Nigerian Journal of Technology (NIJOTECH)
Vol. 45, No. 1, March 2026, pp. 46- 57
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.2026.5390

DESIGN AND OPTIMIZATION OF THE TRAILING ARM FOR A TADPOLE-CONFIGURED ELECTRIC VEHICLE USING A GENERATIVE DESIGN APPROACH

AUTHORS:
*S. Amol[1], N. Sameer[1] and K. S. Raju[2]

AFFILIATIONS:
[1]A. P. Shah Institute of Technology, Thane, Maharashtra, INDIA.
[2]Pacific Academy of Higher Education and Research University, Udaipur, INDIA.

***CORRESPONDING AUTHOR:**
Email: amolshinde01991@gmail.com

ARTICLE HISTORY:
Received: August 03, 2025.
Revised: October, 10 2025.
Accepted: October, 27, 2025.
Published: April 29, 2026.

KEYWORDS:
Lightweight design, Design optimisation, Design iteration, Three-wheeler, Tadpole structure, Electric Vehicle, Generative Design, Trailing- arm.

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Chidozie Charles Nnaji

FUNDING:
None

Abstract

In this research, a small, economical, and secure three-wheel tadpole-structured vehicle was selected to reduce weight and enhance manoeuvrability on crowded city roads. The car employs a double-sided trailing arm (swing arm) that connects a single rear driving wheel to its frame, allowing vertical movement. Designing and optimising the rear wheel assembly in such a structure is crucial, as the driving wheel is attached to the trailing arm. To reduce the overall weight of the assembly, this study focused on the trailing arm. Structural and material lightweight design approaches were employed to create a lightweight component that leverages the advantages of advanced materials. A generative design approach was utilised to iterate on the design of the trailing arm using Autodesk Fusion 360 CAD software. The iterations were then analysed for a maximum load of 2000 N using Ansys software to assess their strength and stiffness. The Best- Worst Method (BWM) Multi-Criteria Decision-Making (MCDM) optimisation technique was applied, considering both beneficial and non-beneficial parameters such as geometry, weight, induced stress, stiffness, and deformation. The optimised design iteration selected through this process resulted in a weight reduction of 0.7 kg, thereby conserving material and reducing manufacturing costs, compactness of system for light vehicles.

1.0 INTRODUCTION

The increased urban population and accompanying rise in the number of cars have presented the automotive industry with a new challenge: the development of compact, fuel-efficient, and secure automobiles [1]. A fresh crop of compact automobiles follows this trend. There has been a recent uptick in interest in these vehicles because of their low fuel consumption, ease of driving, and parking in densely crowded urban areas [2]. In numerous nations, including India, Thailand, Peru, China, and even Italy, three-wheeled vehicles are already integrated into the public transit system [3]. Low fuel costs and zero pollutants are two major benefits of electric three-wheelers. Along with their widespread acceptance, three-wheelers are significant because they are particularly stable while

HOW TO CITE:
Amol, S., Sameer, N. and Raju, K. S. "Design and Optimization of the Trailing Arm for a Tadpole-configured Electric Vehicle using a Generative Design Approach", *Nigerian Journal of Technology*, 2026. 45(1), pp. 46 - 57. https://doi.org/10.4314/njt.2026.5390

performing complex manoeuvres [4]. A variety of solutions to increase their reliability have been presented [5].

The Trailing Arm connects the motorcycle's rear wheel to the frame and is critical to the bike's rear suspension system. The motorcycle's handling, stability, and performance may all benefit from a well-tuned Trailing Arm. The Trailing Arm may be improved in a number of ways [6]. The stability, traction, and handling of a motorbike are all affected by its wheelbase, which in turn is affected by the length of the Trailing Arm. The stability gains from a longer Trailing Arm may not be worth the potential loss of control. The opposite is true as well; a shorter Trailing Arm might increase manoeuvrability but may compromise stability. The trick is to strike a balance between length and steadiness [7, 8]. The Trailing Arm's weight, strength, and flexibility may all be affected by the material it's made out of. The total weight of a motorbike may be reduced by using lightweight materials like aluminium or carbon fibre, while the use of high-strength materials like titanium or steel can increase its durability and strength [9].

Suspension geometry, and hence handling and traction, is affected by the motorcycle's Trailing Arm's form and angle [10]. The degree of squat and anti-squat may be modified by adjusting the Trailing Arm angle, which in turn helps enhance the vehicle's responsiveness and control under acceleration and braking [11]. In a vehicle, the suspension linkage is what attaches the Trailing Arm to the chassis and the shock absorber. Improving the responsiveness and adjustability of the suspension through linkage optimisation can boost the motorcycle's performance and handling [12]. Trailing Arm optimisation is a multi-faceted procedure that must take into account the function of the motorbike, the preferences of the rider, and the limitations of the design. It entails weighing the benefits and drawbacks of different performance qualities and is often carried out with the use of computer simulations and physical testing [13].

An electric vehicle needs to optimise the weight of each component to increase its range and handling of the vehicle [14]. The single rear wheel drive will give the solution for urban traffic and a more stable structure with zero pollution. This paper used a tadpole-shaped electric three-wheeled vehicle structure for the study analysis. Weight distribution, suspension geometry, and tyre choice are a few examples of the requirements for optimisation; each of these elements must be carefully chosen and fine-tuned to achieve the best performance [15]. In addition, it's crucial to evaluate these optimisation strategies in real-world settings and do computer simulations to confirm their efficacy [16].

