SYSTEM SAFETY: HUMAN - TECHNICAL FACILITY – ENVIRONMENT
8(1), 2026, pp. 58-69

LIGHTWEIGHT DESIGN AND SAFETY OPTIMIZATION OF SCISSOR LIFT COMPONENTS USING FEM

DOI: 10.2478/czoto-2026-0006
Received: 13/12/2025
Accepted: 23/01/2026

Michał Bembenek[1] – orcid Id: 0000-0002-7665-8058
Saltanat Nurkusheva[2] – orcid Id: 0009-0007-7263-3797
Vasyl Mykhailiuk[3] – orcid Id: 0000-0002-3329-2068
Ruslan Deineha[3] – orcid Id: 0000-0003-1141-7672
Orest Slabyi[3] – orcid Id: 0000-0002-1274-2875
Łukasz Kowalski[4] – orcid Id: 0000-0002-2866-9000
Monika Osyra[5] – orcid Id: 0000-0002-2525-4897*, e-mail: monika.osyra@pcz.pl*
[1]AGH University of Krakow, al. Adama Mickiewicza 30, 30-059 Kraków, **Poland**
[2]S. Seifullin Kazakh Agrotechnical Research University, Zhenis 62B, Astana 010011, **Kazakhstan**
[3]Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska st., 76019, **Ukraine**
[4]AGH University of Krakow, al. Adama Mickiewicza 30, 30-059 Kraków, **Poland**
[5]Czestochowa University of Technology, al.Armii Krajowej 19B, 42-202 Częstochowa, **Poland**

Abstract: Lifting structures are critical components in the automotive industry, yet their excessive weight and bulk often impede mobility and ease of use. This paper presents a comprehensive study on the structural optimization of a scissor lift, focusing on the topological redesign of its lever. The primary objective is to achieve significant mass reduction while preserving structural integrity, load-bearing capacity, and safety. The core hypothesis is that strategic topological modifications can induce favorable stress redistribution, leading to material savings without compromising safety margins. The research methodology, implemented in the spring of 2024, was based on numerical modeling using the Finite Element Method (FEM) in Ansys Workbench. Numerical analysis of the base lever identified a maximum equivalent stress of 152 MPa, corresponding to a safety factor of 2.27. The proposed optimizations yielded a new lever topology that reduces the component's mass by 39% (to 35 kg) while maintaining a high safety factor of 1.52 under a maximum stress of 226.5 MPa. The results confirm that the proposed design approach successfully enhances the lift's performance-to-weight ratio, offering a viable solution for developing more efficient and portable automotive lifting equipment.
Keywords: lightweight design, structural optimization, finite element method, scissor lift, topological optimization.

