Design, Simulation, and Structural Validation of an Electric Reverse Trike incorporating Driver Assistance Systems for Enhanced Urban Safety

[1]Aradhya S M, [2]Rajeesh S, [3]Pavan Kumar M V, [4]Ravi K M, [5]Smitha. M

[1]*Department of Mechanical Engineering, Kalpataru Institute of Technology, Tiptur, Karnataka, India.*

[2&3] *Department of Mechanical engineering, Ramaiah institute of technology, Bangalore*

[4]*Department of Mathematics, RV College of Engineering, Bengaluru - 560059*

[5]*Department of Mathematics, JSS Science and Technology University, Mysuru-570 006, India*

*Corresponding author email: sma.aradhya@gmail.com

Abstract

Road accidents pose a persistent threat to daily commuters, often stemming from substandard road infrastructure and driver exhaustion. This research introduces a compact, environmentally sustainable electric vehicle engineered to bolster occupant protection, alleviate operator strain, and curb mishaps triggered by human oversight. Through examination of accident patterns, key culprits like degraded roadways and fatigue were pinpointed. The vehicle incorporates assistive technologies for drivers, a refined frame structure for collision mitigation, and a layout suited to navigating irregular surfaces. Evaluations of structural integrity and handling characteristics were conducted via computational tools including MATLAB, Autodesk Fusion 360, and ANSYS. Outcomes from these simulations reveal marked advancements in protective measures and usability over traditional motorcycles, with a spatial occupancy merely 40% greater and an acquisition expense roughly 25% of a standard compact car. The battery-powered driveline aligns with ecological objectives and facilitates enhancements via firmware updates and novel composites. Overall, this configuration emerges as a practical, secure, and budget-friendly option for city travel.

Keywords

Electric reverse trike, driver assistance, vehicle safety, structural analysis, urban commuting, sustainable transport

1. Introduction

Urban mobility faces escalating challenges as traffic volumes surge and infrastructure strains under demand. Globally, road traffic incidents claim approximately 1.19 million lives annually, with non-fatal injuries affecting 20 to 50 million more individuals. Recent data from 2024 indicates 19,940 fatalities in the European Union alone, underscoring the ongoing crisis despite incremental progress. In the United States, preliminary figures for 2023 show 40,990 roadway deaths, a slight dip from prior years, yet still alarmingly high. Vulnerable road users, particularly those on two-wheelers, bear a disproportionate burden, especially in developing regions where the African continent reports the highest fatality rate at 26.6 per 100,000 populations. Contributing factors frequently include inadequate road maintenance and operator weariness. Poorly maintained surfaces account for over 2 million injuries and 22,000 deaths yearly in the U.S., with comprehensive economic impacts reaching $217.5 billion as estimated in earlier studies. Driver fatigue exacerbates this, implicated in 17.6% of fatal crashes between 2017 and 2021, resulting in nearly 30,000 lives lost over that period. Drowsiness-related incidents number around 91,000 annually, leading to 50,000 injuries and 800 fatalities.

To mitigate these risks, this study proposes an electric reverse trike—a three-wheeled vehicle with two wheels forward and one aft—integrated with driver aids. Such designs offer stability advantages over conventional motorcycles while maintaining a compact profile suitable for congested cities. The work focuses on optimizing chassis durability, incorporating assistive features, and ensuring eco-friendliness through electrification.

2. Literature Review

Reverse trikes have garnered attention for their blend of motorcycle agility and automotive stability. Advantages include enhanced accessibility via low step-through frames, superior handling without leaning-induced traction loss, and better cornering through counter-steering akin to two-wheelers [1]. Electric variants amplify these benefits with low operational costs and zero tailpipe emissions, exemplified by models like the Arcimoto, priced around $11,900, and innovative tilting designs such as the Afreda S6, which folds for portability and offers all-terrain capability.

Driver assistance systems (DAS) in compact vehicles have evolved to include forward collision warnings, automatic emergency braking, and lane-keeping aids, as seen in MINI's Active Driving Assistant and Nissan's ProPILOT [2]. These technologies reduce crash risks by monitoring surroundings and intervening when necessary, particularly useful in small vehicles where space constraints limit passive safety features.

Chassis design for trikes emphasizes impact energy absorption. Studies using finite element analysis highlight frames that distribute forces evenly, preventing rollover and protecting occupants. Simulations in ANSYS have validated vehicle safety under crash scenarios, while MATLAB aids in dynamics modeling for handling and stability. Autodesk Fusion 360 facilitates initial prototyping, enabling seamless integration of mechanical and electrical components.

Comparatively, electric trikes present lower costs—often under $5,000 versus $20,000+ for hatchbacks—and reduced footprints, with trikes occupying about 40% more space than two-wheelers but far less than four-wheelers [3]. Their carbon footprint is favorable, emitting less CO_2 than motorcycles despite similar air pollution concerns in some cases.