2.0 MATERIALS AND METHODS

The methodology adopted in this study integrates modern computational design and analytical evaluation techniques to develop a lightweight, structurally sound trailing arm for a three-wheeled electric vehicle configured in a tadpole architecture. The workflow combines generative design**,** finite-element analysis (FEA)**,** and multi-criteria decision-making (MCDM) to ensure both mechanical performance and manufacturability. The process begins with geometric modeling and load definition, followed by generative design exploration to produce multiple lightweight alternatives. Each design iteration is then evaluated through FEA to determine stress, deformation, and stiffness under combined loading conditions. The optimized configuration is selected using the Best–Worst Method (BWM), a quantitative MCDM approach that ranks alternatives based on beneficial and non-beneficial criteria such as geometry, strength, mass, and deflection.

2.1 Tadpole Design

A tadpole design for an electric vehicle consists of two wheels in the front and one wheel in the back. A reverse trike layout is another name for this style of vehicle, as shown in Figure 1. Because the vehicle's weight is shared by all three wheels, it is more stable in this configuration. At higher speeds, in particular, this can improve the vehicle's stability and make it simpler to handle. In addition, having two wheels up front helps enhance the vehicle's handling and agility, particularly in confined locations [12]. Suspension systems that can accommodate the tadpole layout's weight distribution and handling characteristics may be trickier to develop [17].

A vehicle's design will ultimately be decided by several criteria, such as the market segment the vehicle is aimed at, the specifications the vehicle must meet, and the preferences of the maker and the buyer [13]. The vehicle's teardrop form makes it aerodynamic. Air flows readily over the vehicle's bodywork. For its stability, aerodynamics, and fuel efficiency, auto designers are favouring the tadpole design [18]. Many hybrid and electric concept cars feature a three-wheel configuration. Three-wheelers may become increasingly common as cars become more eco-friendly [19].

https://doi.org/10.4314/njt.2026.5390

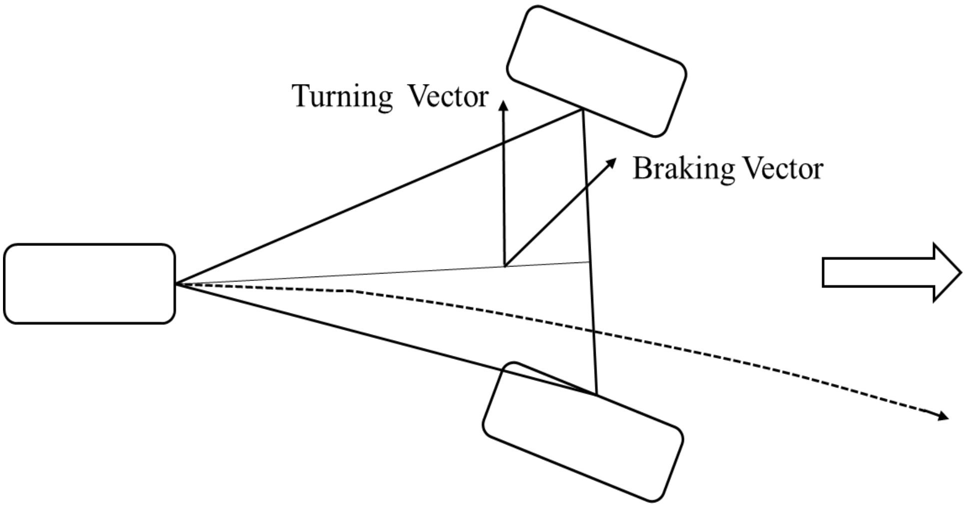


Figure 1: Tadpole vehicle architecture showing two front wheels and a single rear wheel (reverse trike layout).

This configuration improves stability, traction, and aerodynamic efficiency, providing a suitable platform for lightweight electric vehicle suspension optimisation as shown in Figure 1.

2.2 Trailing Arm

A swing-arm is a mechanical device that connects a motorcycle's rear wheel to its body, allowing it to rotate vertically. It is a key component of modern motorcycles and ATVs' rear suspension, holding the rear axle solidly while absorbing bumps and suspension loads. There are various types of swing-arms, including straight, single-sided, dual-sided, pro-link, and banana-shaped models [11]. Straight swing-arms are the most basic and widely used, while single-sided models are designed for easy wheel removal and maintenance. Dual-sided swing arms are more stable and are typically found on heavy-duty motorcycles. Pro-link swing-arms improve suspension performance by using a linkage system between the swing-arm and the shock absorber. The choice of swing-arm type depends on the vehicle's unique requirements and the rider's preferences [12].

2.3 System Lightweight Design

System lightweight design is the process of combining multiple parts or functions into a single system to make it lighter [20]. Strategies for making things lighter include material lightweight design, which utilises the strengths and stiffness of different materials based on their density and properties [21]. This can be achieved by using a single material with high specific properties or by combining different materials in a composite or hybrid. Structure lightweight design optimises the topology, shape, and parameters of parts to reduce weight, focusing on stiffness and structure to achieve a light system [22].

2.4 Generative Design Approach

Generative design is a method that uses algorithms and computer power to create and optimize designs based on specific goals, constraints, and inputs. It involves describing the design's objectives and limitations, generating design options using computational algorithms and techniques like artificial intelligence and machine learning, and assessing and improving the designs [23]. Generative design has advantages such as the ability to generate complex geometries and optimal designs considering factors like cost, weight, and strength, and reduces the need for manual input and iteration during the design phase [24]. It is used in aerospace, automotive, and architecture for applications requiring weight reduction, performance enhancement, and customisation. Additive Manufacturing (AM) is a production method that builds components layer-by-layer from digital models, including fused-deposition modelling, selective-laser melting, and stereo-lithography [25]. This integration of GD and AM forms a closed digital loop from conceptualisation to fabrication, supporting light weighting and functional integration in the proposed trailing-arm design [26].

