plane.

Keywords: Optimization, trailer, loading ramp, mechanism, hydro-cylinder, special vehicle

1. INTRODUCTION

The increase in infrastructure projects demands various construction machines whose characteristics prevent their independent transport from one place to another. In addition to their characteristics, which primarily concern their speed and powertrains, a big problem with their transport is their overall dimensions. Thus, special truck trailers have been developed to transport such machines. The construction of such trailers is quite simple and can be seen in Figure 1.

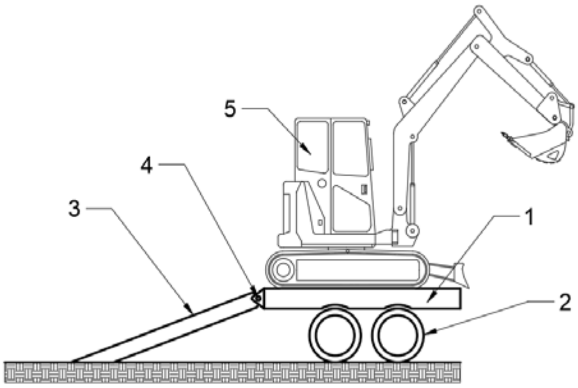

Figure 1: Illustration of a trailer for the transport of heavy machinery

Figure 1 shows: the carrying platform (1), pneumatics (2), loading ramp (3), loading ramp support (4), and the vehicle being transported (5). The part of the trailer used when loading and unloading the vehicles being transported is the subject of the study of this paper. The platform at the very end of the trailer must be lowered onto the ground, thus enabling the construction machine to place onto the trailer with its drive train. After loading the machine, the ramp returns to its original position, meeting the conditions for transporting it to the desired location. Several different solutions are used as a drive for ramp manipulation. The first and the most primitive solution is to move the ramp manually, with the help of human power or with the help of a machine's working device. However, this method is only possible in the case of smaller trailers that transport machines with smaller weights or trailers that transport excavators that enable the ramp to be moved with the excavator's arm. A solution that can also be used is described in paper [1] and involves springs that facilitate the start of the ramp during its manipulation. The described system is shown in Figure 2.

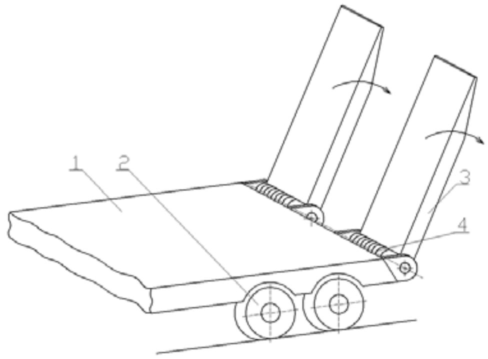

Figure 2: Illustration of the solution with the swathe springs [1]

The parts of the solution that are shown in Figure 2 are the carrying platform (1), pneumatics (2), slipway device, and swathe springs (4).

In transporting heavy machines with large mass, the loading ramps must be more massive and designed to withstand the heavy load when the machine passes over it. In that case, the ramps also have a greater mass, so a mechanism or device is needed for manipulation. Existing solutions involve the use of hydraulic cylinders located near the ramp construction. It is possible to create a mechanism for manipulating the ramp, which will enable the reduction of the force required for the manipulation of the ramp, which will also reduce the force required in the hydraulic cylinder. The lower the force in the hydraulic cylinder, the more it will be possible to install a cylinder with a smaller diameter rod, which will simultaneously require a smaller unit and other hydraulic components. The mentioned mechanism will consist of a system of rods and a lever of a complex shape, which will be supported by a pin on the vehicle's chassis. A mechanism similar to the one described can be found in the article[2]. The drive

*Corresponding author: Dositejeva 19, 36000 Kraljevo, mladenovic.p@mfkv.kg.ac.rs

for manipulating the ramp comes from a hydraulic cylinder, in which one end, i.e. the support, is located on the vehicle's chassis. In contrast, the other end of the cylinder is attached to one arm of the lever of a complex shape. The described system is shown in Figure 3, which occupies a position during transport.

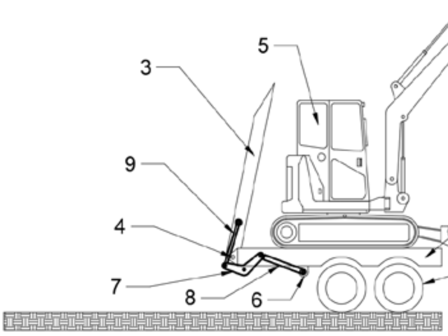

Figure 3: Illustration of the solution with a system of levers and a hydro-cylinder

The components of the system shown in Figure 3 are the carrying platform (1), pneumatics (2), loading ramp (3), loading ramp support (4), the vehicle being transported (5), hydro-cylinder support (6), a lever of a complex shape (7), hydro-cylinder (8), mechanism rod (9).