1. INTRODUCTION

The present research focuses on the structural refinement of a critical actuating component – the lever – through advanced topological optimization techniques. This refinement is pursued not only to enhance the functional efficacy and load-handling performance of the system but also to serve as a case study in the practical application of mass-reduction strategies underpinned by computational engineering methods, such as Finite Element Analysis (FEA). Automotive lift technology has advanced significantly in recent years, particularly in the materials used for its construction. Traditionally, automotive lifts have been made primarily of steel for its strength and durability. However, there has been a growing trend towards using alternative materials to reduce the weight of metal structures (Taub & Babu, 2018; Taub et al., 2019). One such alternative is the incorporation of lightweight alloys, which offer high strength while significantly reducing the overall weight of the lift (Jhaveri et al., 2018). The drive for such mass optimization is linked to the role of lifting systems in constituting integral elements that facilitate service inspections of cars (Nurkusheva et al., 2024). The paper (Wankhede et al., 2018) deals with the analysis and optimization of a hydraulic scissor lift, where the main goal was to reduce lift weight by modifying parameters like the cylinder position and replacing the supporting link of the cylinder, ultimately reducing the cost. Additionally, extensive research has been conducted to analyze and optimize the dynamic behavior (Burian et al., 2014), structural integrity (Pervan et al., 2019), and overall performance of scissor lifts. Research has been aimed at enhancing the performance, efficiency, and safety of scissor lifts through studies focused on optimizing the design (Sanusi et al., 2019; Hyun et al., 2021), (Kashani et al., 2022), improving the hydraulic system (Stawinski et al., 2019), and refining additional enhancements (Spanu et al., 2008). Simultaneously, strength and stiffness simulation analysis determines the mechanism's material and processing technology, while fatigue analysis provides the foundation for subsequent life optimization (Wu et al., 2024). Finite element methods are widely used to evaluate stress distribution and improve the structural performance and fatigue characteristics of mechanical components (Kopey et al., 2025). Additionally, the paper (Rašović et al., 2019) predicts and explains the methodology for structural analysis. In their paper, Picelli et al. (2017) proposed a level set method for solving minimum stress and stress-constrained shape and topology optimization problems. Recent studies have proposed combined optimization methods integrating FEM with intelligent algorithms such as Particle Swarm Optimization to enhance structural performance prediction in complex mechanisms (Starostina et al., 2025). The systematic application of these methodologies contributes to the advancement of the structural integrity, efficiency, and ability to optimize scissor lift systems. The design of the majority of the arm lifts currently employed in the industry is based on the scissor mechanism. However, these designs suffer from a notable drawback: as the mechanism is raised, the connection points with the base and the movable platform narrow, resulting in decreased stability. In the publication by Seidakhmet et al. (2023), the authors introduce a novel lifting device scheme designed to address the aforementioned limitation inherent in scissor-based designs. The optimization of the scissor lift design involves analyzing its structural components (Ciupan et al., 2019) and overall configuration to achieve improved efficiency (Paramasivam et al., 2021), stability, and load-bearing capacity. In the paper by Zhang et al. (2015), calculations were conducted to optimize the strength of the box beams in a scissor lift mechanism with a single hydraulic cylinder. In a study by Du et al. (2018), a novel lifting mechanism powered by an electronic cylinder is introduced, aiming to achieve both lifting and resetting functions. Lastly, researchers (Harris et al., 2010) aimed to enhance the structural strength and load-bearing capacity of the lifting mechanism to ensure its safe and reliable operation. In the work by Dang et al. (2023), research results were obtained regarding the study of double-layered scissor lifts. In a publication (Dang & Nguyen, 2023), a mathematical model was developed using the parametric dimension technique for the configuration and load calculation of double-stage scissor lifts. In a study by Dengiz et al. (2018), researchers designed and analyzed the mechanism of a scissor lift system with a load capacity of 500 kg and a working height of 2 meters. The structural analysis of the system was also investigated using the SolidWorks Simulation Package, from which stress, deflection, and safety factor values of system elements were obtained. In a study by Gonzalez and Asada (2016), a triple scissor lift system with a 6-degree-of-freedom robotic mechanism was investigated. In another publication (Ciupan et al., 2019), a numerical algorithm for optimizing the design of scissor lift platforms was introduced, along with a proposal for a new platform that addresses stability issues of such devices. In a study by Shrivastava et al. (2018), an embedded control system was introduced that can be integrated into existing scissor lifts. Additionally, researchers analyze safety coefficients, maximum loads, and the weight capacity of the lifts (Takesue et al., 2016). These measures and analyses underscore the commitment to ensuring the safety and reliability of automotive lifting systems, thus addressing critical concerns in the field. Previously described studies have been conducted in the field of improving lifting equipment, aiming to optimize various properties and parameters of scissor lifts. For example, a study that combines a novel lightweight multi-material design with advanced topology optimization, a new actuation system, and a predictive safety control would address multiple gaps simultaneously and accelerate innovation (Table 1).

Table 1
Summary of Scissor Lift Research & Identified Gaps

Research Focus Area	Key Contributions (Example Studies)	Primary Goals & Outcomes	Identified Research Gaps & Future Directions
Mass Reduction & Lightwe-ighting	Taub & Babu (2018); Taub et al. (2019); Jhaveri et al. (2018); Wankhede et al. (2018)	Review of lightweighting principles (design, material substitution, multi-materials). Applied studies on reducing lift weight via parameter modification and material choice (e.g., lightweight alloys) to lower cost and improve efficiency	**Integrated Multi-Material Design.** Practical application of the multi-material, optimized design frameworks (from Taub et al.) specifically to scissor lift structures. **Cost-Benefit Analysis.** Comprehensive studies evaluating the trade-off between the higher cost of advanced materials (Al, Mg, composites) and the lifecycle benefits (energy savings, performance) in scissor lift systems. **Joining & Corrosion.** Addressing the challenges of

			joining dissimilar materials and preventing galvanic corrosion in a scissor lift context, as highlighted by Taub et al. (2019)
Structural & Dynamic Analysis	Burian et al. (2014); Pervan et al. (2019); Rašović et al. (2019); Wu et al. (2024); Zhang et al. (2015); Dengiz et al. (2018)	Analysis of dynamic behavior, structural integrity, stress, deflection, and safety factors. Use of simulation tools (e.g., SolidWorks) and methodologies (e.g., level-set topology optimization) to predict performance and establish foundations for fatigue life optimization	**Standardized Fatigue Life Models.** Development of validated, generalizable fatigue life prediction models specific to the cyclic loading patterns of scissor lifts. **Real-World Validation.** More studies comparing high-fidelity simulation results (stress, dynamics) with physical prototype testing under varied operational conditions. **Topology Optimization Application.** Broader application of advanced optimization methods (like Picelli et al.'s level-set method) to entire scissor lift assemblies, not just individual components
Design Optimization & Novel Mechanisms	Sanusi et al. (2019); Hyun et al. (2021); Kashani et al. (2022); Ciupan et al. (2019); Seidakhmet et al. (2023); Dang et al. (2023); Gonzalez & Asada (2016)	Optimization of design parameters for efficiency and stability. Proposal of novel mechanisms to address inherent instability of traditional scissor designs and exploration of complex systems (double/triple-layer, robotic 6-DOF mechanisms)	**Stability-Centric Design**. Further research into novel linkage mechanisms (beyond scissor) that inherently maintain or increase stability with platform elevation. **Performance Benchmarking.** Comparative studies quantifying the efficiency, stability, and cost benefits of new mechanism designs (e.g., Seidakhmet et al.'s model) against optimized traditional scissors. **Control-Structure Co-Design.** Integrated design of novel mechanisms with their dedicated control systems, especially for complex multi-DOF lifts
System Integration & Control	Stawinski et al. (2019); Spanu et al. (2008); Du et al. (2018);	Improvements to hydraulic systems, introduction of electronic/electromechanical actuators (e.g., electronic cylinders), and development	**Energy Efficiency of Actuation.** Holistic analysis of the energy consumption and efficiency of hydraulic vs. electromechanical actuation