2.5 Material Selection

Lightweight structural materials allow automobiles to carry improved emission control, without sacrificing safety, and integrated electrical systems without adding weight. Hybrid, plug-in, and electric cars need lightweight materials [19]. Lightweight materials may reduce the weight of power systems like batteries and electric motors, enhancing

https://doi.org/10.4314/njt.2026.5390

efficiency and all-electric range. Lightweight materials might reduce battery size and cost while maintaining the plug-in car's all-electric range [21].

[21] A study on lightweight materials for trailing arms of electric vehicles found high-strength steel, magnesium, titanium, carbon-fibre composites, and aluminium alloys as the most suitable. Steels offer excellent strength and fatigue life but increase unsprung mass, affecting suspension responsiveness. Magnesium alloys are lighter but have lower yield strength and poor corrosion resistance [22]. Carbon-fibre and glass-fibre composites have excellent stiffness-to-weight ratios but are cost-prohibitive and less suitable for threaded or welded joints. The 7076-T6 aluminium alloy offers the best compromise between weight, strength, and cost, allowing thinner wall sections and weight savings without compromising stiffness. The cost, recycling, integration with cars, and fuel efficiency advantages depend on research and development. Table 1 shows the properties of different materials used for the Trailing Arm.

Table 1: Properties and cost of materials used for trailing Arm

Material	Tensile Strength (MPa)	Approximate Cost Per Kg. (Rs.)
High-strength steel	500	125
Advanced high-strength steel	700	175
Glass fibre composites	3500	200
Titanium	1400	5500
Aluminium and Al matrix composites	240	200
Carbon fibre composites	3500	8000
Magnesium	440	90
7076 T6 Aluminium Alloy	570	600

The 7076 T6 Aluminium alloy material is chosen for the swing-arm of a tadpole-structured electric vehicle due to its cost-effectiveness, strength, and ease of manufacturing. This alloy offers moderate natural corrosion resistance compared to alloys like 6061-T6, due to its higher zinc and copper content. However, this limitation can be controlled through surface protection treatments like anodizing, powder coating, or epoxy painting. Zinc-chromate primers or epoxy sealants are used for joints and fastener zones to prevent galvanic corrosion. With these treatments, 7076-T6 maintains over 90% of its tensile strength after 1000 hours of salt-spray testing. When properly anodised and sealed, the alloy provides adequate corrosion protection for long-term service in electric-vehicle suspension systems, combining high strength, light weight, and sustainable lifecycle performance.

2.6 Optimisation Techniques

The optimisation of the Trailing Arm suspension system is crucial for enhancing its strength, longevity, and performance in tadpole-shaped electric cars. This involves material selection, structural design, and suspension tuning to support the rear wheel of the structure. Different loading conditions, such as static and dynamic conditions, are considered, with equal forces acting on both beams of the Trailing Arm in static conditions and unequal loading on both sides in dynamic conditions [27].

Autodesk Fusion 360 was used as the primary CAD and generative-design tool in a research study. It offers a single platform for modelling, topology optimization, and finite-element analysis. Fusion 360's cloud-based generative design module allows for structurally efficient and lightweight concepts while meeting strength and stiffness requirements. It also links CAD geometry, simulation, and manufacturing, allowing optimized designs to be validated through FEA and prepared for fabrication. Fusion 360 reduces manual design effort, making it suitable for rapid development of lightweight structural components [28]. The design constraints for the generative design include load acting on the swing, stiffness, and weight reduction of the Trailing Arm. Five iterations are generated based on the weight reduction percentage from 70 to 90%. Ansys software is used for static structural analysis, analysing total deformation and maximum principal stress [29].

https://doi.org/10.4314/njt.2026.5390

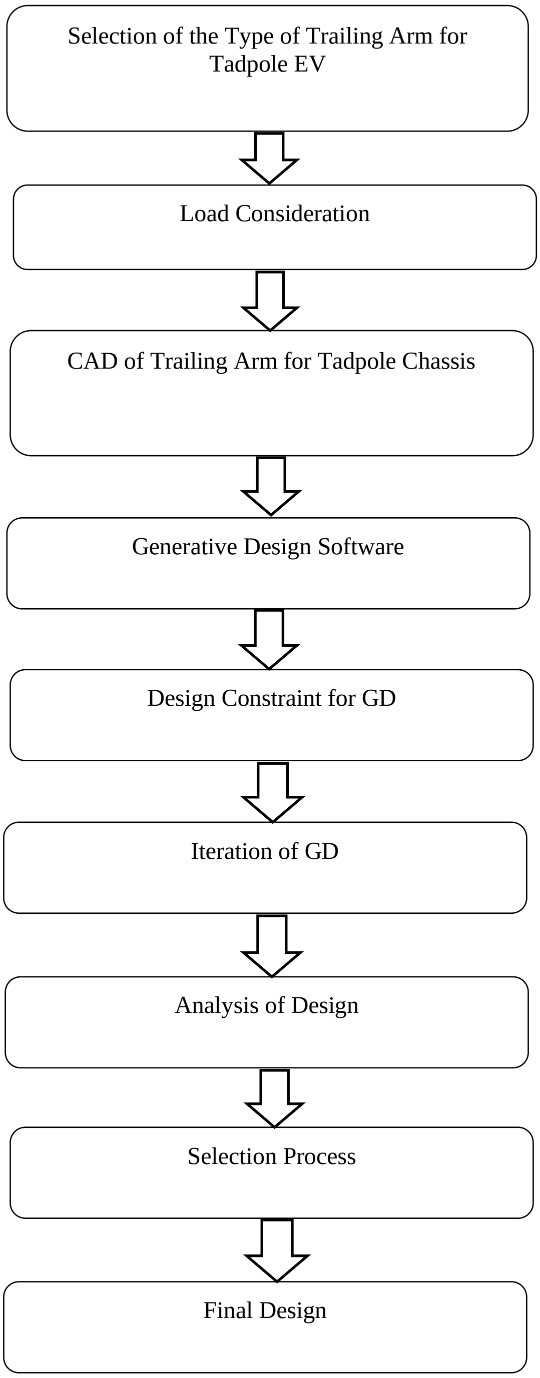


Figure 2: Workflow of the generative-design process for the trailing arm of a tadpole-configured electric vehicle.