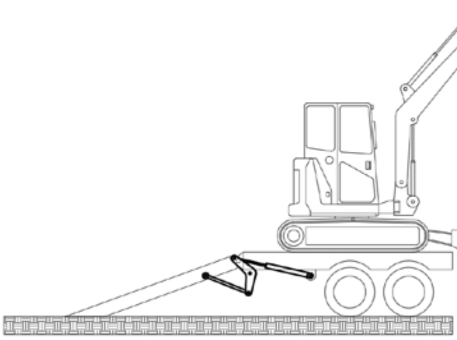

Figure 4: Illustration of the solution in the loading position

Figure 4 shows the position of the parts of the mechanism while loading the vehicle being transported.

The need to reduce manufacturing costs and maintenance of machines and equipment leads to the constant development of new and improvement of already existing solutions to engineering problems. A large number of existing optimization algorithms can be used for this purpose.

Optimization, about which more can be found in the source [3], represents obtaining the most convenient solution from a defined range according to some criterion. In the optimization process, it is necessary to define the objective function and the constraints that will shape the nature of the solution obtained from the optimization. Not all algorithms can be suitable for solving every optimization problem. Still, among many different algorithms, we could choose the one that will help solve the problem best. In this work, the Slime mould algorithm will be used for optimization. In this paper, the Slime mould algorithm, described in more detail in the paper [4], will be used to optimize the problem.

2. SLIME MOULD ALGORITHM

Many algorithms have found inspiration for their creation in nature and phenomena from it, including the slime mould algorithm (SMA) [4]. The usual way of spreading and feeding slime mould inspired the creation of a unique mathematical model that implies the existence of a positive and negative bio-oscillator response in the slime mould, depending on whether the food source is good or not. This requires the use of time-adaptive weighting factors that allow a more accurate and faster finding of a suitable result.

What is specific about the slime mould's behaviour is that even when a good food source is reached, the search for food does not stop. During the exploitation of food, the search for space for a new source does not stop. This makes it possible to find an optimal solution, avoiding reaching a local optimum.

The main stages of optimization can be defined as follows:

- Finding food;
- Approaching food;
- Wrapping food.

and can be schematically represented in Figure 5.

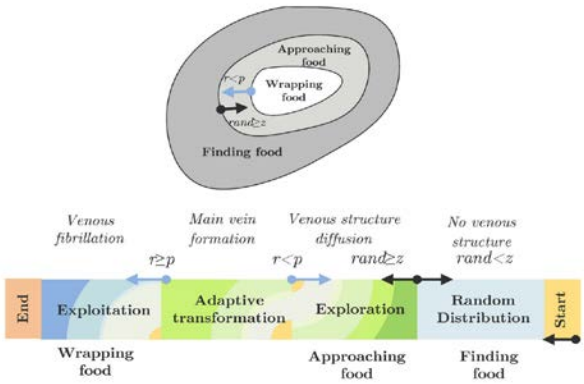

Figure 5: Stages of SMA [4]

The approach to food is achieved through the smell in the air, and for this, the contraction mode formulated as follows is the most responsible:

$$\overrightarrow{X(t+1)} = \begin{cases} \overrightarrow{X_b(t)} + \vec{vb} \cdot (\vec{W} \cdot \overrightarrow{X_A(t)} - \overrightarrow{X_B(t)}), r < p \\ \vec{vc} \cdot \overrightarrow{X(t)}, r \geq p \end{cases} \qquad (1)$$

where vb is a parameter in bounds of [-a, a], t defines the current iteration, vc is a parameter that decreases linearly from the value 1 to zero, $X(t)$ is a vector of slime mould position, $X_A(t)$ and $X_B(t)$ are two random slime mould individuals, and $X_b(t)$ defines single location with the highest odour concentration found. The weight of the slime mould is denoted with W and can be described with equation (2).

$$\overrightarrow{X(SmellIndex(i))} = \begin{cases} 1 + r \cdot \log\left(\dfrac{bf - S(i)}{bf - wF} + 1\right), condition \\ 1 - r \cdot \log\left(\dfrac{bf - S(i)}{bf - wF} + 1\right), others \end{cases} \qquad (2)$$

where r indicates a random value from the interval [0,1], bF denotes the optimal value obtained in the current iteration, wF denotes the worst value obtained in the iterations performed so far, and $SmellIndex$ indicates an array of sorted retrieved values.

Parameter a, used as a limit for one term in equation (1), i.e. vb, is defined by equation (3).

$$a = \operatorname{arctan} h\left(-\left(\frac{t}{max\_t}\right)+1\right) \quad (3)$$

where parameter *max_t* indicates maximum iteration.