	Shrivastava et al. (2018)	of embedded control systems for integration into existing lifts	systems across a full duty cycle. **Smart & Predictive Systems.** Development of IoT-enabled lifts with sensors for predictive maintenance, load monitoring, and adaptive stability control, moving beyond basic embedded control. **Human-Machine Interface (HMI).** Research into intuitive controls, automation features, and safety-interlock systems that integrate with modern control architectures
Safety & Reliability	Harris et al. (2010); Takesue et al. (2016); Paramasivam et al. (2021)	Enhancement of structural strength and load-bearing capacity. Analysis of safety coefficients and maximum load limits to ensure safe and reliable operation	**Dynamic Safety Factors.** Moving beyond static load analysis to define safety factors that account for dynamic shocks, uneven loading, and operator-induced forces. **Failure Mode Libraries.** Creation of comprehensive, publicly available databases documenting common failure modes, their causes, and mitigation strategies for various lift designs. **Human Factor Integration.** Studies on how lift design and control interfaces influence operator error and how design can mitigate it proactively

These studies have identified several shortcomings that affect their efficiency and reliability. Based on the results presented in the literature, as well as the author's own analysis and simulations, improvements to automotive scissor lifts can still be made. This study focuses on investigating the stress-strain characteristics of the scissor lift lever and aims to explore topological optimization methods for reducing its mass.

2. METHODS

Topology optimization represents a subset of structural optimization focused on material layout within a predefined design space. The objective of this methodology is to identify the optimal material distribution that maximizes or minimizes a predefined objective function, such as structural stiffness or fundamental frequency, while adhering to a set of constraints, most notably a target volume fraction. A fundamental distinction from traditional parametric optimization is that topology optimization does not rely on predefined geometric variables. Instead, the design variable is the material density itself

at each point within the design domain, effectively making the optimization parameter a continuous function describing the presence or absence of material throughout the component's volume.
To conduct the topological optimization of the scissor lift lever, an existing prototype of a scissor lift mechanism was utilized as the basis for the simulation. The prototype selected for this study is the Heshbon scissor lift model HL-51G, illustrated in Figure 1. This particular model was chosen due to its established performance characteristics, which provide a suitable foundation for the simulation modeling process.

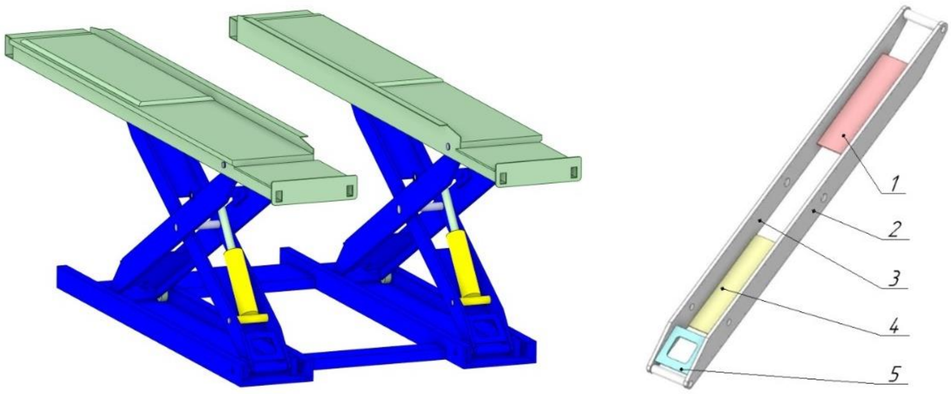
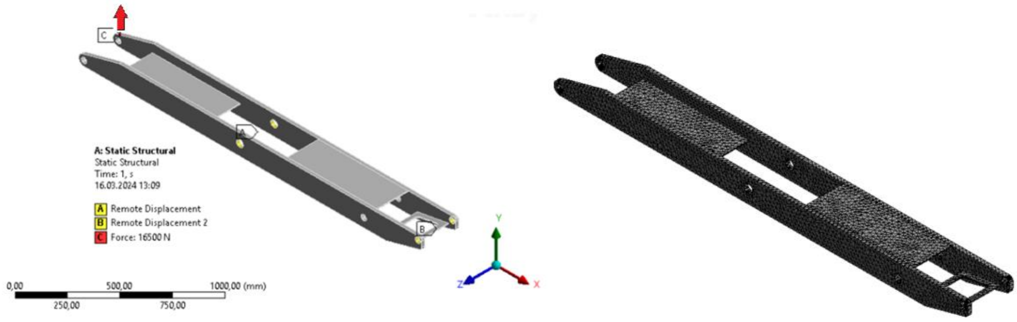