Figure 2 outlines key stages—problem definition, constraint setup, iterative geometry generation, and finite-element validation—leading to the selection of the optimal lightweight design based on strength and manufacturability criteria.

In this study, the Best–Worst Method (BWM), a structured MCDM approach, was employed to determine the optimal trailing-arm iteration. The method identifies the best (most important) and worst (least important) criteria, then evaluates their relative importance using pairwise comparisons [8, 30, 31].

MCDM is widely used in various sectors, including engineering, management, economics, and environmental research. The final design is the final iteration based on the optimum value of all selection parameters, resulting in the optimal swing-arm optimisation. These optimisation techniques are essential for achieving the best handling and stability in tadpole-shaped electric cars [30, 31].

Let,

$$C = \{C_1, C_2 \dots \dots . . C_n\} \quad (1)$$

Equation 1 represents the criteria: geometry, stiffness, mass, stress, and deformation.
The steps of BWM are:

1. **Select the Best and Worst Criteria**

Experts identified *stiffness* as the best and *mass* as the worst criterion.

2. **Determine the Best-to-Others vector**

Where a_{Bj} indicates how much more important the best criterion C_B is over criterion C_j (values between 1–9).

$$A_B = \{a_{B1}, a_{B2} \dots \dots . . a_{Bn}\} \quad (2)$$

3. **Determine the Others-to-Worst vector**

Where, a_{Wj} indicates how much more important criterion C_j is compared to the worst criterion C_W.

$$A_W = \{a_{W1}, a_{W2} \dots \dots . . a_{Wn}\} \quad (3)$$

4. **Compute optimal weights**

The optimal weights $w_1, w_2 \dots\dots\dots w_n$ are obtained by solving:

$$\min_{w,\varepsilon} \sum_j \left|\frac{w_B}{w_j} - a_{Bj}\right| + \left|\frac{w_j}{w_W} - a_{jW}\right| \quad (4)$$

Subject to: $\sum_{j=1}^{n} w_j = 1, w_j \geq 0$

5. **Calculate normalized scores for each iteration**

Each alternative's normalised performance value is obtained using beneficial and non-beneficial criteria normalisation:

$$r_{ij} = \begin{cases} \frac{x_{ij}}{x_j^{max}}, & if\ criteria\ j\ is\ beneficial \\ \frac{x_j^{min}}{x_{ij}}, & if\ criteria\ j\ is\ non-beneficial \end{cases} \quad (5)$$

https://doi.org/10.4314/njt.2026.5390

6. The final composite score is

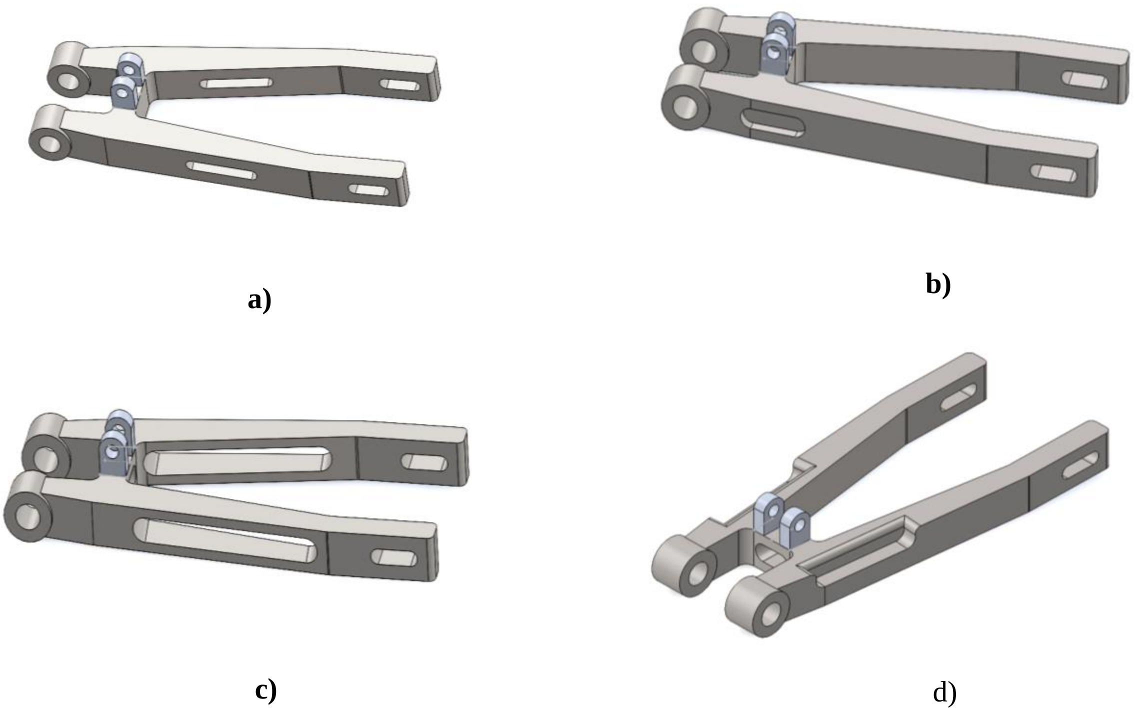
The iteration with the highest S_i is ranked as optimal.

$$S_i = \sum_{j=1}^{n} w_j r_{ij} \qquad (6)$$

3.0 RESULTS AND DISCUSSION

3.1 Generative Design Iteration and Load Applied for Analysis

By using Autodesk Fusion 360 CAD model of the Trailing Arm was prepared and given properties to the model. The initial mass of the Trailing Arm was 11.70 Kg. After application of the generative design concept (Figure 3) and getting different iterations as shown in Table 2, with varying mas



a) b) c) d)

Figure 3: Generative-design iterations of the trailing arm: (a) iteration 1 (baseline geometry), (b) Iteration 2 (moderate mass reduction), (c) iteration 3 (aggressive topology cut), and (d) iteration 4 (balanced design).