The slime mould's search for food is based on the contractions of the vein structures in which the cytoplasm flows. The higher the concentration of food in the new source, the greater the flow of cytoplasm and therefore, the venous structure has a greater thickness. The positive and negative response between vein thickness and food source quality is described mathematically by equation (2).

It can be said that when searching for food, the slime mould searches certain regions so that it leaves the regions where the concentration of food is weaker and goes to the regions with a higher concentration of food. The change in the location of slime mould can be mathematically described using equation (4).

$$\overrightarrow{X^*} = \begin{cases} rand \cdot (UB - LB) + LB, rand < z \\ \overrightarrow{X_b(t)} + \vec{vb} \cdot (\vec{W} \cdot \overrightarrow{X_A(t)} - \overrightarrow{X_B(t)}), r < p \\ \vec{vb} \cdot \overrightarrow{X(t)}, r \geq p \end{cases} \quad (4)$$

where the random value in a range of [0,1] is denoted with r and *rand* and *LB*, *UB* indicates lower and upper boundaries of the search range, respectively.

The source code provided with the article [4] consists of four scripts written in MathWorks Matlab programming language: main.m, initialization.m, SMA.m, Get_Fuctions_details.m.

The main.m script is the script where the number of iterations (T) and the number of search agents (N) are defined. Also, in this script, we have to define many variables for optimization and the exact name of the objective function we want to use for optimization. The objective function is called from the script Get_Fuctions_details.m and must be precisely defined. In this script, it is also necessary to define the number of variables and their limits of the search area. Starting the optimization is done by running the main.m script. At the end of the optimization, we get the best-obtained value and the convergence diagram.

3. MATHEMATICAL MODEL

The development of science and the appearance of an increasing number of real problems in all areas of human life have conditioned the application of mathematical modelling in solving various problems. Before the application of mathematical models, to obtain scientific results, it was necessary to perform a large number of experiments for scientists to confirm their theories and conclusions. Of course, this required a lot of money and precious time, which was a big problem. Therefore, it was necessary to devise a way to confirm scientific assumptions, as an experiment would do, and avoid additional costs by organizing it. This was achieved to some extent by applying mathematical modelling of the problem so that a model would mathematically describe a certain process or phenomenon. The mathematical model of a certain process or phenomenon usually consists of a set of equations, which should describe all the more important phenomena or processes that are important for the observed problem. Integral parts of the equations that represent the mathematical model are its coefficients, which describe and express some characteristics of the environment or object. Models can be simple but also complex, depending on the precision with which the real problem is described. Of course, the more complex the model, the more effort is put into its mathematical modelling, and in most cases, good models are quite complex.

The mechanism that is the subject of this paper is not very complex, so the mathematical model itself is simple. Considering that in this paper, the mechanism is constructed to determine the dimensions of its parts, the sizes of the cross-sections of the mechanism members were neglected, and all attention was paid to their lengths, as well as their characteristic positions and design details. Therefore, the mechanism was simplified and presented by a wire model, Figure 6.

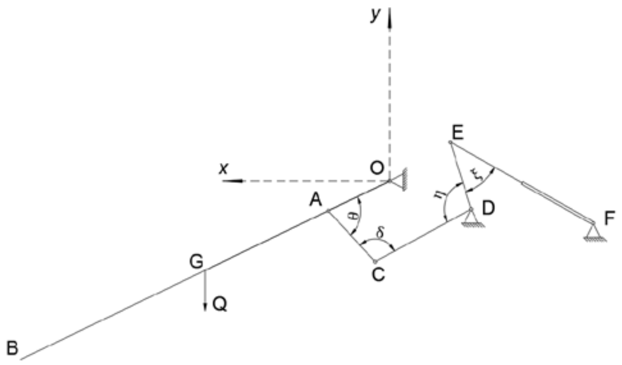

Figure 6: Mechanism wire model

The position of the supports can be seen in Figure 6; they are marked with letters O – for loading ramp support, D – for lever support and F – for hydro-cylinder support. The lengths of the mechanism members are the distances between the points marked in the picture. Considering that the lengths are used for writing the equations of motion and later for calculating the forces in the hydraulic cylinder, for the sake of transparency, new length labels are introduced, which consist of the appropriate indices up to the letter "L ". Table 1 shows the newly introduced marks.

Table 1: The connection between the corresponding marking methods

OB	L_0
OA	L_1
AC	L_2
CD	L_3
DE	L_4

Mechanism members CD and DE are rods or plates that are welded at an appropriate angle and form a single entity representing a complex shape lever. The angle between these plates is shown in Figure 6 and marked with the Greek letter η. In addition to angle η in Figure 6 can be seen angles θ, δ, and ξ as well. These angles change values over time, i.e., while the mechanism is being moved, so it can be said that they are variable.

Point G marks the centre of the ramp, and the force of weight originating from the mass Q acts in it and is directed vertically downwards.