Fig. 1. - Heshbon scissor lift model HL-51G,
3D model of the lift lever. 1 - Upper sheet; 2, 3 - plates; 4 - lower sheet; 5 – spacer

Its main components are the lower plate, the upper plate, and the elements of the scissor mechanism. To achieve the study's primary objective of mass minimization, a three-dimensional solid model of the scissor lift lever was developed to serve as the basis for Finite Element Analysis (FEM). The corresponding figure (Fig. 1) illustrates the complete scissor lift assembly on the left and the isolated lever component on the right. This digital representation of the lever was constructed to be geometrically congruent with the physical component from a full-scale industrial lift, ensuring the fidelity of the subsequent computational simulations and the practical relevance of the optimization results. Before beginning the optimization procedure, it is essential to assess the lift's stress-strain state, for which the Ansys Workbench V22 program is employed. The design scheme of the lift lever, depicted in Figure 2a, serves as the basis for this analysis. The lift lever model is discretized into a finite element grid, as illustrated in Figure 2b, to facilitate detailed stress analysis and optimization procedures. Table 2 shows the boundary conditions used in the simulation.



(a) (b)
Fig. 2. (a) Design of the car lift lever; (b) - Finite element mesh

Table 2
Boundary conditions

Boundary condition	X Component, mm	Y Component, mm	Z Component, mm	Rotation X	Rotation Y	Rotation Z
Remote Displacement 1	0	0	0	0°	0°	Free
Remote Displacement 2	Free	0	0	0°	0°	Free

The amount of load applied to the lift lever is 16500 N and acts in the direction of the Y-axis. This direction of action of the applied load is chosen in accordance with the most severe operating conditions of the lift lever (bending loads are more influential on the stress values compared to compressive loads – when the lift rises to the maximum height). Q345 steel was adopted as the material of the lift parts. Q345 steel has analogues: A572 Grade 50 USA ASTM, Q355 China GB/T, and SPFC 590 Vietnam/Japan JIS. Q345 steel has the following characteristics: Young's modulus 2·1011 Pa, Poisson's ratio 0.3, yield strength 355 MPa, tensile strength 470-630 MPa. The model is divided into a finite element mesh with 19088 elements and 37661 nodes. The mesh elements are tetrahedra.

3. RESULTS AND DISCUSSION

After carrying out the simulation modeling, the distribution of equivalent stresses in the main lift was determined (Fig. 3).

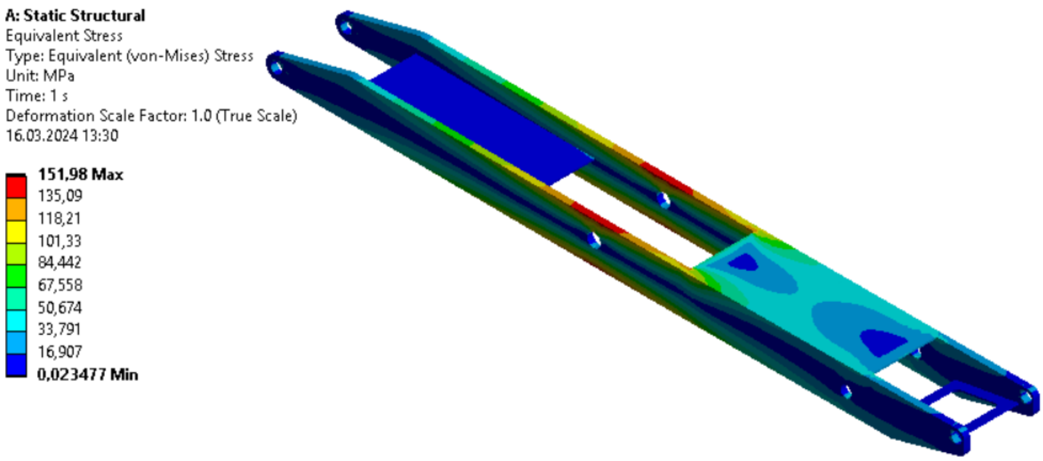


Fig. 3. Distribution of equivalent stresses

Based on the results obtained throughout the study, the distribution of equivalent stress was determined (Fig. 3). Its maximum values occur in the cross-section of the car lift lever near the central holes (where the central axis is installed) and amount to 152 MPa. It should be noted that with the conditions applied, a significant number of sections are observed in the design of the car lift lever in which equivalent stress is low. As a result, these sections do not carry any significant load. Given the applied boundary conditions, total deformation analysis was also performed (Figure 4). Maximum displacement of a node amounted to 8,4 mm, at the location where the force was applied.