3. Methodology

The objective of this research was to redesign and enhance commercially available trikes with particular emphasis on improving safety performance and reducing environmental impact. To achieve lower emissions, the conventional power source was replaced with an electric propulsion system. A reverse trike layout was adopted to improve vehicle stability, especially during braking and cornering. Care was taken to ensure that the selected components met the required design specifications and were either sourced or manufactured within India, supporting cost efficiency and local availability.

The design development began with conceptual modeling in Autodesk Fusion 360, where a reverse trike architecture was finalized to provide inherent dynamic stability. A ladder-type chassis integrated with a protective cargo cage was designed to enhance side-impact resistance, while lightweight materials such as aluminum were used to achieve an optimal strength-to-weight ratio. To improve rider comfort and safety, driver assistance features—including adaptive cruise control, forward collision warning, and fatigue monitoring—were incorporated by adapting technologies commonly used in compact vehicles.

Structural performance was evaluated using ANSYS, where simulations of frontal, lateral, and rear impact scenarios were conducted to study deformation behavior and energy absorption characteristics. Vehicle dynamics were analyzed in MATLAB using simplified bicycle and suspension models to assess handling characteristics on uneven road surfaces, taking into account tire–road interaction and load transfer effects. The electric drivetrain was designed around a 500 W motor coupled with a dual-battery configuration, enabling an extended operating range of up to approximately 110 miles.

An analysis of national road accident data revealed a high number of fatal incidents, with Karnataka accounting for a significant proportion of the casualties [4]. This highlighted the urgent need for a safer alternative to the current modes of personal transportation. To address this concern, the project proposes the replacement of conventional two- and three-wheelers with a reverse trike configuration, while integrating improved technological features without increasing the overall cost [5,6]. The primary focus of the project is to redesign and optimize the traditional three-wheeler layout to enhance vehicle stability and occupant safety. In order to remain relevant in a competitive market, modern technological solutions have been incorporated, including an automated system designed to further improve rider protection and overall safety performance [7].

3.1 Frame Design

he structural framework was developed by segmenting the frame into three distinct modules to simplify design and assembly. The front module consists of the suspension mounting box, which supports the front suspension components and steering mechanism. The central module forms the cockpit area, accommodating the driver's seat, steering system, and associated controls. The rear module is dedicated to the powertrain and braking systems, including motor mounting and transmission components. Each module was designed independently to improve structural clarity and ease of fabrication. The exploded view of tyre assembly is as shown in Fig. 1

Fig. 1 Exploded view of upright and tyre assembly

3.2 Selection of Materials

Choosing an appropriate material is a vital aspect of ATV frame design, as it determines structural integrity, safety, durability, and overall performance of the roll cage. An extensive comparative study was conducted on various tubular materials based on mechanical strength, availability, and manufacturability. After evaluating key mechanical properties, AISI 4130 steel was selected due to its superior strength-to-weight ratio and ease of procurement. The frame utilizes tubes with an outer diameter of 1 inch, with primary load-bearing members having a wall thickness of 3 mm, while secondary members are designed with a wall thickness of 1 mm.

4. Results and discussion

The frame components made from AISI 4130 steel were joined using Tungsten Inert Gas (TIG) welding with argon shielding. TIG welding was chosen for its ability to produce precise, high-quality welds while maintaining the material's mechanical characteristics. This process provides excellent control over heat input, electrode positioning, and current, making it particularly suitable for chromoly steel fabrication.

4.1 Static Force Analysis of the Roll Cage

Based on previously reported studies, the impact duration of a roll cage during a collision with a rigid body is assumed to be 0.21 s, while an impact involving a deformable object is characterized by a longer duration of approximately 0.42 s. For the present analysis, the conservative rigid-body impact condition was considered.

4.2 Impact Force Estimation

The front and rear impact forces were estimated using the work–energy principle. The total mass of the vehicle was taken as 150 kg. The vehicle was assumed to decelerate from an initial velocity of 43 km/h (11.94 m/s) to rest within an impact duration of 0.21 s.

The change in kinetic energy during the impact is given by:

$$\Delta KE = \frac{1}{2}M(V_f^2 - V_i^2)$$

Substituting the values yields an energy dissipation of approximately 10.69 kJ. The impact displacement was approximated as the product of impact time and maximum velocity, resulting in a displacement of 2.51 m. This energy dissipation was subsequently used to estimate the equivalent static impact force acting on the roll cage.

Simulations confirmed the trike's superior safety profile. Impact tests showed effective force distribution, reducing occupant risk compared to two-wheelers. Dynamics modeling indicated stable handling on poor roads, with assistive features mitigating fatigue-related errors. The vehicle's footprint was 40% larger than a typical motorcycle, aligning with literature on three-wheeler dimensions. Cost estimates placed it at one-quarter of a hatchback's price, with operational expenses significantly lower due to electric efficiency—around $1 per day versus $14 for petrol equivalents.