Table 2: Weight reduction and its percentage

Iterations No.	Mass (Kg)	Mass Reduction %
Iteration 1	11.08	2.3%
Iteration 2	11.41	1.00%
Iteration 3	8.75	25.22%
Iteration 4	10.80	7.7%

In the Ansys software, loads were applied as shown in Figure 4. For analysis purposes, at the eye end, fixed support is considered, and vertical forces of 325 N and horizontal forces of 1925 N are applied on the Trailing Arm by considering the bump due to the tyre and forces due to suspension.

https://doi.org/10.4314/njt.2026.5390

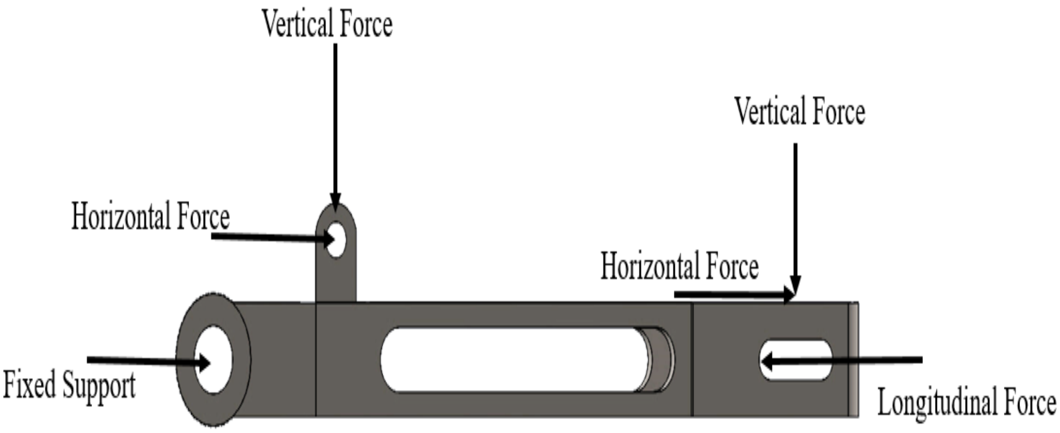


Figure 4: Boundary conditions and applied loads used in ANSYS static analysis.

The finite element analysis (FEA) of optimized trailing-arm models was conducted using ANSYS Mechanical to evaluate stress and deformation characteristics under realistic load conditions. A three-dimensional solid mesh was generated using SOLID187 tetrahedral elements, with an automatic adaptive strategy for complex geometries and stress concentration regions. A mesh-independence study was conducted to ensure the reliability of the numerical solution. The coarse mesh contained approximately 80,000 elements, the medium mesh 150,000, and the fine mesh 230,000 elements. The variation in maximum principal stress between the medium and fine mesh levels was found to be less than 5%, confirming mesh convergence. The material of the trailing arm was defined as isotropic and linearly elastic, corresponding to 7076-T6 aluminium alloy with an elastic modulus E = 71 GPa, Poisson's ratio $v = 0.33$, and density $\rho = 2810\,\text{kg/m}^3$. The convergence validation was carried out by comparing the maximum principal stress and tip deflection results obtained from different mesh levels as shown in Table 3. The final analysis indicated a maximum deflection of 0.34 mm and a peak principal stress of approximately 35 MPa, both well within the allowable limits for 7076-T6 aluminium alloy.

A modal analysis in ANSYS determined the first natural frequency of the trailing arm at approximately 112 Hz, well above the typical tricycle excitation range (0–25 Hz), confirming absence of resonance under normal operating conditions