The coordinate system is also shown in Figure 6, and its coordinate origin is at point O with the axes directed as shown.

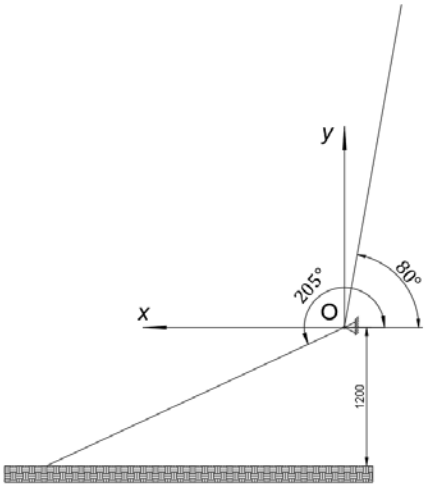

Figure 7: The position of the ramp at the beginning and end of the movement

Figure 7 shows the limit positions of the ramp, marked by the angles the ramp creates with the *x*-axis.

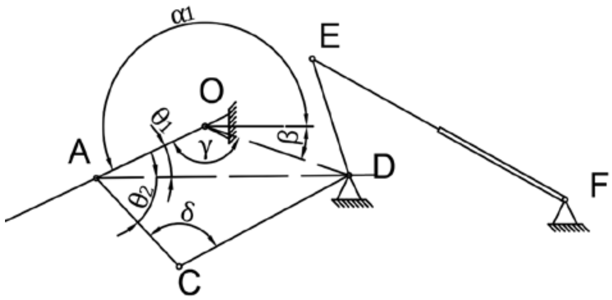

Figure 8: Auxiliary angles between members of the mechanism

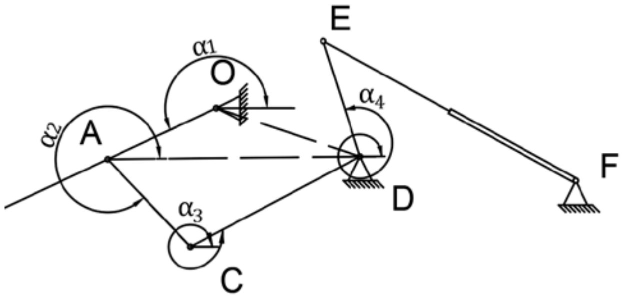

Figure 9: Angles between the mechanism members and the horizontal axis

The auxiliary angles shown in Figures 8 and 9 were defined to calculate and update the position of the mechanism members during its motion.

The positions of the lever support (D) and the hydraulic cylinder support (F) are optimization variables whose position is defined by coordinates in the direction of the coordinate axes. For the calculation, it is necessary to define the distance between the support of the lever and the support of the ramp, and it can be calculated using Equation 5.

$$L_{OD} = \sqrt{X_D^2 + Y_D^2} \tag{5}$$

Angle β can be calculated using equation (6).

$$\beta = \arctan\left(\frac{Y_D}{X_D}\right) \tag{6}$$

Due to the complexity of the mechanism and its movement, it is necessary to create a mathematical model of its movement depending on certain conditions that must be met. Due to the constant change of the angle, a counter was introduced that defines the position of the ramp in the range from 80 to 205 degrees, as shown in Figure 7. This counter is denoted by i so that for the value of $i=1$, angle α_1 has a value of 80 degrees.

The position of points A and B during movement can be defined using the following equations.

$$X_B(i) = L_0 \cdot \cos(\alpha_1(i)) \tag{7}$$

$$Y_B(i) = L_0 \cdot \sin(\alpha_1(i)) \tag{8}$$

$$X_A(i) = L_1 \cdot \cos(\alpha_1(i)) \tag{9}$$

$$Y_A(i) = L_1 \cdot \sin(\alpha_1(i)) \tag{10}$$

The calculation of angle θ depends on the value of angle α_1. If the condition defined with equation (11) is met, angle θ is calculated using equations (12-16).

$$\alpha_1(i) < 180 - \beta \tag{11}$$

$$\gamma(i) = \beta + \alpha_1 \tag{12}$$

$$AD(i) = \sqrt{L_1^2 + L_{OD}^2 - 2 \cdot L_1 \cdot L_{OD} \cdot \cos(\gamma(i))} \tag{13}$$

$$\theta_1 = \arccos\left(\left(L_2^2 + AD(i)^2 - L_3^2\right) / \left(2 \cdot L_2 \cdot AD(i)\right)\right) \tag{14}$$

$$\theta_2 = \arccos\left(\left(L_1^2 + AD(i)^2 - L_{OD}^2\right) / \left(2 \cdot L_1 \cdot AD(i)\right)\right) \tag{15}$$

$$\theta(i) = \theta_1(i) - \theta_2(i) \tag{16}$$

If the condition defined with equation (11) is not met, angle θ is calculated using equations (17-21).