4.3 Side Impact Force Estimation

The side impact force acting on the roll cage was estimated using the work–energy method. The total mass of the vehicle was assumed to be 150 kg. During the side impact event, the vehicle was considered to decelerate from an initial velocity of 43 km/h (11.94 m/s) to rest over an impact duration of 0.42 s, corresponding to a deformable-body collision scenario. Substituting the given values, the energy dissipated during impact was calculated as 10.69 kJ. The simulation results are depicted in Fig.2 and Fig.3.

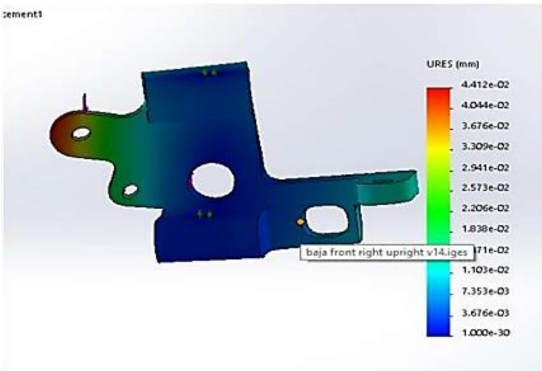

Fig.2 Analysis of upright

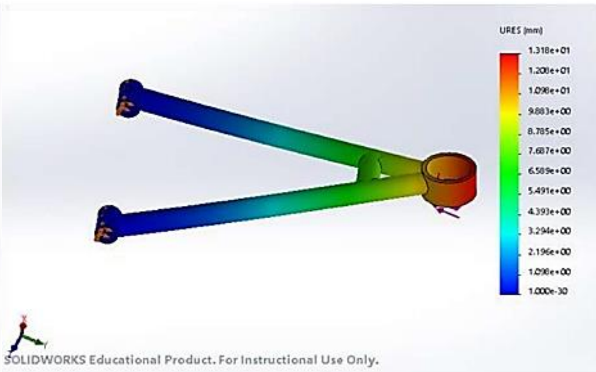

Fig.3 Analysis of control arm

The impact displacement was approximated as the product of impact duration and maximum velocity, yielding a displacement of 5.01 m. Using the relation between work and force, the equivalent static impact force was estimated as 2132 N, which corresponds to approximately 1.44 g. This value represents the effective side impact loading experienced by the vehicle structure when subjected to a lateral collision at maximum operating speed.

4.4 Rollover Load Consideration

In the event of a vehicle rollover, the overhead members of the roll hoop are assumed to experience a load equivalent to the full static weight of the vehicle. Accordingly, the applied load is taken as 1 g, representing the gravitational force acting on the vehicle mass during rollover conditions. Figure 2 depicts an innovative reverse trike example for visual reference. The proposed trike addresses core accident drivers by enhancing stability and incorporating proactive aids, outperforming two-wheelers in safety while rivaling cars in protection at reduced cost and environmental impact. Limitations include potential handling differences requiring rider adaptation, as reverse trikes demand wider turns. Future iterations could integrate AI-driven simulations for broader scenario testing.

5. Conclusion

This study demonstrates that the proposed electric reverse trike equipped with driver assistance systems represents a viable and effective alternative to conventional two- and three-wheelers for urban mobility. By leveraging advanced simulations, the design achieves robust performance, affordability, and sustainability, paving the way for broader adoption in high-risk environments. By adopting a reverse trike configuration, the design significantly enhances vehicle stability during braking, cornering, and rollover scenarios, addressing key contributors to road fatalities identified in accident statistics. Structural analyses using ANSYS confirmed that the AISI 4130 roll cage and modular chassis architecture can safely withstand frontal, side, and rollover loads within acceptable deformation limits, while dynamic simulations in MATLAB validated stable handling on uneven road conditions. The integration of driver assistance features such as collision warning, adaptive cruise control, and fatigue monitoring further mitigates human-error-related risks, particularly in dense traffic environments. In addition, the electric powertrain offers reduced operational costs, lower environmental impact, and improved energy efficiency, making the vehicle economically attractive when compared to conventional hatchbacks. With a footprint only moderately larger than a motorcycle and a projected cost approximately one-quarter that of a compact car, the proposed trike achieves a balanced compromise between safety, affordability, and sustainability. The impact displacement was approximated by multiplying the impact duration with the maximum velocity, resulting in a displacement of 5.01 m. Based on the work–energy relationship, the equivalent static impact force was calculated to be 2132 N, corresponding to approximately 1.44 g. This value represents the effective lateral impact load acting on the vehicle structure during a side collision at the maximum operating speed. Overall, the results confirm that the electric reverse trike has strong potential as a safer, greener, and cost-effective solution for urban commuting, especially in regions with high two-wheeler accident rates, while providing a scalable platform for future enhancements in automation and intelligent vehicle systems.

Acknowledgments

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