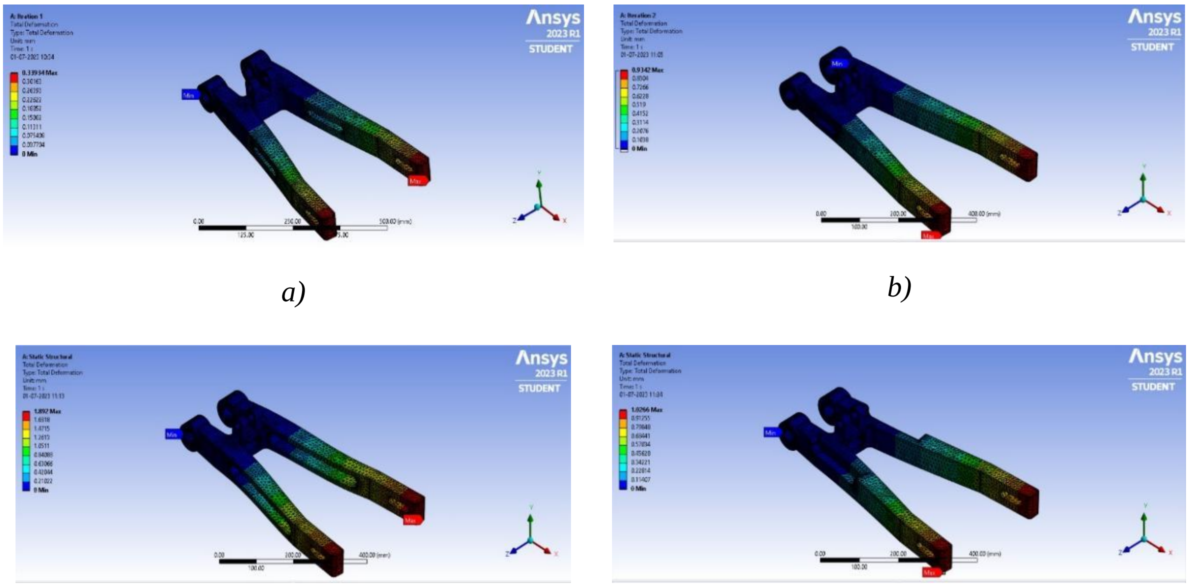
Table 3: Mesh-independence study

Mesh level	**Elements**	**Max stress (MPa)**	**Deflection (mm)**	**ΔStress %**	**Decision**
Coarse	80 000	36.8	0.354	–	
Medium	150 000	35.6	0.341	3.3	
Fine	230 000	35.4	0.339	0.6	Accepted

Also, longitudinal force due to acceleration and braking is applied at 2000 N. Ranking for the geometry parameters is assigned as shown in Table 4 as per the manufacturability and aesthetics of the Trailing Arm.

Dividing parameters into beneficial and non-beneficial categories as per their effect on the Trailing Arm as maximum or minimum. So, considering Geometry and stiffness as beneficial parameters, as they should be maximum and mass, stresses induced, and deformation as non-beneficial parameters, as they should be minimum. Values were observed for different parameters after Ansys, as shown in Figure 5 andd applying the generative design concept for each iteration, as shown in Table 5.

https://doi.org/10.4314/njt.2026.5390



a) *b)*

c) d)

Figure 5: ANSYS simulation results for (a–d) iterations showing maximum principal stress contours.

Table 4: Ranking for geometry parameter

Description	**Ranking**
Low	1
Below Average	2
Average	3
Good	4
Excellent	5

Table 5: Observed values of different parameters

Beneficial			**Non Beneficial**			
Iteration	**Geometry**	**Stiffness**	**Mass (Kg)**	**Stress (MPa)**	**Deformation (mm)**	
1	4	5893.79	11.08	35.582	0.33934	
2	5	2140.87	11.41	25.502	0.9342	
3	2	1057.08	8.75	53.634	1.892	
4	1	1948.18	10.8	23.002	1.0266	
Max	**5**	**5893.79**	**8.75**	**23.002**	**0.33934**	Min

For decision-making by using multi-criteria, here considering the maximum value of beneficial criteria and the minimum value of non-beneficial criteria. After dividing these values by actual values will get the multiplication factor as shown in Table 6.

After getting the multiplication factors assigned weightage to each criterion as per importance in the tadpole structured electric vehicle, the total weightage for deciding the optimised iteration of Trailing Arm for tadpole EV is shown in Table 7.

https://doi.org/10.4314/njt.2026.5390

Table 6: Multiplication factors for parameter.

Beneficial			Non Beneficial		
Iteration	**Geometry**	**Stiffness**	**Mass**	**Stress**	**Deformation**
1	0.8	1	0.7897111913	0.64645045	1
2	1	0.3632416493	0.7668711656	0.90196847	0.363241276
3	0.4	0.1793548803	1	0.42886974	0.1793551797
4	0.2	0.3305479157	0.8101851852	1	0.3305474381

Table 7: Total weightage of parameters and ranking

	Beneficial		Non Beneficial			Total	
Weightage	**20**	**25**	**20**	**20**	**15**	**100**	**Ranking**
Iteration	**Geometry**	**Stiffness**	**Mass**	**Stress**	**Total Displacement**	**Total**	
1	16	25	15.80	12.92	15	84.72	1
2	20	9.08	15.33	18.03	5.44	67.90	2
3	8	4.48	20	8.57	2.69	43.75	4
4	4	8.26	16.20	20	4.95	53.42	3

3.2 Discussion

As seen in Table 8, the optimised trailing-arm design operates well below the material's strength limits. The maximum principal stress of approximately 35 MPa represents only 7 % of the yield strength of 7076-T6 aluminium, providing a factor of safety exceeding 14 under combined loading conditions. The computed deflection of 0.34 mm indicates high bending stiffness, ensuring minimal geometry distortion during operation. Likewise, the induced cyclic stresses remain under 20 % of the material's fatigue limit, ensuring long-term durability. Since the working temperature in the suspension rarely exceeds 60 °C, creep deformation is negligible. Overall, these results confirm that the optimised design not only achieves the desired weight reduction but also satisfies all strength and reliability requirements of the chosen material.

Table 8: Comparison of Optimised Design Results with Standard Material Properties of 7076-T6 Aluminium Alloy

Property	**Standard Value (7076-T6)**	**Optimized Design Value (from FEA / Experiment)**	**% of Standard Value Utilised**
Yield Strength	500	35	7.0 %
Ultimate Tensile Strength	570	–	–
Fatigue Strength	160	28	17.5 %
Flexural Strength	510	42	8.2 %
Impact Strength (Charpy)	25–30	4.2 (equiv.)	–
Creep Strength (at 100°C / 10^3 h)	150	–	–
Maximum Principal Stress	–	35	–
Deflection at Wheel Hub	–	0.34	–
Factor of Safety (FOS)	≥ 1.5 (design)	14.2	–

The trailing-arm design of a tadpole electric vehicle (EV) has been optimised, resulting in a 6% reduction in component weight. This improvement has significant practical implications, as it improves ride quality, handling, and energy efficiency. The generatively optimised geometry also enhances

https://doi.org/10.4314/njt.2026.5390

stiffness-to-weight ratio, improving structural rigidity while maintaining safe stress and deformation limits. This balance contributes to improved cornering stability and reduced body roll, critical for the asymmetric tadpole layout. The lighter suspension arm also leads to a 1.8% mass reduction, resulting in a 2%-3.3% improvement in energy efficiency for a typical 4 kWh battery system. The new design also improves manufacturability and maintenance accessibility, reducing machining time and material waste while maintaining compatibility with existing mounting and brake interfaces. This aligns with sustainable manufacturing objectives and can serve as a modular platform for future EV prototypes. The generative-design-based optimisation offers holistic performance improvements, including better suspension compliance, lower energy use, improved handling, and manufacturability advantages.