$$\gamma(i) = 360° - \beta - \alpha_1 \tag{17}$$

$$AD(i) = \sqrt{L_1^2 + L_{OD}^2 - 2 \cdot L_1 \cdot L_{OD} \cdot \cos(\gamma(i))} \tag{18}$$

$$\theta_1 = \arccos\left(\left(L_1^2 + AD(i)^2 - L_{OD}^2\right) / \left(2 \cdot L_1 \cdot AD(i)\right)\right) \tag{19}$$

$$\theta_2 = \arccos\left(\left(L_2^2 + AD(i)^2 - L_3^2\right) / \left(2 \cdot L_2 \cdot AD(i)\right)\right) \tag{20}$$

$$\theta(i) = \theta_1(i) + \theta_2(i) \tag{21}$$

The angles shown in Figures 8 and 9 are obtained using equations (22-25). They are used to calculate the position of the corresponding points of the mechanism members.

$$\alpha_2(i) = \alpha_1(i) + 180 - \theta(i) \tag{22}$$

$$\delta(i) = \arccos\left(\left(L_2^2 + L_3^2 - AD(i)^2\right) / \left(2 \cdot L_2 \cdot L_3\right)\right) \tag{23}$$

$$\alpha_3(i) = \alpha_2(i) + 180 - \delta(i) \tag{24}$$

$$\alpha_4(i) = 180 - (360 - \alpha_3(i)) - \eta \tag{25}$$

The obtained angles can be used to calculate the coordinates of the remaining points needed to obtain a simulation of the movement and calculate the force at the hydraulic cylinder.

$$X_E(i) = X_D + L_4 \cdot \cos(\alpha_4(i)) \tag{26}$$

$$Y_E(i) = Y_D + L_4 \cdot \sin(\alpha_4(i)) \tag{27}$$

$$X_C(i) = X_A + L_2 \cdot \cos(\alpha_2(i)) \tag{28}$$

$$Y_C(i) = Y_A + L_2 \cdot \sin(\alpha_2(i)) \tag{29}$$

Length FE represents the length of the extended hydraulic cylinder, which changes during movement. Equation (30) describes this change in length.

$$FE = L_{FE} = \sqrt{\left(X_E(i) - X_F\right)^2 + \left(Y_E(i) - Y_F\right)^2} \qquad (30)$$

The length calculated by equation (30) is needed to calculate the stroke of the hydraulic cylinder, which is a very important item when constructing a system in which the hydraulic cylinder exists. This value also represents one of the limitations in the optimization procedure because it must satisfy the appropriate condition. The stroke of the hydraulic cylinder is calculated using equation (31) as the difference of the length FE in the final and initial positions of the ramp.

$$stroke = L_{FE}(end) - L_{FE}(start) \qquad (31)$$

To calculate the angle ξ, it is necessary to determine the distance between the supports D and F, which has a constant value, using equation (32).

$$L_{DF} = \sqrt{\left(X_F - X_D\right)^2 + \left(Y_F - Y_D\right)^2} \qquad (32)$$

Now the angle ξ can be defined by equation (33).

$$\xi(i) = \arccos\left(\left(L_4^2 + L_{FE}^2 - L_{DF}(i)^2\right) / \left(2 \cdot L_4 \cdot L_{FE}\right)\right) \qquad (33)$$

The load acting on the members of the mechanism originates from the mass of the loading arm acting at point G and, for safety, is adopted to have a higher value than it is realistic. It is assumed that the mass of the loading ramp is 500 kg. Equation (34) is used to calculate which force of own weight acts at point G.

$$F_Q = Q \cdot g = 500kg \cdot 9{,}81\frac{m}{s^2} = 4905N \qquad (34)$$

where g is the acceleration of the earth's gravity, and Q is the mass of the loading ramp.

The force in the hydraulic cylinder can be obtained using the two moment-equilibrium equations for points O and D. More about the influence of the position of the hydraulic cylinder can be found in the paper [5]. These equilibrium conditions are described by equations (35) and (36). Along with these equations, the pictures corresponding to the mentioned moment equations are shown in Figures 10 and 11.