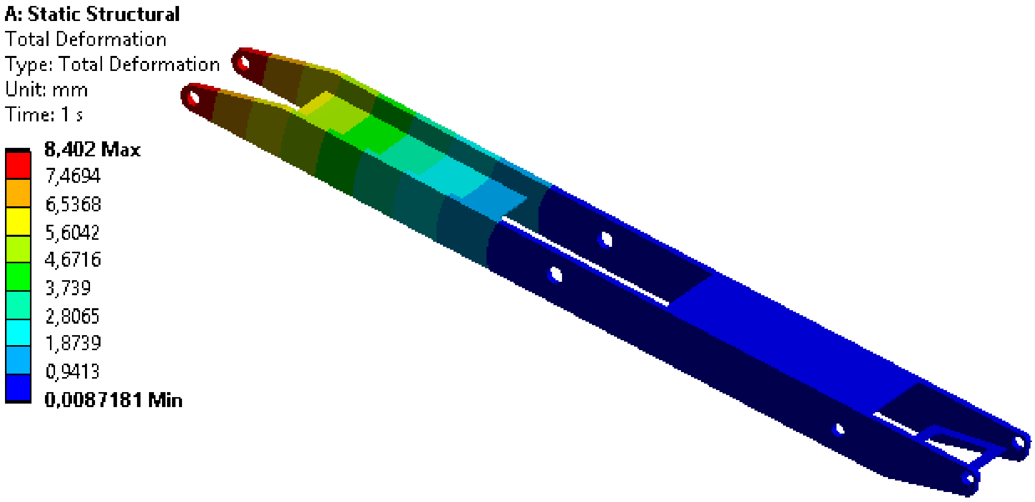


Fig. 4. Total deformation of the lever under load, in mm

Following the analysis, a topological optimization was performed to reduce the system's weight, utilizing the Structural Optimization module in the Ansys Workbench program. The original weight of the lift lever structure before optimization is 92 kg. Figure 5 shows the areas of the lift lever design that can be optimized (blue) and that remain unchanged (red).

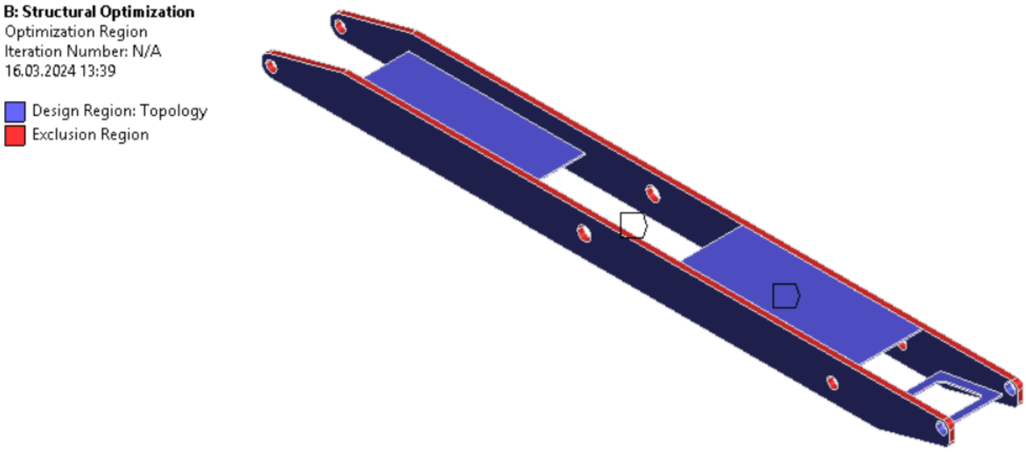


Fig. 5. Areas for optimizing the design of the lift lever

The goal of optimization is to reduce the weight of the car lift lever structure while ensuring its strength and rigidity. The topological optimization process aims to achieve this by strategically removing material from non-critical areas of the structure while reinforcing essential load-bearing regions. Figure 6 illustrates the outcome of the topological optimization process, presenting the proposed altered shape of the car lift lever structure. In this representation, areas that can be safely removed are highlighted in blue. At the same time, critical regions that must be retained are marked in red, showcasing an optimized design that balances weight reduction with structural integrity.