4.0 CONCLUSION

Generative design software involves producing several CAD solutions that satisfy predefined constraints. Multi-Criteria Decision Making (MCDM) is an important tool for making a choice between many options, as it takes into account a number of elements, or criteria, to make a final choice. In this paper, by applying the generative design method and Multi-Criteria Decision Making (MCDM) process, the weight of the Trailing Arm for a tadpole structured electric vehicle is assessed with its initial weight of 11.7 Kg. From the results, iteration number one ranks first, indicating that it is the optimized design for the trailing arm made of 7076-T6 aluminium alloy. In this iteration, the weight is reduced by 0.7 kg, the geometry is optimized for ease of manufacturing, and the design achieves higher strength with allowable stress and deformation limits.

REFERENCES

[1] Khandar, C. and Kosankar, S., “A Review of Vehicular Pollution in Urban India and Its Effects on Human Health,” *Journal of Advanced Laboratory Research in Biology*, 5(3), pp. 54-61, 2014. [Online]. Available: https://journals.sospublication.co.in/ab/article/view/157

[2] D’Amato, G. and Akdis, C. A., “Global Warming, Climate Change, Air Pollution and Allergies,” *Allergy*, 75(9), pp. 2158–2160, 2020. doi: 10.1111/all.14527.

[3] Xu, B., Sharif, A., Shahbaz, M. and Dong, K., “Have Electric Vehicles Effectively Addressed CO2 Emissions? Analysis of Eight Leading Countries Using Quantile-On-Quantile Regression Approach,” *Sustainable Production and Consumption*, 27(1), pp. 1205–1214, 2021. doi:10.1016/j.spc.2021.03.002.

[4] Zope, A., Swami, R. K. and Patil, A., “Lean Six Sigma Barriers with Potential Solutions in Electrical Vehicle Assembly: A Review,” in *Proceedings on Engineering Sciences*, 5(3), pp. 375–382, 2023. doi:10.24874/PES05.03.002.

[5] Gnann, T., Stephens, T. S., Lin, Z., Plötz, P., Liu, C. and Brokate, J., “What Drives the Market for Plug-In Electric Vehicles? - A Review of International PEV Market Diffusion Models,” *Renewable and Sustainable Energy Reviews*, 93(1), pp. 158–164, 2018. doi: 10.1016/j.rser.2018.03.055.

[6] Ijaz, M., Lan, L., Zahid M., and Jamal, A., “A Comparative Study of Machine Learning Classifiers for Injury Severity Prediction of Crashes Involving Three-Wheeled Motorized Rickshaw,” *Accident Analysis & Prevention*, 154(1), pp. 106–118, 2021. doi:10.1016/j.aap.2021.106094.

[7] Luo, S. J., Fu, Y. T. and Zhou, Y. X., “Perceptual Matching of Shape Design Style Between Wheel Hub and Car Type,” *International Journal of Industrial Ergonomics*, 42(1), pp. 90–102, 2012. doi:10.1016/j.ergon.2011.10.001.

[8] Tang, C., He, L. and Khajepour, A., “Design and Analysis of an Integrated Suspension Tilting Mechanism for Narrow Urban Vehicles,” *Mechanism and Machine Theory*, 120 (1), pp. 225–238, 2018. doi:10.1016/j.mechmachtheory.2017.09.025.

[9] Patil, K., Rajpurohit, G., Magade, R. and Shirphule, A., “Design and Analysis of Single Sided Swing Arm for Modified Bike,” *International Research Journal of Engineering and Technology*, 6(5), pp. 876-879, 2019.

[10] Zope, A. Swami, R. K. and Patil, A. “SEM approach for Analysis of Lean Six Sigma Barriers to Electric Vehicle Assembly,” *Automotive Experiences*, 6(2), pp. 416–428, 2023. doi:10.31603/ae.9690.

[11] Sariman, F. C., Rahangmetan, K. A. and Asmal, S., “Analysis of Static Characteristics of A Motorcycle Swing Arm of A Twin-Shock Suspension Type Using the Finite Element Method,” IOP *Conference Series: Earth and Environmental Science*, 343(1), pp.1-6, 2019. doi:10.1088/1755-1315/343/1/012165.

[12] Powar, A., Joshi, H., Khuley, S. and Yesane, D. P., “Analysis and Topological Optimization of Motorcycle Swing-Arm,” *International Journal of Current Engineering and Technology*, 1 (6), pp.270-274, 2016.

https://doi.org/10.4314/njt.2026.5390

[13] Palanivendhan, M., Devanand, Chandradass, S., Philip, J., and Sajith Reddy, S., "Design and Analysis of 3-Wheeler Chassis," *Materials Today: Proceedings*, 45(1), pp. 6958–6968, 2021. doi:10.1016/j.matpr.2021.01.417.

[14] Shriganesh, R. Y. and Amol, S. S. "Revolutionizing Electric Vehicles: The Potential of Supercapacitors As Game-Changing Energy Storage," *Futuristic Trends in Mechanical Engineering*, 3(1), pp. 177–183, 2024.