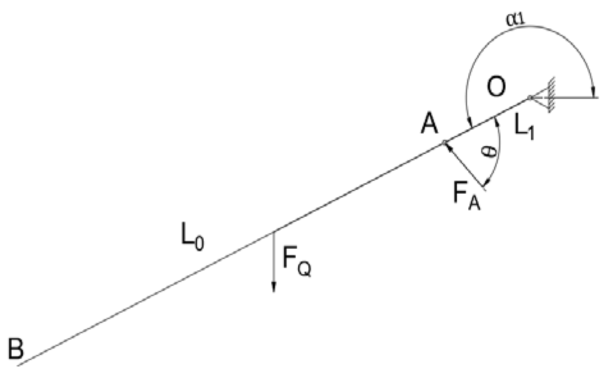

Figure 10: The wire model described by equation (35)

$$\sum M_O = Q \cdot \frac{L_0}{2} \cdot \cos(\alpha_1) - F_A \cdot L_1 \cdot \sin(\theta) \qquad (35)$$

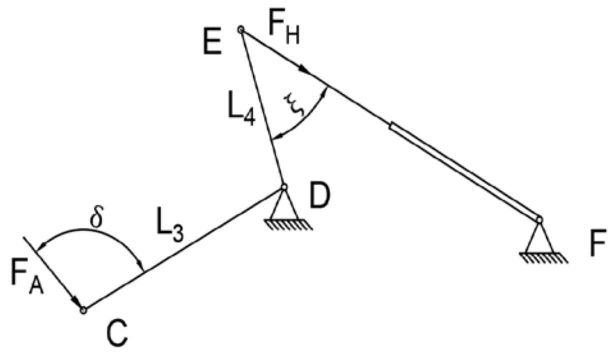

Figure 11: The wire model described by equation (36)

$$\sum M_D = F_A \cdot L_3 \cdot \sin(\delta) - F_H \cdot L_4 \cdot \sin(\xi) \qquad (36)$$

Equating the equations to zero based on the equilibrium conditions, the equations for obtaining the force in the hydraulic cylinder were obtained and are shown by equations (37) and (38).

$$F_A(i) = \frac{-F_Q \cdot L_0 \cdot \cos(\alpha_1(i))}{2 \cdot L_1 \cdot \sin(\theta(i))} \qquad (37)$$

$$F_H(i) = \frac{-F_A(i) \cdot L_3 \cdot \sin(\delta(i))}{L_4 \cdot \sin(\xi(i))} \qquad (38)$$

The counter next to the labels shows that the obtained values are variable during movement.

4. OBJECTIVE FUNCTIONS, LIMITS OF SEARCHING AREA, AND CONSTRAINTS

4.1. Objective function

The objective functions in optimization can differ depending on what we want to achieve. The mathematical model makes it possible to calculate the force in the hydraulic cylinder, so using the final equation (38) as an objective function is possible. Therefore, the objective function equation is equation (39).

$$o = F_H \qquad (39)$$

When programming the objective function, we must consider that the force value can be negative or positive, so it is necessary to take the absolute value. In addition, it is necessary to consider the penal function that enables compliance with all constraints that have been defined. Optimization aims to reduce the force in the hydraulic cylinder as much as possible.

4.2. Limits of searching

This optimization problem has nine quantities that need to be optimized: four quantities are lengths, one is angle and four are support coordinates. The lengths that need to be optimized are L_1, L_2, L_3 and L_4. Their dimensions should be between 200mm and 1200mm for constructive reasons. The angle to be optimized is the angle between the rods L_3 and L_4, denoted by η. The angle range can be between 50 and 160 degrees. The positions of the supports that need to be optimized are marked with the letters D and F. In this case, we have four optimization variables whose limits depend on the coordinate direction, and those values are shown in equations (42) and (43).

These constraints are written in vector form and are shown by equations (40) and (41).

$$LB = \left[L_{1,\min}, L_{2,\min}, L_{3,\min}, L_{4,\min}, \eta_{\min}, X_{D,\min}, Y_{D,\min}, X_{F,\min}, Y_{D,\min}\right] \qquad (40)$$

$$UB = \left[L_{1,\max}, L_{2,\max}, L_{3,\max}, L_{4,\max}, \eta_{\max}, X_{D,\max}, Y_{D,\max}, X_{F,\max}, Y_{D,\max} \right] \quad (41)$$

where LB denotes lower boundaries, and UB denotes upper boundaries.

$$LB = [200, 200, 200, 200, 50, 200, -400, 1000, -400] \quad (42)$$

$$UB = [1200, 1200, 1200, 1200, 160, 1000, 0, 1600, 0] \quad (43)$$

Equations (43) and (44) show the numerical values of the limits of the optimization variables.