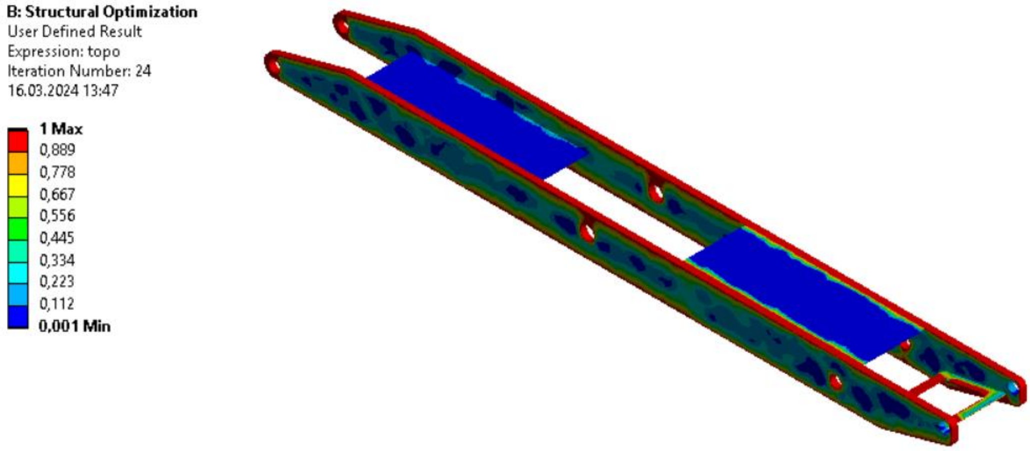


Fig. 6. Results of topological optimization of the lift lever design

Furthermore, Figure 7 demonstrates the "topological density" at a coefficient of 0.3. The topological density coefficient represents the ratio of material present in a given design space compared to the maximum allowable material volume, with a lower coefficient indicating a more optimized and lightweight structure. A coefficient of 0.3 suggests that the optimized car lift lever design retains 30% of the material present in the initial structure, emphasizing the significant weight reduction achieved through the topological optimization process while maintaining structural robustness.

Fig. 7. The topological density at a coefficient of 0.3

After processing the optimized model, the proposed design of the lift lever, as depicted in Figure 8, embodies the culmination of the topological optimization process. The resulting lift lever design exemplifies the potential of topological optimization techniques in enhancing the performance and efficiency of mechanical components.

The weight of the optimized lift lever model is 35 kg, representing a 39% reduction compared to the unoptimized design. This substantial decrease in weight not only contributes to improved efficiency but also underscores the effectiveness of the topological optimization process in achieving lightweight yet robust structural designs. To validate the strength and integrity of the optimized lift lever structure, repeated simulation modeling was conducted under similar boundary conditions as those applied to the unoptimized design.

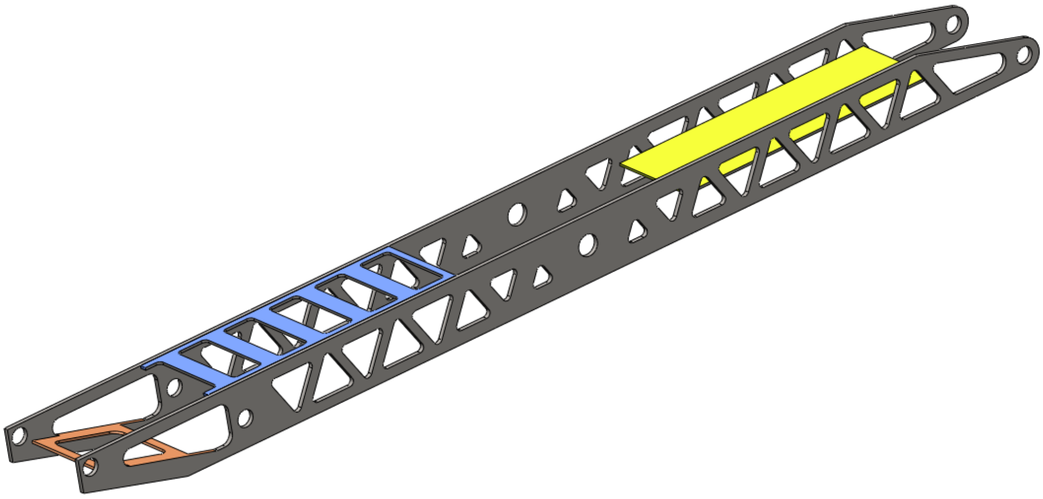


Fig.8. Proposed optimized lift lever model

Numerical analysis of the optimized lever design confirms its structural integrity through the observed distribution of equivalent stresses. The stress field indicates that the topologically optimized geometry successfully manages and redistributes operational loads, with no areas exceeding critical thresholds, thereby ensuring structural stability. This favorable stress pattern validates the design's ability to maintain performance despite a significant reduction in mass.

Furthermore, deformation analysis of the optimized component reveals a maximum displacement of 10.6 mm (Fig. 9). This deformation behavior is consistent with the pattern observed in the pre-optimization model, indicating that the fundamental structural response has been preserved. The minimal change in the deformation value, despite the substantial mass reduction, serves to corroborate the success of the topological optimization process.