[15] Zope, A., Swami, R. K. and Patil, A., "Electric Vehicles: Consumer Perceptions and Expectations," in *Lecture Notes in Mechanical Engineering: Recent Advances in Operations Management and Optimization Select Proceedings of CPIE 2023*, 1(1), pp. 221–236, 2024. doi:10.1007/978-981-99-7445-0_20.

[16] Zope, A., Swami, R. K. and Patil, A., "Topsis based Ranking of Lean Six Sigma Barriers to Electric Vehicle Assembly," in *2023 IEEE 3rd International Conference on Sustainable Energy and Future Electric Transportation (SEFET), IEEE*, 1(1), pp. 1–8, 2023. doi:10.1109/SeFeT57834.2023.10245316.

[17] Shinde, A., Swami, R. K. and Nanivadekar, S., "Advances and Innovations in Small Electric Vehicles Structural Design: A Review," *Lecture Notes in Electrical Engineering, Recent Advances in Power Electronics and Drives: Select Proceedings of EPREC 2024*, 2 (1), pp. 263–275, 2025. doi:10.1007/978-981-97-6091-6_18.

[18] Gupta, S., Poonia, S., Swami,R. K. and Shrivastava, A., "Design and Implementation of the Electric Bicycle with Efficient Controller," in *Lecture Notes in Electrical Engineering Intelligent Computing Techniques for Smart Energy Systems Proceedings of ICTSES* 2021, 862(1), pp. 541–552. 2022. doi:10.1007/978-981-19-0252-9_49.

[19] Shinde, A. S., Nanivadekar, S. S., Swami, R. K. and Kumar, A., "Review of Advanced Materials Used in Electric Vehicle Applications," *Tools, Techniques, and Advancements in Engineering Materials Science*, IGI Publishing, India, 1(1), pp. 51–68. 2025. doi:10.4018/979-8-3693-5513-8.ch004.

[20] Maherchandani, J. K., Joshi, R. R., Tirole, R. R., Swami, R. K. and Ganthia, B. P., "Performance Comparison Analysis of Energy Management Strategies for Hybrid Electric Vehicles," in *International Conference on Electric Power and Renewable Energy*, 1(1) pp. 245–254, 2022. doi:10.1007/978-981-16-9239-0_18.

[21] Rosenthal, S., Maaß, F., Kamaliev, M., Hahn, M., Gies, S. and Tekkaya, A. E., "Lightweight in Automotive Components by Forming Technology," *Automotive Innovation*, 3(3), pp. 195–209, 2020. doi:10.1007/s42154-020-00103-3.

[22] Zhang, W. and Xu, J., "Advanced Lightweight Materials for Automobiles: *A review," Materials & Design*, 221(1), pp. 1-20, 2022. doi:10.1016/j.matdes.2022.110994.

[23] Khan S. and Awan, M. J., "A Generative Design Technique for Exploring Shape Variations," *Advanced Engineering Informatics*, 38 (1), pp. 712–724, 2018. doi: 10.1016/j.aei.2018.10.005.

[24] Briard, T., Segonds, F. and Zamariola, N., "G-DfAM: A Methodological Proposal of Generative Design for Additive Manufacturing in the Automotive Industry," *International Journal on Interactive Design and Manufacturing*, 14(3), pp. 875–886, 2020. doi: 10.1007/s12008-020-00669-6.

[25] Toptas, E. "Innovative Approach to the Design of Mechanical Parts," *Journal of Mechatronics and Artificial Intelligence in Engineering*, 1(1), pp. 14–20, 2020. doi:10.21595/jmai.2020.21473

[26] Nitheesh, B. K. Sathya Vijaya Ram, P. Neranjen, S. Naveenkanna, M. Jithin, K.V. Rajesh, P. K. "Mass Optimization using Generative Design for Rear Accessory Assembly in A Two-Wheeler," *International Journal of Mechanical Engineering*, 6(3), pp. 2143-2148, 2021.

[27] Shinde, A. S., Chavan, B. R. and Patankar, S. M., "Results: Investigation for Effect of Parameters on Corrugated Wire Mesh Laminates Strength," *International Advanced Research Journal in Science, Engineering and Technology*, 8(6), pp. 324-329, 2021. doi:10.17148/IARJSET.2021.865.

[28] Ruddle, A. R. and Martin, A. J. M., "Adapting Automotive EMC to Meet the Needs of the 21st Century," *IEEE Electromagnetic Compatibility Magazine*, 8(3), pp. 75–85, 2019. doi: 10.1109/MEMC.2019.8878241.

[29] Wachter, C., Schüttoff, M., Rinderknecht, F., Goletz, M., Ehebrecht, D., Lenz, B., Kühnel M. and Hanke, B., "Electric Three-Wheelers as an Alternative to Combustion-Engined Autorickshaws in Dar Es Salaam - Generation of a Standard Drive Cycle, Power Train Modelling and Simulation of the Energy

Demand of Light Electric Vehicles," in *Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER), IEEE*, 1(1), pp. 1–5. 2020. doi:10.1109/EVER48776.2020.9242941.

[30] Diwakar, V. D., Nedumthaly, S. R. and Prakash, R., "Objective Based Modelling and Simulation within a Context of an Electric Vehicle Development Program," *World Electric Vehicle Symposium and Exhibition (EVS27), IEEE*, 1(1), pp. 1–8, 2013. doi:10.1109/EVS.2013.6914876.

[31] Rezaei, J. "Best-Worst Multi-Criteria Decision-Making Method," *Omega*, 53(1), pp. 49–57, 2014. doi:10.1016/j.omega.2014.11.009.

https://doi.org/10.4314/njt.2026.5390