4.3. Constraints

Constraints play a significant role in the optimization process, shaping the solutions that will be obtained. In the concrete optimization problem, the constraints are of great importance, and there will be 19 of them. Above all, these constraints serve to avoid structurally unfeasible solutions and enable the desired trajectory of the mechanism members. Constraints, in this case, can be divided into three groups:

- constraints in the starting position;
- constraints during the movement of the ramp;
- constraints in the end position.

$$g(1) = -\theta(i) < 0 \quad (44)$$

$$g(2) = \theta(i) - 180 < 0 \quad (45)$$

$$g(3) = -\delta(i) < 0 \quad (46)$$

$$g(4) = \delta(i) - 180 < 0 \quad (47)$$

Equations (44-47) define the limit for the angles between the mechanism members, which must be in the range of [0°,180°].

$$g(5) = Y_E(1) - 200 < 0 \quad (48)$$

$$g(6) = -500 - Y_E(1) < 0 \quad (49)$$

$$g(7) = Y_E(end) - 200 < 0 \quad (50)$$

$$g(8) = -1200 - Y_E(end) < 0 \quad (51)$$

$$g(9) = -1200 - Y_E(i) < 0 \quad (52)$$

Equations (48-52) limit the positions of point E at the beginning and end of the movement and during the movement. So that at the beginning of the movement, the vertical coordinate of point E must be within limits (53), while the same limit at the end of the movement is defined by equation (54).

$$-500 < Y_E(1) < 200 \quad (53)$$

$$-1200 < Y_E(end) < 200 \quad (54)$$

The limits of the position of point C are defined by the equations (55-61).

$$g(10) = -200 - X_C(1) < 0 \quad (55)$$

$$g(11) = -500 - Y_C(1) < 0 \quad (56)$$

$$g(12) = -500 - Y_C(1) < 0 \quad (57)$$

$$g(13) = Y_C(end) - 1000 < 0 \quad (58)$$

$$g(14) = -1000 - Y_C(end) < 0 \quad (59)$$

$$g(15) = -1200 - Y_C(i) < 0 \quad (60)$$

Equation (55) defines the condition (61) for the position of point C in the horizontal direction. Equations (56-59) define the constraints of the vertical coordinate in the starting (62) and ending (63) positions.

$$X_C(1) > -200 \quad (61)$$

$$-500 < Y_C(1) < 200 \quad (62)$$

$$-1000 < Y_C(end) < 1000 \quad (63)$$

Due to the required measure for the installation of the hydraulic cylinder, it is necessary to limit its stroke as defined by equations (64) and (65).

$$stroke < L_{FE}(1) + 100 \quad (64)$$

$$stroke < 1000 \quad (65)$$

The introduced constraints are defined by equations (66) and (67).

$$g(16) = stroke - 1000 < 0 \quad (66)$$

$$g(17) = stroke - 100 - L_{FE}(1) < 0 \quad (67)$$

Limitations related to the mutual horizontal distance between supports D and F are described by equation (68) and defined by equations (69) and (70).

$$800 < X_D - X_F < 1500 \quad (68)$$

$$g(18) = X_D - X_F - 1500 < 0 \quad (69)$$

$$g(19) = 800 - X_D + X_F < 0 \quad (70)$$

5. RESULTS

After the optimization, certain results of the described variables were obtained. The parameters defined before starting the optimization were the number of iterations, the number of searching agents and the number of variables defined within the main.m script as follows:

- T=1000 – number of iterations;
- N=60 – number of searching agents;
- dimSize=9 – number of variables.

The results of the optimization process are shown in Table 2.

Table 2: Optimization results

L_1 [mm]	1200
L_2 [mm]	1200
L_3 [mm]	749.28686
L_4 [mm]	408.52464
η [°]	111.16211
X_D [mm]	497.94503
Y_D [mm]	-400
X_F [mm]	1535.3268
Y_F [mm]	-231.54711

Figure 12 shows the appearance of the mechanism with the adopted dimensions obtained in the optimization, which occupies the position with the maximum force in the hydraulic cylinder.

For the mechanism defined in this way, the objective function, i.e. the force value in the hydraulic cylinder, is shown by equation (71). Considering that the value of the force changes from a positive to a negative sign, the obtained value represents the absolute value of force that occurs in the appropriate position of the ramp.

$$o = F_H = 29817N = 29.817kN \quad (71)$$

$$stroke = 547.8mm \quad (72)$$

Equation (72) shows the stroke that needs to be achieved for the dimensions of the mechanism adopted to realize the ramp positions defined for the start and end of the movement.