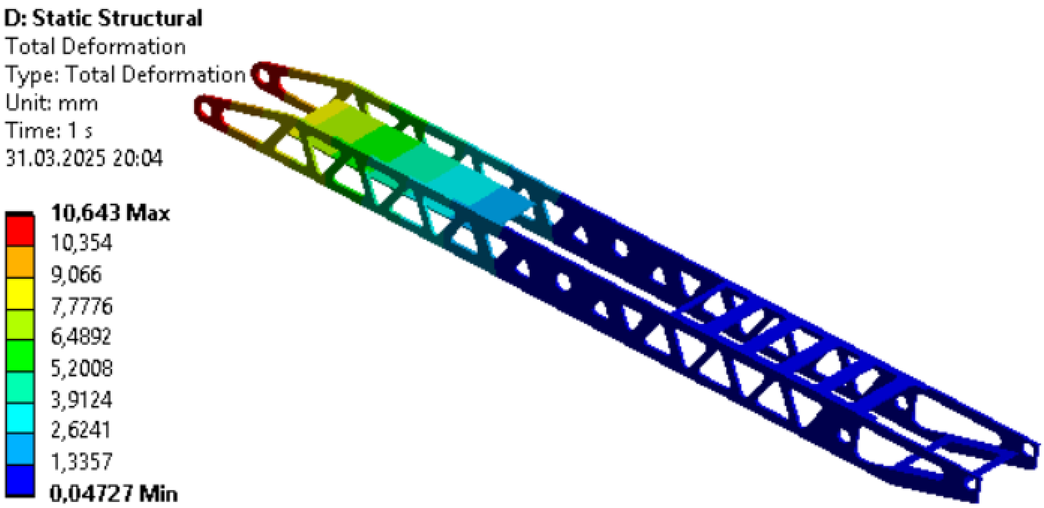


Fig. 9. Total deformation analysis of the optimized structure

The results collectively demonstrate that the approach achieved a balanced and effective compromise between weight reduction and the preservation of structural performance.

4. CONCLUSION

Stress analysis of the initial lever design revealed a non-uniform stress distribution, with the most critical stress concentrations localized in specific regions. The maximum equivalent (von Mises) stress of 152 MPa was identified within the cross-sections of the component, predominantly in the vicinity of the central mounting holes. These zones were consequently identified as critical stress risers and primary areas for potential failure. This quantification of the stress field provided a crucial empirical foundation, highlighting the necessity for a targeted design refinement to mitigate these peak stresses, thereby improving the component's structural efficiency and ensuring its long-term operational durability under cyclic loading conditions. The topological optimization of the lift lever design was meticulously carried out using the Structural Optimization module of the ANSYS Workbench program. By leveraging advanced computational tools and algorithms, the optimization process successfully reduced the mass of the lever structure by 39% compared to the initial design. This substantial weight reduction signifies the effectiveness of the optimization strategy in achieving a lighter yet robust structure that meets performance requirements. Adopting this optimized design can directly lead to more portable and cost-effective lifting equipment for the automotive service industry.

ACKNOWLEDGEMENTS

The present article originated as part of a research internships "Using advanced FEM modeling to simulate mechanical engineering processes" of Vasyl Mykhailiuk and "Solving optimization problems in mechanical engineering using advanced FEM modeling" of Ruslan Deineha at the AGH University of Krakow, Faculty of Mechanical Engineering and Robotics, Department of Manufacturing Systems. A concept for this study was presented at the 2nd International Scientific Conference on Modeling and Computer Engineering in Mechanical Engineering (MCEME 2024), Lviv, Ukraine.

REFERENCES

Burian, M., Havlik, J., Folta, Z., Trochta, M., Marsalek, P. 2014. *Solution the Drive Lifting Scissor Platforms*, MM Science Journal, 2014(4), 19–26.

Ciupan, C., Ciupan, E., Pop, E. 2019. *Algorithm for designing a hydraulic scissor lifting platform*, MATEC Web of Conferences, 299, 03012.

Dang, A.-T., Nguyen, D.-V., Nguyen, D.-N. 2023. *Applying Parametric Analysis in Enhancing Performance for Double-Layer Scissor Lifts*, Strojniški vestnik - Journal of Mechanical Engineering, 69(5), 299–307.

Dang, A.-T., Nguyen, T.T.N. 2023. *Investigation on the Design of Double-Stage Scissor Lifts Based on Parametric Dimension Technique*, Machines, 11(7), 684.

Dengiz, C., Şenel, M., Yıldızlı, K., Koç, E. 2018. *Design and Analysis of Scissor Lifting System by Using Finite Elements Method*, Universal Journal of Materials Science, 6(3), 58-63.

Du, M.Q., Yang, X.Q., He, W., Zhao, D.F. 2018. *Mechanism Design and Simulation Analysis of a New Baggage Diversion Lifting Mechanism*, Proceedings of the 6th International Conference on Control, Mechatronics and Automation, New York, NY, USA: ACM, 92–96.

Gonzalez, D.J., Asada, H.H. 2016. *Triple Scissor Extender: A 6-DOF lifting and positioning robot*, 2016 IEEE International Conference on Robotics and Automation (ICRA), IEEE, 847–853.

Harris, J.R., Powers, J.R., Pan, C.S., Boehler, B. 2010. *Fall arrest characteristics of a scissor lift*, Journal of Safety Research, 41(3), 213–220.

Hyun, H., Park, M., Lee, D., Lee, J. 2021. *Tower Crane Location Optimization for Heavy Unit Lifting in High-Rise Modular Construction*, Buildings, 11(3), 121.