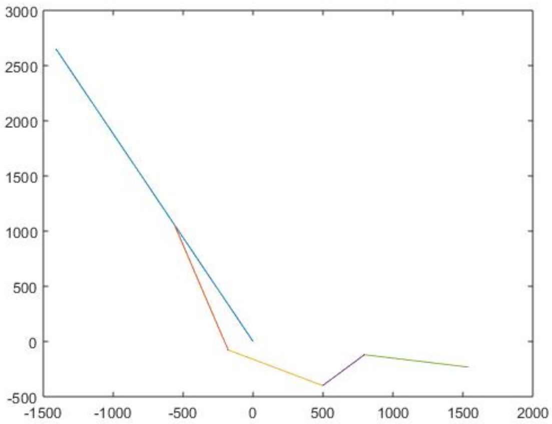

Figure 12: The most loaded position of the mechanism

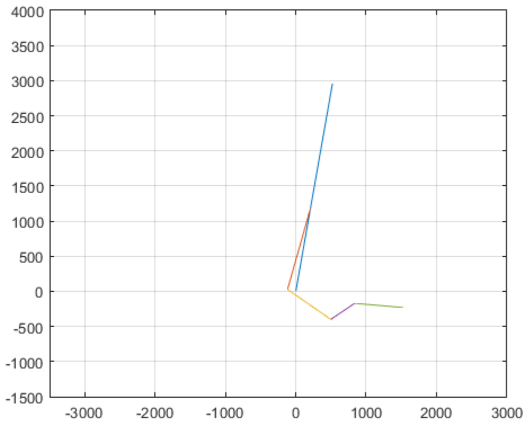

Figure 13: Starting position of the mechanism

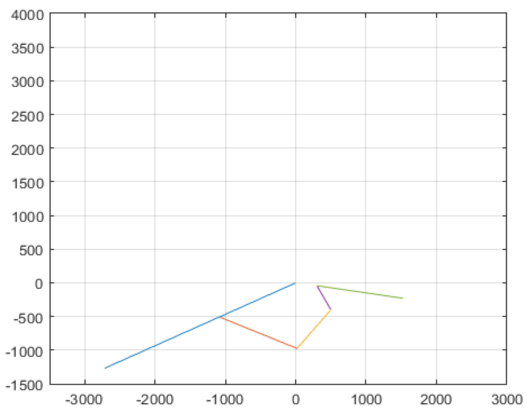

Figure 14: Ending position of the mechanism

Figures 13 and 14 show the initial and final positions of the loading mechanism members after the optimization process.

Figure 15 shows the diagram of the force change in the hydraulic cylinder depending on the change in the angle at which the ramp overlaps with the horizontal axis.

By looking at the diagram shown in Figure 15, it can be concluded which positions of mechanism members create the greatest force in the hydraulic cylinder. In addition to the perpendicular distance of the weight force from the axis of rotation, the angle of θ that the lever AC overlaps with the ramp has a significant influence.

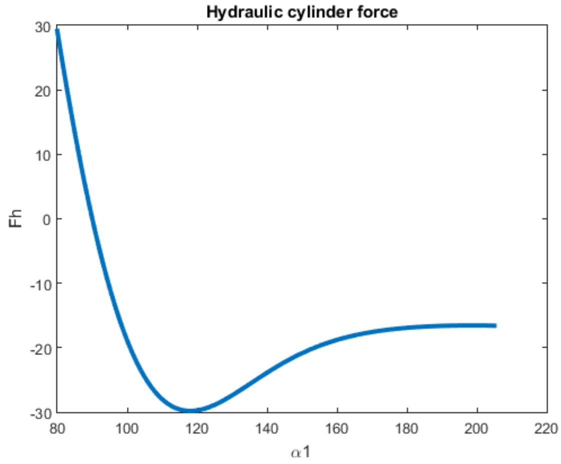

Figure 15: Hydraulic-cylinder force change

6. CONCLUSION

Optimization resulted in a solution that enables using the smallest hydraulic cylinder with the smallest force acting in it. Increasing the dimensions of the members of the mechanism makes it possible to reduce the force due to the increase in the moment arm. Limitations in the vehicle's overall dimensions make it impossible to adopt large lengths of mechanism members, resulting in a greater force in the hydraulic cylinder than expected.

ACKNOWLEDGEMENTS

This work has been supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia through the Contracts for the scientific research financing in 2023, 451-03-47/2023-01/200102 and 451-03-47/2023-01/200108.

REFERENCES

[1] M. Gašić, M. Savković, N. Zdravković, G. Marković, "Development of Devices Used for Loading the Heavy Machines on to the Freight Trailers", Mechanics Transport Communication, Issue 3, (2011)

[2] M. Savković, G. Marković, N. Zdravković, B. Milovanović, G. Pavlović, M. Gašić, B. Sredojević, "Development and Design of the Special Vehicle for the Transportation of Heavy Weight Construction Machines", Proceedings of Seventh International Conference "Transport and Logistics", Niš (Serbia), 6th December 2019 (2019)

[3] J. R. R. A. Martins, A. Ning, "Engineering Design Optimization", Cambridge University Press (England), (2021)

[4] S. Li, H. Chen, M. Wang, A. A. Heidari, S. Mirjalili, "Slime Mould Algorithm: A New Method for Stochastic Optimization", Future Generation Computer Systems, Vol. 111, pp 300-323, (2020)

[5] N. Zdravković, M. Savković, G. Marković, G. Pavlović, "The Impact of the Position of the Hydraulic Cylinder Mounting Point on the Chassis Coad in Mobile Elevating Work Platforms", Proceedings of Sixth International Conference "Transport and Logistics", Niš (Serbia), 25-26 May 2017 (2017)