Jhaveri, K., Lewis, G.M., Sullivan, J.L., Keoleian, G.A. 2018. *Life cycle assessment of thin-wall ductile cast iron for automotive lightweighting applications*, Sustainable Materials and Technologies, 15, 1–8.

Kashani, A.R., Camp, C.V., Rostamian, M., Azizi, K., Gandomi, A.H. 2022. *Population-based optimization in structural engineering: a review*, Artificial Intelligence Review, 55(1), 345–452.

Kopey, I., Kopey, B., Mykhailiuk, V. 2025. Improvement of fatigue characteristics of hybrid sucker rod connection. Archives of Engineering Knowledge, 11(1), 30–34.

Nurkusheva, S., Bembenek, M., Berdychowski, M., Gajdzik, B., Wolniak, R. 2024. *An Analysis of the Correct Frequency of the Service Inspections of German Passenger Cars – A Case Study on Kazakhstan and Poland*, Vehicles, 6(2), 553-570.

Paramasivam, V., Tilahun, S., Jembere, A.K., Selvaraj, S.K. 2021. *Analytical investigation of hydraulic scissor lift for modular industrial plants in Ethiopia*, Materials Today: Proceedings, 46, 7596-7601.

Pervan, N., Muminovic, A.J., Muminovic, A., Delic, M. 2019. *Development of Parametric CAD Model and Structural Analysis of the Car Jack*, Advances in Science and Technology Research Journal, 13(2), 24–30.

Picelli, R., Townsend, S., Brampton, C., Norato, J., Kim, H.A. 2017. *Stress-based shape and topology optimization with the level set method*, Computer Methods in Applied Mechanics and Engineering, 329, 1–23.

Rašović, N., Vucina, A., Obad, M. 2019. *Stress analysis of lifting table using finite element method*, IOP Conference Series: Materials Science and Engineering, 659(1), 012032.

Sanusi, H., Ishak, M.R., Hussin, M.S., Yuzairi, A.R., Imran, M.S., Sauli, S.A. 2019. *Optimisation of scissor lifting machine structures using finite element analysis (FEA)*, AIP Conference Proceedings, 2129(1), 020003.

Seidakhmet, A., Tuleshov, A., Jamalov, N., Jomartov, A., Cieslik, J., Abduraimov, A., Kamal, A., Kaliyev, M., Bissembayev, K. 2023. *Research of Kinematics and Dynamics of the Lever Lifting Mechanism Used in the Mobile Automotive Lift*, Applied Sciences, 13(20), 11361.

Shrivastava, N., Pande, A., Lele, J., Kampassi, K. 2018. *Embedded Control System for Self Adjusting Scissor Lift*, 2018 Fourth International Conference on Computing Communication Control and Automation (ICCUBEA), Pune, India, 1–5.

Spanu, A., Stoenescu, A., Anghel, F. 2008. *CAD method used for improving the performances of lifting systems used for vehicles*, International Symposium of the Danube-Adria-Association-for-Automation-and-Manufacturing, Annals of DAAAM & Proceedings,1277–1278.

Starostina, Z., Doudkin, M., & Kim, A. 2025. *Methodology for calculating the structural characteristics of a hexapod using the particle swarm optimization method and the finite element method*, Archives of Engineering Knowledge, 11(1), 20–24.

Stawinski, L., Kosucki, A., Morawiec, A., Sikora, M. 2019. *A new approach for control the velocity of the hydrostatic system for scissor lift with fixed displacement pump*, Archives of Civil and Mechanical Engineering, 19(4), 1104-1115.

Takesue, N., Komoda, Y., Murayama, H., Fujiwara, K., Fujimoto, H. 2016. *Scissor lift with real-time self-adjustment ability based on variable gravity compensation mechanism*, Advanced Robotics, 30(15), 1014–1026.

Taub, A.I., Babu, S.S. 2018. *Opportunities and challenges for introducing new lightweight metals in transportation*, International Journal of Powder Metallurgy, 54(3), 27–33.

Taub, A., Moor, E., Luo, A., Matlock, D.K., Speer, J.G., Vaidya, U. 2019. *Materials for Automotive Lightweighting*, Annual Review of Materials Research, 49, 327–359.

Wankhede, S.D., Joshi, S.S., Bagwan, L.J., Wadmare, A.V. 2018. *Analysis and Optimization of Hydraulic Scissor Lift*, IOSR Journal of Engineer

Wu, J., Hongqing, L., Hu, P., Pengfei, Y., Jiang, B., Wilfried, T.A. 2024. *Simulation and Optimization of Scissors Mechanism of Electric Charging Bow*, Lecture Notes in Electrical Engineering, 1067, 523–532.

Zhang, W., Zhang, X.F., Yan, C., Xiang, S.J., Wang, L.W. 2015. *A characteristic triangle method on input vectors of scissor lift mechanism and its applications in modeling and analysis*, Journal of Advanced Mechanical Design, Systems, and Manufacturing, 9(3), JAMDSM0042.